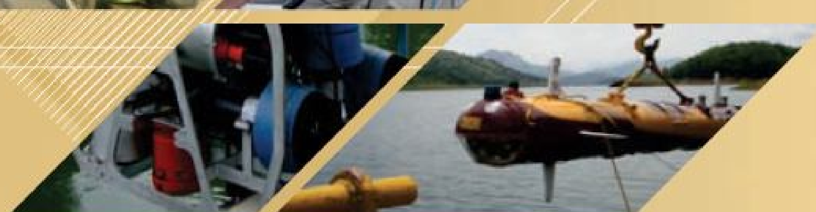
वार्षिक प्रतिवेदन
Annual Report
2011 - 12



सी. एस. आई. आर – केन्द्रीय यान्त्रिक अभियान्त्रिकी अनुसंधान संस्थान, दुर्गापुर

CSIR - CENTRAL MECHANICAL ENGINEERING RESEARCH INSTITUTE, DURGAPUR

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CSIR - Central Mechanical Engineering Research Institute, Durgapur

About CSIR-CMERI

As a constituent member under the Council of Scientific & Industrial research, the ambit of the CSIR – Central Mechanical Engineering Research Institute, Durgapur – a premier establishment of national standing dedicated to research and development – extends over mechanical engineering and allied and advanced disciplines of science and technology.

The Institute employs over 500 scientific and technical staff with a rich blend of expertise and experience in different disciplines of engineering and science.

Besides conducting frontline research in varied areas, the Institute dedicates its R&D efforts towards different mission mode programmes to disseminate appropriate technological solutions for poverty alleviation, societal improvement, energy security, food security, defence, etc.

CSIR-CMERI has developed as many as 150 products and processes of which 26 have been awarded prestigious national awards. More than 120 licensees have obtained know-how for various products and processes developed for commercial exploitation.

CSIR-CMERI has a dedicated team of highly qualified professionals and support staff well balanced in terms of youth and experience. The manpower available at CSIR-CMERI is comparable to the very best available in India.

CSIR-CMERI is making steady inroads into such areas as Robotics, Mechatronics, Micro Systems Technology, Cybernetics, Manufacturing, Precision Farming, etc. and is assuming leadership in many of these emerging front-end interdisciplinary domains.

Thrust Areas

- Underwater Robotics, Surface Robotics & Mechatronics
- Micro Systems Technology, Surface Engineering & Tribology
- Materials, Processes, Chemistry & Synthetic Biology
- Advanced Design, Manufacturing, Foundry
- Design Dynamics, Simulation and Analysis, Immersive Visualization
- Thermal Engineering
- Cybernetics, Electronics & Embedded Systems, Drives & Control
- Precision & Conservation Farm Machinery

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From the Director's Desk

Impending Changes in Engineering

Miniaturization is a major feature in the advanced and futuristic machines for many reasons as indicated below

- Lower cost and higher packing density makes it possible to incorporate a variety of sensors which is essential to make a machine intelligent and autonomous.
- Miniaturization is mandatory for any non invasive human health monitoring system.
- Miniaturized devices consume low energy and material consumption is low for such devices resulting in better conservation of resources.
- Intelligent devices and smart actuators are mandatory components of newer machines.

New physical and chemical devices for small scale may be necessary for many applications. Therefore the new generation engineering professionals require formal training in the following areas:

- Molecular Dynamics
- Synthetic Biology
- Smart Macromolecules and Intelligent Materials
- Self Assembly and Self organization followed by
- Self learning, Self correction and Self replication

The engineering profession is facing some major challenges. With the advanced technology, systems are generally reaching new levels of complexity. Today a modern aircraft demands a system in which embedded devices are networked to sense, monitor, and control physical hardware components. More than half the effort of development and production is for embedded devices, software, and system integration. These are all in addition to the issues of structures, aerodynamics, propulsion, guidance, navigation and control. Design teams are also growing more complex as the variety of technology and new sciences in a system is increasingly demanding interdisciplinary collaboration.

During the course of a project, all the key members rarely meet in person. High-tech companies are having increasing difficulty in filling positions of strategic importance to maintain their competitive edge in the global market. This is particularly true for manufacturing of complex systems, requiring workers with competency in science, technology, engineering, and mathematics (STEM) to operate, maintain, and repair sophisticated computer driven manufacturing devices and industrial robots. It is also true for workers servicing complex systems, such as newer aircrafts or automobiles (vehicles). Traditional engineering disciplines and formal engineering programs are often inadequate for meeting the challenges of the current and emerging complex systems. For one reason, established disciplinary boundaries do not mix well with the interdisciplinary nature of complex systems. The rapidly transitioning scenario has given rise to a number of interesting situations. For example, one typically finds that bio-XX related programs are growing well, though these disciplines require more thoughtful integration. It is also seen that chemical and mechanical engineering is increasingly claiming most of the Energy space. It is now felt that a thorough background in electrical and electronic devices shall have to occupy a significant part of all engineering disciplines. In parallel, electrical end electronics engineering shall have to make more space for computing.

Design approaches based on the traditional top-down systems engineering – which work for the fully predictable response of the system in a well-understood environment – are beginning to collapse in the new scenario as the cost of new machines and clean room environments grows exponentially with newer technologies. In addition, physical limits typical of the different photolithographic processes are becoming hindrances. Unforeseen problems are cropping up in heat dissipation where smaller geometries and conventional materials are being used.

To address these limitations, new bottom-up engineering approaches are emerging for complex systems consisting of many interacting components. The approach is inspired by nature and aided by chemistry and biology to assemble and control growth of crystals and cells. The advantage of the bottom-up approach consists in allowing smaller geometries than photolithography. Certain structures such as Carbon Nanotubes and Si nanowires are grown through a bottom-up process. In addition, novel technologies such as organic semiconductors employ bottom-up processes to pattern them. The bottom-up approach renders formation of films and structures much easier and is more economical than top-down in that it does not waste material to etching.

As mentioned earlier, traditional engineering disciplines and formal engineering programs are often found inadequate for meeting the challenges of the current and emerging complex systems. These complex systems range from smart vehicles to smart powergrids, intelligent transportation and healthcare systems to smart underwater robots. Here is a typical example. A long tail might seem like a dangerous appendage for a lizard. After all, the more there is for a predator to grab. However, biomechanical researchers have found that a lizard's tail has an important function: it helps the animal keep its balance. When running at full speed, a lizard uses its tail to adjust its attitude and recover from stumbles. It even works when the lizard flips. Does a tail perform the same for scurrying robots? Researchers at the University of California, Berkeley added a tail to a robotic car they named TAILBOT, but they discovered that maintaining balance isn't as simple as throwing one's tail in the air, as team leader Professor Robert Full, a professor of integrative biology reported.

The research team was made up of undergraduate and graduate engineering and biology students. Robots and lizards have to adjust the angle of their tails just right to counteract the effect of a stumble. According to Professor Full, "We showed for the first time that lizards swing their tails up or down to counteract the rotation of their bodies, keeping them stable."

Prof. Full and his students used high-speed videography to record how an African redhead agama lizard handled leaps from a platform that had different degrees of traction, from slippery to rough. The researchers coaxed the lizards to run down a track, vault off an obstacle, and land on a vertical surface. When the friction on the obstacle was reduced, lizards slipped, potentially causing their bodies to spin out of control. The team found that the lizard must swing its tail upward to prevent a forward pitch, the kind that could send it head-over-heels into a tree. The researchers created a mathematical model to better understand the reptile's skills and to see how they could be translated to a robot.

CSIR-CMERI has done excellently in many areas of science and technology in the current year. Five axis micro milling machine, Reconfigurable microfactory, Voice controlled robotic wheel chair, Strategic robots for nuclear power plants, Moderinzation of some sections of Durgapur Steel Plant, Development of novel heat pipes for space applications, Optimtization of the process of rheo pressure die casting, Design and development of dc-dc and dc-ac converters for power system applications are a few to mention amongst notable technologies developed and nurtured at CSIR-CMERI. The annual report will echo all the activities mentioned above.

Today plenty of complex machine components are manufactured by a technique known as DMD (Direct Metal Deposition). The application includes a computer controlling a laser to direct the laser energy onto the powder to produce a sintered mass. The computer either determines or is programmed with the boundaries of determined cross sectional regions of the part. For each cross-section, the aim of the laser beam is scanned over a layer of powder and the beam is switched on to sinter only the powder within the boundaries of the cross-section. The powder is applied in successive layers and sintered until the complete part is formed.

Similarly, today, artificial or replacement tissue is commonly grown on collagen scaffolds that contain biological starter cells. The end goal here is the growing of a biocompatible piece of tissue to repair or replace a patient's own damaged body part such as bone, cartilage, blood vessels, or skin. Method of the future is bio-printing, which will eventually take tissue engineers well beyond the realm of growing replacement tissue and into printing replacement organs. Prof. Hod Lipson, Professor of Mechanical and Aerospace Engineering and Computer and Information Science at Cornell University is working on this. Plenty of exciting things are happening in bio-printing. The ultimate solution is that we will move away from replacement parts made from engineering material and go for living implants made out of our own cells that are alive. An example of an engineering material might include a titanium implant that replaces a worn jaw or hip joint. The method is much the same as additive manufacturing, in which a printer deposits a material, layer by layer, until a three dimensional object is made. For bio-printing, the material used is likely to be living cells taken directly from the patient's body and infused into an ink or gel to keep them alive. After printing the material is incubated in a cell culture environment that mimics human body conditions until it fuses or becomes otherwise usable.

Are we prepared to face such challenges at CSIR? Continuous and lifelong learning are the key components that can keep us scientifically relevant, useful and attractive. Here at CSIR-CMERI, we require transdisciplinary research teams. We require striving for excellence in newer technologies and newer devices, by making full play of our intellect and complete utilization of the existence of AcSIR (Academy of Scientific and Innovative Research).

Gautam Biswas

निदेशक की कलम से

अभियांत्रिकी मे सासन्न परिवर्तन

मुझे यह सूचित करते हुए अपार हर्ष हो रहा है कि इस साल सी.एम.ई.आर.आई. ने विज्ञान एवं प्रौद्योगिकी के कई क्षेत्रों में उत्कृष्ट प्रदर्शन किया है।

पाँच अक्षों वाली माइक्रो मिलिंग मसीन, पुनर्रचना योग्य माइक्रोफैक्ट्री, ध्वनी-नियंत्रित रोबोटिक व्हीलचेयर, नाभिकीय विद्युत् संयंत्रों के लिए सामरिक रोबोट, दुर्गापुर इस्पात के कुछ विभागों का आधुनिकीकरण, अंतरिख में प्रयोग किए जाने वाली नई किस्म की तापन-लियाँ, रियो प्रेशर डाई कास्टिंग पद्धति का ऑपटिमाइजेशन, विद्युत तंत्र के लिए डीसी-डीसी एवं डीसी-एसी परिवर्त्तकों का प्रारुपण एवं विकास जैसे कुछ शानदार काम हुए जो अन्य उल्लेखनीय तकनीकी विकास के कामों में अपना विशिष्ट सीन रखते हैं। वार्षिक प्रतिवेदन में इन सब गतिविधियों की विस्तृत चर्चा रहेगी।

मैं इस अवसर पर उन विषयों की विशद चर्चा करने जा रहा हुँ जो सी.एस.आई.आर.-सी.एम.ई.आर.आई. द्वारा भविष्य में किए जाने वाले अनुसंधान एवं विकास कार्य के लिए बहुत महत्वपूर्ण हैं। हम सभी जानते हैं कि उन्नत एवम् भविष्योन्मुखी यंत्रो में लघु-रूपान्तरण एक बड़ी विशेषता बन कर उभर रही है। इसके निम्नलिखित कारण है:-

- कम लागत एवं उच्च संकुलन सघनता विभिन्न प्रकार के संवेदकों के समावेश को संभव बनाते हैं, जो कि एक यंत्र को कुशल एवं स्वायत्त बनाने के लिए आवश्यक है।
- मानव शरीर के बाहर से ही स्वास्थ्य जाँच हेतु प्रयुक्त उपकरणों में लघु-रुपान्तरण अनिवार्य हो गया है।
- लघु-रुपान्तरित उपकरणों में ऊर्जा एवम् पदार्थ की कम खपत होती है, जिसके फलस्वरुप संसाधनों का बेहतर संरक्षण होता है।
- विशिष्ट उपकरण एवम् चुस्त प्रवर्तक नई मशीनों के अनिवार्य अंग बन गए हैं।

ऐसे छोटे पैमाने की यंत्रों के लिए नये भौतिक व रासायनिक सिद्धान्तों की आवश्यकता पर सकती है।

अतएव, अभियांत्रिक उपकरणों की नई पीढ़ी को इन क्षेत्रों में प्रशिक्षित करने की जरुरत है।

- आणविक गतिकी
- संश्लेषण जीवविज्ञान
- चुस्त सुक्ष्म अणु एवं विशिष्ट पदार्थ
- स्व-समायोजन एवं स्व-संगठन के पश्चात् स्व-शिक्षा, स्व-संशोघन एवंम् स्व-प्रतिकृति

अभियांत्रिकी पेशा कुछ बढ़ी चुनौतियों का सामना कर रहा है। उन्नत तकनीक से यु क्त होने के कारण मशीन-तंत्र जटिलता के नये स्तरों तक पहुँच रहा है। आजकल एक आधुनिक वायुयान को एक ऐसे तंत्र की जरुरत है जिसमें महसुस करने, निगरानी रखने एवं धातुनिर्मित अवयवों को नियंत्रित करने की क्षमता रखने वाले अंत:स्थापित उपकरण गुंथे हुए हों। विकास एवं उत्पादन में लगने वाले अधिकांश प्रयास अंत:स्थापित उपकरण,

सॉफ्टवेयर और तंत्र समाकलन में लग जाते हैं। ये सब संरचना, वायुगतिकी, प्रणोदन, मार्गदर्शन, वायुपरिवहन एवं तंत्र–नियंत्रण जैसे मसलों के अतिरिक्त है।

नये प्रकार के विज्ञान एवं तकनीकों से सम्बद्ध तंत्रो में अन्तर्विषयक सहकार्य की बढती आवश्यकताओं के मद्देनजर समुचित परिकल्पना दलों का गठन दिनानुदिन जटिल होता जा रहा है।

किसी परियोजना की कार्यावधि में सभी प्रमुख सदस्यों का व्यक्तिगत रुप से मिलना दुर्लभ होता है। उच्च–तकनीक सम्पन्न उद्योग इकाईयाँ विश्व–बाज़ार में अपनी प्रतिस्पर्धात्मक जगह बनाए रखने के लिए महत्व के पदों पर नियुक्ति हेतु कठिनाईयाँ महसूस कर रहे हैं। ये बात खासकर उन इकाईयों पर लागू होती है, जहाँ संश्लिष्ट मशीन–तंत्र का निर्माण होता है। वहाँ उन्हें ऐसे कामगारों की जरुरत होती है जो विज्ञान, तकनीक, अभियांत्रिकी और गणित (स्टेम) में निपुण हों जिससे कि वे कम्प्यूटर–चालित निर्माण उपकरणों एवं औद्योगिक रोबटों को चलाने, उनके रख–रखाव और मरम्मत के काम कर सकें। ये बातें उन कामगारों के लिए भी लागू होती हैं जो नए तरीके के वायुयान या अन्य वाहनों जैसे जटिल तंत्रों के रख–रखाव से जुड़े हैं। पारंपरिक अभियांत्रिक विषय एवं औपचारिक अभियांत्रिक शिक्षा–कार्यक्रम वर्त्तमान और आने वाले जटिल मशीन–तंत्रों की चुनौतियों से निपटने के मामले में अक्सर उपर्याप्त सिद्व होते हैं। एक कारण से, स्थापित विषय सीमाएँ जटिल तंत्रों की अंतर्विषयक प्रकृति से अच्छी तरह मेल नहीं रख पाते हैं तथा पारंपरिक अधेगामी तंत्र अभियांत्रिकी पर आधारित प्रारुप पद्धतियाँ, जो कि एक परिचित वातावरण में तंत्र की पूर्व अपेक्षित प्रतिक्रिया के लिए उपयुक्त हैं, इन परिस्थितियों में काम नहीं कर पाती हैं। कई पारस्परिक क्रियाशील घटकों से युक्त तंत्रो के लिए नई उर्ध्वगामी अभियांत्रिक दृष्टिकोण अपनाने की जरुरत है। जटिल तंत्रो का क्षेत्र–विस्तार चुस्त यान से लेकर चुस्त विद्युतग्रिड तक, सुरक्षित यातायात व स्वास्थ्य प्रणालियों से लेकर चुस्त अन्तर्जलीय रोवोट तक है। एक विशिष्ट उदाहरण प्रस्तुत है। किसी छिपकली के लिए एक लम्बी पुंछ एक खतरनाक उपांग की तरह लग सकता है।

हालाँकि, जैवयांत्रिक शोघकर्ताओं ने पाया है कि एक छिपकली की पूंछ एक महत्वपूर्ण कार्य कर सकती है। यह जीव को अपना संतुलन बनाए रखने में मदद करता है। जब तक छिपकली पूरी रफ्तार से चल रही है तो अपनी पुंछ का उपयोग अपने संतुलन को समायोजित करने और अवरोधों से उबरने में करती है। छिपकली के झटका भारने में भी उसकी पुँछ इसी प्रकार के काम करती है। कौलिफोर्निया विश्वविद्यालय, बर्कले में शोधकर्ताओं ने एक रोबोट–युक्त कार में पुँछ जोड़ दी और उसे 'टेलबोट' नाम दिया। परन्तु उन्होंने पाया कि संतुलन बनाए रखना उतना आसान नहीं है जितना कि हवा में पूंछ फेंकना। शोधकर्ताओं के अगुवा प्रो. रॉबर्ट फुल ने ये बातें बताई, जो कि सम्पूर्णात्मक जीवविज्ञान के प्राध्यापक हैं।

शोधदल में पूर्वस्नातक एवं स्नातक स्तर के अभियांत्रिकी और जीवविज्ञान के छात्रो के शामिल किया गया था। रोबोट और छिपकली किसी अबरोध के प्रभाव को निष्फल बरने कि लिए अपने पूंछ को सही कोण पर ले जाते हैं। प्रो. फुल के अनुसार, ''हमने पहली बार ये दिखाया कि छिपकलियाँ अपने पूंछों को उपर या नीचे की और घुमाकर उपने शरीर को घूर्णन के प्रभाव से बचाते हुए संतुलन बनाए रखती हैं।''

प्रो. फुल एवं उनके छात्रों ने उच्चगति विडियोग्राफी का इस्तेमाल कर यह रिकॉर्ड किया कि एक लालबालों वाला ''अगमा'' छिपकली किस प्रकार से विभिन्न प्रकार की खिंचाई (चिकनी से खुरदुरे) से भरपूर सतह पर कुदते हुए अपने आप को नियंत्रित करती है। शोधकर्त्ताओं ने छिपकलियों को इस काम के लिए राजी किया कि वे एक पट्टी पर दौड़े और किसी ठोकर के आने पर उसे छलांग लगा कर पार करते हुए एक उदग्र सतह पर अपने को स्थापित करें।

जब अवरोध का घर्षण कम किया गया, छिपकलियाँ फिसल गई जिसमें उनका शारीरिक संतुलन बिगड़ गया। शोधदल ने पाया कि छिपकली को अपनी अग्रगति रोकने के लिए पूँछ को ऊपर की और घुमाना पड़ता है। शोधकर्ताओं ने एक गणितीय मॉडल बनाया जिससे कि सरीसृप के कौशल को बेहतर तरीके से समझा जा सके और उन्हें एक रोबोट की तरह व्यवहार किया जा सके।

इन दिनों बहुत प्रकार के जटिल मशीन अवयवों का डी.एम.डी. (डायरेक्ट मेटल डिपोजिशन) तकनीक के जरिए निर्माण किया जाता है। इस पद्वति में एक कम्पूटर–नियंत्रित लेजर अपनी ऊर्जा को धातु–चूर्ण पर केन्द्रित करती है जिससे एक सुगठित द्रव्य का निर्माण होता है। कम्प्यूटर, निर्माण किए जाने वाले मशीनी हिस्से के अनुभागीय क्षेत्रों का या तो निर्धारण करता है या फिर उसे उन क्षेत्रों से संबंधित आँकड़े प्रदान किए जाते हैं। प्रत्येक अनुप्रस्थीय अनुभाग के लिए धातु–चूर्ण की परत को लेजर किरणों से प्रकाशित किया जाता है

और उन्हें उस अनुभाग की सीमाओं तक ही रखा जाता है। इसी प्रकार की क्रिया अन्य परतों पर दुहराकर सम्पूर्ण हिस्से का निर्माण कर लिया जाता है।

इसी तरह आजकल कृत्रिम या प्रतिस्थापन ऊतक का निर्माण आमतौर पर कोलाजेन स्केफोल्ड पर किया जाता है जिनमें जैविक स्टार्टर सेल लगे होने हैं। यहाँ लक्ष्य होता है एक जैवसंगत ऊतक के टुकड़े बनाने का जो मरीज के अपने ही क्षतिग्रस्त शरीर के हिस्से की मरम्मत कर सके या उसे प्रतिस्थापित ही कर सके यथा हड्डी, कार्टिलेज, रक्तवाहिकाएँ, त्वचा। भविष्य की प्रणाली जैव-मुद्रण होगी जहाँ ऊतक अभियंता ऊनकों के निर्माण से आगे बढ़कर अंगप्रतिस्थापन के मुद्रण-तंत्र को विकसित करेंगे। कॉर्नेल विश्व-विद्यालय के "मैकेनिकल व एरोस्पेश इंजिनियरिंग तथा कम्प्यूटर व सूचना विज्ञान" विभाग के प्रोफेसर इस विषय पर काम कर रहे हैं। जैव-मुद्रण के क्षेत्र में बहुत से रोमांचक काम हो रहे हैं। इन सबका अंतिम लक्ष्य है इंजिनियरिंग पदार्थो से बनने वाले प्रतिस्थापन अंग की जगह हमारी अपनी ही जीवित कोशिकाओं से बने सजीव प्रत्यारोपण अंग तैयार करना। टाइटेनियम से निर्मित प्रत्यारोपण इंजिनियरिंग पदार्थ एक उदाहरण है, जो एक क्षय हो चुके जबड़े या कुल्हे को प्रतिस्थापित करता है। यह प्रणाली योगकारी निर्माण प्रक्रिया की तरह है जिसमें एक मुद्रक परत-दर-परत पदार्थ को जमा करते हुए एक त्रिआयामी वस्तु का निर्माण करता है। जैवमुद्रण के लिए मरीज के शरीर से सीधे निकाले हुए जीवित कोशिकाओं को एक स्याही या जेल में रखा जाएगा ताकि वे जीवित रह सकें। मुद्रण के पश्चात पदार्थ को मानवशरीर से मिलते-जुलते वातावरण में तब तक विकसित किया जाता है, जबतक कि वह व्यवहार में लाने लायक न हो जाय।

क्या इम सी.एम.आई.आर. में इस तरह की चुनौतियों का सामना करने के लिए तैयार हैं? सतत शिक्षा और आजीवन सीखने का आग्रह वे प्रमुख घटक हैं जो हमें वैज्ञानिक रूप से प्रासंगिक, उपयोगी एवं आकर्षक बनाए रख सकते हैं। यहाँ सी.एस.आई.आर.-सी. एम.ई.आर.आई. में हमें अनतर्विषयक शोध दल बनाने की जरुरत है। हमें आवश्यकता इस बात की है कि हम अपनी बुद्धि एवं ए.सी. एस.आई.आर. के अस्तित्व का पूरा उपयोग करते हुए नई तकनीक एवं नए उपकरणों के क्षेत्र में अपनी उत्कृष्टता बनाए रखने के लिए प्रयत्नशील रहें।

गौतम बिश्वास

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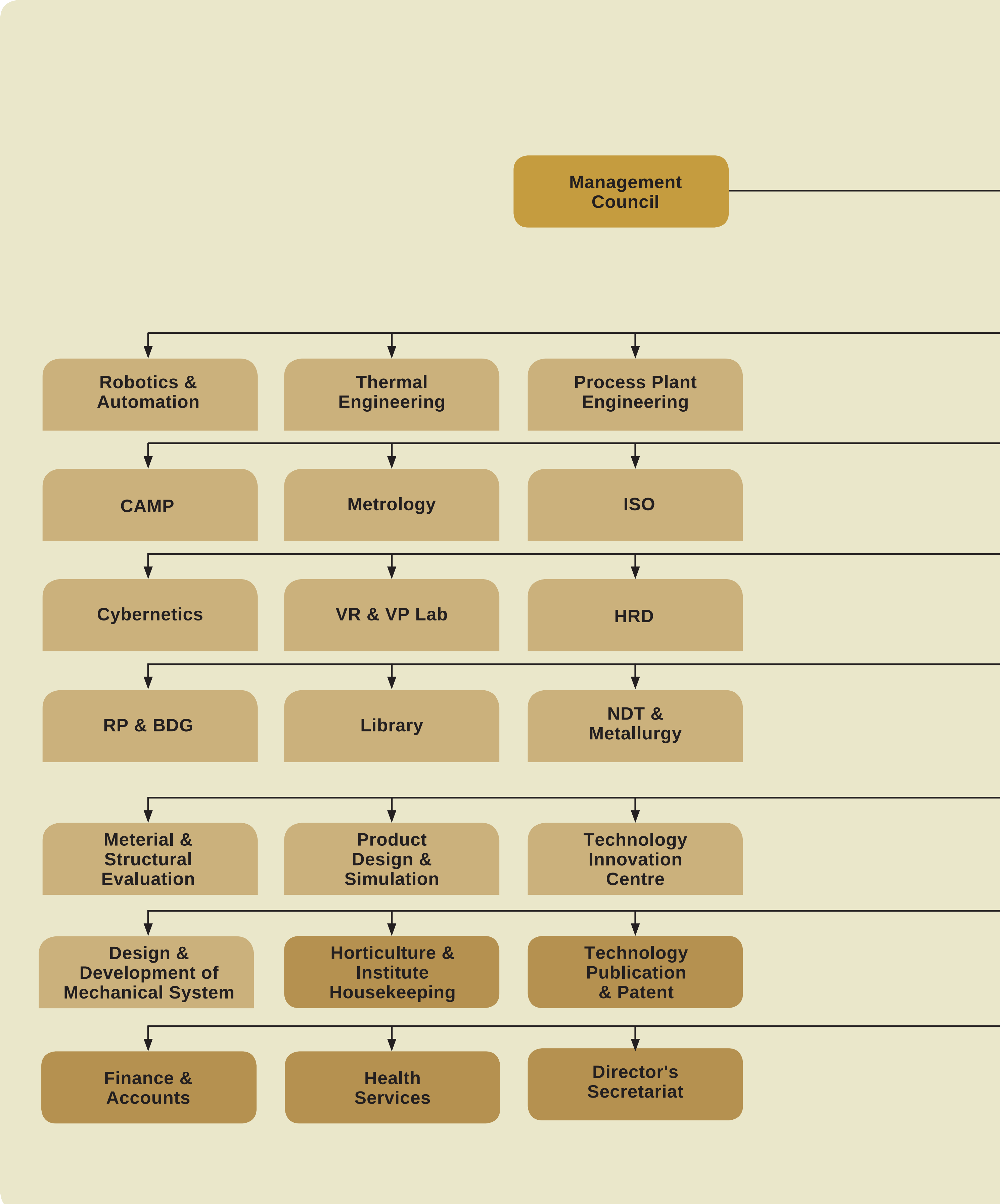
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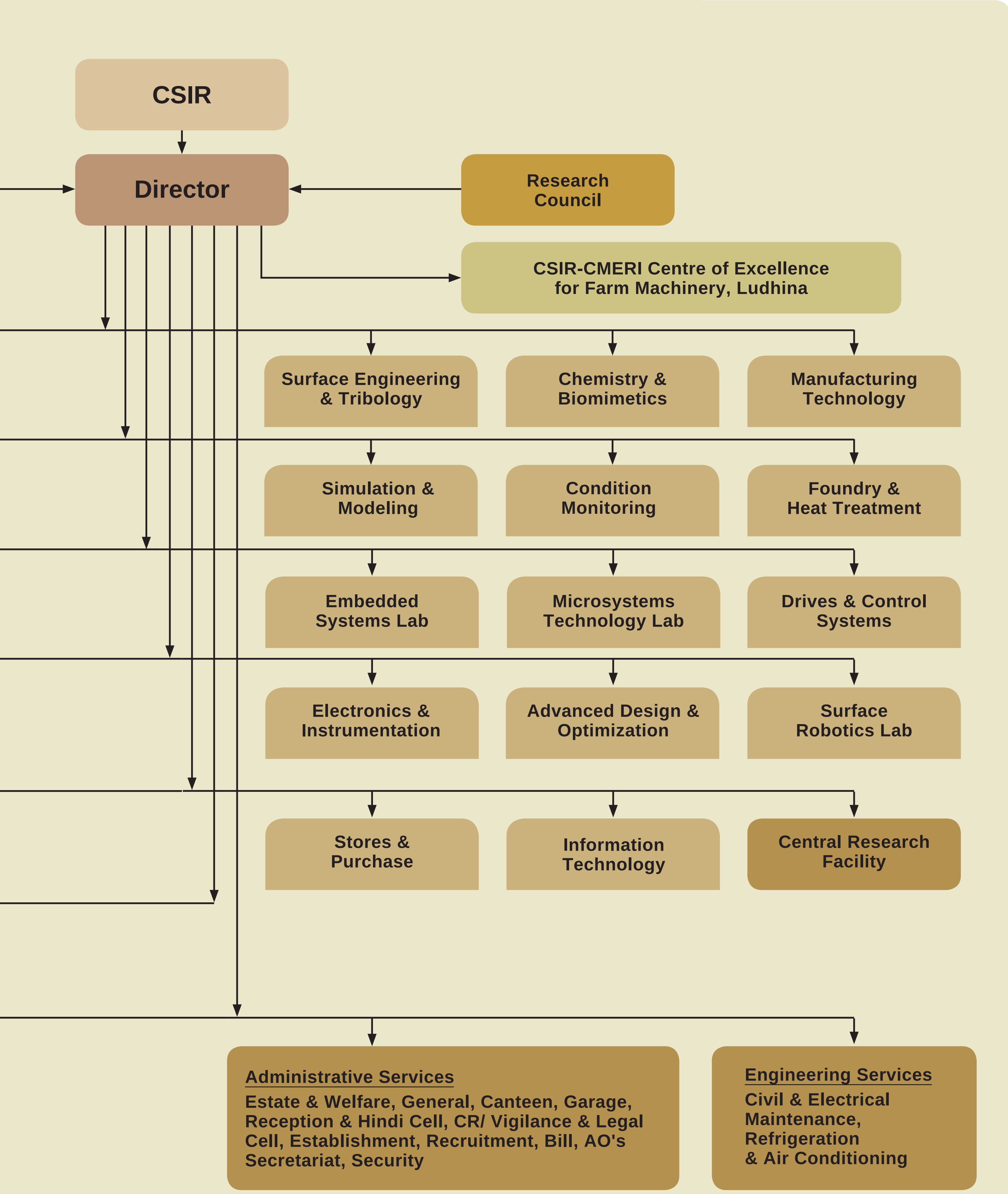

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Research Initiatives in the Recent Years

- Hybrid Controller for Micro/Nano Positioning
- Design of Light-weight Composite Cylinders for Storage of Compressed Natural Gas for Mobile Applications
- Damage Assessment, Residual Life Assessment and Failure Analysis of Power and Process Plant Components
- Diabetic Retinopathy
- Simulation & Modelling
- Autonomous Underwater Vehicle, AUV-150: A CSIR Initiative Towards Unmanned Oceanographic Exploration
- Precision Engineering and Metrology

Research Initiatives in the Recent years

Hybrid Controller for Micro/Nano Positioning

Introduction

The past two and half decade have witnessed the rapid growth of nano-science and nano-technology. Nano-technology is the science of understanding and control of matter at dimensions of 100nm or less. Nano-surfaces having geometric structures smaller than 100nm amplify certain chemical, physical and biological properties specific to the nanometric scale. The nano-surfaces behave differently with environments such as catalysts, magnetic energy, electronic emission/absorption, optical, antibacterial and pro-bacterial effects, etc. which has already been exploited for several high end applications. Currently, the demand for engineering of these nano-surfaces is growing rapidly. It can be applied to most industrial fields, including electronics, information & communication, mechanics, chemistry, bioengineering and energy, and the domain exhibits a remarkable potential to benefit human civilization. Ultra precision positioning technique-encompassing a host of technologies including mechanics, electronics, optics, control, design and processing has become a very important part of developing precision machines for manufacturing nano-systems. In ultra precision positioning, techniques such as scanning tunnelling microscope (STM) [1] and atomic force microscope (AFM) [2] have fundamentally changed research in numerous areas including biology, chemistry, materials science and physics.

In general, novel nano-positioning tools are also needed for the positioning of wafers, mask alignment and semiconductor inspection systems. Furthermore, they are vital in molecular biology for imaging, alignment and nano-manipulation as required, for example, in cell tracking and DNA analysis, nano-materials testing, nano-assembly and the manufacturing of small objects. Such nano-positioning systems are also crucial in optical alignment systems and even in next-generation space telescopes. The vast range of applications with operation under such diverse conditions poses new challenges for the control of nano-positioning devices because they necessitate high resolution, high bandwidth and robust control designs.

With increasing miniaturization, the ultra-precision positioning systems with long strokes of hundreds of millimeters in nanometer-accuracy are becoming more and more attractive. Most applications implementing high-resolution fast positioning systems ([3]-[5]) use piezo actuators. Indeed, the intrinsic piezoelectric characteristics make such actuators most suitable for fast and fine positioning over a very short stroke. Since this short stroke (≈100 μm) is not sufficient for different applications, the use of a double-stage structure is proposed to help in overcoming the intrinsic drawbacks of single piezo actuators [6]. A similar approach on a smaller scale, combining the effect of a fine piezoelectric with a coarse voice-coil has been recently proposed for Hard Disk Drives ([7], [8]).

The actuators generally used at the nano scale are piezoelectric actuators, magnetostrictive actuators, MEMS-based electrostatic actuators, MEMS-based electrostatic surface actuators, MEMS-based electromagnetic actuators and MEMS-based thermal actuators. Among these, the piezo actuator is most popular and is used widely for nanopositioning applications. PZT actuators have many advantages such as excellent operating bandwidth, generation of large mechanical forces in a compact design and for small amounts of power, etc. However, piezoelectric actuators have the disadvantages of hysteresis, resonant frequency and creep behaviours, which can be overcome by proper control system design. Other than that the main disadvantage is its stroke range, which is limited to 100 μm. It is therefore proposed that along with the precision actuator (piezo actuator) with nm accuracy, a coarse positioning actuator with μm accuracy be combined with a secondary stage to overcome the stroke limitation. There are quite a few options that can be used as a coarse positioning actuator e.g. DC servo motors, permanent magnet linear motors (PMLMs), Linear switched reluctance motors (LSRMs), permanent magnet stepper motors, voice coil motors, etc. Some companies are involved in designing and manufacturing nano positioning systems with DC motor/ stepper motor combined with piezo actuators.

In the 12th five year plan, CSIR-CMERI has submitted a sub project entitled **Development of Micro Machines** under a MEGA project. A challenging task associated with this project is the development of micro/nano positioning control system. The Electronics and Instrumentation Group of CSIR-CMERI has taken this opportunity to design and develop a micro/nano positioning control system. Permanent magnet stepper motors (PMSM) with micro stepping facility will be considered as the coarse positioning actuator along with a piezo actuator as the precision actuator. A hybrid positioning control system will be built to optimally combine the effect of the two stages on the controlled output position so as to reach the desired accuracy for micro machines. This article describes in brief the overall control strategy of the dual stage hybrid system and the different control issues and approaches for controlling the position of the piezo actuator and the PMSMs.

Global Control Strategy

A hybrid control structure for a double-stage mechanical system shall be developed to reach nanometer accuracy at high bandwidth over large displacements of several centimeter. A piezoelectric actuator with nm accuracy will be used for precision positioning while a permanent magnet (PM) stepper motor with μm accuracy will handle the long travel distance, i.e. the coarse positioning. The schematic diagram of the overall control system is shown in Figure 1. The hybrid control system can be broken down into the two steps. In the first step, development of a coarse positioning controller with micro stepping control drive for the stepper motor undergoing large stroke operation is proposed. During the coarse positioning process, the corresponding controller with actuator (stepper motor) will be used to control the positioning stage with large travel range and high-speed abilities. Once the output response reaches a preselected final value within the steady-state position error (e.g., 20μm), the control model

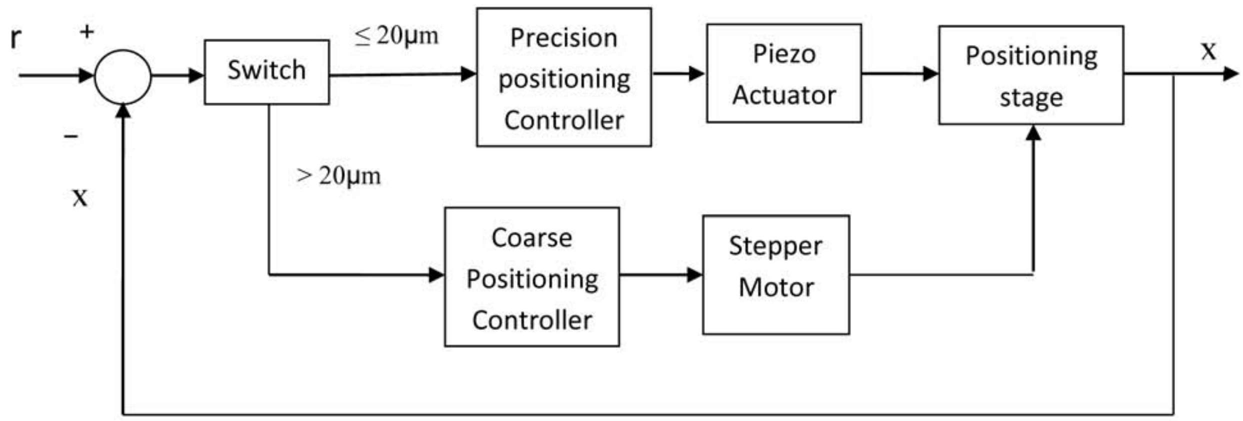

Figure 1. Schematic diagram of the system

is switched to the precision positioning control loop consisting of the precision positioning controller and the piezo actuator to reach the final position with nm accuracy.

Control Issues and Approaches of Micro Stepping Stepper Motor

Microstepping controller can be used to improve the motion stability and resolution of permanent magnet stepper motors (PMSMs). Open-loop microstepping PMSMs have high position resolution (depending on the step number) and largely eliminates the jerky characters typical of low-speed PMSM operations and noises at intermediate speeds [10]. On the other hand, in open-loop microstepping control, currents are decreased due to the back emfs and phase lags are experienced due to the phase inductances. Thus, various feedback control methods have been developed to improve the performance of microstepping [11]–[18].

Microstepping with proportional and integral (PI) current feedbacks was used to compensate for the back-emf in [11]. For low cost and simple implementation, pulse width modulation (PWM) drivers with current proportional and integral (PI) feedback have been used in industry applications [12], [13].

PI feedback alone fails to effectively compensate for the effects of both the back-emfs and the inductances. Microstepping with PI current feedback and feed-forward was proposed to improve the tracking performance of the desired currents [14]. A microstepping method with a proportional-integral-derivative (PID) controller has also been designed [15] which reduces the effects of random signals on the accuracy, but the stability of the closed-loop was not proven. Furthermore, this method requires position feedback.

Lyapunov-based controller for microstepping proposed in [16] guarantees exponential convergences of the currents to the desired currents required for microstepping, but requires full state feedback. To resolve this problem, a passive nonlinear observer was designed to estimate the full state [17]. In [18], an adaptive observer-based nonlinear control for microstepping was designed to track the desired position and estimate the phase resistances. The velocity and the phase resistances are estimated in the adaptive observer.

Various nonlinear controllers have been developed in order to improve the position tracking performance of the PMSMs by using direct-quadrature (DQ) transformation [19]–[23].

Robust adaptive nonlinear control algorithm will be implemented in microstepping stepper motor as coarse positioning controller to achieve the desire performance.

Control Issues and Approaches in Piezo Actuator

Due to the increasing interest in using model-based control design techniques of piezoelectric actuators to improve the precision and speed of the devices, interest has been rekindled in understanding the dynamics of these actuators. A number of studies have been performed in this area, e.g., [24]–[28] and the references therein. The challenges, issues and approaches of the control of piezoelectric actuators are discussed in this section.

- Creep: Creep is an undesirable property common to piezoelectric actuators. It can result in significant loss in precision when positioning is required over a long period of time. Piezoelectric creep is related to the effect of the applied voltage on the remnant polarization of the piezo actuator. A number of approaches have been proposed to deal with this phenomenon e.g. Nonlinear Creep Model, Linear Creep Model, etc.
- Hysteresis: Hysteresis is the main form of nonlinearity in piezoelectric transducers between the displacement and electric field strength. It causes positioning errors which critically limit the operating speed and range of piezoactuators.
- Vibrations: Vibrations constitute a major obstacle in achieving high-speed nanopositioning in applications such as scanning probe microscope (SPM). The vibrations are induced when the positioning bandwidth is increased relative to the first resonant mode of the piezoelectric actuator.
- Modelling Errors: The system performance (controller design) should be robust to the presence of modelling errors due to parameter variations and unmodeled dynamics.
- Moreover, the controller design has to consider tradeoffs between the bandwidth, precision, and range of a piezoelectric actuator.

The different approaches on controller development for nanopositioning with piezoelectric actuators are broadly classified into feedback, feed-forward, iterative, and sensorless controls.

Feedback: The integral controller can overcome creep and hysteresis effects and lead to precision positioning since the vibration dynamics is not dominant at low frequencies. The proportional-integral-derivative (PID) feedback controllers are used for nanopositioning [29], [30] and are popular in SPM applications [31]. Also, considerable research effort has gone into the automated tuning of the PID parameters [32] as well as in rendering the existing integral controllers more robust [33]. The main challenge in feedback design is performance improvement while maintaining the stability of the overall system in the presence of parameter uncertainty and unmodeled high-frequency vibration modes [34]. Advanced control techniques have therefore been applied to significantly improve the precision and bandwidth of piezoelectric actuators used in nanopositioning. These control techniques include state feedback [35], adaptive methods [36], [37], and lead/lag methods [38]. Furthermore, robust control techniques have been developed in [39], [40] and [41].

Feed-forward: Several methods have been proposed to deal with hysteresis in piezoceramics, most of which are based on feed-forward inverse compensation schemes, which invert mathematical models of the hysteresis nonlinearity to determine hysteresis-compensating inputs. Such hysteresis inverse is sufficient during low-frequency operation since creep can be corrected using feedback and vibrations are not significant at low frequencies. The inversion is a two-step process. First the hysteresis is variously fitted with polynomials [42], exponentials [43], the Preisach model [44], the MRC model [45], the Prandtle–Ishlinskii model [46], multiple linear-play models [47], differential equation models [48], deterministic path models [49], etc. Then the model is inverted in a second step. An alternative approach is to directly capture the inverse model (e.g., using a Preisach technique) and use it to determine the input signal [50]. In particular, inversion-based feed-forward controllers (which are model-based) cannot correct for tracking errors due to plant uncertainties [51]. Therefore, it is necessary to use feedback in conjunction with feed-forward to reduce uncertainty-caused errors in the inverse input.

Iterative Control: If the positioning application is repetitive (e.g., periodic scanning of the SPM probe), iterative methods can be used to improve the positioning performance. Adaptive and iterative control approaches lead to a reduction in hysteresis effects, and thereby an improvement in positioning precision, e.g., [32], [36], and [37]. Iterative control can significantly increase the operational bandwidth of piezoelectric actuators without loss of positioning precision.

Sensorless Control: The idea of sensorless control of scan-induced vibrations in piezoelectric tube scanners is based on the observation that a piezoelectric transducer can function as an actuator, a sensor, or both simultaneously. Exploiting this embedded sensing capability of piezoelectric transducers eliminates the need for an external sensor in feedback-based vibration control systems.

Conclusion

To achieve nanometer accuracy over high-frequency bandwidth and large total spatial displacement (several centimeters), a double-stage system combining a piezo actuator and a permanent magnet stepper motor with micro stepping facility has been proposed. Different issues and control approaches for driving the PMSM and to drive the piezoelectric actuator will be modelled for simulation study followed by the experimental model. Commercial entities such as M/S Physik Instrumente (PI) - Germany, Attocube Systems AG Company - Germany and M/S Aerotech - USA design and manufacture such products. The knowledge gathered through the implementation of the present proposal will be useful in the future for the development of high precision control systems for different applications.

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Research Initiatives in the Recent years

Design of Light-weight Composite Cylinders for Storage of Compressed Natural Gas for Mobile Applications

Introduction

The design of light-weight composite pressure vessels for operation at very high pressures is a complex problem involving many considerations including definition of the operating and permissible stress levels, failure criteria, material behavior, etc. For the purpose of developing the design philosophy and the relative operational limitations of various approaches, the elastic strength or yielding pressure of the vessel is used as the criterion of failure.

A typical CNG Type II cylinder includes a metal liner and a composite wrap (Figure 1). This pressure vessel is also called hoop-wrapped since the composite wrap is only around the cylinder sidewall in the hoop (or circumferential) direction. This pressure vessel is so designed that the liner without the wrap can withstand the maximum filling pressure (1.25 times the service pressure). The metal liner supports up to 55% of the internal gas pressure and composite wrap supports the remaining 45%. The liners are manufactured using AISI 4130 low alloy steel or AA 6061-T6 aluminum alloy and the composite wrap is manufactured from glass or carbon fibers in epoxy or polyester resin. Thus, a CNG Type II cylinder is lighter than a CNG Type I cylinder, which is a fully metallic cylinder.

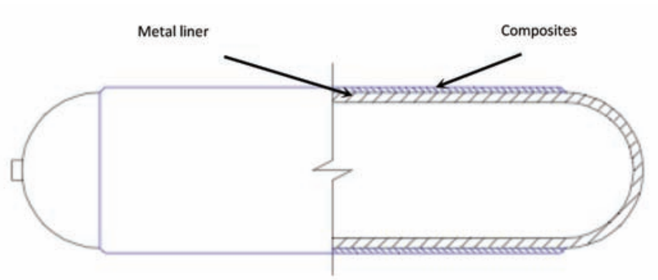

Figure 1. Cross-section of CNG-2 (Hoop-wrapped) cylinder

Analysis and Design of the Composite Cylinder using FEM

Figure 2 shows the major design parameters of the Type II storage vessel. It is desired to calculate the optimum thicknesses of the liner and composite wrap, and the dome profile. These

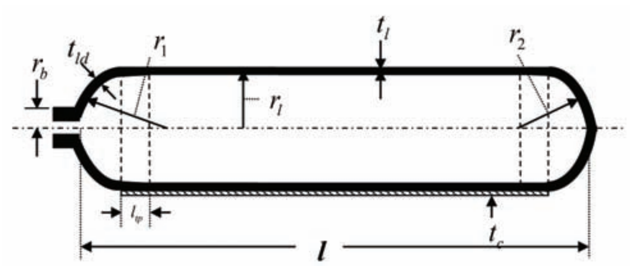

Figure 2. The generic geometry of the cylinder showing the design parameters.

parameters are determined using an analytical method as well as by finite element analysis (FEA). The commercial FEA software ANSYS (Version 14.0) has been used to perform stress analysis of the pressure vessel. The finite element model for analyzing the vessel is a three-dimensional (3-D) quarter model, the shape and element division of which are shown in Figure 3. Hexahedral elements have been used for the finite element analysis because of its overall accuracy and appropriateness along the direction of thickness. A sufficient number of elements were taken along the direction of thickness of the metal liner and the composite

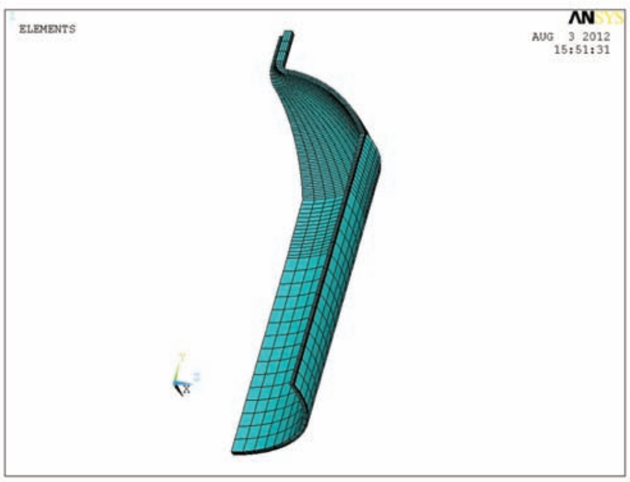

Figure 3. The shape and element division of the pressure vessel model

material. SOLID185 and 3-D 8-Node Structural Solid elements are used to mesh the metal liner, whereas SOLSH190 and 3-D 8-Node Layered Structural Solid elements are used for the composite material. A symmetric constraint condition in the tangential direction and a constrained displacement in the axial direction have been applied to the model. Finite element analysis was conducted by applying the design pressure on the inner surface of the metal liner.

Finite Element Results

Figure 4 depicts the von-Mises stress distribution in the metal liner (having no composite wrap) of thickness 4.5 mm while subjected to a typical internal pressure of 26.0 MPa. It is observed that the von-Mises stress is largely within the yield limit of the material, except in a very thin band near the cylinder-dome junction. This can be avoided by smoothening the geometry at this junction where abrupt change in curvature takes place.

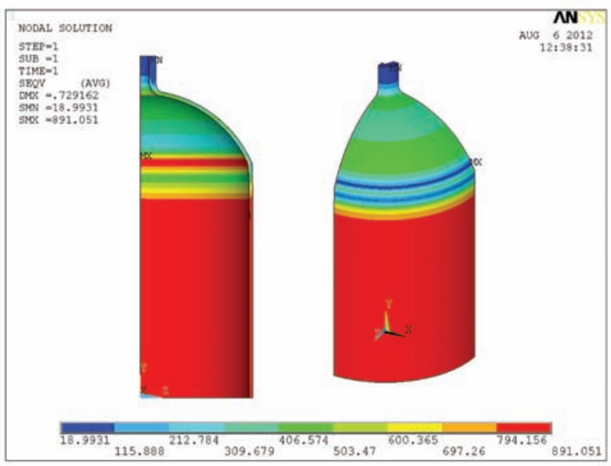

Figure 4. von-Mises stress distribution in the liner on loading at 26.0 MPa.

The radial and circumferential stress distributions in the composite hoop wrap are shown in Figures 5 and 6.

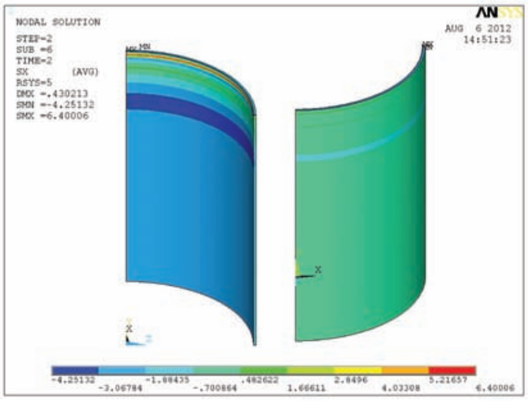

Figure 5. Residual radial stress distribution in the hoop wrap of the pressure vessel.

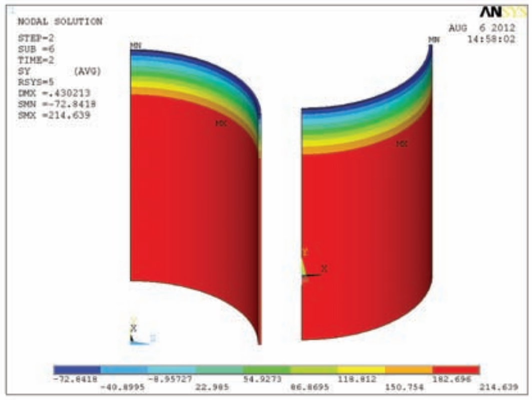

Figure 6. Residual circumferential stress distribution in the hoop wrap of the pressure vessel.

Research Initiatives in the Recent years

Damage Assessment, Residual Life Assessment and Failure Analysis of Power and Process Plant Components

The NDT & Metallurgy Group of CSIR-CMERI has high creditability and a wealth of experience in the field of Damage assessment, Component integrity assessment, Residual Life Assessment (RLA) and in-service failure studies of the power and process plant components. These activities directly contribute to significant improvement in useful life of the individual components of the different thermal power and process plants. The studies are important in respect of cost effective renovation and modernization of ageing thermal power stations. Many of the power plants in India are old and require appropriate renovation for future operation, which needs in-depth study of the present component damage. Component integrity and Residual Life Assessment provides the damage assessment trend of individual components. Failure analysis is also important to predict the root cause/s of the failure/s and also the remedial action that need be taken to avoid similar failure in future. The beneficiaries of the studies include industries like NTPC, DVC, WBSEB, CESC, PSEB, Hindalco and many other power plants.

The institute has developed a strong interface with various power and process plants across India over a long period of time, and life assessment related activities are considered to be one of the major thrust areas in CSIR-CMERI. CSIR-CMERI is recognized as a **Well Known Remanent Life Assessment Organization** by the **Central Boiler Board, Ministry of Commerce and Industries, Government of India**.

Apart from the projectes and activities related to Life Assessment and Failure analysis, this Group is recently undertaking a clutch of R&D projects in the area of high temperature damage assessment, remaining life assessment, high temperature corrosion and fatigue & fracture. The major ongoing project/ activities in the year 2011-2012 undertaken by the Group are as follows.

1. Component Integrity and Life Assessment study of different Boiler components (U-1, 2, 3 & 4) at CESC, Titagarh, Kolkata

The objective of the project is to review damage assessment trend and to formulate futuristic approach to avoid any unscheduled outages. Damage assessment due to high temperature creep, thermal fatigue, corrosion, oxidation, erosion, etc. is carried out through different Non-Destructive testing including in-situ metallography (surface replication) and hardness. The

Remaining Life Assessment study of the critical components is carried out by applying various models of high temperature damage. In-situ nondestructive examination of the components is carried out in the plant site and the results are analyzed in the laboratory. The project report contains run, repair and replacement of the individual component, which are necessary for the life extension and renovation and modernization programme. Some of the significant results are incorporated in Figure 1.

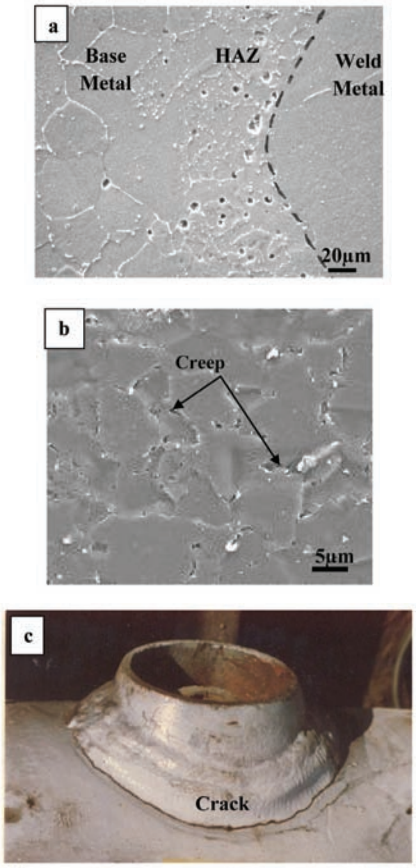

Figure 1. (a) Creep Damage assessment of weld-HAZ – base metal of thick walled platen superheater outlet header, (b) Oriented creep cavities at the grain boundaries of service exposed main steam line and (c) Circumferential crack in Secondary Superheater outlet header.

2. Validation of existing RLA data using ALIAS software and creating a RLA database for In power plants TAREMaC Network project under 11th Five Year Plan

Various methodologies are used to estimate the remaining life of the components from the Non Destructive inspection data as well as evaluation of the microstructure. Input data is collected from on-site inspection. Based on the data, remaining lie assessment of the components is carried out, which needs to be refined for real life prediction. The data are also used as input for validation through the ALIAS software. Collected primary data are restructured by the ALIAS software to formulate a guideline for component replacement.

3. High temperature corrosion protection of Cr- Mo steel by the use of reactive Oxide Coating

The primary objective of this project is to study the performance of different reactive oxide coatings (CeO_2 and Y_2O_3) over Cr-Mo steels to improve high temperature corrosion resistance in different industrial applications (thermal power plants and petroleum refineries). The project also aims to create a new research facility in CSIR-CMERI on High Temperature Corrosion testing of different materials used for the industry. The research facility includes high temperature vertical tubular furnace with thermo gravimetric attachments, powder jet coating machine and optical microscope. The different reactive oxide powders (CeO_2 and Y_2O_3) are used for coating over Cr-Mo steel substrate. The coated specimens are heated in a high temperature furnace for measuring the corrosion rate through thermogravimetric studies. Post-corroded specimens are then characterized in SEM, EDS and XRD to examine the scale morphology. Some of the results emanating from preliminary studies are highlighted in Figure 2 and Figure 3.

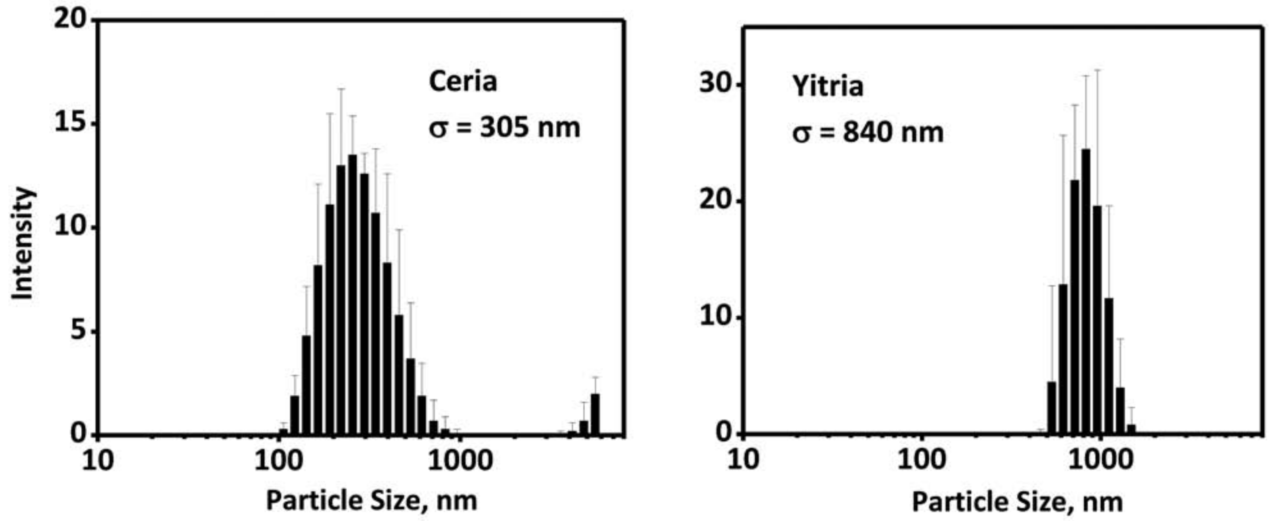

Figure 2. Particle size analysis of CeO_2 and Y_2O_3 powder before coating

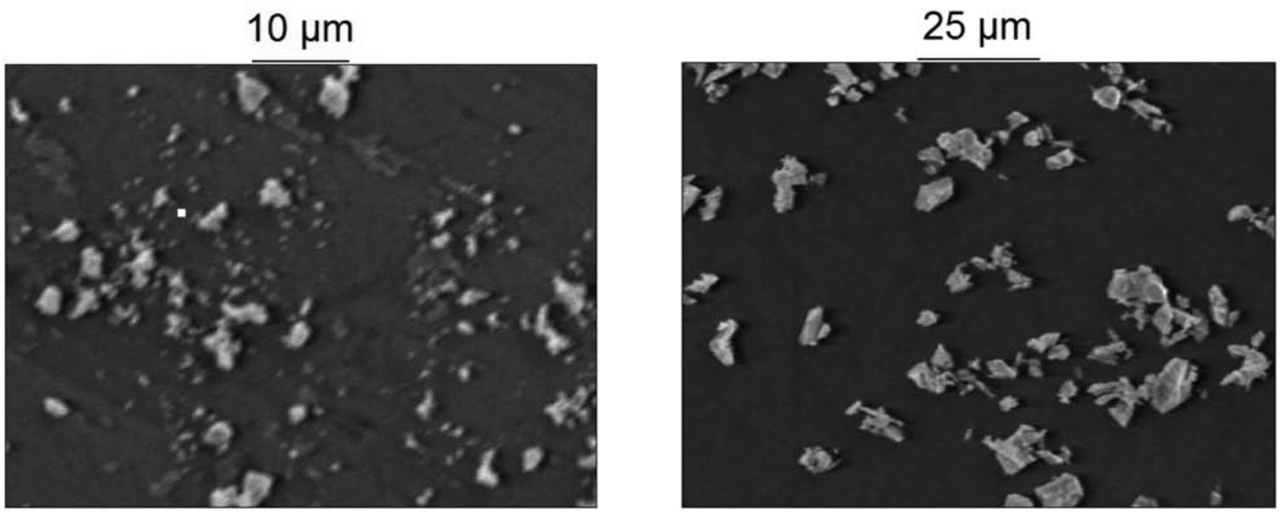

Figure 3. SEM examinations of particle morphology of (a) CeO_2 and (b) Y_2O_3 powder

4. Industry sponsored RLA and failure analysis

RLA and failure analysis was carried out in DVC, Chandrapura and Bokaro, CESC, Gardenrich and Titagarh as sponsored activities. The aim of the study is to generate information regarding component damage and probable root cause/s of failures, which is essential need for the industries for useful running of the component. Some of the significant results are shown in Figure 4 and Figure 5.

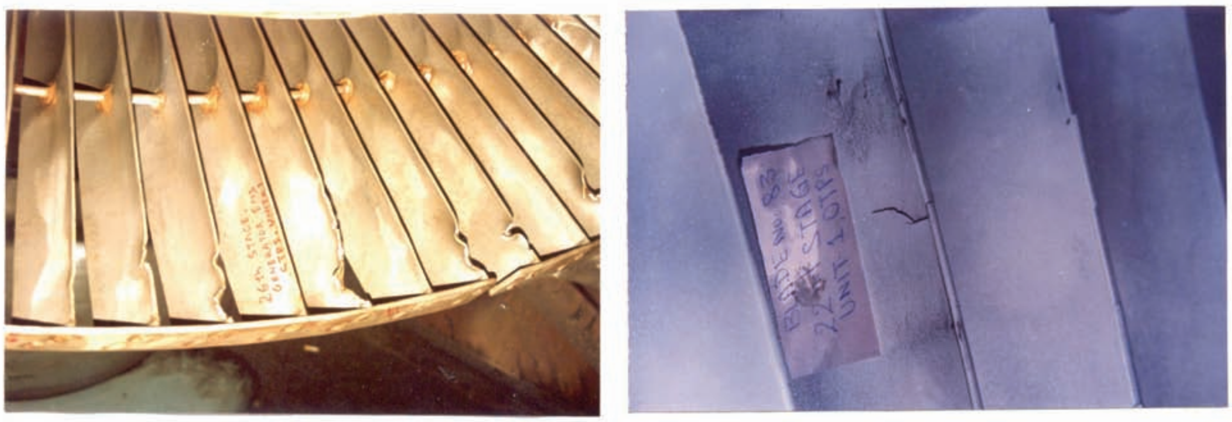

Figure 4. Non Destructive Examination reveals (a) Dent marks in turbine blades and (b) Cracks on turbine blades

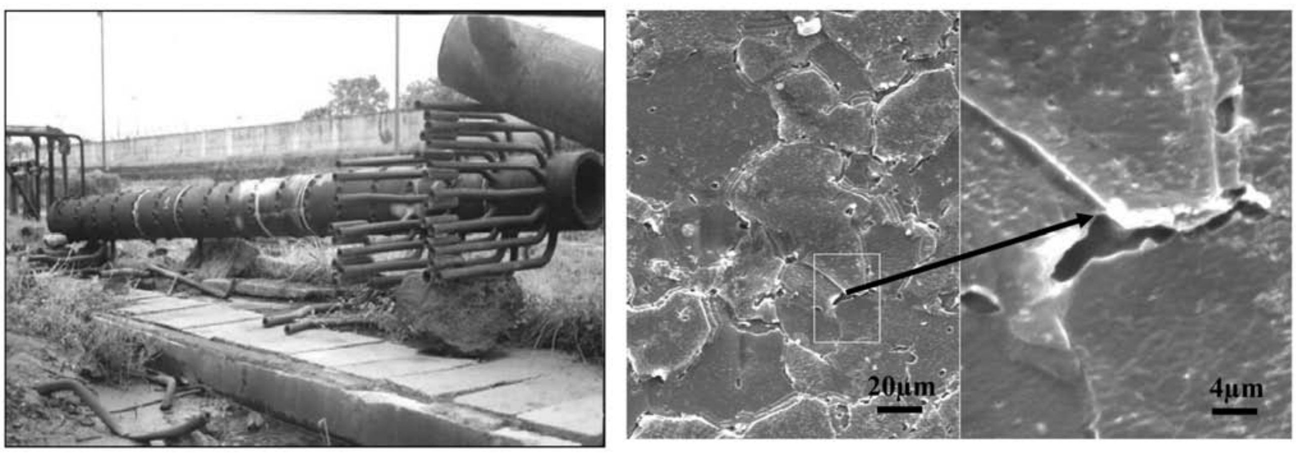

Figure 5. (a) As received photograph of premature failure of the platen superheater outlet header and (b) Micro structural analysis shows the creep cracking at the grain boundaries at the failure zone

Academic Research Activities

In-situ microstructural and sub-structural variations of AISI 304 LN stainless steel during monotonic and cyclic fracture tests

Preliminary research work has been carried out at the University of Bayreuth, Germany as part of the Boyscast Fellowship awarded to one Scientist of the Group. In this work, structural variation ahead of crack tip during monotonic fracture toughness and cyclic fracture toughness tests of AISI 304LN stainless steel have been investigated. The monotonic fracture toughness tests are carried out using standard J-integral technique whereas the cyclic fracture toughness tests are evaluated using periodic unloading to different extents fixed by a predetermined stress-ratio, R. The associated structural variations adjacent to the fracture surfaces are characterized in terms of the nature and the amount of deformation-induced martensite using microstructural analysis, X-ray diffraction, hardness measurement, ferrofluid technique and transmission electron microscope (TEM). The obtained results reveal that monotonic fracture toughness specimens exhibit higher deformation-induced martensite as compared to cyclic fracture toughness specimens, and the latter exhibits variation in the martensite content with change in the R ratio. The dislocation substructure also changes rapidly with decreasing stress ratio for cyclically deformed samples. Associated significant structural variations in cyclic fracture toughness specimens have been explained by variation in energy expended during crack propagation and different residual stress fields ahead of cracks in cyclic fracture toughness as compared to monotonic fracture toughness specimens. Some of the significant results are shown in the Figures 6 through 9.

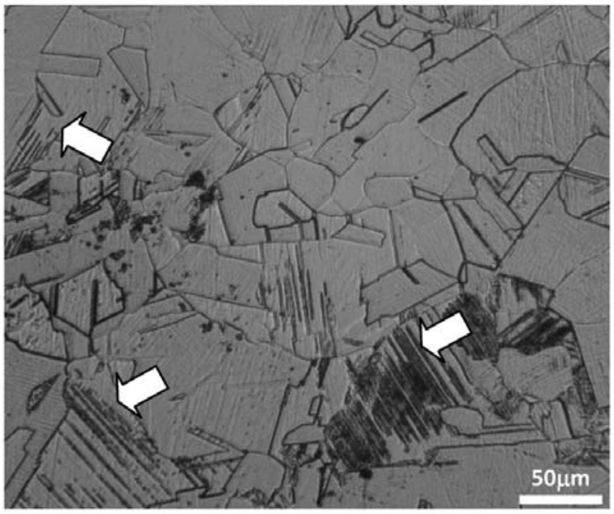

Figure 6. Formation of deformation-induced martensite in AISI 304LN SS

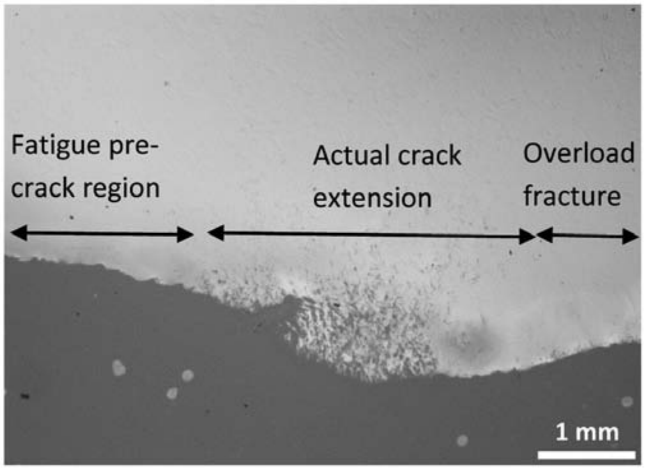

Figure 7. Deformation induced martensite in AISI 304LN SS near the crack front revealed by coating the region by ferrofluid.

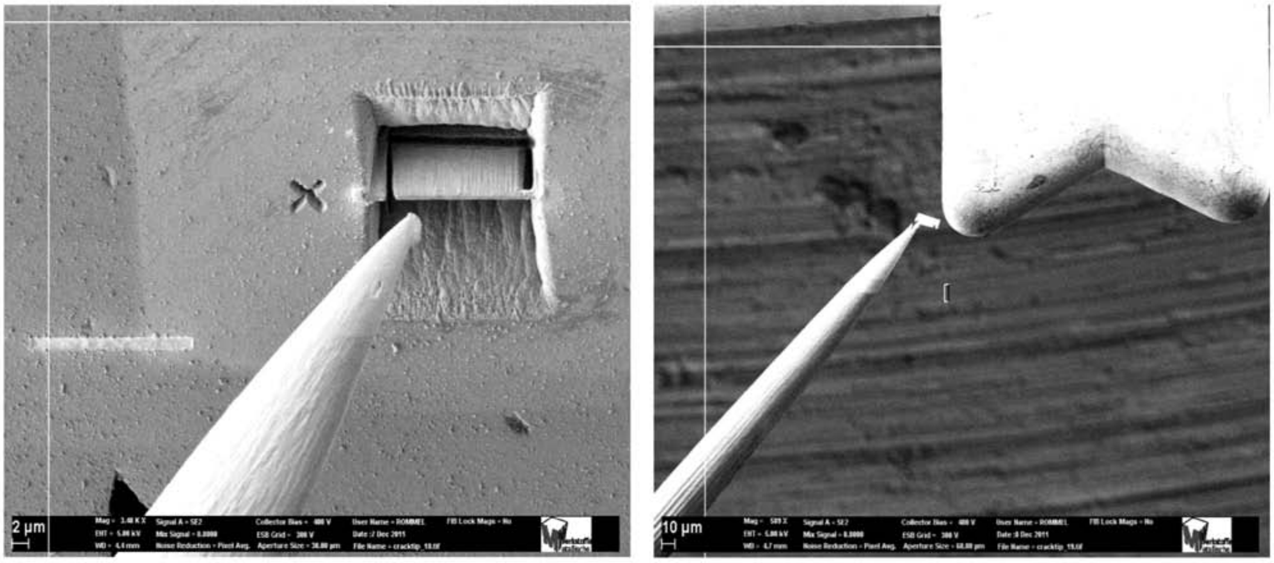

Figure 8. Extraction of FIB lamellae near the crack front for TEM analysis.

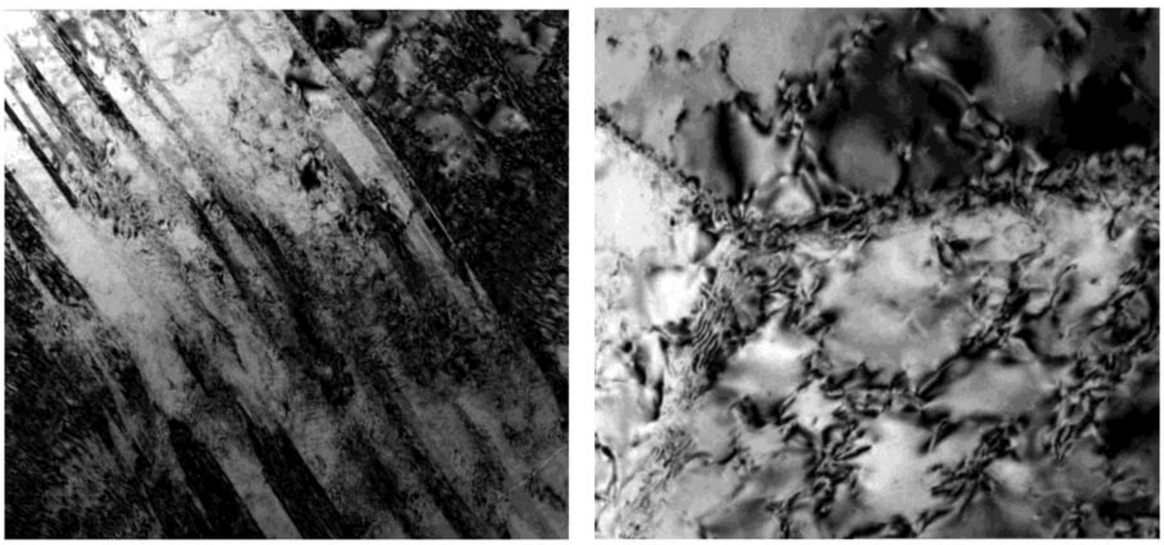

Figure 9. TEM analysis reveals (a) Presence of martensite in monotonic specimens and (b) Presence of cell structure in cyclic specimens.

Participation in 12th FY Megaproject

A project entitled **Nano scale reactive oxide coatings for high temperature corrosion resistance applications** has been submitted under the mega project **Robotics and Micro machines.** The primary objective of this project is to study the performance of nanoscale reactive coatings for the improvement of the high temperature corrosion of different industrial components like boilers, turbines, aerospace and petrochemical and refinery industries. The research work proposes to develop nanoscale reactive oxide coatings over substrates of Cr-Mo steels, stainless steel and Ni base super alloys for improvement of corrosion resistance in high temperature components. Different nanoscale reactive oxide powders (CeO_2, Y_2O_3 and YSZ) are to be used as coatings. The coated materials would then suitably be heated in a furnace with thermogravimetric attachments for high temperature corrosion studies. The corrosion rate, reaction kinetics and the scale morphology of the post-corroded specimens would be studied.

Research Initiatives in the Recent years

Diabetic Retinopathy

Introduction

Diabetic Retinopathy (DR) is an eye disease which occurs due to diabetes, where damages of the small blood vessels in the retina take place resulting in loss of vision. The risk of the disease increases with age and therefore, middle aged and older diabetics are prone to Diabetic Retinopathy. According to the National Diabetes Information data (US), a total of 20.8 million people i.e. 7% of the US population have diabetes out of which only 14.6 million cases are diagnosed. Further, the risk of blindness in patients with diabetes is 25% more than those without. India also has the highest number of diabetics in world with DR, which is the sixth biggest cause of vision impairment in the country. The disease, however, can be cured on precise, early and thorough regular screening, thereby preventing loss of vision for many Indians.

Color fundus images are used by ophthalmologists to study eye diseases like diabetic retinopathy. For doctors, it is very important to clearly detect and distinguish the blood leakages, haemorrhages and lesions from amongst the numerous blood vessels that are present in the eye. An important feature of this serious blinding disease is that detectable changes takes place in the retina (as shown in Figure 1) which can be cured using laser treatment, if detected at an early stage. Detection of DR at an initial stage helps in reducing its severity and consequently has far reaching consequences.

It is well known that image enhancement techniques improve the quality of retinal images. Enhancing the image improves the image quality so that the processed image is better than

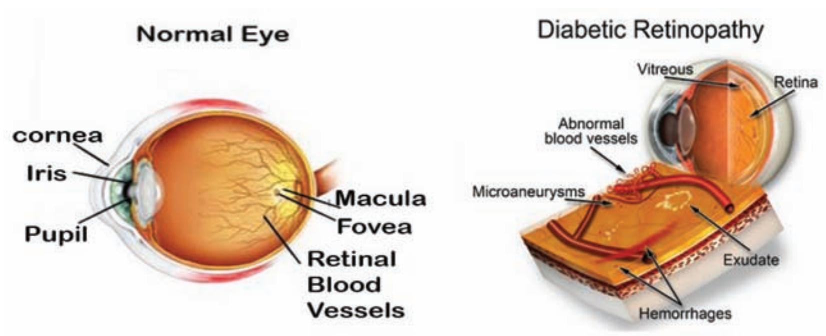

Figure1. Observable changes in diabetic retinopathy affected eye as compared to a normal eye

the original image for a specific application or a set of objectives. It improves the quality of low contrast images i.e., enlarges the intensity difference among objects and background. The aim of image enhancement is to improve the interpretability or perception of information in images for human viewers or to provide better input for other automated image processing techniques.

Retinal images are acquired with digital fundus camera, which captures the illumination reflected from the retinal surface. Despite the controlled condition under which imaging takes place, there are many patient-dependent aspects which are difficult to control. Thus, most retinal images suffer from non-uniform illumination. Some of the contributing factors are:

a. The curved surface of the retina: consequently, all retinal regions cannot be illuminated uniformly
b. Imaging requires a dilated pupil: the degree of dilation is highly variable across patients
c. Unexpected movements of the patient's eye: the bright flash-light makes the patient move his/her eye away from the view of the camera involuntarily
d. Presence of other diseases such as cataract which can block the light reaching the retina

These factors result in images having a large luminosity and contrast variability within and across images. Hence, for reliable diagnoses, whether manual or automated, an image normalization step is necessary.

Research Background

Recent statistics provided by the National Eye Institute estimate that 40 to 45 percent of Americans having diabetes are affected by diabetic retinopathy due to which around 24,000 people turn blind every year. Retinopathy is a progressive disease, which can advance from the mild to the proliferative stage. There are three stages: (i) early stage or non-proliferate diabetic retinopathy (NPDR) or background retinopathy, (ii) maculopathy and (iii) progressive or proliferate retinopathy. These stages of DR are shown in Figure 2.

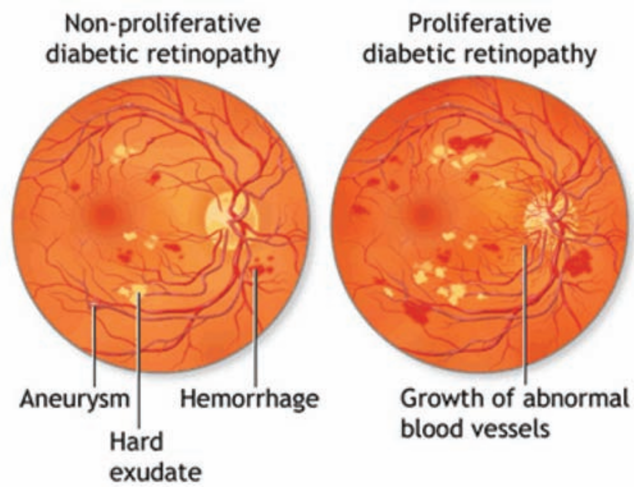

Figure 2. Main stages of Retinopathy with the disorders

The early stage is further classified into mild NPDR and moderate-to-severe NPDR. In mild NPDR, signs such as microaneurysms, dot and blot haemorrhages and hard or intra-retinal exudates are seen in the retinal images. Microaneurysms are small, round and dark red dots with sharp margins and are often temporal to macula. Their size ranges from 20 to 200 microns i.e., less than $1/12^{th}$ the diameter of an average optic disc and are first detectable signs of retinopathy. Haemorrhages are of two types: Flame and Dot-blot haemorrhages. Flame haemorrhages occur at the nerve fibres and they originate from pre-capillary arterioles, which are located at the inner layer of the retina. Dot and blot haemorrhages are round, smaller than microaneurysms and occur at the various levels of the retina, especially at the venous end of capillaries. Hard exudates are shiny, irregularly shaped and found near prominent microaneurysms or at the edges of retinal oedema. In the early stage, the vision is rarely affected and the disease can be identified only by regular dilated eye examinations.

In moderate to severe NPDR, the signs discussed in mild NPDR are present in excess and in addition to this cotton wool spots, venous beading, venous loops and intra-retinal micro vascular abnormalities (IRMA) are observed. Cotton wool spots or soft exudates are infractions in the nerve fibre layers of retina which are round or oval in shape, pale yellow-white in colour and are results of capillary occlusions causing permanent damages to the functions of retina. IRMA represents areas of dilated capillaries located in the retinal planes. Venous beading relates to localized increase in the venous calibre, which resembles a string of beads. This disorder affects the veins in the retina and is always found with microanurys, which helps in differentiating DR from other retinal diseases.

Diabetic Maculopathy is a stage where fluid leaks out of the damaged vessels and accumulates at the centre of the retina called macula (which helps in seeing the details of the vision very clearly) causing permanent loss of vision. This 'water logging' of the macula area is called clinically significant macular oedema and can be treated by laser treatment.

Proliferate diabetic retinopathy, which is defined as the growth of abnormal new vessels (neovascularization) on the inner surface of the retina, are divided into two categories: neovasculature of the optic disk (NVD) and neovascularisation elsewhere in the retina (NVE). The above stages can be seen clearly in Figure 3 which shows different changes that

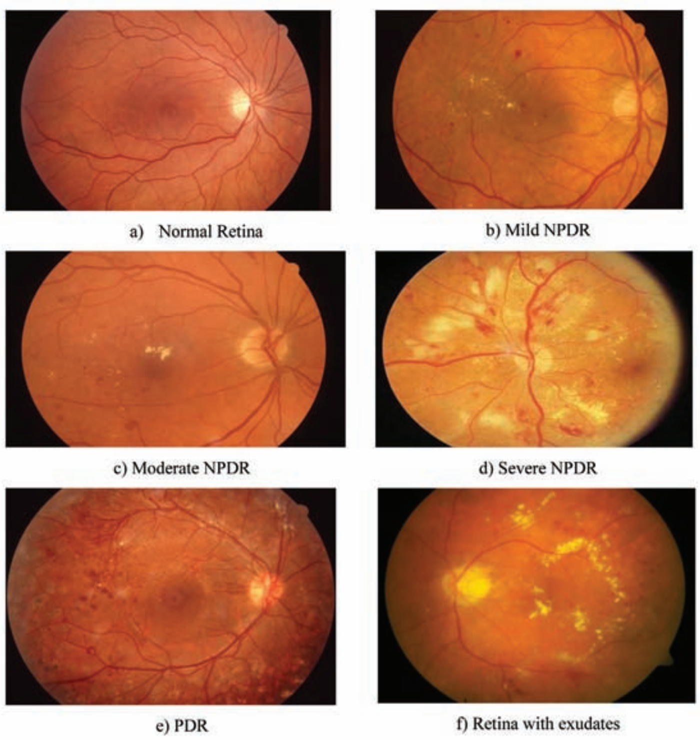

Figure 3. Different stages of Diabetic Retinopathy

take place in the retina of a DR patient over a period of time.

Proposed Research Work

Research to be undertaken on DR at CSIR-CMERI proposes to develop a prototype of an intelligent portable device which can test the retina by *in situ* photography and image processing for the purpose of early detection of diabetic retinopathy without qualified medical intervention. The detailed schematic is shown in the Figure 4.

The retinal images are obtained with a fundus digital imaging camera. These images are routed through the pre-processing stage before subjecting the same to actual algorithms. Here the Contrast Limited Adaptive Histogram Technique (CLAHE) algorithm is selected for image enhancement. The defect is classified into Non-proliferative DR (NPDR), Mild, Moderate, Severe and Very Severe categories. The classification is done using the rule based algorithm which operates on the image where individual images are divided into 4 quadrants. If at least one microaneurysm such as clinically detectable lesion, retinal haemorrhages, hard or soft exudates is present in at least one quadrant, then it can be categorised as mild NPDR. Microaneurysms and/or dot and blot haemorrhages such as soft exudates (cotton wool spots) venous beading or IRMA (intraretinal microvascular abnormalities) present in at least one quadrant can be categorised under moderate NPDR. Presence of microaneurysms

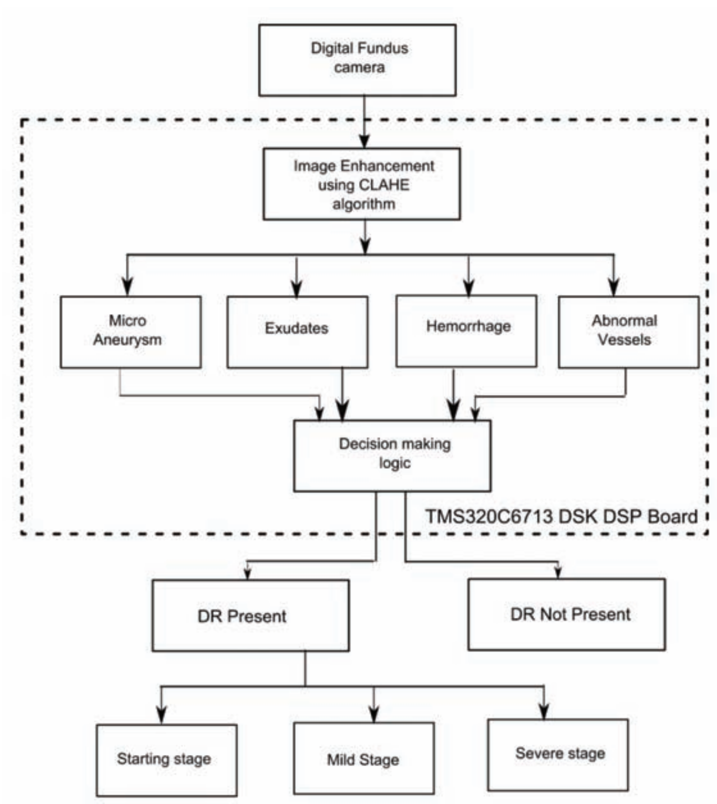

Figure 4. The detailed schematic view

or hemorrhages in all 4 quadrants or Moderate IRMA / Venous beading in 2 or more quadrants or abnormal blood vessel growth at least 1 quadrant follows what is commonly known as the 4-2-1 rule and is categorized as severe. For very severe any two of the features of the 4-2-1 rule is present.

Conclusion

Early delectation of diabetic retinopathy will have highly positive impact on the health of eye of the rural and also a part of urban population, who cannot get their retina tested in time because of the lack of awareness or hospital facility in their vicinity.

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Research Initiatives in the Recent years

Simulation & Modelling

From its very inception, the Simulation & Modelling Laboratory of CSIR-CMERI has been actively engaged in numerical simulation and mathematical modelling of transport processes occurring in diverse fields of engineering and physics. Both fundamental as well as strong application-oriented studies are undertaken by the concerned Scientists to understand the basic underlying physics of the pertinent transport phenomena. The group has already created and nurtured state-of-the-art computational facilities in terms of hardware and software to cater to the constant need for massively involved computational works under the mentorship of the Director, CSIR-CMERI, who himself is an internationally acclaimed expert in Computational Fluid Dynamics (CFD). Indigenous codes based on finite element, finite difference and finite volume Navier-Stokes solver, immersed boundary (IB), AUSM+ scheme, lattice Boltzmann method are developed for various fundamental problems; commercially available CFD solver 'Fluent' is also used for topologically complicated problems commonly encountered in industrial applications.

Lab-on-a-chip devices, commonly referred to as "micro total analysis systems (µTAS)" and made possible by the advent of microfabrication technology, miniaturization and integration of biomedical and biotechnological protocols are becoming increasingly important in the fields of genomics, proteomics and clinical analysis. There has been a flurry of multidisciplinary research centered around microfluidic and biological systems. A big challenge is being undertaken by the group to understand through numerical simulation the interfacial characteristics of two-layer electroosmotic micro-flows occurring under the action of time periodic electrical fields (Figure 1). The upper fluid layer may be considered to be electrically non-conducting, so that electroosmosis in the bottom layer transmits the

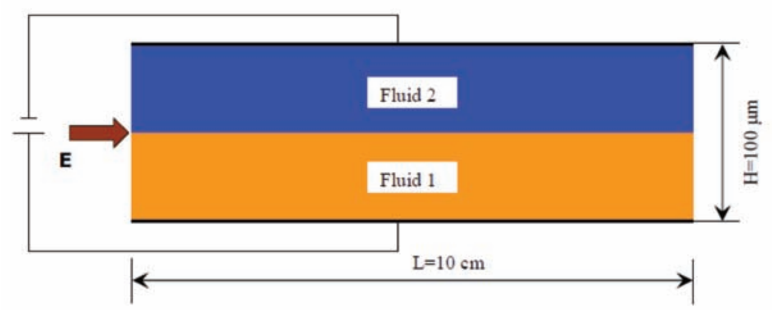


Figure 1. Two layer electroosmotic flow in microchannel under time periodic electric field

necessary shear to the upper layer for inducing a relative motion between the two layers as a consequence of an applied electrical field. Such two-fluid flows in microchannels are often used in biological analysis, such as during ion exchange or solvent extraction from one phase to another phase, transport of non-polar fluids using electroosmotic flows, etc.

Another important work in this category in which the future activity of the group will be directed would comprise comprehending the dynamical response of living biological cells in microscale conduits in response to either a chemically changing environment or shear stress imparted by the background flow. This turns out to be of profound importance in designing and optimizing advanced lab-on-a-chip based biomicrofluidic devices.

Computational studies of fluid flow and heat transfer in high energy materials processing applications have been a subject of intense research for several decades. Scientists of the group are engaged in formulating accurate mathematical models to address the coupled turbulent momentum, heat and species transport during molten metal-pool convection in association with continuous evolution of solid-liquid interface typically encountered in high energy materials processing applications such as laser cutting, laser drilling, laser cladding and laser surface alloying (Figure 2), etc.

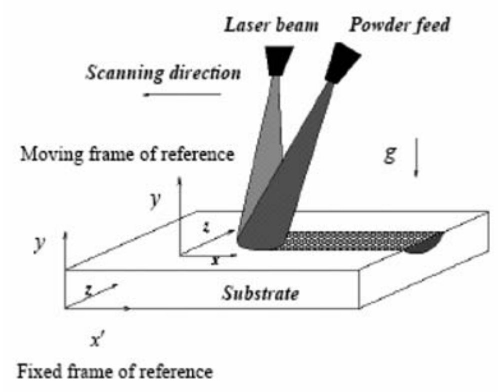


Figure 2. Schematic of a conventional laser surface alloying process

Bubble dispersion in a liquid is an important factor in the development of various gas liquid devices used in process industries. Bubble dispersions are commonly produced by blowing gas into a liquid through either perforated plates or by nozzle grids. To understand the physics of bubble formation, dispersion and to enable assessment of the performance characteristics of the plates and grids, it is necessary to know about the mechanism of gas bubble formation at a single nozzle or orifice. Comprehensive research is being undertaken to study the dynamics of bubbles in a flowing liquid environment (Figure 3).

Simulation of aerodynamic and heat transfer characteristics over variously shaped bluff bodies (either stationary or moving) with different configurations have tremendous engineering importance, since these are often found crucial in numerous devices such as heat exchangers, solar heating systems, natural circulation boilers, nuclear reactors, dry cooling towers, electronic cooling, vortex flow meters & flow dividers, probes and sensors and so on.

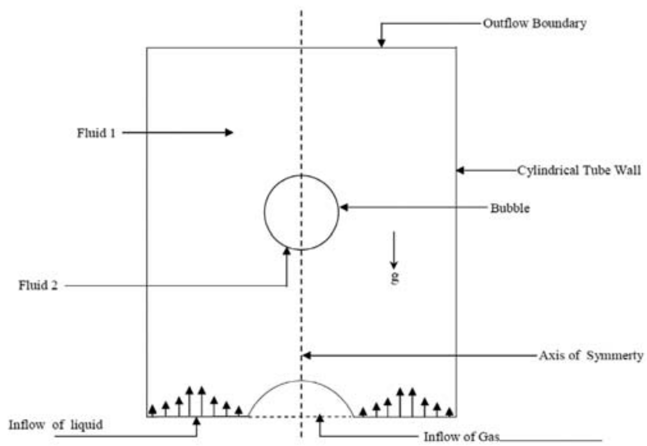


Figure 3. Schematic of the Co-Flowing liquid system

The group has conducted several studies on such transport processes to understand the fundamental aspects of vortex dynamics (Figure 4) and thermal transport (Figure 5) for low to moderate Reynolds number laminar regime.

The immersed boundary (IB) technique, capable of handling complex geometries within the framework of a rectangular grid system has been employed to develop CFD solvers in both two and three dimensions. The main aim was to solve flow over an Autonomous Underwater Vehicle (AUV) developed at CSIR-CMERI (Figure 6). The geometry is complex, with eight fins attached to an axisymmetric hull. The developed solver has shown the wake of the vehicle through vorticity, isosurface plots and is currently undergoing rigorous testing in various geometries like a circular cylinder in two-dimensions (Figure 4) and a sphere in three-dimensions (Figure 7). The IB method is also useful in simulating flow over pitching and heaving fins of small aspect ratios which can help in propulsion and maneuvers of biomimetic vehicles of the future, the latter being an area where the Robotics and Automation Group of CSIR-CMERI is actively involved. A flapping

Figure 4. Vortex shedding from a circular cylinder

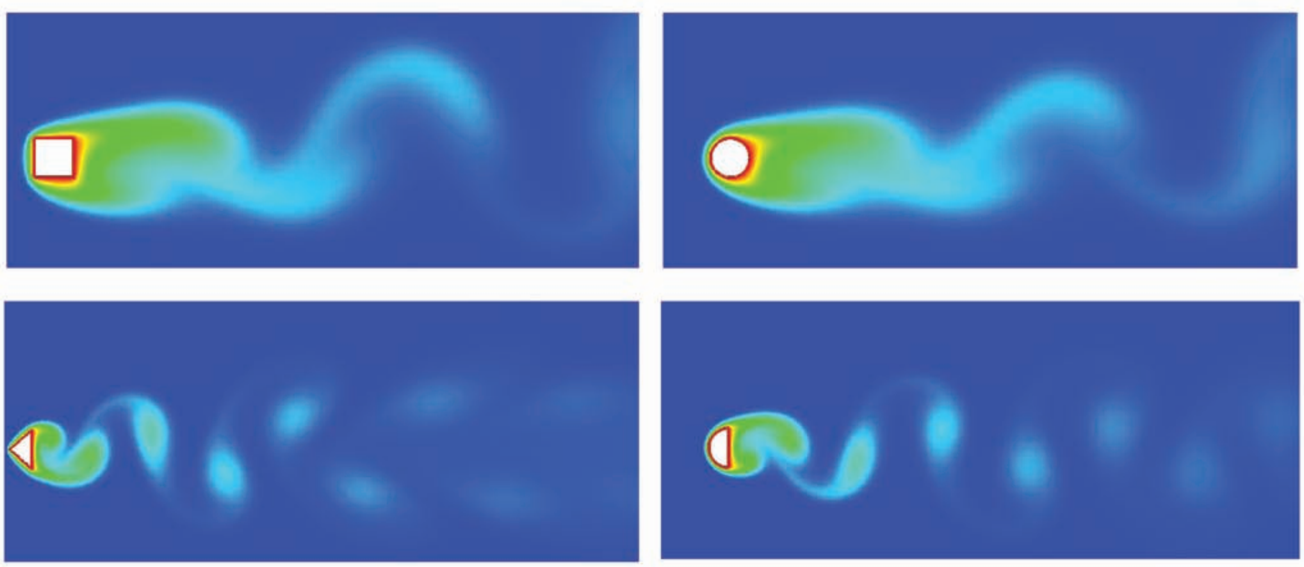


Figure 5. Thermal transport around variously shaped bluff obstacles

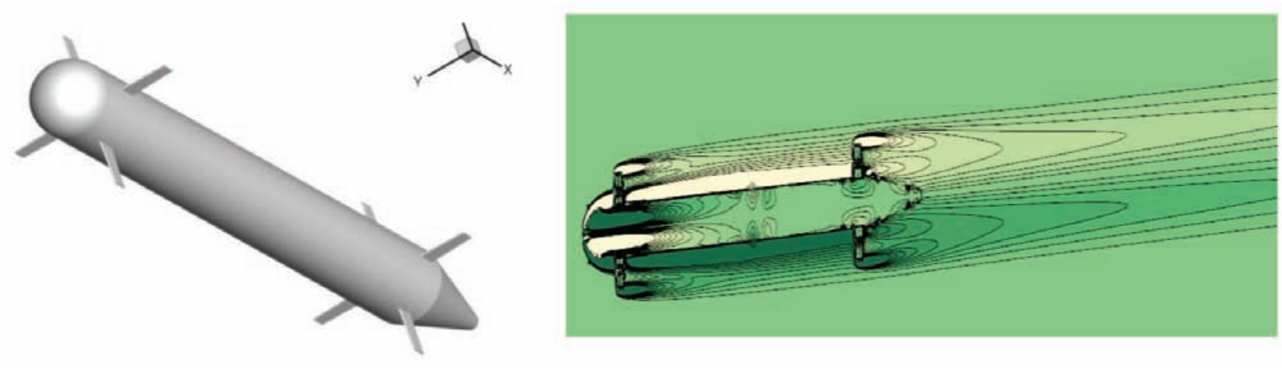


Figure 6. The 3D AUV model (left) and the corresponding vorticity contours (right) at z = 0 plane

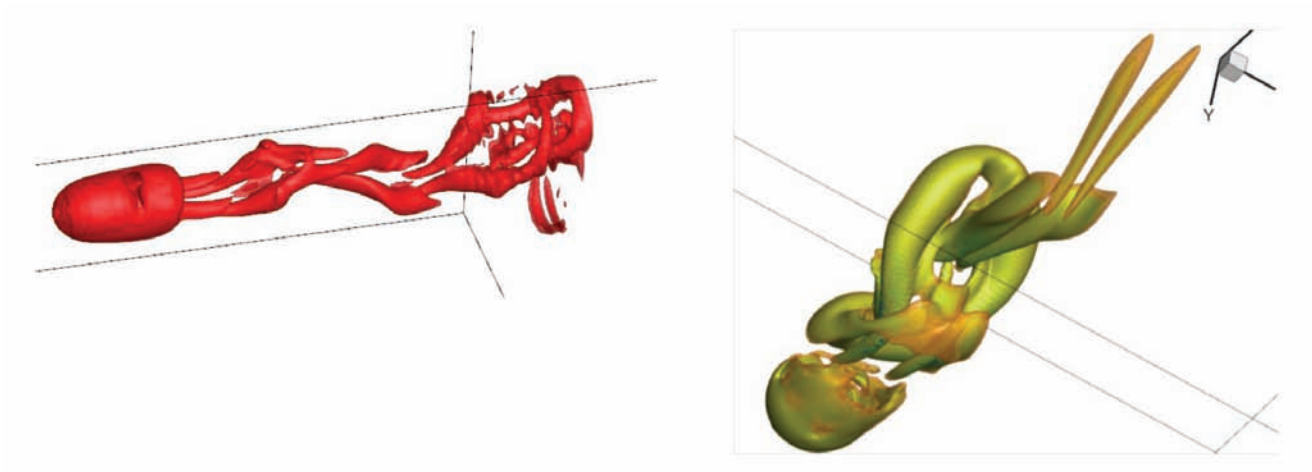


Figure 7. Hairpin structures behind a sphere (3D simulation)

flat plate in two dimensions has been simulated to test the capability of the IB technique to handle moving bodies. The group has a specific plan to take this forward and simulate more complicated fin shaped objects – both rigid and flexible. In the latter case one needs to account for the elastic forces within the fins and this adds to the complexity of the problem, which then falls in the category of Fluid-Structure Interaction problems (FSI). The developed 3D solvers use Message Passing Interface (MPI) to communicate between processes in the parallel environment of a modern workstation or cluster machine, and therefore run regularly with an excess of 10 million nodes. This parallel capability is essential in resolving flow over complex geometries of engineering interest, particularly at higher Reynolds numbers.

A comprehensive numerical study is also going on to predict the aerodynamics for the vortex induced/forced vibration at the moderate Reynolds number range. The vortex induced vibrations are important due to its applications in different engineering fields such as bridges, stacks, transmission lines, offshore structures, marine cables, etc. Some initial studies are also being carried out to understand the detailed dynamics of vortex induced forced vibration (Figure 8).

Proton Exchange Membrane (PEM) fuel cell holds enormous potential to offer an alternative for zero-emission power sources in automotive and backup power applications. Water management is one of the key issues to improve the cell performance of the PEM fuel cells. A rigorous three dimensional numerical simulation is being carried out to understand the water droplet mobility in serpentine gas flow channel (Figure 9) with a wide range of surface properties, effects of inlet air velocities and droplet positions (center or off-center, bottom or top) by using the commercial CFD package *Fluent*. The liquid-gas interface is tracked following the volume-of-fluid (VOF) method available in *Fluent*. It is observed that the droplet transport is greatly affected by the surface wettability properties, inlet velocities and initial droplet positions. Super hydrophobic surface property is not always preferable for designing the gas flow channels and depends upon the inlet velocity conditions, droplet positions, etc.

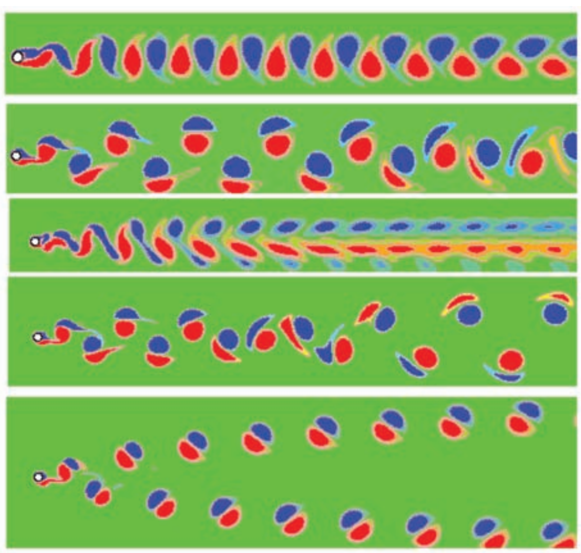


Figure 8. Vortex shedding pattern for forced in-line vibration

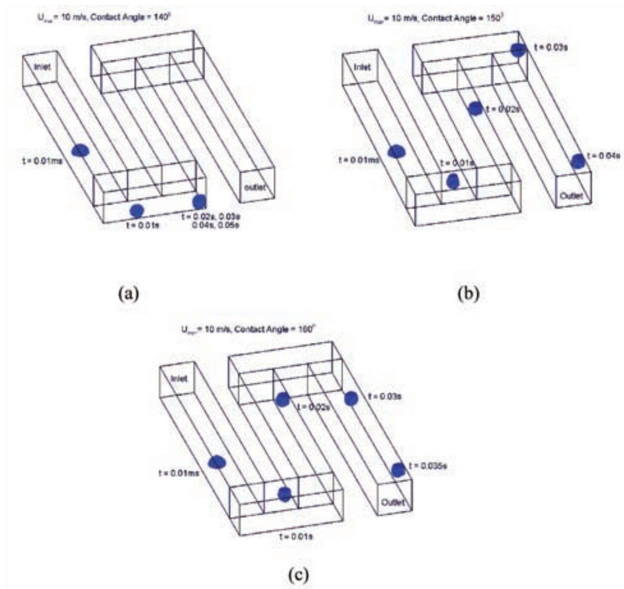


Figure 9. Droplet transport (center of bottom wall) at different instants on hydrophobic surfaces for the maximum inlet velocity 10m/sec through the serpentine gas flow channel

On the compressible side, a shock tube generated vortex has been simulated and its interaction with a wall facing the shock tube has been analyzed (Figure 10). The developed solver is axisymmetric and uses AUSM+ scheme with second and higher order MUSCL interpolation and low dissipative and dispersive multi-stage time stepping schemes. This work will be extended to estimate shock loading of objects.

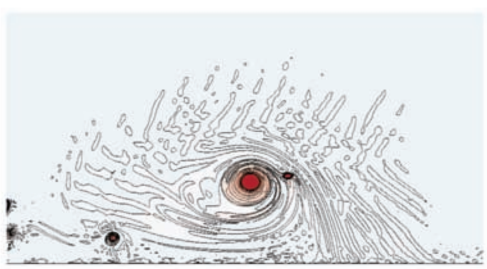


Figure 10. Vortex evolution at the open end of the shock tube

Research Initiatives in the Recent years

Autonomous Underwater Vehicle, *AUV-150*: A CSIR Initiative Towards Unmanned Oceanographic Exploration

Introduction

Increasing need for unmanned underwater explorations has led to the phenomenal development of Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) over the past decade. Countries like the USA, the UK, Sweden, Japan and many more have come up with unique unmanned underwater systems capable of carrying out a myriad of specified tasks, ranging from oceanographic studies to laying underwater cables and inspection. However, in comparison to ROVs, AUVs including gliders have offered better economic potential in terms of development and more specifically for trouble-free operation. Keeping in view the huge popularity and efficacy of AUVs, CSIR-CMERI recently undertook a pioneering project towards the development of an Indian AUV under a research programme sponsored by the Ministry of Earth Sciences, Government of India. The envisaged vehicle capabilities included seabed mapping and profiling of physical characteristics like variations of salinity, temperature and conductivity with different pressure levels. The vehicle was specified for an operational depth of 150 meter keeping in mind the significance of studies in coastal waters.

Final Prototype Length: 4.8m Diameter: 0.5m Material: Aluminium-alloy Total weight: 485 kgf Buoyancy force: 490 kgf

A thorough and painstaking process thus began for developing a fully working system of the AUV-150 as it was christened considering its operational depth. After qualifying the vehicle through repeated lab tests and sheltered water experimentation, the team could establish its endurance and sea-worthiness by testing the AUV-150 out in the open seas at the Bay of Bengal, 40 km off the Chennai coast. Performance matched the predictions quite closely as the vehicle fared through troubled sea-waters at various depths. Different underwater missions were executed and interesting results were revealed through profiling sensors like CTD and SONAR. In the present context of the narrative, brief discussions regarding the experimental results shall be provided.

Sea Environment

Sea trials for AUV-150 were conducted off the Chennai coast of the Bay of Bengal on-board the research vessel “Sagar Nidhi” provided by the NIOT to verify the sea-worthiness of the entire system including its design and set of functionalities. Due to significant ocean currents, AUV-150 suffered from heavy drifts immediately after deployment into sea-water. As reported from the Ship Current Profiler, NORENCO, weak subsea currents (~1 knot) were present up to a depth of 85m. Contrastingly, a strong subsea current close to a velocity of 12 knot (~ 6 meter/sec) was found to be prevailing at the specified depth of 150m, and its effect was manifested in the data recorded from the navigational sub-system.

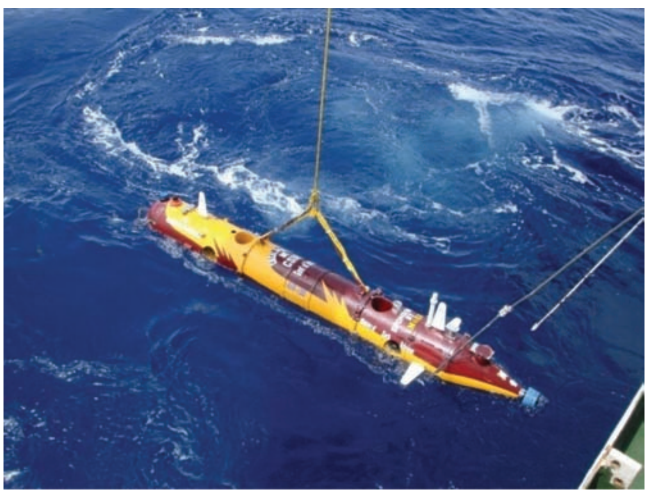


Figure 1. AUV being deployed in the Bay of Bengal

However, AUV-150 reached a depth of 150m with an accuracy of ±0.7 m of depth within the estimated mission duration.

Performance Highlights

One of the major performance highlights of AUV-150 was its exceptional roll stability, which is a pre-requisite for effective seabed mapping. The vehicle roll was also found to be restricted within 4^0~7^0 during a depth correction for 81m and similar behavior were also noticed during depth corrections for 150m. During both the depth corrections, the roll stability was achieved in the form of passive control implemented mechanically through design. This showed that the roll is stabilized by passive control methodology actualized through mechanical design. Similar performance was also achieved for operation at a depth of 150m, which has been indicated in Figure 2.

Moreover, bathymetric mapping was effectively carried out using Side Scan SONAR. A Contour map was developed through integration of data obtained from the navigational sub-system, the echo-sounder and the Side Scan SONAR. A surface was rendered in 3D as a representation of the underwater terrain, and this is shown in

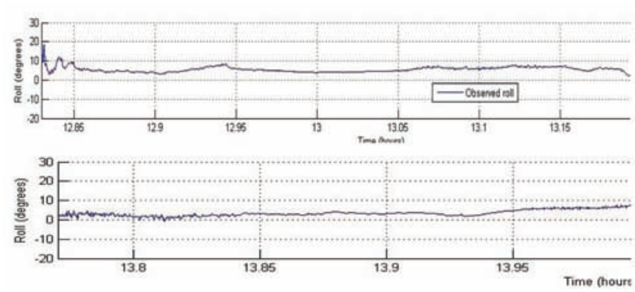


Figure 2. Roll stability graphs during depth corrections for (top) 80 meter and (bottom) 150 meter

Figure 3. Positional information of the vehicle like heading, depth and UTM coordinates were fused with data obtained from the SONAR. The surface is generated over an area centering the global position of P44, 1470883.576 Northing/452521.915 Easting in the Universal Transverse Mercator (UTM) reference frame. The surface represents a continental shelf and the illustrated elevation is as observed by the AUV 150 at a depth of 150m with an accuracy of ±100 ~ 700 cm.

The surface is extended over an area of 468 meter along the Geographic East and 1140 meter along the Geographic North.

Physical Profiling by AUV-150

Payload data as recorded by AUV-150 is shown in Figures 4–6. The CTD profiler records a very insignificant variation of salinity across depths of 80 to 150 meter. As is evident from Figure 4, salinity increases from 32 PSU at the surface to 34.77 at a depth of 78.23 meter. This varies till 100 meter and subsequently remains at an almost constant level through a depth of 50 meter more. The data as recorded by the CTD is consistent with the fact that variations in salinity in open seas remain small except for nearness to rivers or melting ice. The characteristics during hovering after

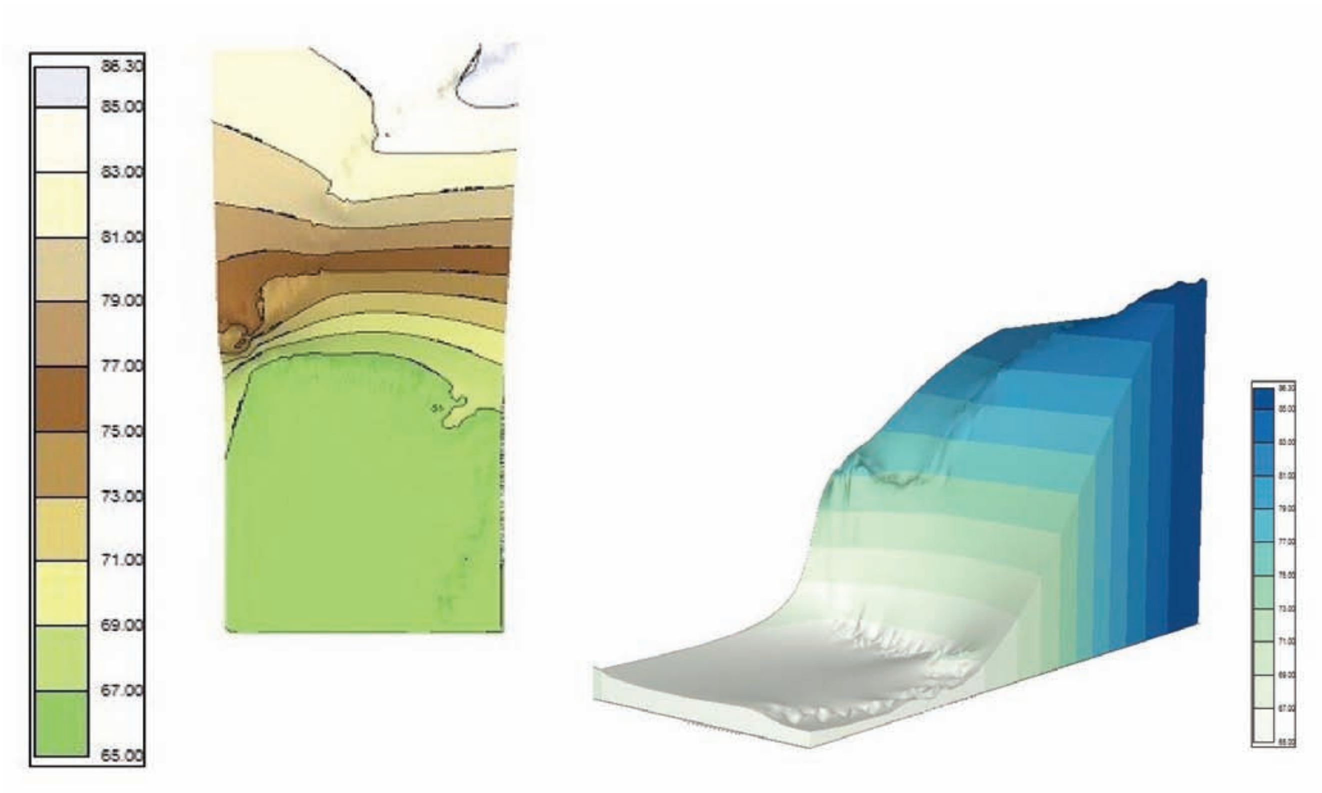


Figure 3. 3D rendering for a surface from post-processing of data as obtained from Side Scan SONAR

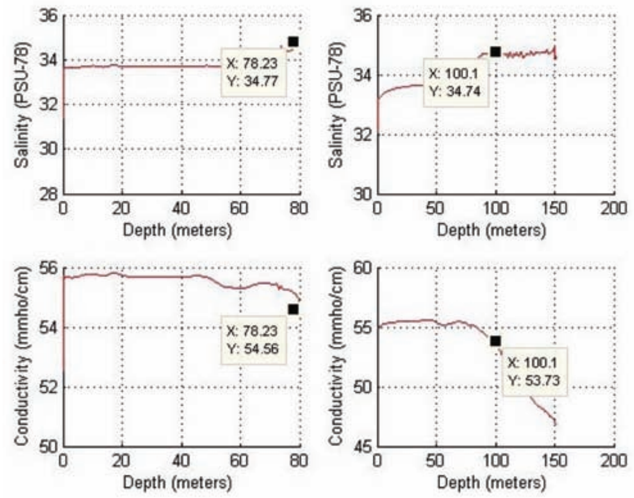


Figure 4. Plot for salinity and conductivity Vs depth achieved by AUV-150 for 80 and 150 meter

attaining the depth exhibits similar behavior. Conductivity being a function of salinity varies only slightly as well from a recorded value of 56 mmho/cm to 54.5 mmho/cm across a depth of 80 meter. Interestingly however, there is a sharp fall in the value of conductivity as recorded by the CTD below 100 meter of depth up to 150 meter.

On the other side, the CTD profiler recorded significant temperature variations across depths of 80 and 150 meter. While temperature varied from 29.34°C on the surface to 26.7°C through 80 meter, a variation of about 11°C from 29°C at the surface to 18°C at a depth of 150 meter was recorded. Variations in temperature were found to be nonlinear up to a depth of 100 meter. Subsequently, for a further increase of depth up to 150 meter, the temperature varied almost linearly for another 50 meter from 25.93°C to 18°C. After attaining a particular depth, the AUV hovered there for quite some time and it was observed that the temperature dropped sharply in spite of the depth remaining the same. The recorded slope of temperature variation up to 100 meter is approximately 0.03°C/m whereas a greater slope of 0.12°C/m was recorded across a depth from 100 to 150 meter. Accordingly density is seen to vary slowly from 1021 to 1023 kg/m^3 across 80 meter. However, a sharp and almost linear increase in density is observed across a depth of 50 meter down below 100 meter from 1023 kg/m^3 to 1025 kg/m^3. This is particularly attributed to the sharp fall in temperature.

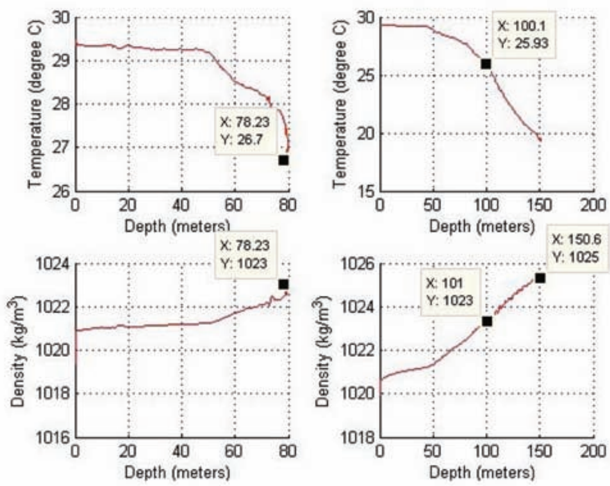


Figure 5. Plot for temperature and density Vs depth achieved by AUV-150 for 80 and 150 meter

Predictably, the sound speed varied with temperature, depth, salinity and conductivity of sea water. The sound speed decreased with increase in depth i.e. with decline of temperature, as depicted in Figure 6. The same CTD profiler recorded sound speed variations from 1543.24m/sec to 1519.23m/sec at a depth of 150m. Therefore, recorded differences of 24.01m/sec and 4.89m/sec in sound speed were observed corresponding to operational depths of 150m and 80m respectively. It may be stated that the recorded sound speed profiles were found to be similar in characteristic to that obtained from the widely used McKenzie model (shown in blue line) for estimating the sound speed using salinity, temperature and depth information. However, a constant offset is evident between the modeled speed and the recorded speed.

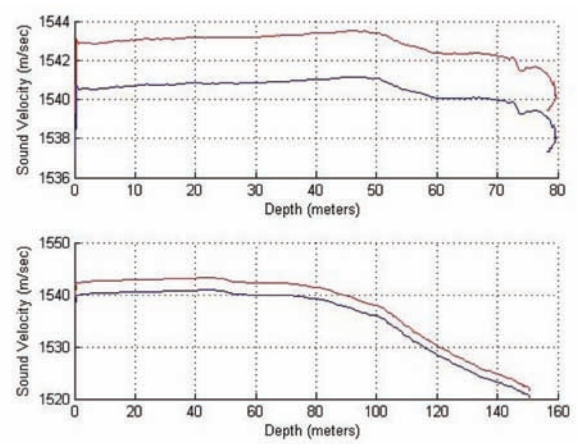


Figure 6. Plot for Sound Velocity (as recorded by CTD and McKenzie Model) Vs depth achieved by AUV-150 for 80 and 150 meter

The recorded SVP (sound velocity profile) as shown in figure 6 is in close conformity to the typical SVP for sea water, as is shown in Figure 7, which demonstrates that the velocity of sound typically reduces nonlinearly up to 1000m of depth. Since the operational depth of AUV-150 is 150m, which falls within the seasonal thermocline region, the recorded nonlinear nature of the sound velocity profile as recorded by the CTD Profiler is perfectly in keeping with the typical SVP.

Conclusion

This article records some of the features of effectiveness of the developed AUV-150, an autonomous underwater vehicle operational up to 150 meter, towards seabed mapping and physical profiling of sea-waters. The observations regarding conductivity, salinity and temperature variations are quite interesting and are consistent with theoretical projections. This further inspires us to extend the development of AUV technology under the patronage of CSIR towards cutting-edge scientific ventures, and take this further to deepwater explorations and long duration surveys. The AUV-150 can probably pioneer the development of a series of forthcoming unmanned intelligent explorers of the unchartered waters, which can prospectively enrich our knowledge and perception of seas and oceans.

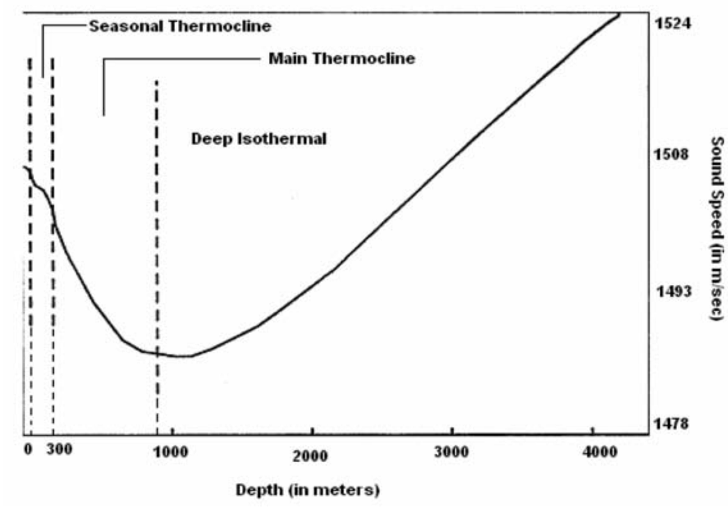


Figure 7. SVP- Sound Velocity Profile (Theoretical)

Research Initiatives in the Recent years

Precision Engineering and Metrology

The Precision Engineering and Metrology group of CSIR-CMERI has capability and considerable experience in the field of high accuracy measurements, research on tool condition monitoring, micro electric discharge machining (EDM) and calibration of precision gauges and instruments as per NABL accreditation standards. This group is developing technology for high-accuracy three-dimensional translational stage, tool condition monitoring system, automatic characterization of micrographs and fractographs using image processing and novel techniques for calibration systems. This laboratory also facilitates and serves the nation in calibration and testing of mechanical instruments with high level best measurement capability. The major activities of Precision Engineering and Metrology group undertaken in 2011-12 are listed below.

1. Tool Condition Monitoring System Using Digital Image Processing

Quality improvement of finished products in a production environment can be accomplished by monitoring the condition of a cutting tool as well as a machine tool. As the machining time increases, the cutting tool wears out because of friction, temperature increase, diffusion phenomena, chip welding with cutting tool, fracture and breakage, etc. resulting in flank wear, crater wear, diffusion wear, nose wear, notch wear, etc. Consequently, the output parameters of machining process viz. forces, machining sound, chatter, machine tool vibration, machining power, current, surface finish are significantly affected. To monitor the machining process for reducing tool downtime, these output parameters are to be measured and monitored using dynamometer, acoustic emission sensors, accelerometer, Hall Effect sensors, contact based surface profilers, etc. All these methods are used for detecting the degree of tool wear. In addition, some techniques exist for measuring the cutting tool wear directly from the cutting tool images. All these tool wears affect the quality of the machined surface. The surface images can be representative of the degree of tool wear. The Precision Engineering and Metrology laboratory is making use of this method to develop a tool condition monitoring technique for identifying the degree of tool wear by analyzing surface texture of machined surfaces with the assistance of digital image processing. This non-invasive technique of tool condition monitoring offers predominant advantages over other existing methods. For example, this method does not involve subjecting the machined texture under examination to forces or loads, thereby rendering redundant the use of contact profiler for surface roughness measurement. Secondly, this non-contact method can easily be adopted for on-machine tool application. Moreover, this particular monitoring system is more flexible and less expensive than other systems. A further advantage of this system is that it can be remotely operated, which proves quite helpful in case of unmanned production systems. In contrast to acoustic emission monitoring systems, this technique is not dependent on the frequency of the chatter and directionality and is further unaffected by the high frequency forces. The advancement of machine vision sensors has also contributed to the acceptance of industrial image processing, since machine vision sensors are less sensitive to adverse industrial environments. Image processing and pattern recognition has brought about the possibility of extracting proper features for tool condition monitoring. A further merit of this technique resides in the fact that there is no need to disengage the cutting tool inserts for tool wear measurement, which further obviates the chances of misalignment. In this technique, machined (turned, milled, shaped, etc.) surfaces are captured using a CCD (Charged Coupled Device) camera and a fiber optic guided lighting system just after the machining operation while retaining the job on the machine tool. After the acquisition, the machined surface images are processed using different image texture analysis techniques and the appropriate texture features for defining the degree of tool wear are extracted. These features are then correlated with the measured flank wear of the cutting tool in turning and milling experiments. The experimental set-up for tool condition monitoring system using digital image processing in turning is shown in Figure 1.

Figure 1. Experimental set-up for tool condition monitoring system using digital image processing

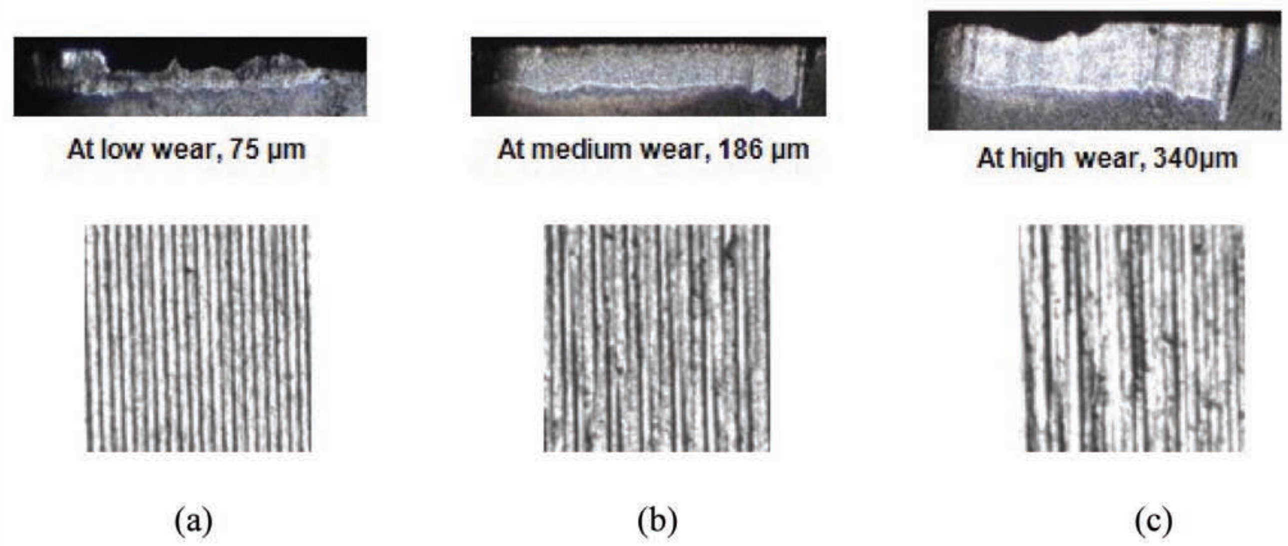


Figure 2. Cutting tool flank wear profile and corresponding machined surface images for (a) low wear, (b) medium wear and (c) high or severe wear

As the cutting tool wears out, the machined surface gets rougher which can be clearly understood from Figure 2, which depicts the images of flank wears produced and the corresponding machined surface images in turning operation for sharp, semi-dull and dull tools [Figure 2(a) 2(b) and 2(c)].

A systematic variation of extracted image texture features of turned surfaces at different machining parameters with cutting time and progressive wear obtained for evolving a new non-contact technique of tool condition monitoring.

Future scope

This group is now trying to develop the real time tool condition monitoring system using image processing and pattern recognition. For this requirement, there is a need to improve the image acquisition system and evolution of pattern classification technique.

2. Automatic characterization of fractographs using image processing

Fractogrphs carry the information of the failure process of a material. The images of the fracture surfaces can be analyzed for extracting the information of failure automatically. The Metrology laboratory and the NDT & Metallurgy Group of CSIR-CMERI have together characterized fractographs resulting from a tensile test of AISI 304LN stainless steel specimen at different strain rates and have extracted the appropriate features for characterization. Fractographs resulting from an impact test of Al 7075 alloy at different processing conditions have also been characterized. This methodology leads to the unmanned characterization systems of material and also reduces the time of characterization.

Future scope

Till now, characterization has been carried out for the fracture surface only. Characterization of microstructure, weld zone, corroded surface and real-time inspection of different power plant components have been planned as part of the future work.

3. Feasibility Study of Miniature Interferometers for High Accuracy Three-dimensional Translational Stage

As part of another research venture, the Metrology laboratory is in the process of developing a three dimensional translational stage with a positioning accuracy of 50 nm. The volumetric range of the stage will be 50mm x 350mm x 350mm with a resolution of 0.5nm for the interferometer. This venture has been supported by the Department of Science and Technology, Government of India. This project is in collaboration with Prof. K. F. Ehmann, Northwestern University, USA. The stage will have a parallel kinematic platform for high stiffness, low Abbe error and lesser cumulative error.

4. Research on Micro EDM

The Precision Engineering and Metrology Group is also involved in investigating the influence of the size and shape factors of electrodes in micro electric discharge machining (EDM) and to establish a relationship with the discharge characteristics. The study includes investigation of scaling effects in multi-scale micro-EDM machining, monitoring of electrode wear, tolerance modeling in micro-EDM for prismatic crater geometry and determination of optimal machining parameters for different shapes of electrode for different combinations of tool and workpiece materials. The key contribution from this effort is knowledge-based understanding of the influence of geometry and size effects in micro-EDM discharge characteristics, electrode wear, dimensional accuracy and metallurgical effect on crack formation. This would enable

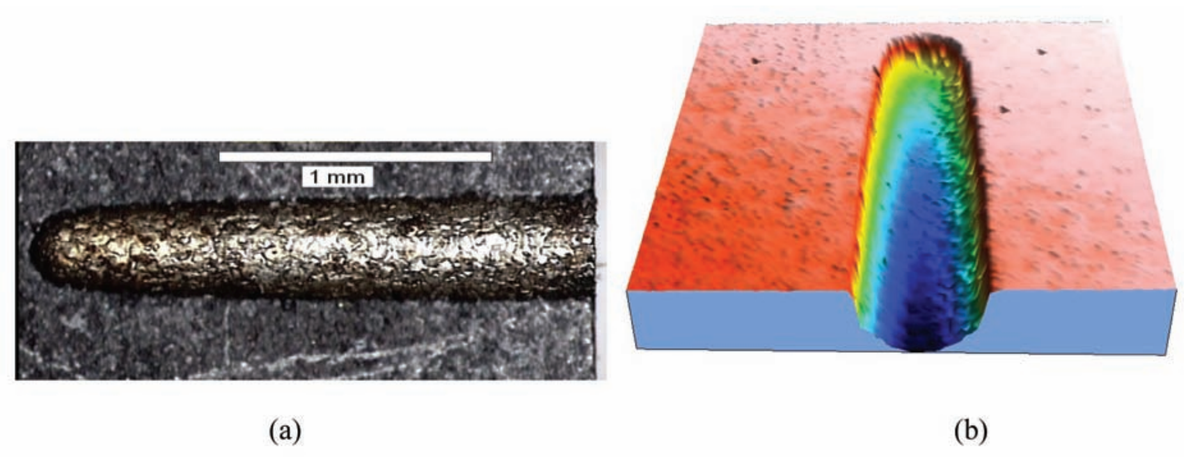


Figure 3. View of opened micro hole taken in (a) Optical Microscope and in (b) 3D Surface Profiler

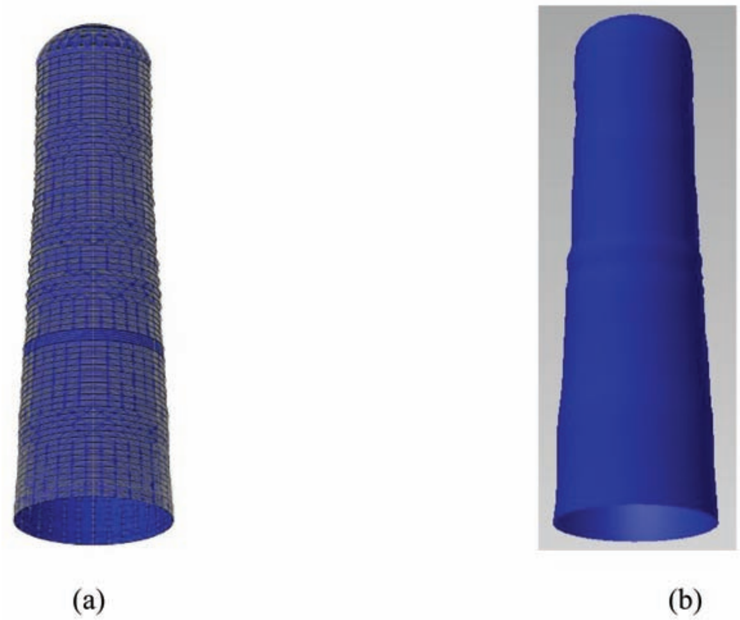


Figure 4. (a) Realistic view and (b) 3D shape (drawn in Autodesk Inventor) of blind micro hole.

the micro-EDM to be used as a user-friendly production technology, which, in its turn, will influence the designing of micro parts and devices for better manufacturing in micro scales.

5. Other Measurement Activities

3D surface topography measurement of OFHC copper component used in linear accelerator of radio frequency quadruple

The assignment required improvement of surface finish for oxygen-free high conductive (OFHC) copper work piece by high speed end-milling operation. In the process of research towards this end, it was found that the most significant contributing parameter of machining was tool corner radius for both one-dimensional and areal surface roughness. Step-over of machining was the next significant contributor for areal surface roughness which was less significant in case of one-dimensional surface roughness. Since areal surface roughness was measured over an area, step-over obviously contributed more than the spindle speed.

Complex shape measurement

The Precision Engineering and Metrology Group also involves itself in measurement of various complex features. For example, this group measured the surface profile of a aerofoil (blade) and a case magazine using a continuous laser scanning and touch scanning probe attached to a co-ordinate measuring machine (CMM) as shown in Figures 6(a) and 6(b) respectively.

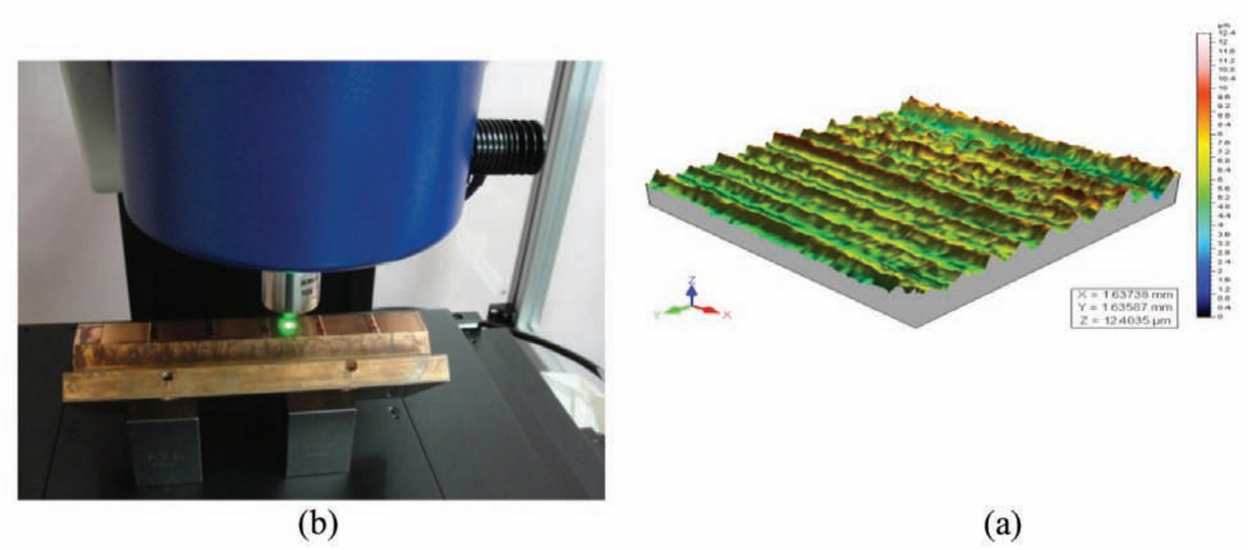


Figure 5. (a) Measurement set-up of machined surface of OFHC copper and (b) resulting surface topography

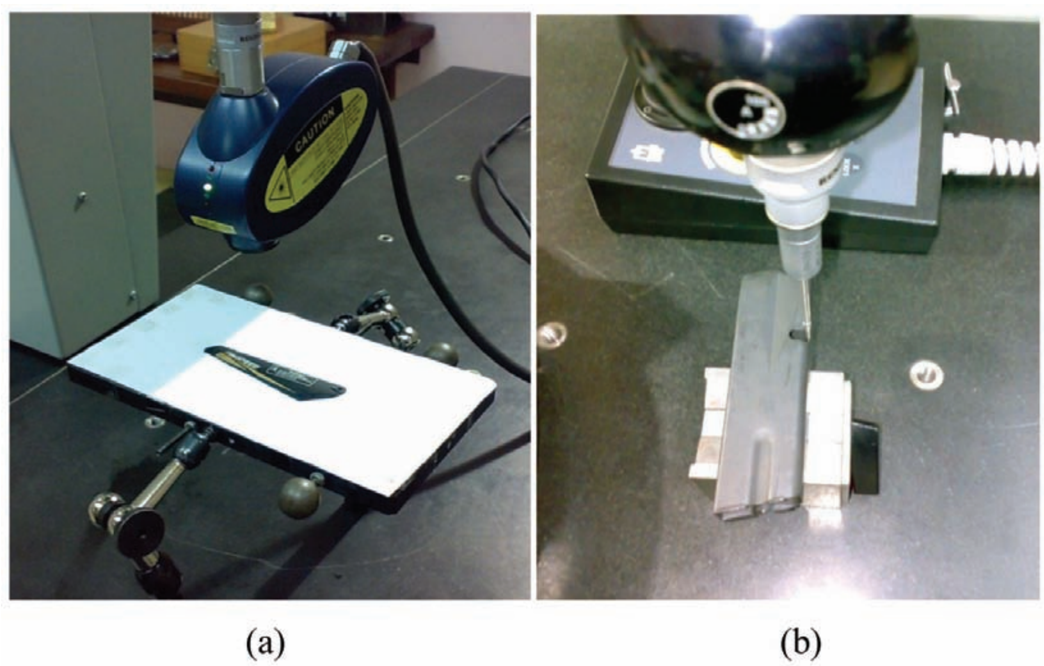


Figure 6. Measurement of (a) aerofoil blade using laser scanning probe and (b) case magazine using touch probe attached with CMM

Network Initiatives

Supra Institutional Project on Capability in Mobile Robot Development for Industrial, Outdoor and Hazardous Applications

Micro Part Handling Systems for Robotic Assembly Using Ionic Polymer Metal Composite (IPMC)

Serpentine Robot CSERP-X

Network Initiatives

Supra Institutional Project on *Capability in Mobile Robot Development for Industrial, Outdoor and Hazardous Applications*

The Surface Robotics Group is one of the major R&D groups in the field of robotics in CMERI. Invention and innovative design is the core strength of this group. Major and sub areas of research which form the basis of activities in Surface Robotics Lab are

Major Areas:

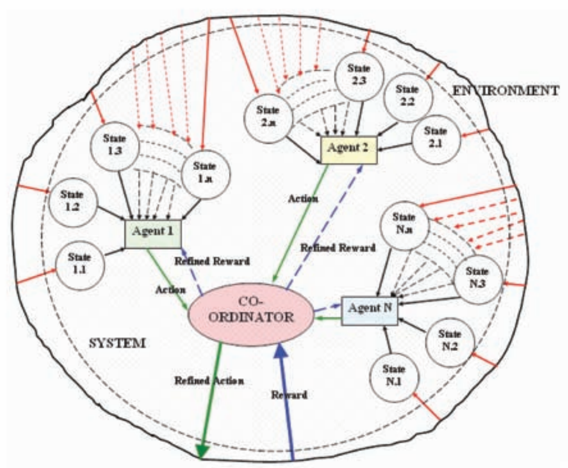
a. Deliberative model based navigation

b. Behavior based Robotics with Reinforcement Learning

Sub Areas:

- Command & Control Architecture
- Integration and fusion of Multiple Sensory Information including Computer Vision

Deliberative model based navigation assumes the kinematic and/or dynamic model of the system is precisely known and the sensor model detects the environmental changes so as to perform navigational and exploration tasks whereas

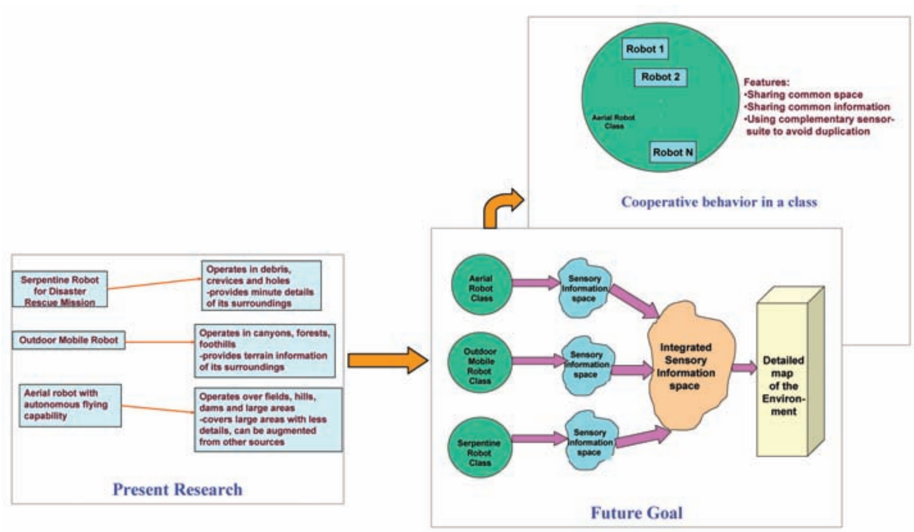


Generalized multi-agent Q-learning for a system. The system is divided in two main parts: different agents and the co-ordinator. System interacts with the environment with the help of co-ordinator.

behavior based navigation does not require models for the system or the environment. It is essentially a direct sensor-to-actuator mapping that does not rely on the explicit world model. Behavior-based robotics is reactive due to its dependence on modeless approach using direct action through sensory stimulus. Obviously such approach on navigation is not considered as an optimal one, yet it perhaps constitutes the best possible action given a set of sensory stimuli from its spatial neighborhood. Even though such action is sub-optimal, yet this is arguably more rational for navigational task for the simple reason that in case of obstacle-free path planning nearby objects exercise more influence than any obstacle or objects located far from the robots. Reinforcement learning is a system-environment interaction with the help of reward/ punishment methodology against a previous action executed depending on the previous state of the system. This helps the robot to act more rationally and in a subjective manner even when the environment changes to a completely unknown/ unpredictable mode.

Over time, the group has developed expertise in terrain modeling and sensor fusion using various estimation theories, an essential feature of these navigating robots. Using the two approaches stated above, diverse suite of mobile robots including all terrain robots, aerial robots, serpentine robots, amphibious robots have been developed for operation under various terrain conditions.

A Supra Institutional Project on **Capability in mobile robot development for industrial, outdoor and hazardous applications** was carried out during the 11th Five Year Plan with emphasis on developing ***Decentralized cooperative exploration strategy with multi-agent systems***. Decentralized cooperation and coordination mechanism across multiple agents (robots), ensures more efficient exploration, helps in avoiding spatial conflicts and are cost effective. This can be achieved through cooperative behavior within a class of robots which share common information, use complementary sensor-suites and avoid unnecessary duplication of sensors.



Decentralized cooperative exploration strategy with a multi-agent system

The primary aim of this Project was the enhancement of indigenous capability for launching efficient operations like disaster rescue mission through last minute augmentation of valuable information. Besides disaster rescue missions, inspection, law enforcement and security and surveillance can also benefit from such robotic systems in general. The four major sub-activities under Supra Institutional Project on robotics under 11th five-year plan were:

1. Design and development of a serpentine robot for disaster rescue mission
2. Design and development of a compact outdoor mobile robot with autonomous navigation for terrain exploration and explosive detection capability
3. Developing autonomous flying capability of a rotary-winged flying robot (RWFR) for inspection and surveillance
4. Design and development of vision guided mobile robotic system for handling hazardous materials.

1. Design and Development of a Serpentine Robot for Disaster Rescue Mission

Terrestrial locomotion can be broadly classified into three categories based on the mechanism employed. These are popularly termed as wheeled, legged and limbless locomotion. Perhaps the most fascinating locomotion is limbless locomotion that is generally performed by serpents. Wheeled locomotion and legged locomotion have been studied by many researchers with various degrees of detail. On the contrary, limbless locomotion has attracted scant interest. In limbless locomotion (of a serpent), the cyclic changes in the body shape is primarily responsible for locomotion. Scientific contribution of this stated activity lies in the understanding of this science of limbless terrestrial locomotion by designing and developing a hyper redundant untethered serpentine robot.

In case of a serpentine robot, design is principally guided by gait implementation philosophy. CSERP-X (CMERI SERPent) series of robots can perform multiple gaits depending upon the requirement. Serpentine gaits implemented here are the results of body waves in two orthogonal planes. To allow it to undulate on both horizontal and vertical planes the design needs to be flexible and compliant in both the directions. The experimental serpentine robot is essentially a seven degree of freedom robotic arm with on-board battery pack, microcontroller, wireless camera, light, and Infra Red (IR) obstacle detection system. The brief specification of the system is given in Table below.

Overall length	807 mm
Number of Segments	8
Number of joint actuators	7 R/C servos
Joint actuator torque	9 kg-cm
Joint to joint distance	96 mm
Segment cross section	70 mm x 70 mm
Overall weight (Including battery)	1.26 kg
Obstacle detection	IR based
On board micro controller	PIC 16F84A
Power source:	
Servo actuators	6x900 mAh@6 V DC
µ-controller and other electronics	900 mAh@6 V DC
Camera, video transmitter & light	9 V DC

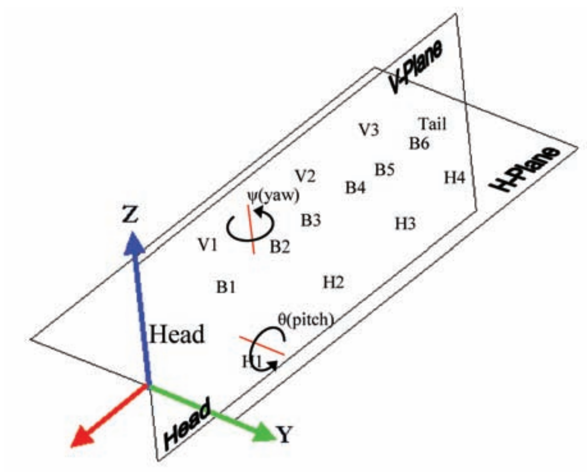
Kinematic Model

Kinematic freedom of the model can be better understood from the figure below. Adjacent joint axes are perpendicular to each other providing overall flexibility in two orthogonal planes i.e. horizontal and vertical planes (H-Plane and V-Plane). The body segments of the serpentine robot are named as:

Head – B1 – B2 – B3 – B4 – B5 – B6 – Tail

Considering spatial orientation of the robot, four actuators have axes on the horizontal plane (viz. H1, H2, H3 and H4) controlling pitch and three actuators on the vertical plane (V1, V2, and V3) for yaw.

The pattern of oscillation of each servo is governed by the microcontroller and termed



Kinematic model of the robot (CSERP-X).

as *servo orientation function*, which are time dependent and sinusoidal in nature. Characteristics of orientation functions are governed by parameters such as mean, amplitude, period and phase.

Gait Implementation

Various combinations of parameters of servo orientation functions produce different gaits. Period dictates how fast a gait will be performed. Though various gaits were implemented successfully, the results of sidewinding and rectilinear gait implementation are presented here. Orientation function parameters were programmatically transferred to the onboard microcontroller of the serpentine robot for gait implementation.

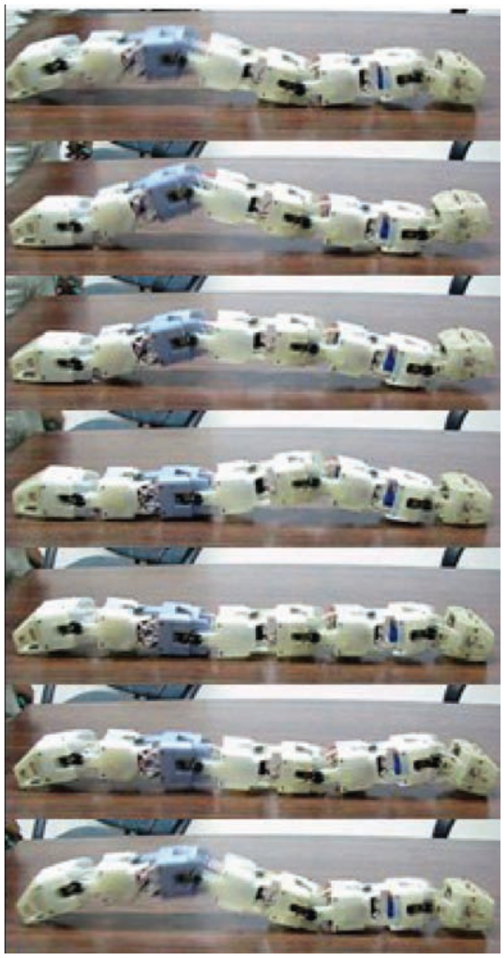
Sidewinding

It is a mode of sidewise movement where a portion of the body gets lifted, is moved laterally and placed on the ground. Sidewise undulations are relatively larger than V-Plane undulations. V-Plane undulations help in locomotion even on loose soil or sand and depending upon the soil condition the parameters may be adjusted. Plots of servo orientation functions are segregated for H-plane and V-plane to avoid clutter.

Caterpillar Rectilinear

This is a non serpentine gait, but can be easily implemented in a serpentine robot like this. In this mode of locomotion a pure sinusoidal wave is generated on the V-plane only and it travels through the length of the body. The direction of motion of this wave is from the rear to the front while the robot moves forward. The serpent moves without any one of the segments sliding on the ground.

Gait sequence of sidewinding locomotion. Frames are not necessarily at regular interval.

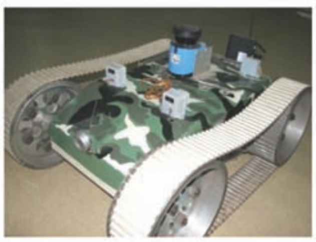


Caterpillar Rectilinear gait sequence.

2. Design and Development of a Compact Outdoor Mobile Robot with Autonomous Navigation for Terrain Exploration and Explosive Detection Capability

Unlike serpentine robots, Outdoor Mobile Robots (OMR) cater to a much larger area. They are used for terrain exploration by crossing obstacles and ditches, for climbing stairs and operating in sand, gravel, mud and grass. Mars Rover is a good example of this kind of robot. Application wise, they are a boon to the defence sector for explosive & IED detection with an onboard dexterous manipulator for diffusing these explosives and also for the atomic energy sector for handling toxic and hazardous materials.

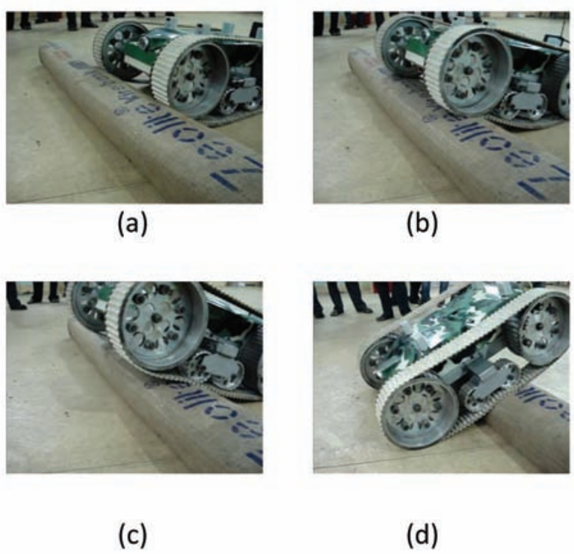
The strategy for autonomous navigation mainly in outdoor terrains needs special attention. This issue has to be addressed not only by the software level, but also with hardware or mechanisms. Scientific contribution lies in the



Major Technical Specifications:

- Size: 1000 X 670 X 315 mm
- Weight: 45 Kg
- Endurance: 0.5 Hr
- Speed: 0.5 m/s (avg); 1.5 m/s (max)
- Power: On-board Li-Ion Battery
- Sensors: IR Sensors, SICK laser, Compass, Wireless Camera
- Communications: TCP/IP and RF Communications
- Processor: PC 104+ based SBC/ Arduino Microcontroller Board

The experimental prototype of OMR with the tentative technical specifications



Demonstration of the obstacle overriding capability current work on evolving various navigational techniques in deliberative and reactive domains. Some of them use voice command while some are controlled by joystick for remote operations. These have been implemented in different robotic systems intended for different applications. Algorithms have been developed for autonomous navigation in unknown/ unpredictable environments fusing behaviour-based robotics and robot learning.

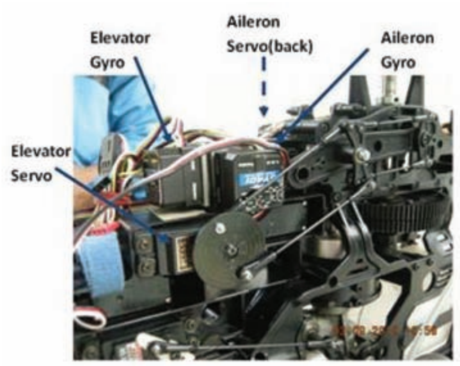
3. Developing Autonomous Flying Capability of a Rotary-winged Flying robot (RWFR) for Inspection and Surveillance

Flying robots encompass any other area not achievable by other types of surface mobile robots. In view of their precise maneuverability, rotary winged flying robots are most popular and indispensable for surveillance, inspection, search and rescue missions. Typical missions of flying robots require flying at low speeds to follow a path or to hover near an object of interest.

For hover, the main objective is to control the dynamic behavior of RWFR. As the physical nature of a Rotary Winged Flying Robot (RWFR) is complex in regard of shape and motion, simple intuitive mathematical modeling fails as the non-linear aerodynamic forces and gravity acts in a non-intuitive manner. Due to limited accuracy of the dynamic model, the RWFR attitude dynamics is conditionally stable where a minimum amount of attitude feedback is required for system stability. Scientific excellence lies in attitude stabilization with accelerated response using feedback from the gyroscope mounted on the aileron and elevator axes to attain a high attitude control bandwidth in response to an attitude reference input.

RWFR System Architecture

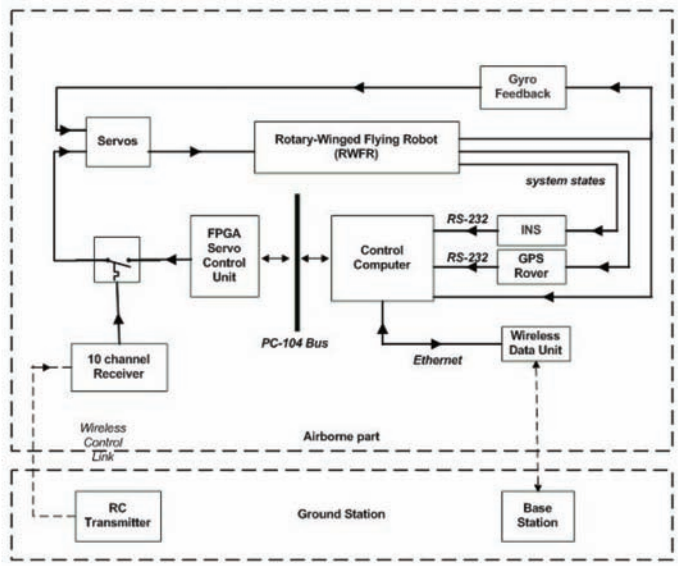
The physical system of RWFR, as shown in the figure, has two angular velocity gyros mounted on lateral and longitudinal axes for robust feedback control needed for attitude stabilization. For feedback control, NAV440 inertial navigational sensor is mounted underneath the chassis as close to the system centre of gravity (CG) as possible. This minimizes any lever effect that can introduce direct errors in measured rotation relative to



Two AVCS gyros mounted on lateral (aileron) and longitudinal (elevator) axes

the system axis. For flight computer system, RWFR is equipped with Pentium-M 1.6GHz based SBC with 1 MB cache and PC/104+ expansion site running on Windows operating system. A PC/104+ based high-speed digital FPGA card is mounted on the SBC to allow high-speed data throughput. This includes generating PWM outputs using programmable clocks for controlling the servos as well as for measuring the pulse width of incoming PWM signals from angular velocity gyros.

RWFR system architecture exhibits dual mode control. The manual control of RWFR is through a remote controlled radio system consisting of a transmitter and a 10-channel



RWFR Architecture

receiver. 8 channels out of the 10 are used: four for controlling the aileron, elevator, rudder and throttle/pitch and three are used as aileron, elevator and rudder gyro sensitivity channels. The final channel acts as a system mode selector that switches between the control signals from the transmitter and RWFR computer system and routes them to the respective servos. This enables the user to activate and deactivate the auto controller and manually control the RWFR as and when necessary.

4. Design and Development of Vision Guided Mobile Robotic System for Handling Hazardous Materials

Vision guided mobile robot navigates autonomously in unstructured indoor environment by vision and laser. Such a robot proves extremely useful for hazardous environments, especially for nuclear power plants where human operators cannot be deployed. It is also useful for inspection of indoor environments with some potential danger of hidden mines or explosives. Scientific excellence lies in autonomous navigation in indoor spaces using feature based map of the environment by stereo vision camera and occupancy grid based map by laser data. Feature based map helps in localization of the robot and the occupancy grid map helps in autonomous path planning.

Description of the system

The robotic system is equipped with stereo vision system, Laser Range Finder and a compass. The data acquired by the sensors is processed by the on board computer. The operator interacts with the system through a GUI at the client side. During inspection i.e., mission period it localizes itself by feature based SLAM with the help of the stereo vision system. In parallel, it develops an occupancy grid map by LRF data. After the completion of the mission, it returns by proper path planning with the help of the occupancy grid map. It is driven by two wheels, which in turn are driven

by two DC motors independently. It carries the power pack, SBC and necessary electronic hardware for control and communication.

During navigation through different given via points, stereo images along with laser data have been collected. At a particular position or via point images (left and right) are matched to get the 3D information of each feature. At the same time, data-association of different features viewed in different instances is also matched by Scale Invariant Feature Transform (SIFT) algorithm.

As we diversify and bolster our research in robotics, we propose a few new concepts and ideas as well as extend our present research work done under 11th five year plan on Supra Institutional Project to make them more commercially viable. The main objectives of the proposed project were:

- To develop mobile robots with enhanced capability for security and surveillance applied to various areas such as border patrolling, mine detection, IED detection & handling
- To study the feasibility of robotic applications in underground mines
- To build capability in rover technology for planetary explorations
- To develop service robots for building and other structures

The above objectives led to break up of the project in three sub tasks, each having a common aim towards developing "Decentralized cooperative exploration strategy with multi-agent systems". This further enhanced decentralized cooperation and coordination mechanism across multiple agents (robots) and ensured more efficient exploration, avoidance of spatial conflicts and offered a cost effective solution. This was achieved through cooperative behavior within a class of robots, which share common information, use complementary sensor-suite and avoid unnecessary duplication of sensors.

When the sensory system for each agent (robot) is totally different in nature and perception range, this concept can also be further extended to cooperative behavior between different classes, thereby building a system where each activity merges the acquired information in a global map of the environment increasing final accuracy, quality of localization and reducing the occurrence of spatial conflicts.

Network Initiatives

Micro Part Handling Systems for Robotic Assembly Using Ionic Polymer Metal Composite (IPMC)

Introduction

A micro system facilitates the assembly operation of very small mechanical/electronic components using miniature actuators like ionic polymer metal composite (IPMC). These actuators are capable of performing functional tasks in automation such as grasping and micro manipulation. For achieving these tasks, the micro manipulator is an essential tool for automation at the industrial level. Appropriate automation assists the human operator in picking up microscopically small components, holding them and placing them in the right position. This improves the product quality, reliability and further goes on to decrease the product cost. In this aspect, handling and manipulation tasks require a flexible, light weight and cost effective product. CSIR-CMERI is focusing on evolving new designs of micro gripping systems along with micro manipulators which offer flexibility in handling of pegs and its manipulation in a large work space. The programme for development of such prototypes constitute application parts of the Network initiative NWP-30.

Objective of the project

The project aims to design and develop micro manipulation systems along with IPMC based micro grippers for desktop handling of micro parts. For this purpose, new designs are attempted and their characteristics are identified.

Salient achievements summarizing contributions towards technology development and research outputs

Under this project, the following activities have been carried out and the achievements highlighted:

I. Development of IPMC Based Micro Gripper with Micro Manipulator

In order to achieve linear and sequential pick & place and peg-in-hole assembly operation in a 3-D environment, the manipulator needs at least 3 degrees of freedom (DOF) and a compliant micro gripper which can adjust the orientation of peg, rotational motions and executes the assembly in linearly. Such a micro manipulator with three DOF was designed and the schematic CAD model is shown in Figure 1(a). The micro manipulator consists of two shaft mechanisms to achieve two rotational motions and one sliding lead-screw mechanism to provide the translational motion. The two shaft mechanisms are identical in size and shape and are operated through individual servo motors. These two mechanisms are orthogonal to each other where the first shaft mechanism is responsible for the edgeway movement and second shaft mechanism allows the vertical movement. A sliding lead-screw mechanism is operated by a stepper motor which performs the linear motion to achieve the target hole position. A micro gripper is fitted at the extreme end of the lead screw mechanism by a retrofit / fastening arrangement so that the micro gripper can be used as an integral part during assembly with the micro manipulator and can easily be replaced. This micro gripper needs compliance for dexterity handling. Therefore, the micro gripper is constructed using IPMCs. In the designed micro gripper, two IPMC strips are used as two fingers. One IPMC finger is actuated through electrical pulses of voltage ranging from 0-3V while the other IPMC finger is placed at a sufficient distance and actuated by change of polarity. One IPMC finger bends on one side and other finger demonstrates opposite behavior when a reverse voltage is applied. The fingers thus bend in opposite directions for holding a micro component like a micro pin or a peg and can support a weight up to 10 mg. The sample may now be moved over the work space (60 mm) through the micro manipulator. This design is verified by developing a prototype of micro manipulator as shown in Figure 1(b).

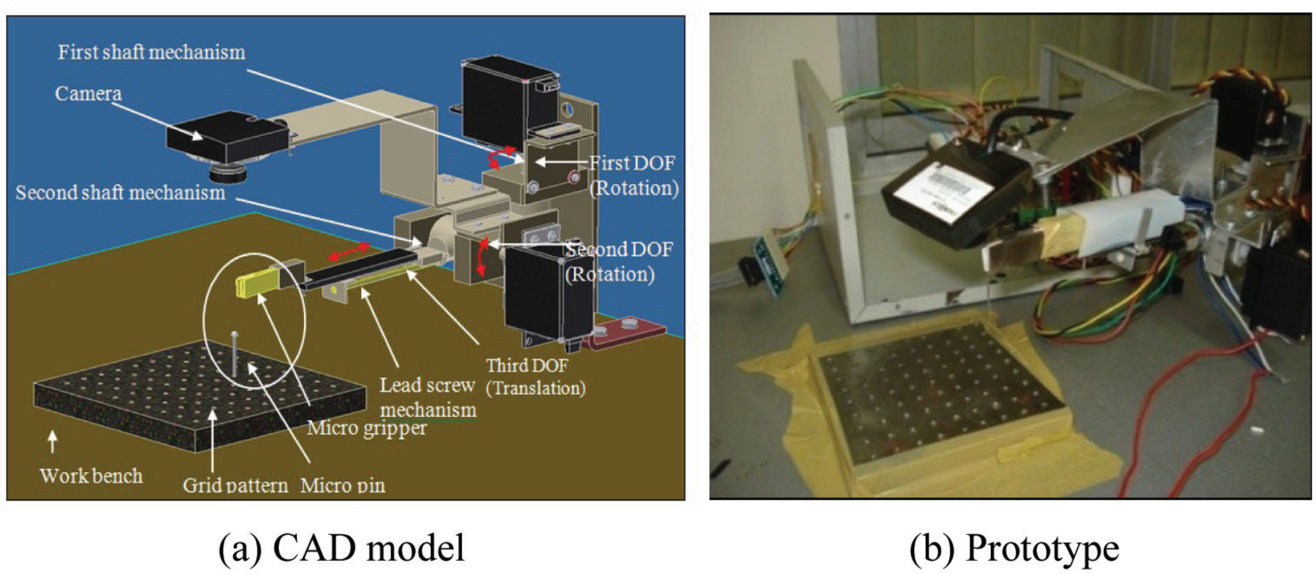


Figure 1. IPMC based micro gripper with micro manipulator

II. Development of Multi Micro Manipulation System Using IPMC Micro Grippers

The objective of this task is to design and develop four micro manipulation systems on a single work bench to achieve the manipulation task in a large work space. The CAD model of the assembly operation is shown in Figure 2 (a). As handling of micro parts is a challenging issue in the large work space of an assembly, an 81 holes grid pattern (9×9) is designed for handling the peg. The total size of the 81 holes grid pattern is 120 mm×120 mm where the distance between two holes is kept 10 mm. For smooth and proper handling of parts, the grid pattern is divided into four zones e.g. Zone-I, Zone-II, Zone-III and Zone-IV because each manipulator performs the manipulation only for a small region (60 mm × 60 mm), 60 mm being the total travel distance of one manipulator. Each zone is designed with 16 (4×4) holes. Therefore, four micro manipulators are integrated perpendicular to each other in a single work bench. Two micro manipulators can perform the operation accurately in each of the two different zones. The assembly operation of the 4-4 holes lying on the centre line of intersection of each zone is achieved by the manipulators placed respectively at M1, M2, M3 & M4 positions and one hole lying at the intersection of the two centre lines can be reached by any one of the manipulators from their respective position, thereby allowing easy manipulation and perfect peg-in-hole assembly. For viewing the grid pattern and identifying the exact position of a hole, a web camera interfaced with a computer is integrated atop the second shaft mechanism. When micro manipulators perform the operations, an operator can visualize and distinguish the operation from the desktop computer platform. A prototype of multi micro manipulation system is developed and manipulation task is demonstrated as shown in Fig. 2(b).

III. Development of Three Finger Micro Gripper for Micro Manipulation using IPMCs

This task involves evolution of a new design of micro gripper which consists of three fingers made of IPMC (Ionic Polymer Metal Composite) that are individually activated, and all connected to the wrist which is made of perspex. The wrist along with all fingers is connected to a single IPMC based flexible micro robotic arm as shown in Figure 3 (a). During operation, the three IPMC based fingers grasp the object and

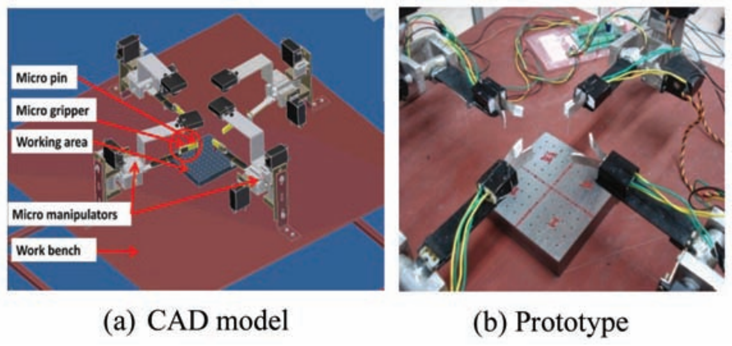


Figure 2. Multi micro manipulation system using IPMC micro grippers

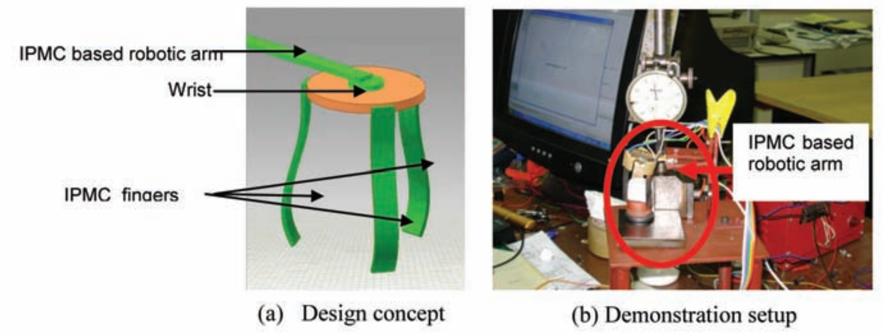


Figure 3. IPMC based micro gripper for RCC assembly

a single IPMC flexible micro robotic arm lifts the object. Remote centre compliance (RCC) based micro gripper is developed to facilitate the insertion of peg-in-hole (PIH) operation for micro assembly. The performance of PIH is demonstrated in a prototype and a single IPMC flexible micro robotic arm is used to lift the object as shown in Figure 3(b).

IV. Capability in Bio-mimetic Behavior of IPMC Artificial Muscle using EMG Signal for Micro Gripper

The objective of this task is to examine the bio-mimetic behavior of IPMC through EMG signal and transference of this bio-mimetic movement to a single link IPMC based micro robotic arm as shown in Figure 4. When a forearm moves in different angles, the signal generated is transferred to the IPMC which allows bending. This bending behavior is utilized as a single link IPMC based micro robotic arm for micro manipulation. The performance of the single link IPMC based micro robotic arm shows reasonable lifting capability. For actuation of the IPMC, a voltage ranging upto ±5mV is acquired through a human forearm via EMG signal. After acquiring this data, the voltage signal is amplified upto ±3V with a reasonable amplification factor (450-650) through PXI system. This voltage signal is then supplied to a single link IPMC based lifting arm for manipulation purpose as shown in Figure 5.

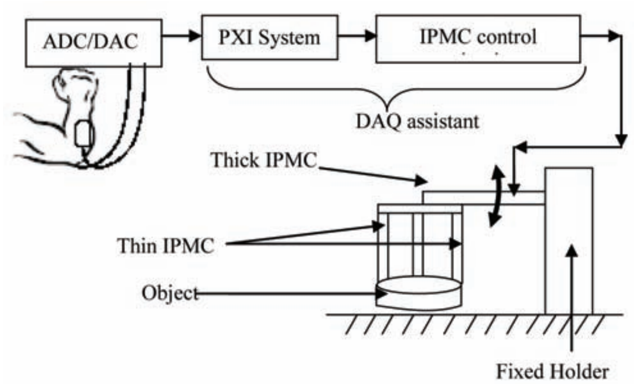


Figure 4. Layout of single IPMC micro robotic arm actuated through muscles

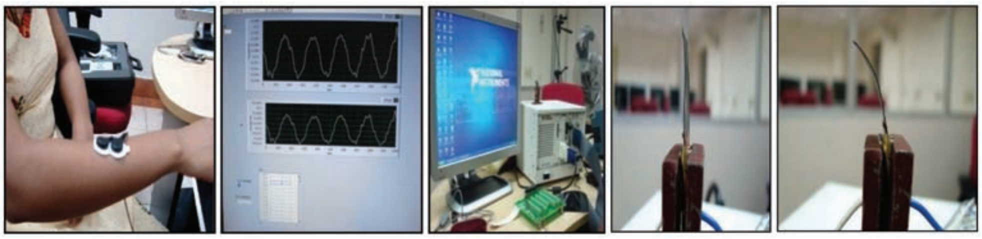


Figure 5. Stages of activation of IPMC through our muscles via EMG signal

The IPMC based micro robotic arm moves in a manner similar to a human forearm with displacements up to 14 mm.

V. Development of Robotic Micro Assembly Using IPMC for Adding Compliance in a Flexible 4 Bar Mechanism

A novel design of micro compliant assembly using flexible 4-bar mechanism and ionic polymer metal composite (IPMC) was proposed under this task for pick & place and peg-in-hole operations, as illustrated in Figure 6. An IPMC based compliant micro gripper is introduced at the centre of a coupler through an arm link in a flexible crank rocker 4-bar mechanism so that micro assembly operations for handling of micro objects can be attempted. When the flexible link mechanism performs operation in a full cycle, the paths generated by the mechanism are disturbed due to the transference of the contact reaction forces from the object (peg) to the coupler during assembly. For controlling and correcting these paths, an IPMC is also used as an active patch/actuator which is placed at an appropriate location on the coupler. The path of the flexible coupler is actively controlled by the IPMC patch and misalignment is compensated by compliant IPMC micro gripper. An IPMC based flexible 4 bar robotic system is fabricated and demonstrated that accommodates

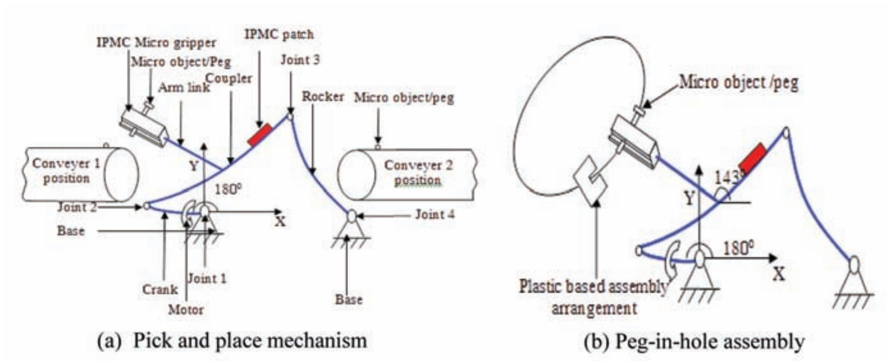


Figure 6. An IPMC based compliant micro assembly using a flexible 4 bar mechanism

deformation and error in paths of the compliant micro assembly as shown in Figure 7.

For demonstration of peg-in-hole assembly, each step of testing set up is shown in Figure 8. First, peg is held by an IPMC micro gripper in the mechanism; thereafter the peg starts the insertion at the chamfered position of the hole. When the peg touches the chamfered position, the compliant IPMC micro gripper corrects the lateral and angular misalignments. Subsequently, the peg attains the middle position of the slot (hole) and the IPMC based micro gripper opens for releasing the peg. After release, the mechanism is operated in the reverse manner for reaching the same position but the mechanism does not attain the same path. This takes place because the micro gripper does not carry the peg while reversing the mechanism. For achieving the same path, an IPMC patch is activated. This potential shows that paths of a flexible 4 bar based robotic system can be controlled through IPMC and assembly done by adding the IPMC compliant micro gripper.

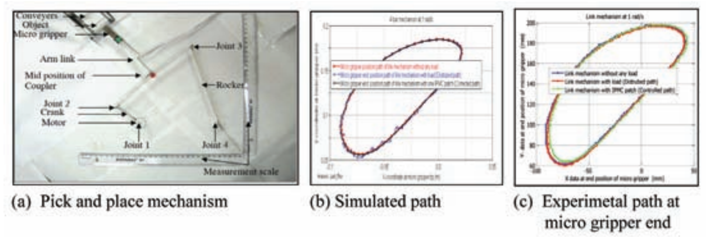


Figure 7. Design of an IPMC based robotic micro assembly operations using flexible 4 bar mechanism

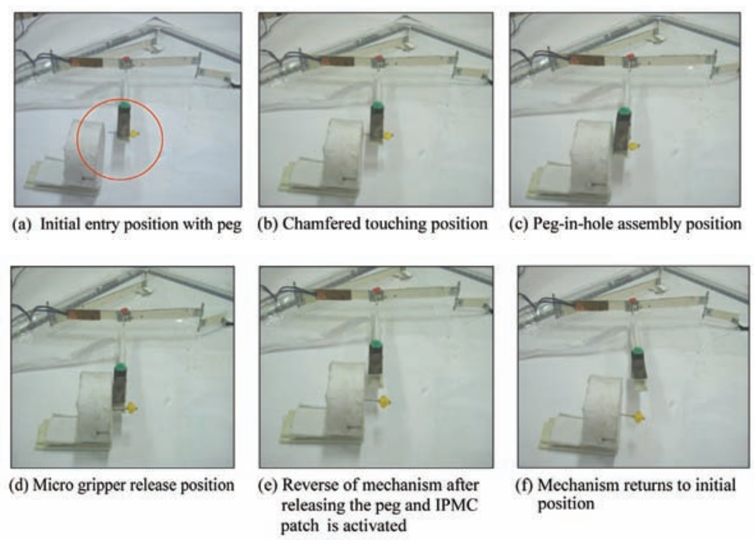


Figure 8. Demonstration of micro assembly operations by a compliant mechanism

Network Initiatives

Serpentine Robot CSERP-X

Considerable research and in varying degrees of detail have gone into the study of wheeled and legged locomotion as opposed to limbless locomotion, which seems to have attracted limited interest. Cyclic changes in the body shape is primarily responsible for limbless locomotion, like that of a serpent. SIR-CMERI devoted considerable R&D efforts in the area of limbless locomotion through the development of an experimental serpentine robot for implementation of various serpentine and non-serpentine gaits using hyper-redundant configuration. The serpentine robot thus designed had eight rigid segments, each connected to the adjacent one using actuated rotary joints. The main characteristics of the robot were its highly optimized design, lighter weight and modular configuration with low overall density. Serpentine gaits were simulated and verified in appropriate simulation environment for design and optimization of control parameters prior to implementation. Contributions made through this research include an experimental serpentine robot for experimentation with serpentine robot locomotion, Joint Orientation Function (JOF) and evolution of a new formalism for control of highly articulated robotic systems.

Many robotic systems employing serpentine locomotion have been developed at various research laboratories. Some notable efforts in this direction were studied, which provide reasonably good insight into the various aspects of research and development with serpentine robots. Studies were undertaken from the point of view of their design philosophy and gait implementation techniques. A comprehensive comparison of the serpentine robots has been prepared and included as Table-1. It shows a clear classification of the robots based on their propulsion mechanism, nature of joints and similar criteria. Performance of the CSERP-X – the serpentine robot developed for this research – is also compared. CSERP-X or CSIR-CMERI Serpent is one of the robots developed in the CSERP series.

Shape

Increasing the articulation makes a serpentine robot more realistic. However, many other constraints come into picture with the increase of articulation. More articulation means more joints and each of these must be driven by actuators, which also demand more power and complex control. In its shape, the serpentine robot is similar to that of a *death adder*, which has a low slenderness as compared to other snakes. A *death adder* has a broad, triangular head, a narrow neck and a short, stout body,

Table 1. Comparison of serpentine robots based on design philosophy.

			Propulsion					Joint Type		Joint DOF					
			External			Body Undulation									
Sl.	**Name**	**Laboratory**	Leg	Track	Active Wheel	Passive Wheel	Without Wheel	Active	Passive	Yaw	Pitch	Roll	Prismatic	**Tethered**	**Reference**
01	OmniPede	University of Michigan	X					X		X	X			X	[Granosik 05]
02	Moira	Kobe University		X				X		X	X			X	[Osuka 03, 04]
03	OmnitTread	University of Michigan		X				X		X	X			X	[Granosik Borenstein 05]
04	Kohga	ECU		X				X	X	X	X	X			[Kamegawa 04] [Miyanaka 07]
05	Soryu	Tokyo Tech		X				X		X	X	X		X	[Hirose 99] [Osuka 04]
06	GMD Snake-2	GMD			X			X		X	X			X	[Klaassen 99]
07	MAKROPlus	GMRD BMBF			X			X		X	X	X			[Adria 04]
08	Pipeline Explorer	NREC			X			X			X	X			[NREC 10]
09	Genbu 3	Tokyo Tech			X				X	X	X	X	X		[Kimura 02, 04]
10	Sneaky	CALTECH				X		X		X	X	X	X		[Burdick 92]
11	ACM-III	Tokyo Tech				X		X		X	X			X	[Hirose 04]
12	ACM-R3	Tokyo Tech				X		X		X	X				[Hirose 04]
13	ACM-R3n	Tokyo Tech				X		X		X	X				[Yamada 07]
14	ACM-R5	Tokyo Tech				X		X		X	X				[Yu 09]
15	SR-2	FIBO				X		X		X				X	[Wiriyacharoensonthorn 02]
16	AmphiBot	EPFL					X	X		X					[Crespi 05] [Ijspeert 07]
17	Worm Robot	MIT					X	X		X					[Conradt 03]
18	Slim Slime	Tokyo Tech					X	X		X	X		X	X	[Aoki 02]
19	Anna Konda	SINTEF					X	X		X	X			X	[Liljebäck 06]
20	Aiko	SINTEF					X	X		X	X			X	[Transeth 07, 08]
21	CSERP-X	CMERI, CSIR					X	X		X	X				[Maity 10]

which terminates abruptly in a very short, thin tail termed as 'lure'. Most specimens are less than two feet in length.

Articulation

In case of a biological snake, a collection of vertebrae forms the link. The angular freedom between the vertebrae is very small but as they are large in number and shorter in length, a snake can subtend a small body curvature. When curling laterally, five to ten vertebrae can make an angle of 90°. The same can, however, be achieved for the robot using a single joint. To provide greater mobility, the body of the serpentine robots have a number of segments. Each segment joins to the adjacent one with the help of an actuated joint. The main challenge in designing a snake robot is deploying actuated joints within a tight volume with minimal length and cross sectional areas of the links between the joints. One DOF actuated joint that fits in a confined space is comparatively easier to design. The common approach is to stack two 1-DOF joints orthogonally on top of each other (Figure 2b) to achieve both *dextro-sinistral* and *dorso-ventral* flexibility. In the context of serpentine robots, these flexibilities may be termed as '*yaw*' and '*pitch*' respectively. Other joint designs such as actuated universal joints [Brown 07] [Shammas 03], angular swivel joints [Ikada 87] and prismatic joints [Kimura 02] are also used, but they are complicated and specific to the robot design.

Practically, design and control of stacked 2-DOF joints are easy and it imparts good

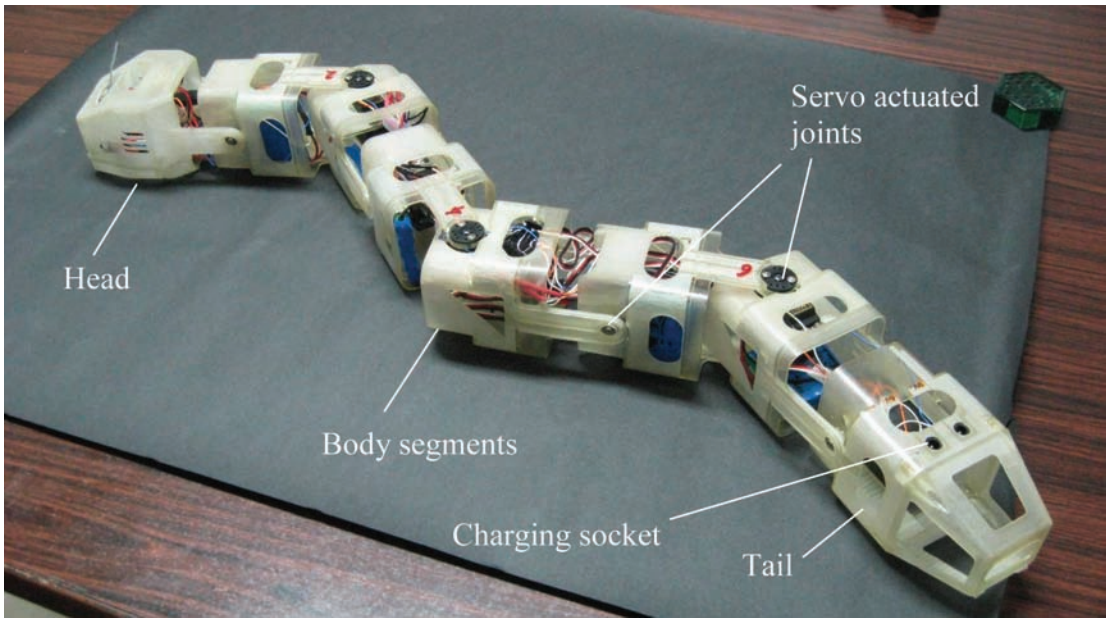


Figure 1. Experimental sepentine robot (CSERP-X) with eight segments. The robot has slenderness and aspect ratio comparable to that of a Death Adder.

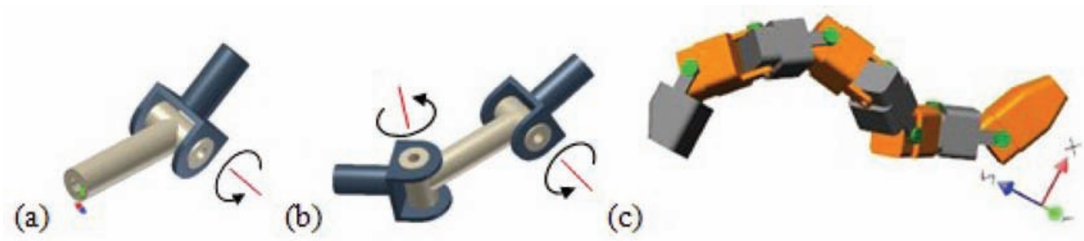


Figure 2. Articulation with (a) 1-DOF, (b) orthogonal stack of two 1-DOF joints. (c) The kinematic model of the serpentine robot with stacked 2-DOF articulation shows overall flexibility in 3D space.

overall flexibility to a hyper-redundant system (Figure 2c). Moreover, the higher the number of joints, the better is the resemblance with a real snake. At the same time, control of so many actuated joints introduce design complexity as more joints demand more power, and therefore there is a need for optimizing the number of joints. The robot is controlled by an onboard microcontroller and even low-end microcontrollers are expected to provide at least eight I/O channels. For this reason, a serpentine robot with eight segments connected by seven motor actuators was considered to be a better option. The free I/O channel might be used to interface the IR detector for the purpose of obstacle detection.

Weight

In terms of its morphology, a snake enjoys weight-bearing advantage and so does a serpentine robot. The whole body of a serpentine robot can bear the weight in a distributed fashion. It creates pressure points only when it moves, thus taking advantage of the ground reaction. The weight of a robotic system is an important metric that often decides its performance, particularly in terms of the operating speed and endurance. If the weight is more, energy spent in locomotion is more. In case of a fully deployable system, there could be a finite number of batteries onboard. To economize on energy the system should therefore be as light as possible.

Power-to-weight ratio (or specific power) is a metric commonly applied to mobile systems to compare one design to another. As a result, weight optimization is an essential task.

Battery

In terms of energy density and specific power, metal hydride cells are somewhat better than the NiCad batteries. NiMH batteries are readily available in different shapes and sizes and they have a comparatively faster charging rate. Li-ion cells, though far superior, are expensive. Considering all these, CSERP-X used NiMH battery packs, where several cells were series connected to supply the overall voltage required. This voltage, in practice, changes. The voltage drops when a current flows; the voltage again rises when the battery charges. Every battery module contained five NiMH cells and six such battery modules, each of 4500mAh@6V DC constituted the power pack for powering the servos. These modules in turn were connected in parallel for storing more power. A 200mAh@9V battery pack powers the camera and video transmitter. A separate 6V power pack provides power to the microprocessor and associated electronics.

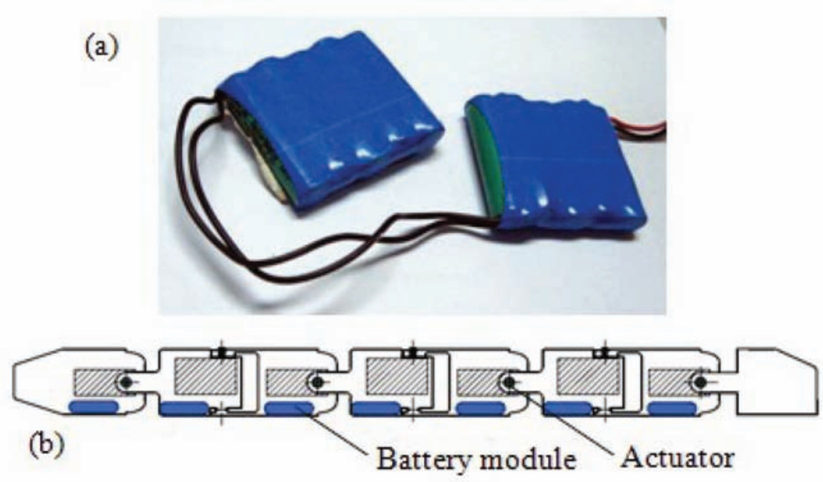


Figure 3. (a) Battery modules each consisting of five numbers of 900mAh @1.2V NiMH cells, (b) Total battery weight is distributed among the robot segments in modules by carefully grouping the cells.

Rotary Actuators

Radio control or R/C servos are small DC geared motors with onboard electronics that provide closed-loop position feedback control. Without a servo, one has to consider a small DC motor coupled to a gear reducer, control electronics and motor driver separately, which is expensive, consumes more space and is unwieldy. On the other hand, R/C servos are very robust, compact and cost effective. Only for this reason, R/C Servos find wide use in robotic systems such as scaled models of aircraft, helicopters, cars and boats.

A potentiometer attached to the shaft of the motor rotates along with it. Due to this, the rotation of the R/C Servo is limited to

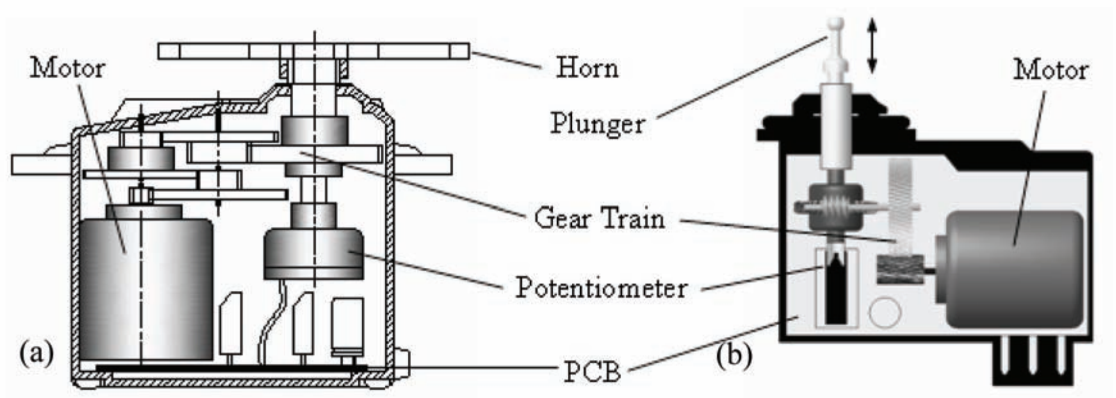


Figure 4. R/C Servo uses potentiometer for positional feedback. The figures show typical component layout of commercially available servos. (a) Rotary type servo has a horn that can rotate about its axis (b) Linear servo has a plunger, which can pull or push.

approximately 180° and these do not find application where continuous rotation is required. The system, however, proves quite good for limited positional control.

Servos can be of either rotary or linear types. For instance, linear servos find application in modern vehicles for such applications as adjusting the tilt of the headlight beam. Servos use Pulse Width Modulation (PWM) technique to control the position of the output shaft. The pulse is fed to the servo via a control line. For the experimental serpentine robot, the control signal is programmatically controlled and fed through the digital out ports of the PIC microcontroller. The input control signal is a pulse varying between 1 and 2 milliseconds (ms) delivered at a frequency between 50 and 60 Hz, which the servo internally converts to a corresponding voltage. For each position of the motor shaft and potentiometer, a unique voltage is produced. The servo feedback circuit constantly compares the potentiometer signal to the input control signal provided by the microcontroller. The internal comparator moves the motor shaft and potentiometer either in the forward or reverse direction until the two signals are same. The shaft of the motor can be positioned through 180° of rotation, depending on the width of the input signal. The shaft of the motor is connected to a high reduction multistage gearbox and is capable of producing considerable torque from a small motor.

Segments

The final design took into account all considerations like shape, size, equipment and electronics. The system took shape gradually after successive iterations, the basic dimensions of which are shown in Figure 5. The final design accommodated six body segments, a head and a tail. Body segments are identical in shape and size, but the head and tail segments are slightly different. The head segment houses some sensors and the tail houses other components like the battery charging point and the LED indicator. The overall system has 7-DOF with seven joints actuated by R/C servo actuators. Four of these joint actuators have horizontal axes while three have vertical axes. Some gaits utilize all four sides of the body segments. Segments were chosen to have square cross sections so that the robot exhibited uniformity in all states of its gait. Variation in the *dorsal* and *ventral* shapes led to anomalous behaviour in various stages of gaits that utilized all the

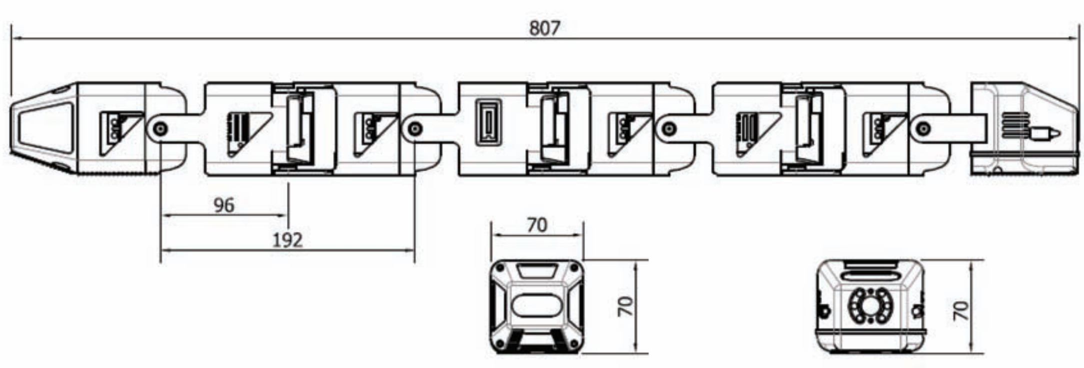


Figure 5. Overall dimension of the serpentine robot CSERP-X.

four faces of the body segment such as in *lateral roll*. Sleeved with a skin the robot has a total volume is about 3675 cm^3 and an overall density of 0.34 g/cm^3.

Table 2. A brief specification of CSERP-X

Overall length	807 mm
Number of segments	8
Number of joint actuators	7 R/C servos
Joint actuator torque	9 kg-cm
Joint to joint	96 mm
Segment cross section	70 mm x 70 mm
Overall weight (including battery)	1.26 kg
Obstacle detection	IR based
On board microcontroller	PIC 16F84A
Power source:	
Servo actuators	6x4500mAh@6V
µ-controller and other electronics	4500mAh@6V
Camera, video transmitter & light	9V

All the robot segments were fabricated through Rapid Prototyping (RP) technology. RP is an additive manufacturing technology where a three-dimensional object is created by deposition of successive layers of material.

Robot segments were fabricated with relatively new 'PolyJet Technology', which enabled simultaneous jetting of photopolymer materials and subsequent curing with UV ray [Objet 10]. Components were designed in a highly optimized manner employing thin walled cells. Each body segment weighed approximately 43.5 gm, and the head and tail segments weighed 63.5 gm and 57.5 gm respectively. The segments were tough enough to withstand the impact arising out of various gaits during locomotion.

System Architecture

The purpose of the experimental serpentine robot is to experiment with serpentine gaits; the system architecture was therefore designed to facilitate the intended purpose.

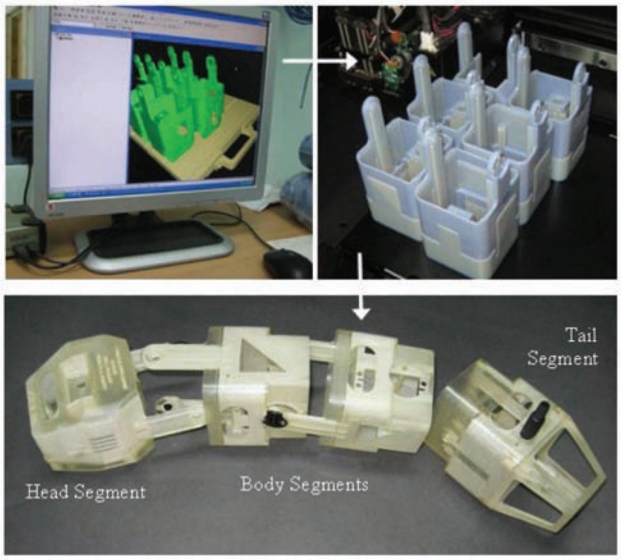


Figure 6. Body segments of the serpentine robot fabricated through 3D printing route.

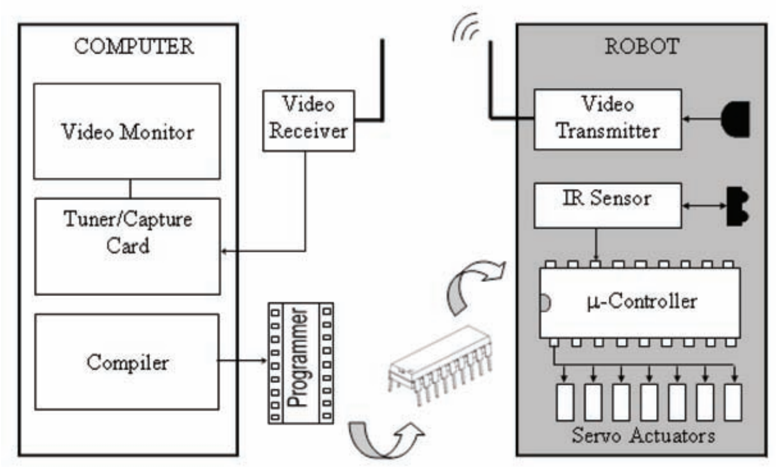


Figure 7. The system architecture of CSERP-X.

Locomotion gaits were deployed offline with the pre-programmed microcontrollers replaced physically into the serpentine robot.

The serpentine module is fully deployable and does not have any umbilical cord or other cable connection for command signal or power supply. An on-board microprocessor takes the total control of the system and the robot carries all the battery packs along with it. This limits its mission time. However, deployment of locomotion gaits are accurate and uninterrupted, as it does not have to drag the tether along all the time. The video data is transmitted online to a remote computer.

Electronics

Electronics constitutes an important part of the serpentine robot as it takes care of the flow of information, decision-making and overall control of the system. There are seven rotary actuators, all distributed along the length of the robot and these actuators need signals and separate power supply in order to perform the designated tasks. The microcontroller board is placed inside one of the segments (Controller Segment) and the cables run throughout the length of the robot to transmit signal to the servos. A window is provided to the segment (Figure 8a) for allowing easy access to the microcontroller as for the present robot the microcontrollers are programmed separately and placed into the robot. Selection of servo as rotary actuator considerably reduces the volume of electronics that goes into a serpentine robot and the requirement of design of separate motor control system, analysis of transient response, fine-tuning of feedback loop, determination of proper gear ratio for the required speed, selection of motor, custom amplifier and motor driver are all eliminated in the process.

The controller board and the servos are powered separately. The controller board consists of a PIC16F84A microcontroller and a minimum of other parts. The advantage of a microcontroller is that power demand and electronics could be kept minimal, making microcontrollers ideal for use with small robots and other applications where computing power is needed. Microcontrollers are popular because the chip can be reprogrammed easily to perform different functions. Programmable Interface Controller (PIC) is a family of microcontrollers

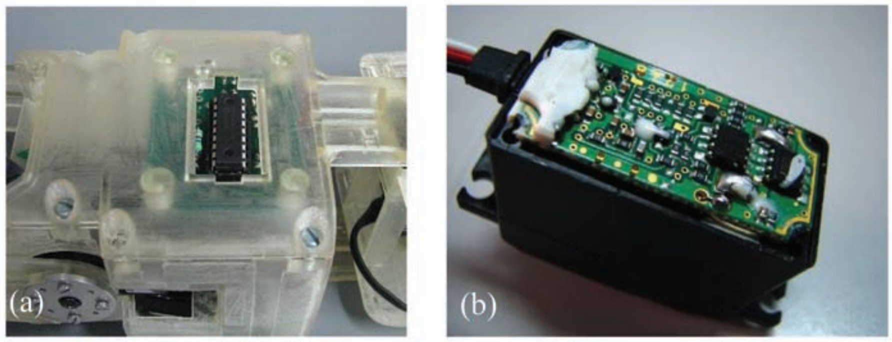


Figure 8. (a) The microcontroller window at the controller segment (b) Servo Internal Electronics.

developed by Microchip [Microchip 10]. The PIC 16F84A is an 18-pin device with an 8-bit data bus and registers, and employs a reduced instruction set computer (RISC) CPU. A 4-MHz crystal is used for the clock input that can be clocked up to a frequency of 20-MHz. Running machine code at 4 million cycles per second can be considered pretty fast for this application. The microcontroller is equipped with two input/output (I/O) ports, port A and port B.

Each port has two individually associated registers. The first register is the TRIS (Tri State) register. The value loaded into this register determines whether the individual pins of the port are being treated as inputs or outputs. The other register is the address of the port itself. Once the ports have been configured using the TRIS register, data can then be written to or read from the port using the port register address. Port B (RB0 to RB7) has eight I/O lines available and Port A has five I/O lines (RA0 to RA4). Besides the controller

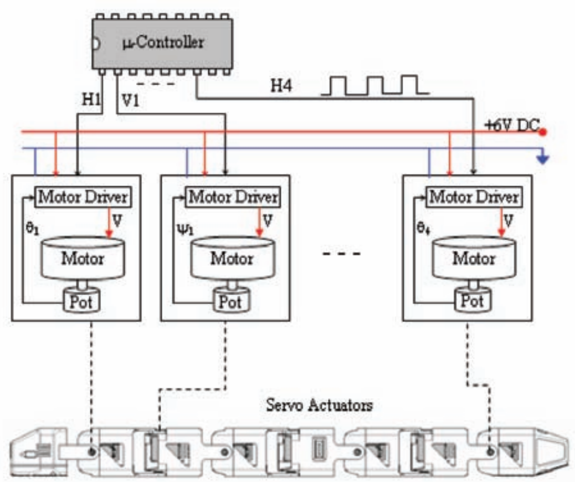


Figure 9. Schematic diagram showing signal, power and ground connection of servos. Seven such servos (H1, V1, H2, V2, H3, V3 and H4) are used as joint actuators.

board, an IR sensor board is mounted inside the head segment. The IR obstacle detection system located at the front of the robot sends signals to the microcontroller. Based on its application, a snake robot can be fitted with various sensors, such as ultrasonic sensor, image sensor, gas sensor, temperature sensor and illumination sensor [Choi 05], [Ito 06]. Some sensors provide immediate feedback and influence the activity of the system whereas others remain passive and are used for data acquisition and further processing. Some sensors that have been incorporated into the experimental serpentine robot are discussed here.

The video camera mounted at the head segment of the robot provides video and audio feedbacks online. A narrow passage may not be well illuminated; consequently, the video quality might be poor. There is an array of white LEDs surrounding the camera for providing sufficient light for good image quality. The camera is equipped with CMOS image sensor and the inbuilt transmitter sends signals at a frequency of 1.2GHz up to a distance of 100 m when there is a line of sight. On the other end, a small receiver receives and outputs the analogue signal either to a video monitor or to a computer through an analogue-to-digital frame grabber card for further processing. A 9V battery pack separately powers the camera system. All these batteries are charged with an external battery charger through the charging ports located at the tail segment of the robot. The video image is often jerky when the robot performs locomotion. To obtain a steady image of the surrounding, *survey posture* was devised. The IR obstacle detection system mounted on the head segment consists of a suitably mounted IR emitter and a detector (PNA4602M). Upon detection of any obstacle, the state signal is received at RB1 of the microcontroller and subsequently the turning subroutine is activated.

Programming

A PicBasic Pro Compiler developed by MicroEngineering Labs [MEL 10] was appropriately programmed for simulation of gaits. The PicBasic Pro Compiler was evolved

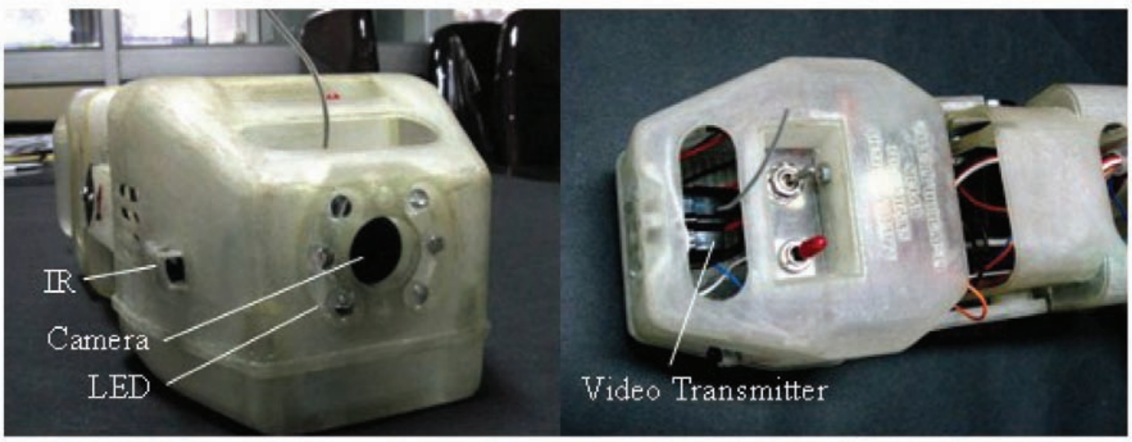


Figure 10. Mounting of different sensors on the head segment. White LED light surrounding the camera helps to take better picture even in low light condition.

from BASIC Stamp and has most of the libraries and functions. Since it is a true compiler, programs execute much faster and generate both assembly code and hex code (machine code). PicBasic Pro (PBP) was set to create files that run on a PIC16F84A- clocked at 4 MHz.

The PIC16F84A and 16F87x devices contain between 64 and 256 bytes of non-volatile data memory that is used to store program data and other parameters, even when the power is switched off. This data area can be accessed simply by using the PicBasic Pro Compiler's READ and WRITE commands. Program code is always permanently stored in the PICmicro's code space irrespective of the power state. The PicBasic Pro Compiler generates standard 8-bit Merged Intel HEX files. Mathematical formulation of all the gait sequences was carried out. Based on these formulations the coding for various locomotion types was evolved. The microcontroller programmed with various gait sequences and logical routines were deployed into the controller card of the serpentine robot [Figure 11]. Controlling a servo with PIC microcontroller is easy with PicBasic. Pulses can be generated on a specified pin of the microcontroller by using PULSOUT command for a specified period. Toggling the state of the pin twice generates the pulse; thus, the initial state of the pin determines the polarity of the pulse. The resolution of PULSOUT is dependent on the oscillator frequency.

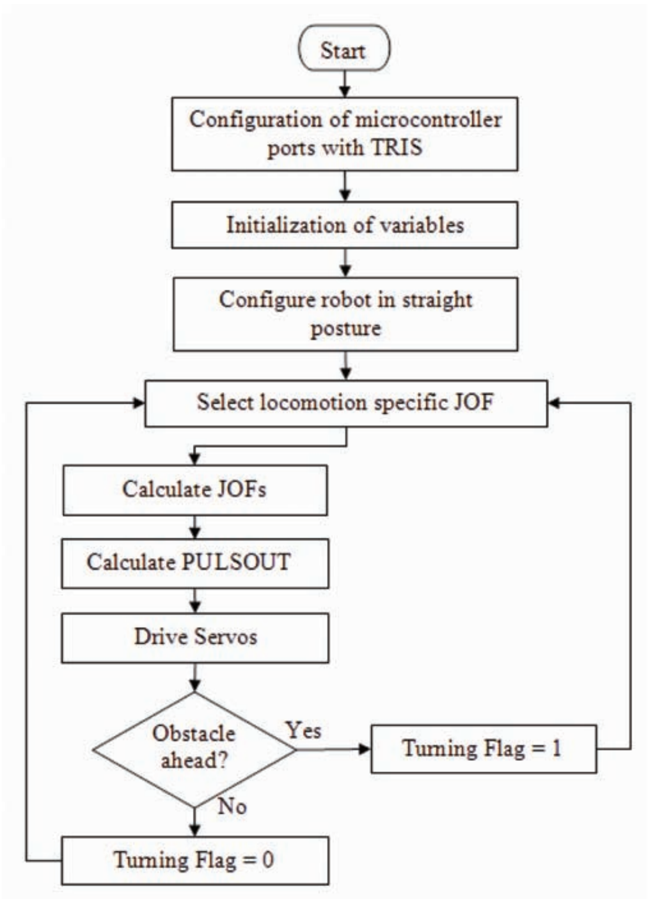


Figure 11. Flowchart for the microcontroller programming.

Kinematic Simulation

The design process is iterative in nature and involves simulation in CAE environment. If a design does not work in simulation, it is most likely to fail on implementation. A highly optimized 3D model of the robot was prepared and exported to the CAE environment for kinematic and dynamic analyses. CAE solvers use numerical methods to solve dynamic simulation problems. The solution of the motion of mechanical systems is governed by differential equations arising from the principles of mechanics. The solution evolves through a process known as *numerical integration*. While many numerical integration methods exist, the most widely used are Euler integration and Kutta-Merson integration. Euler integration techniques are faster, though not as accurate as Kutta-Merson integration. Euler integration may be used to obtain an approximate idea of the motion. A first order differential equation of the form $y = f(y,t)$ is solved for time $(t+h)$ in a single step, i.e. $y = (t+h) = y(t) + fh(y(t),t)$. On the other hand, the Kutta-Merson integration technique uses several steps to calculate the same to come up with a fairly accurate result [Fox 62]. During the course of a simulation, the solver constantly monitors various errors such as interpenetrating bodies and constraint violations. At each integration step, the solver checks its computation results to verify whether the model satisfies the error bounds. Reducing the time step reduces error substantially. Parameters are to be set such that this error is within acceptable bounds.

The simulation model of the serpentine robot was generated using basic 3D model data used for the design of the experimental system. To reduce computational load a simple simulation model was adopted as compared to the actual design of the serpentine robot. Special attention was provided to the overall shape and size and other critical dimensions. The simulation model of the serpentine robot was made as realistic as possible keeping room for approximation very low. As ACIS geometries were needed for the simulation environment it converts curves and curved geometries with a set of polygons or

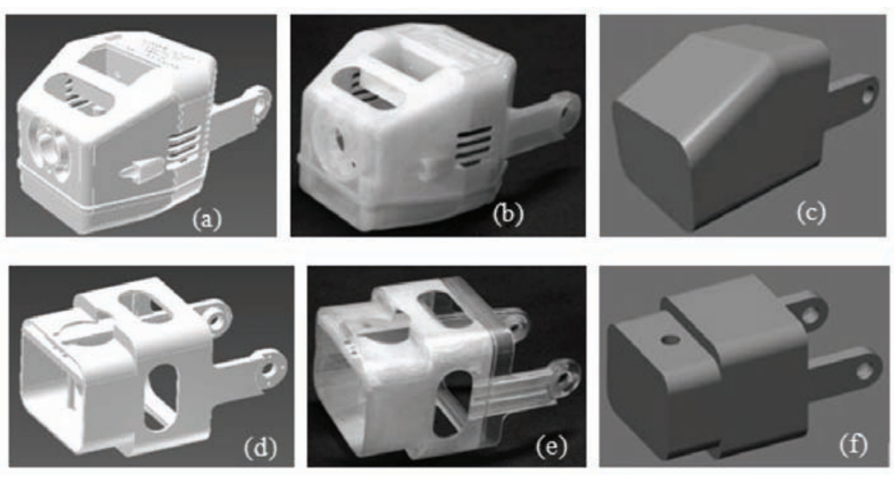


Figure 12. The head segment of the experimental serpentine robot (a) as designed, (b) as built, and (c) as prepared for simulation environment and the body segment of the snake robot (d) as designed, (e) as built, and (f) as prepared for simulation environment.

planar surfaces. This process is often known as *faceting*. To fine-tune the geometric complexity of the objects, non-linear and curved features were optimized. On a tessellated surface, *Surface Deviation* and *Normal Deviation* can highly influence the contact/collision behaviour. An optimized geometry was carefully prepared to obtain better simulation performance without sacrificing realistic simulation results. Various studies were carried out to make the serpentine model move in the simulation environment [NASTRAN 04].

There is one-is-to-one correspondence between the experimental serpentine robot and the simulation model of the robot as the model geometry was prepared in line with the actual robot. In Figure 13, the joint locations shown in green are constrained with the mathematical model of the robot kinematics. As such, all the joint constraints are made responsive to corresponding *joint orientation functions* and mathematical model used for gait implementation was verified in simulation environment prior to deployment on the robot.

It is important to note whether the gaits that are generated in simulation are meaningful or not. Simulation helps to study the locomotion behaviours and to improve their efficiency by adjusting parameters of the mathematical model. The same was implemented on the robot to prove the model validity. The simulation environment can be considered to be the replica of the actual case scenarios. Moreover, the simulation environment combines (i) the simulation model of the robot, (ii) environmental parameters and (iii) the mathematical models of locomotion.

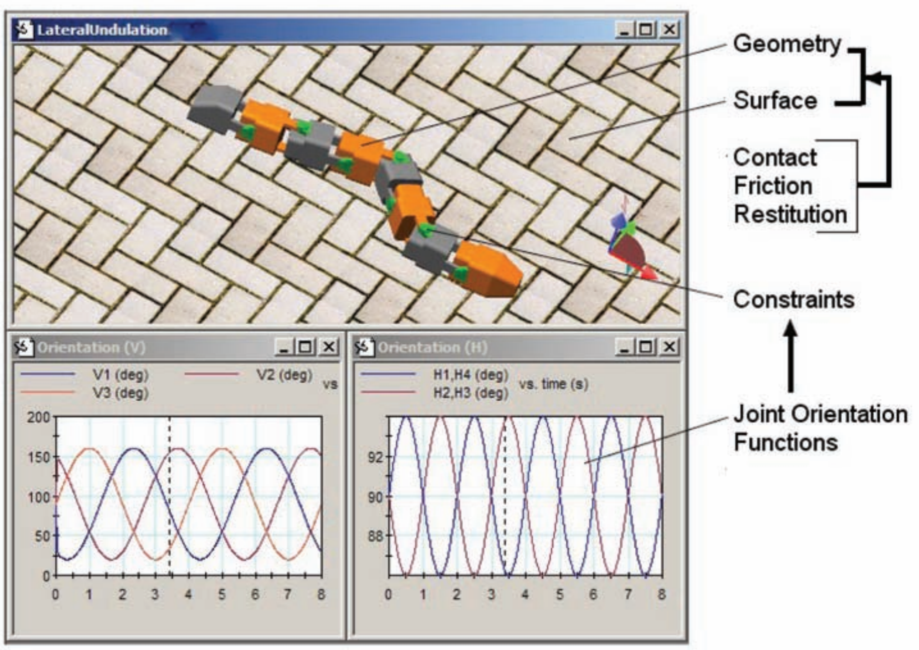


Figure 13. Experimentation with gaits in simulation environment [Maity 11]. The joint constraints are actuated with joint orientation functions to produce desired locomotion. Contact, friction and restitution were modelled between the surface and the simulation geometry.

Summary

The final shape of the serpentine robot provides a highly articulated seven degree of freedom machine with on-board battery pack, microcontroller, wireless camera, LED light, and IR obstacle detection system. The experimental serpentine robot provides an excellent platform for experimentation with gaits. Its modular and identical segments can be replaced or augmented easily. The robot was designed without tether keeping in mind that attached cables may influence its gait behaviour. For experimentation with swimming gaits, a thin flexible sleeve was used as skin, which protects the internal electronics from coming in contact with water. Flexibility on both horizontal and vertical plane helps in implementation of *coupled orthogonal joints orientation functions*. Some of the sensors used entailed high cost, but were added to improve the utility of the robot. For locomotion videos, interested readers may refer http://www.cmeri.res.in/rnd/srlab/srobot.html.

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Looking Ahead

- Nanosuspensions: Bridging the Gap between the Hydrodynamic and Boundary Lubrication
- Insight into Rheo Pressure Die Casting
- Self-Organized Nano-Patterning of Thin Confined Bilayers Employing Molecular Dynamic Simulations
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Looking Ahead

Nanosuspensions: Bridging the Gap between the Hydrodynamic and Boundary Lubrication

The technical function of numerous engineering systems depends on processes of motion. A strong attempt has been made over the years to provide enough lubrication to keep the contacting surfaces well separated from each other. The role of a lubricant is similar to that of a peace-keeping force: its main function is to prevent the opposing surfaces from coming into close contact with each other at the atomic level. The most effective way to reduce friction and wear is to separate the two sliding surfaces by means of a lubricating film (third body), such as a film of solid lubricant, oil, grease, or gas (Figure 1). The tribological requirements for film lubrication to improve performance, life and reliability have increased dramatically in line with the development of modern space-age mechanical systems. The selection of lubrication method and its application techniques establish the tribological performances in terms of friction, wear and endurance life.

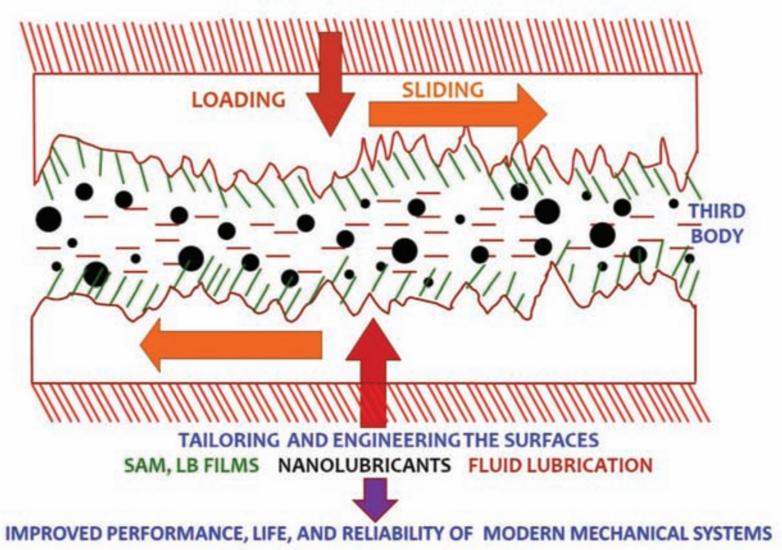


Figure 1. Schematic showing two contacting surfaces well separated by means of a lubricating film (third body).

Traditional Fluid Lubrication

In sliding tribology, to impart boundary lubrication properties to a lubricant, beneficial products of reaction between the metal parts and the traditional anti-wear and extreme-pressure additives such as MODTC and ZnDTP are generated in-situ. The use of traditional lubricant additives in automotive and industrial lubrication creates many problems of toxicity and pollution. Traditional lubrication fluids create hydrostatic and hydrodynamic pressures to support the load and to protect the surfaces from shear and abrasion. A 'non-reaction' route is to allow functionalization of the solid surface by organic molecules dispersed in the liquid lubricants. The chemical additives generate protective thin films against the inevitable asperity contacts. These molecules however have limited load bearing capacity and thermal stability. Therefore the resulting film in the contact does not necessarily guarantee the protection of the surfaces. The adhesive and cohesive strength, and the density and thickness of the film all contribute to its effectiveness. The film also functions to redistribute the stresses at the interface, providing an easily-shearable sacrificial layer and increasing the real area of contact by physically smoothing out the relative roughness, thereby lowering the contact pressure.

Most of the fluid lubricant works in the boundary lubrication regime of the Stribeck curve (*Figure 2*). However, at the boundary lubrication regime where the contact pressures are very high, the asperities undergo plastic deformation and the thickness of the fluid film decreases, resulting in an increase in the contact temperature and formation of a chemical film that might be corrosive. Therefore the life of the sacrificial film is too small as it wears out quickly with repeated sliding under high contact pressures. Gas emissions by these additives are harmful for the environment and the slow degradation of the additives hinder the tribological properties.

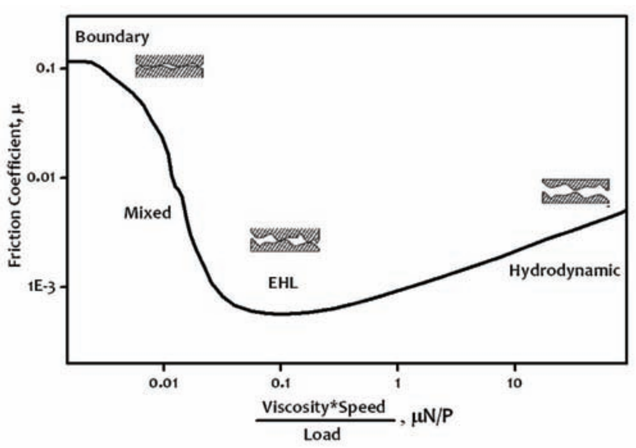


Figure 2. Stribeck curve (Variation in coefficient of friction with viscosity, velocity and load for fluid lubricated contact).

Concepts of Nanolubrication

New lubrication concepts are therefore envisioned to address the shortcomings of conventional fluid film lubrication for the boundary lubrication regime. Initiatives are taken to evolve a new generation of lubricants based on the development of additives for lubrication using solid lubricant nanoparticles. A solid lubricant is any material used as a thin film or a powder on a surface to provide protection from damage during relative movement and reduce friction and wear. Solid lubrication is achieved by self-lubricating solids or by imposing a solid material having low shear strength and high wear resistance between the interacting surfaces in relative motion. The solid material may be a dispersion in oils and greases, a loose powder or a coating. Solid lubricants are used when liquid lubricants do not meet the advanced requirements of modern technology mostly in the boundary lubrication regime. These are very useful for the applications needed to meet critical operating conditions such as pressure and temperature for which fluid lubricants are ineffective or undesirable.

Therefore the combination of the above two lubrication structures, i.e., solid lubricant particles suspended in fluid lubricant, is useful for the modern mechanical systems over the entire lubrication regime. Nanoparticles have generated increasing interest as extreme pressure and anti-wear additive for liquid lubricants. Lamellar materials of metal disulphide type (MoS_2, WS_2) are known to have excellent lubricating properties. These solid particles, generally of a layered structure, shear easily under traction to yield low friction. The low friction of metal dichalcogenides, MX_2 (M = W, Mo; X = S, Se) is usually due to interplanar mechanical weakness intrinsic to their crystal structures with M-X atoms covalently bonded in planar hexagonal arrays with each M atom surrounded by a trigonal prism of X atoms. Strong covalent forces bind M and X atoms within a lamella, whereas adjacent lamellae interact through relatively weak van der Waals forces. The weak inter-lamellar bonding facilitates easy shear when the direction of sliding is parallel to the planes of the material. Under the action of a shear force, intracrystalline slip occurs in the weak interplanar regions. They are widely used either as solid lubricants for space applications or as additives dispersed in a lubricating base.

When small particles are dispersed in fluids, it is possible to enhance their lubricity and thermal response. The lubrication and cooling mechanism has remained 'particle' specific and properties such as interlayer low shear strength of layered particles, plasticity of phosphates, elasticity of fullerenes, formation of low shear strength reacted films, high thermal conductivity of metal nanoparticles and carbon based materials are mechanisms attributed to support the use of nanoparticles. Depending on their size and shape, lubrication is provided either by rolling or by sliding (Figure 3) between the contacts.

The compressibility of the spherical particles under load and inter-planar slip of the layered particles are the factors which decide individual lubrication behaviours. Compression of particles can be attributed to a number of mechanisms: (i) rearrangement of the grains, (ii) fracture and rearrangement of the grains and (iii) distortion

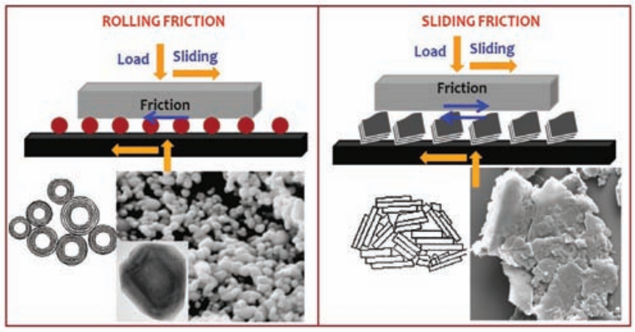


Figure 3. Schematic showing the mechanism of rolling and sliding friction.

or deformation of the grains. It is expected that the first two mechanisms of compression can primarily occur for the spherical nanoparticle while the layered particles may also be distorted and bent due to their platelet shape. The behavior of the solid lubricant particles at the low-pressure range is determined mainly by the slippery nature of the particles. The spherical nanoparticle shows the best slippery nature in comparison to layered particles at low pressure compression. This behavior may be attributed to the close, ovoid shape of the IF allowing easy intergranular friction under low hydrostatic pressure. However, the effect of the spherical materials as boundary lubricant decreases at high loads and sliding velocities and this has been attributed to the presence of voids and defects in the IF and the aggregation of the nanoparticle in the ambient humidity. The damage of spherical nanoparticle is believed to occur by the gradual peeling off of the external sheets. On the contrary, although the platelet particles exhibit heavy damage under high pressure, the performance of these lubricants is better than that of the spherical particles.

Aqueous Lubrication

Recently, "zero oil" lubrication using water as dispensing medium, which is a natural and renewable resource unlike oils is attracting considerable research attention. When compared to petroleum oils, water-based fluids possess significant advantages, such as reduced environmental pollution, high thermal conductivity, fire resistance, low cost and better cooling. These advantages in addition to lubrication are expected to prove useful in many aspects of an actual application, but certain additives are required to improve the poor lubricity of water. Water is a polar compound and in contact with metals forms chemical bonds with the surface atoms, leading to high adhesion and friction; it is therefore a poor lubricant. It also has poor load bearing properties, a low stiffness in confinement and also suffers from the inability to transmit the pressures required to support rotating machinery. Water has a low viscosity which, under lightly loaded hydrodynamic conditions, accounts for low friction. However in boundary lubrication, the low viscosity of water takes a contact readily into the boundary lubrication regime even when the pressures are modest and the speed is moderate. The concern is how to derive advantage of the environmentally friendly and low-cost features of water but ensure its ability to serve as a lubricant. Slight modification by – for example addition of inorganic nanoparticles (metal oxides, borates, phosphates, etc.) – increases the viscosity of water, thereby enhancing its applicability as a lubricant.

The progress in chemistry and technology has made it possible to synthesize nanoparticles of various metals, metal oxides, chalcogenides, phosphates, carbonates, borates, etc. When particles are small, their physical and chemical properties differ from those of the bulk material. They have high chemical and physical stability even under extreme conditions, increased load-bearing capacity and can creep into the tiniest spaces between contacting surfaces. A major problem in using nanoparticles is agglomeration. The properties of agglomerated particles can differ from the properties of individual nanoparticles. Colloidal stabilization of the nanoparticles by ultrasonic dispersion and by using surfactants and surface functionalization of nanoparticles are the significant methods for stabilization of nanoparticles. From the tribological point of view, some of these surface functionalized nanoparticles can show superior properties in comparison to the bare ones.

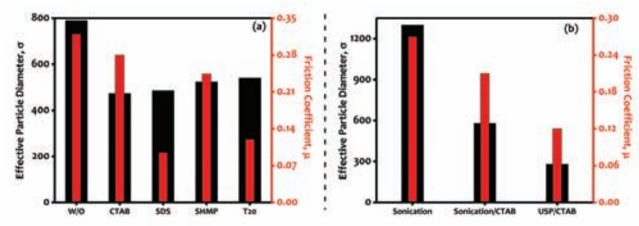


Figure 4. The effective particle size and friction coefficient for (a) spherical Cu particles suspended in water medium without any surfactant and with SDS, CTAB, Sodium Hexa Meta Phosphate (SHMP) and Tween 20 (b) Layered MoS2 particles suspended in water mixed under normal sonication, with 1mM CTAB and with ultrasonic probe and CTAB.

Potential Applications

Compared to traditional additives, nanolubricant particles are relatively insensitive to temperature; thus the tribochemical reactions are limited. Nanolubricant particles thus reduce wear to extend the life of moving parts and alleviate friction, which reduces noise, heat and vibration. Environmental benefits include reduced energy consumption, extended relubrication and decreased air pollution. The lower cost of maintenance, extended equipment life, improved machine performance and reduced downtime provide significant economic benefits.

Natural tribological systems involve soft surfaces. Such soft surfaces deform elastically under external load and result in an increase in the contact area and a relatively low contact pressure regime. This is why liquids whose viscosity increases only slightly with pressure (such as water) can form lubricating films in soft contacts. This property sparked extensive study of aqueous lubrication of elastic polymers and inorganic nanoparticles and led to applications in tires, seals, windshield wipers, biomedical implants, etc.

Owing to its behavior as a natural coolant, water lubrication is preferred in most industrial processes such as reservoir pumps, hot and cold rolling in steel plants and oil-water emulsions for metal cutting application. It is also preferred in the mining industry so as to prohibit flammable materials from underground working areas. It is preferred also in food, textile and pharmaceutical industries to avoid oil contamination.

Looking Ahead

Insight into Rheo Pressure Die Casting

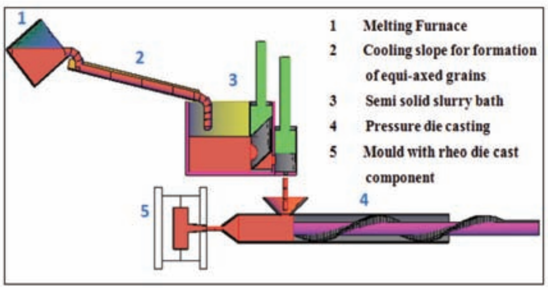
Semi-solid processing of metals (alloys) came into existence in 1970's and is now considered to be a potential manufacturing technology for components for automobile, aviation, electronic and machine tool industries. Semi solid metal processing enables manufacturing of near net-shaped components with good mechanical and tribological properties and with high-dimensional tolerance accuracy.

Rheo-pressure die casting is a type of semi-solid processing technology which has significant advantages over conventional die casting, such as minimizing the macrosegregation and solidification shrinkage and reducing the forming temperature. The key feature that allows the formability of semi-solid alloys into complex shapes is the thixotropic flow behavior at semi-solid temperature, which is caused by the non-dendritic morphology of the primary phase in the microstructure. Such flow properties and formability are not possible with conventional die casting techniques.

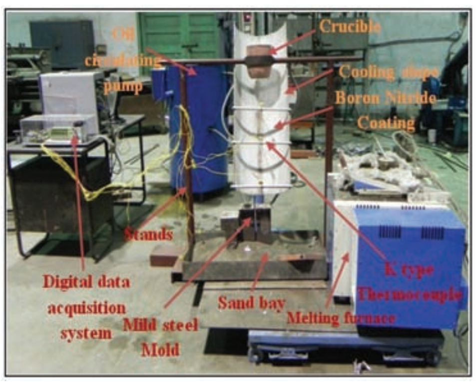
Several processes are available for preparation of semi-solid slurry. These include stir casting, electromagnetic stirring, mechanical or ultrasonic vibration, low pouring temperature and partial remelting, stress-induced and melt-activated (SIMA) process, thermo-mechanical processing, magnetohydrodynamic (MHD) stirring, and cooling slope. However, most of the above methods have proven to be too complex as well as expensive for successful commercial exploitation of semi-solid processing technology. In this respect, the cooling slope method offers some promise, as it is one of the simplest and most cost effective processes to prepare the semi-solid slurry for thixocasting and rheocasting. In this work cooling slope has been used keeping in view the production of semi-solid slurry on demand for successive pressure die casting for component development. When superheated molten alloy flows over the cooling slope, the temperature drops below the liquidus temperature and α -Al crystals starts to nucleate. The initial contact with the cold surface of the slope promotes the necessary undercooling for solid nucleation; therefore solid crystals appear in the region. α-Al crystals form globular equiaxed grains and the melt assumes the properties of a semi-solid slurry up to the end of the slope.

A study being conducted at CSIR-CMERI envisages bridging the gap between experimental investigations and recent numerical simulations. The numerical simulations performed by earlier researchers lack experimental validation. The experimental findings available in the literature show results differing from each other. In this context, there is a necessity of undertaking a comprehensive and experimentally validated numerical study of cooling slope slurry production of aluminium alloys. This is the focus of the present study, which is done using A356 aluminum alloy. The main objective of the numerical model is to relate the process variables such as pouring temperature, slope angle and wall temperature of the slope to the slurry temperature distribution, velocity field and solid fraction distribution. Moreover, phase filed model has also been developed to study the microstructure evolution in the semi-solid slurry during flow through the cooling slope.

Key Findings of the Project



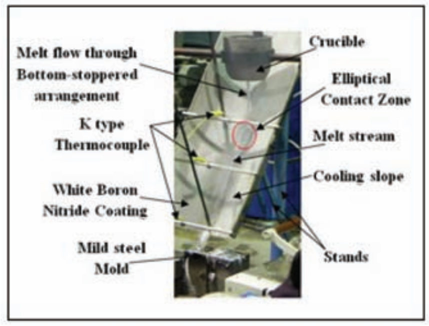
Schematic of Rheo-pressure die casting system.



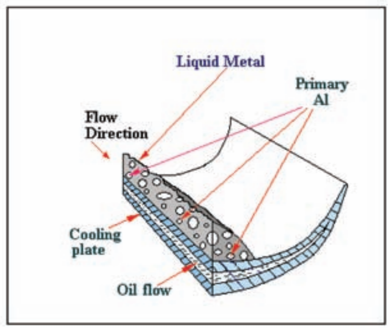
Photograph of Experimental facility.

Si	Mg	Mn	Cu	Fe	Ti	Al
6.8	0.34	0.18	0.14	0.11	0.04	92.39

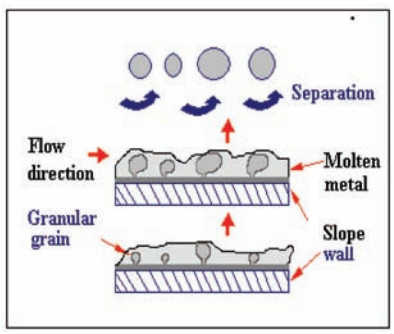
Chemical composition of A356 aluminium alloy.



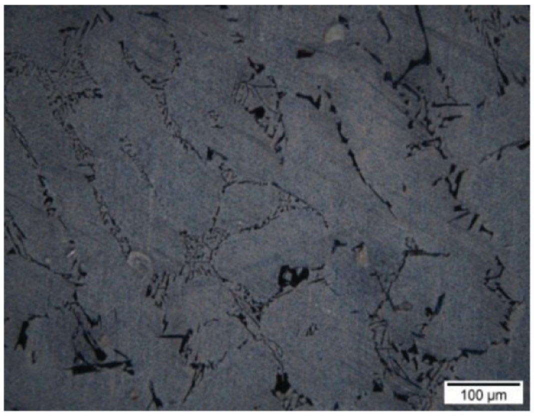
Evolution of solid phase.



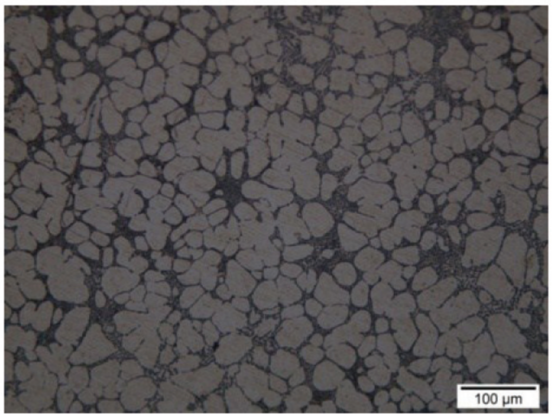
Heterogeneous nucleation at Cooling slope wall.



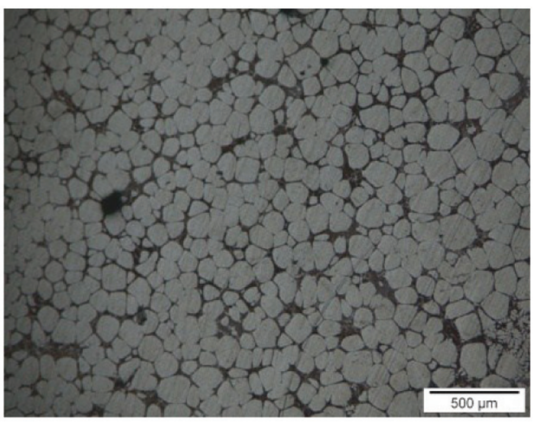
Mechanism of grain formation.



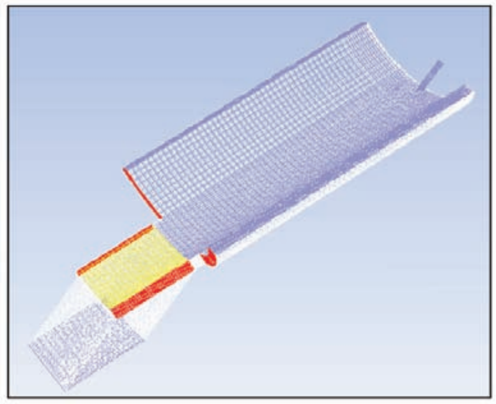
Dendritic microstructure of the parent alloy.



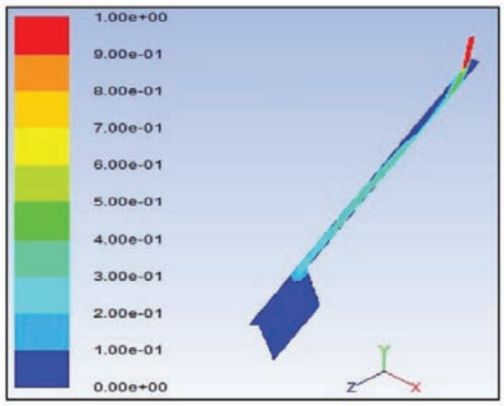
Equiaxed structure after processing through cooling slope.



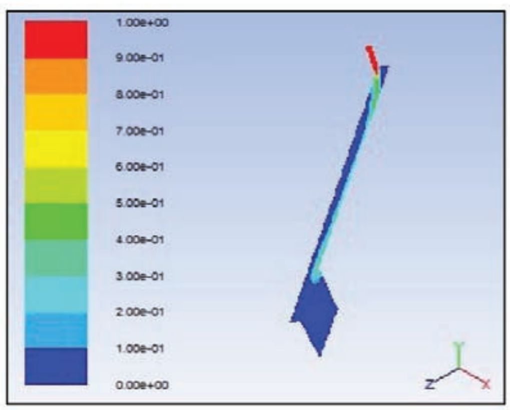
Globular structure after isothermal holding of the semi-solid slurry.



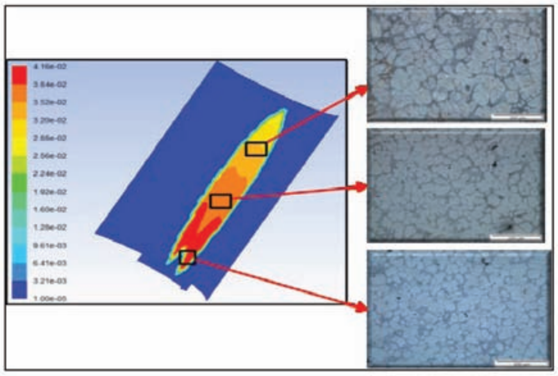
Grid of the Cooling channel and holding bath.



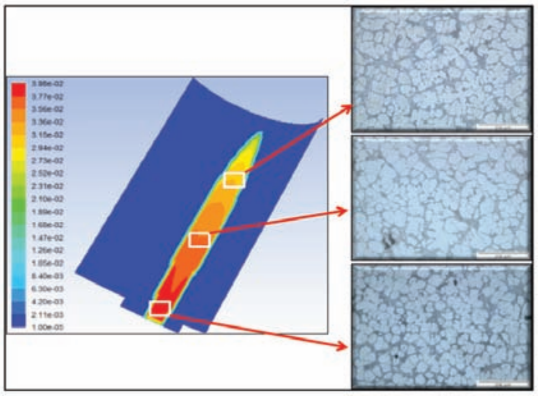
Primary phase profile for 45° slope angle



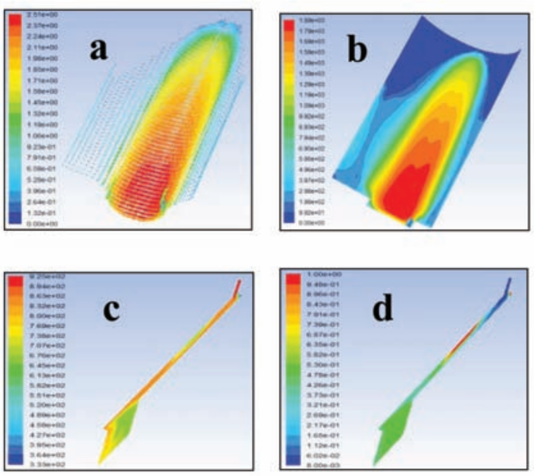
Primary phase profile for 60° slope angle



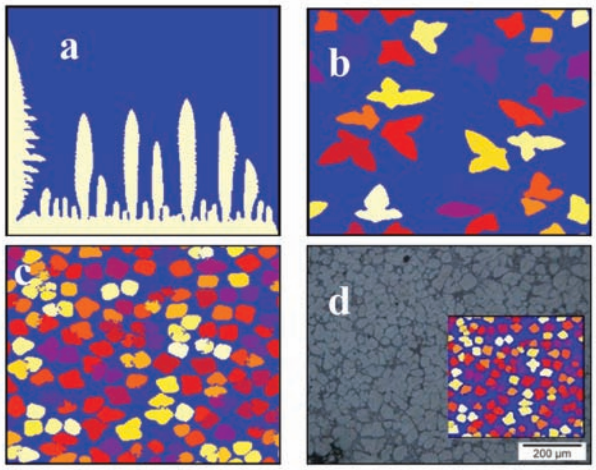
Grain evolution for 45° slope angle.



Grain evolution for 60° slope angle.



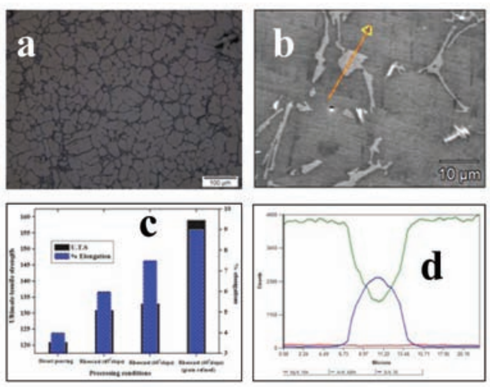
(a) Velocity vector, (b) Strain rate, (c) Temperature profile and (d) Relative solid fraction.



a) Dendritic, (b) Equiaxed dendritic, (c) Equiaxed globular and (d) Experimental validation of microstructure.

Exp. No.	Flow Angle (Degree)	Pouring Temp. (° C)	Coolant Temp. (° C)	Length of metal travel (mm)
1.	30	630	60	300
2.	30	640	100	500
3.	30	650	150	800
4.	45	630	100	800
5.	45	640	150	300
6.	45	650	60	500
7.	60	630	150	300
8.	60	640	100	800
9.	60	650	60	500

Taguchi experimental design.



(a) Grain refined structure, (b) SEM image of (a), (c) Mechanical properties and (d) Al/Si concentration transverse to the grain boundary.

Numerical model of the cooling slope semi-solid generation technique has been developed using Eulerian multiphase flow approach. Eight sets of numerical simulations have been carried out to reveal the effect of some key process variables such as pouring temperature, tilt angle and wall temperature of the slope on the state of the semi-solid slurry. Out of the case studies performed, the best processing condition has been identified as 60°slope angle, 925K pouring temperature and 333K slope wall temperature. These processing conditions result in a solid fraction of 0.42, slurry temperature of 862K at the exit of the slope, maximum degree of sphericity 0.75 and minimum grain size of 38μm of the primary α-Al phase, all of which has been evaluated experimentally. The experimental results are in close agreement with the corresponding predicted data using the present numerical model.

Looking Ahead

Self-Organized Nano-Patterning of Thin Confined Bilayers Employing Molecular Dynamic Simulations

Molecular dynamics simulations are employed to investigate the pathways of self-organization of ultrathin (< 100 nm) bilayer films under confinement, as shown in Figure 1. Whenever two immiscible thin liquid films are placed on one another a deformable liquid-liquid interface is produced. Instability appears at the liquid-liquid interface due to the competition between interfacial tension and van der Waals interactions if this bilayer is confined between two solid substrates. Surface tension tries to stabilize the interface, whereas van der Waals force tries to destabilize it. If the bilayer is sufficiently thin and confined between solid substrates, then van der Waals interaction becomes dominant and the effect of surface tension is suppressed. Dewetting occurs as a result at certain parts of the films which leads to the formation of holes and droplets in nano dimensions.

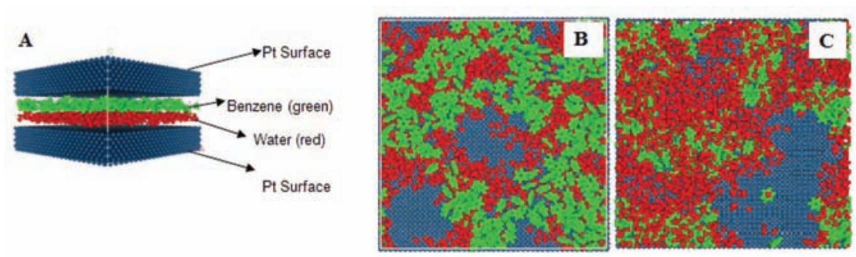


Figure 1. (A) A typical confined bilayer system. Plots (B) and (C) show the top views of some equilibrium morphologies.

The bilayers may be classified based on the macroscopic dewetting behaviours of the films between the confining surfaces and simulations are performed to uncover the various routes to spontaneous dewetting. The study shows that the reduced interfacial tension at the confined interface facilitates nanostructure formation when the films are really thin (< 2 nm). A host of interesting embedded and encapsulated nanostructures in the form of holes and droplets are obtained from the simulations under varied conditions. These encapsulated nanostructures have applications in the development of futuristic solar panels, fuel cell electrodes, drug-delivery modules, self-cleaning surfaces, and nano-fluidic devices. Figure 2 shows a typical morphology evolution when a 1 nm thick bilayer of benzene and water is confined between two Platinum (Pt) surfaces.

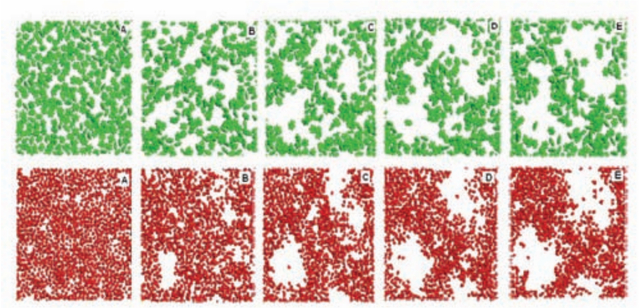


Figure 2. Time evolution of benzene (green) and water (red) layer. (A) - (E) show the snapshots at 0, 5, 10, 15, 20 ps respectively.

Simulations with physical and chemical patterns on the rigid surfaces reveal that a long-range ordering can be imposed on these self-organized nano-patterns (Figure 3). Importantly, we could find out the conditions from disorder to order under the influence of the surface heterogeneities. The pathways to fabricate a host of interesting patterns such as embedded and encapsulated nano channels and nano droplets investigated in this work can be of significant importance in the development of several futuristic micro/ nano devices.

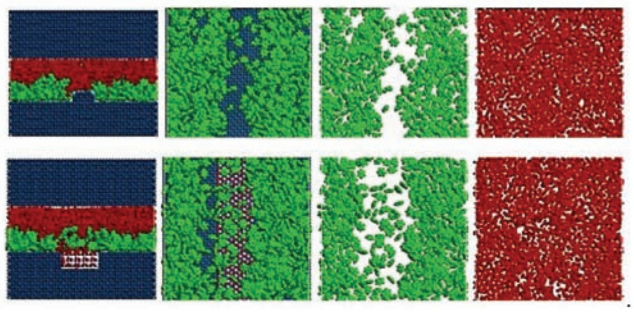


Figure 3. Formation of nano channel induced by physical heterogeneity (first row) and chemical heterogeneity (second row). From left the 1st snap shows side view of the system, 2nd snap shows the benzene layer on Pt base, 3rd and 4th ones show the images of benzene and water layer after 25 ps of dynamics.

Looking Ahead

Thermoelectric Refrigeration: A Potential Eco-friendly Refrigeration Technology

Background:

In recent years, with the increase in awareness towards environmental degradation due to production, use and disposal of heat carrier Chlorofluorocarbon (CFC) and Hydro Chlorofluorocarbon (HCFC) fluids in conventional refrigeration systems has become a subject of great concern. One of the serious threats to the environment is the depletion of the stratospheric ozone layer. The presence of CFCs and HCFCs in the troposphere region also plays a significant role in increasing the greenhouse effect. Besides, these kinds of refrigeration systems have limitations of using grid power and the same cannot be utilised for remote applications. Researchers are continuously striving to develop eco-friendly refrigeration technologies like thermoelectric, adsorption, magnetic and thermoacoustic refrigeration. Thermoelectric refrigeration emerges as a potential eco-friendly refrigeration technology due to the distinct advantage of absence of moving parts, greater reliability, portability and compatibility with Solar PV cell generated DC power which is suitable for remote applications. In consideration of these challenges CSIR-CMERI initiated research activities in this promising field of refrigeration.

Introduction:

Thermoelectric refrigeration works on the principle of the Peltier effect, where due to the passage of direct current between two electrically dissimilar materials heat is absorbed or liberated at the junction. The direction of the heat flow depends on the direction of the applied electric current and the relative Seebeck coefficient of the two materials. A Peltier module or thermoelectric cooling module (Figure 1) is a solid-state active heat pump where a number of p- and n-type semiconductor couples are connected electrically in series and thermally in parallel and are sandwiched between two thermally conductive and electrically insulated substrates. The refrigeration capability of a semiconductor material is measured by a dimensionless thermoelectric parameter, usually written as ZT, where T is the temperature (usually room temperature) and Z depends on a combined effect of the material's Seebeck coefficient, thermal conductivity and electrical resistivity over the operational temperature range of hot and cold sides and varies generally between 0.6 to 1 for commonly known thermoelectric materials.

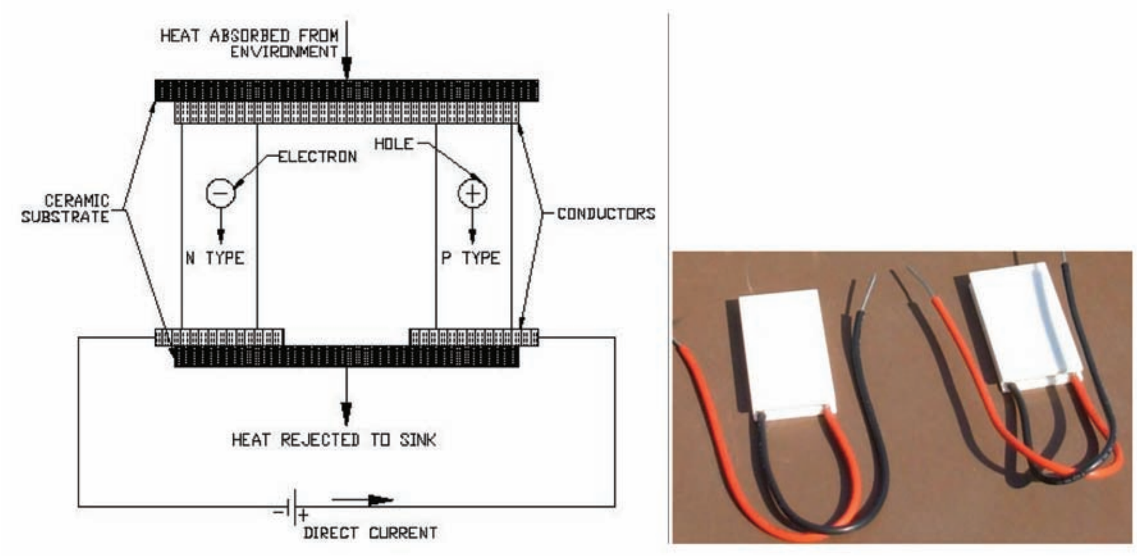


Figure 1. Schematic diagram and photograph of thermoelectric cooling module

The cooling efficiency of thermoelectric module is defined as the coefficient of performance and is expressed as:

$$COP = \frac{\text{Rate of heat absorbed at cold junction}}{\text{Overall rate of expenditure of electrical energy}}$$

Research initiative on Thermoelectric Refrigeration:

An experimental set-up (Figure 2) has been developed to conduct experiments for evaluation of cooling performances of single thermoelectric modules. The test set-up consists of a variable DC power supply unit for supplying variable DC voltage to the thermoelectric modules. For online performance recording and display of thermoelectric module, a computer interfaced 8-Channel data acquisition system with temperature sensors and humidity sensor has been used.

An experimental thermoelectric refrigeration system (Figure 3) working on solar photovoltaic (PV) cells to generate DC voltage has been developed by CSIR-CMERI researchers. A refrigeration box with refrigeration capacity of 1000 ml has been developed by using four thermoelectric modules to reduce the internal temperature of the refrigeration space. Cold side of thermoelectric modules was mounted on a copper sheet and the hot sides were fixed to the heat sink fan assembly. Four black anodized plate-fin heat-sink fan assemblies were used for each module to enhance the heat dissipation rate.

A DC power supply system has been developed to power the developed thermoelectric refrigeration cabinet for remote applications. This system consists of two solar PV panels fixed on a frame with provision of angle variation for optimum solar incidence on the PV panels. The electric charge produced by solar cells has

Figure 2. Thermoelectric refrigeration experimental test setup

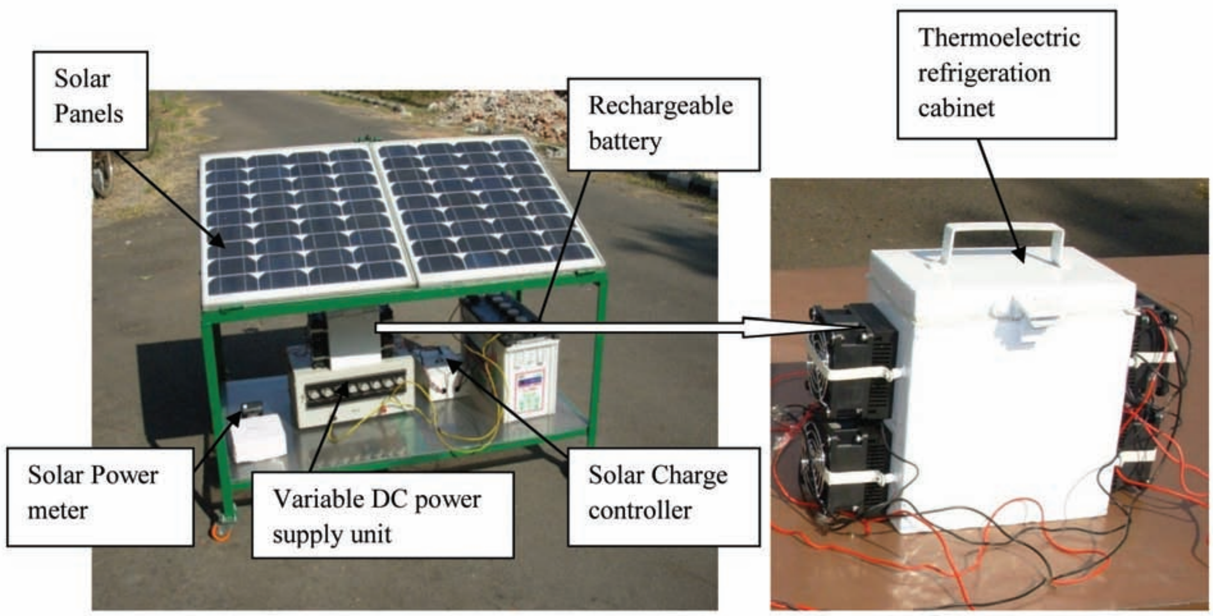


Figure 3. Experimental Thermoelectric refrigeration system

been controlled by a charge controller and used to charge a solar PV compatible rechargeable battery. A DC variable power supply unit has been used for supplying DC voltage to the thermoelectric cooling modules and heat sink fan assemblies of the thermoelectric refrigeration cabinet.

Experiments were conducted for performance evaluation of single thermoelectric cooling module. The performance of the thermoelectric module was evaluated at variable input electrical current conditions and at natural as well as forced air convection condition for heat dissipation from the hot side of the modules. The test result shows that for input electrical current $0.5I_{maxi}$ and at forced air convection condition the performances of single TEM were optimum. Experiments were conducted with these optimized conditions on the developed experimental thermoelectric refrigerator and test result (Figure 4) shows a temperature reduction of 11.5^0C in the refrigeration space with respect to an ambient temperature of 30^0C within the first 70 minutes.

The research literature shows that thermoelectric cooling systems are generally around 5–15% as efficient compared to 40–60% achieved by conventional compression cooling system. This is basically limited by thermoelectric material property (Figure of merit) and efficiency of the heat exchange system. Efforts are being taken for development of thermoelectric materials with increased figures of merit and development of efficient heat exchange technology with a view to possible commercial use of thermoelectric refrigeration.

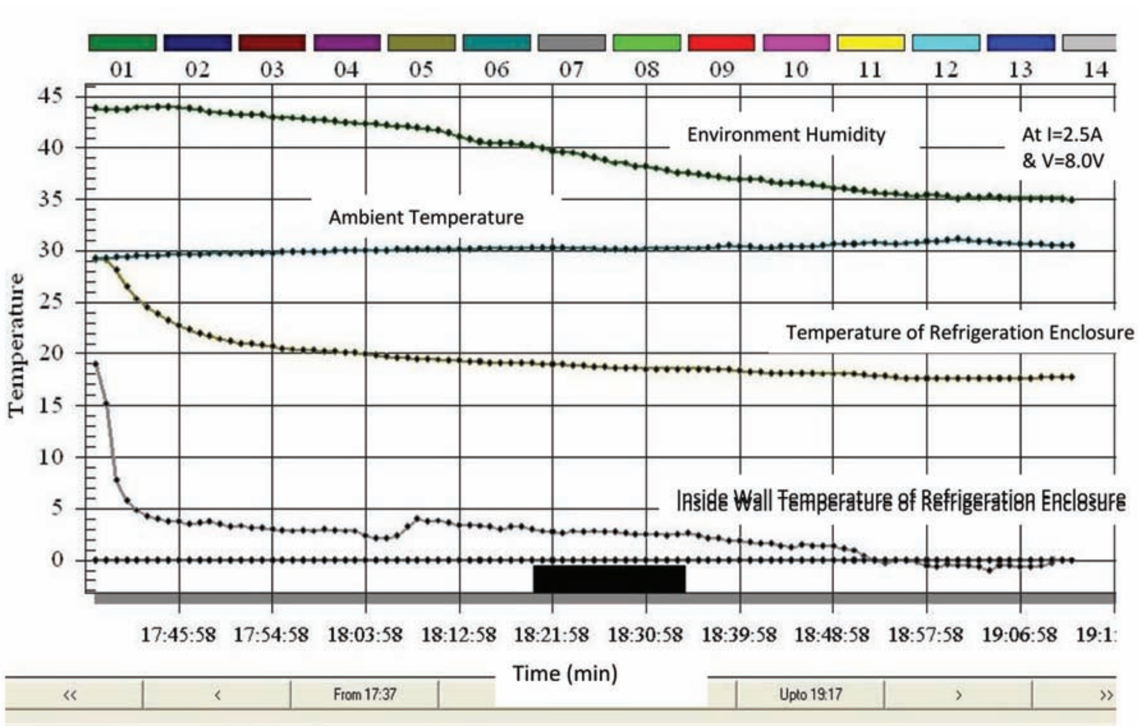


Figure 4. Experimental results of thermoelectric refrigeration system

Looking Ahead

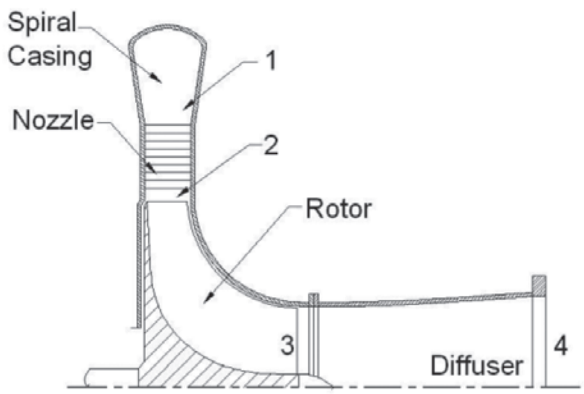
Turbo machines for Environmental Control System

Introduction

An Environmental Control System (ECS) is usually designed to provide a comfortable environment within a specified enclosed space, which needs to maintain temperature, humidity and pressure within acceptable limits while meeting the thermal load of the enclosed environment. The ECS has to meet the demand of converting unfriendly environments to a comfortable one, like in an aircraft. Air is usually bled from the main compressor before combustion and subsequently cooled in most of the big aircrafts by adopting a Bootstrap refrigeration cycle, which makes the system lighter, compact, reliable and cheap. The most crucial and challenging component of such a system is the turbo-expander, mostly Inward Radial Flow (IRF) gas turbine. The turbine has inherent advantages like design simplicity, compactness, high expansion ratio (~4:1) in a single stage and finds wide application. On the other hand, addressing secondary flow phenomena, achieving dynamic balancing and developing proper air bearing to cope with the high rotating velocity (40,000–120,000 rpm) of the rotor are issues of challenge in designing IRF turbines. CSIR-CMERI has initiated research for developing IRF turbines coupled with centrifugal compressors to suit the requirements of environmental control systems. The needed turbo machine, along with a sophisticated test rig has been designed and developed by the team of CSIR-CMERI and the designed system is under extensive experimentation.

Turbine

The fluid flow through the inward radial flow turbine is mostly in the radial direction form the outer radius (2) to the inner radius (3) without any significant variation of flow in the axial direction. The work is done by the fluid on the rotor by continuous change in momentum in the flowing fluid from the inlet to the outlet. In other words, available energy in the flowing fluid is utilized by the turbine, which results in a very high speed of the rotor and continuous drop of temperature in the fluid flowing from the inlet to the outlet.



T temperature, K
P pressure , Pa
K specific heat ratio
Subscript
1 nozzle entry
2 nozzle exit
3 rotor exit
4 diffuser exit
is isentropic

Figure 1. Meridional view of rotor & stator

IRF Rotor

Isentropic Enthalpy Drop,

$$\Delta h_{is} = c_p (T_1 - T_{3is})$$

Where, $T_{3is} = \dfrac{T_1}{r_p^{\frac{k-1}{k}}}$ and pressure ratio, $r_p = \dfrac{P_1}{P_2}$

Table -I Turbine Details	
Fluid	**Air**
Capacity	250 m^3/hr
Pressure ratio	4:1
Max Operating speed	40000 rpm
Impeller outlet diameter	63.4 mm
No. of vanes in impeller	20
Turbine Type	Inward Radial Flow, Reaction type

The CSIR-CMERI Team has judiciously optimized the dimensionless design parameters, specific speed and specific diameter for a given Reynolds Numbers, blade Mach numbers and the specific heat ratio. It needs many iterations to optimize operating speed, expansion ratio and turbine flow rate.

Research is being continued to select the optimum value of degree of reaction for the specific application of the turbine. The 50% reaction turbine is mostly designed for optimum efficiency, though it poses some difficulties for small IRF turbines with high expansion ratio in a single stage. In the present design, 30% degree of reaction has been considered to allow fluid whirl velocity at the inlet higher than rotor peripheral velocity. An in-depth analysis has

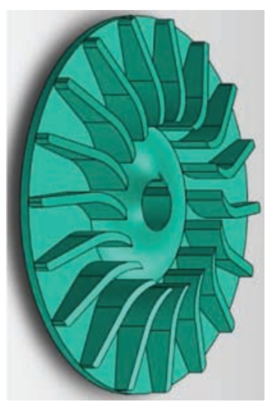


Figure 2. 3-D view of rotor

been performed to achieve optimum rotor vane spacing and vane thickness of rotor. The team is conducting detailed flow simulation with a view to establish the transverse and radial pressure gradients from the leading to the trailing edge and secondary flow phenomenon in the cross direction the turbine blade to blade flow passages. The team is making use of constant temperature anemometer, slanted hot film probe and mutli holes probe to quantity the secondary flow pattern in the stationery zone.

The Compressor

The centrifugal compressor is coupled with the inward radial flow gas turbine to protect the gas turbine from no-load operation. The impeller of the compressor is radially bladed and interfaced with a diffuser and enclosed in a volute. The shaft is supported by aerostatic journal bearing and axial thrust of the compressor is mostly balanced by the axial thrust of the coupled gas turbine; the remaining axial thrust is supported by thrust air bearing.

Table -II (Compressor Details)	
Fluid	**Air**
Capacity	250 m^3/hr
Pressure ratio	1.3
Max Operating speed	40000 rpm
Impeller outlet diameter	77 mm
No. of vanes in impeller	12

The design and off-design performance of a single stage centrifugal compressor – which consists of a rotating impeller interfacing with a stationery diffuser – has been studied experimentally and numerically adopting Fluent 14. Total pressure and velocity distribution in nominal operating condition are shown in Figure 3 and Figure 4.

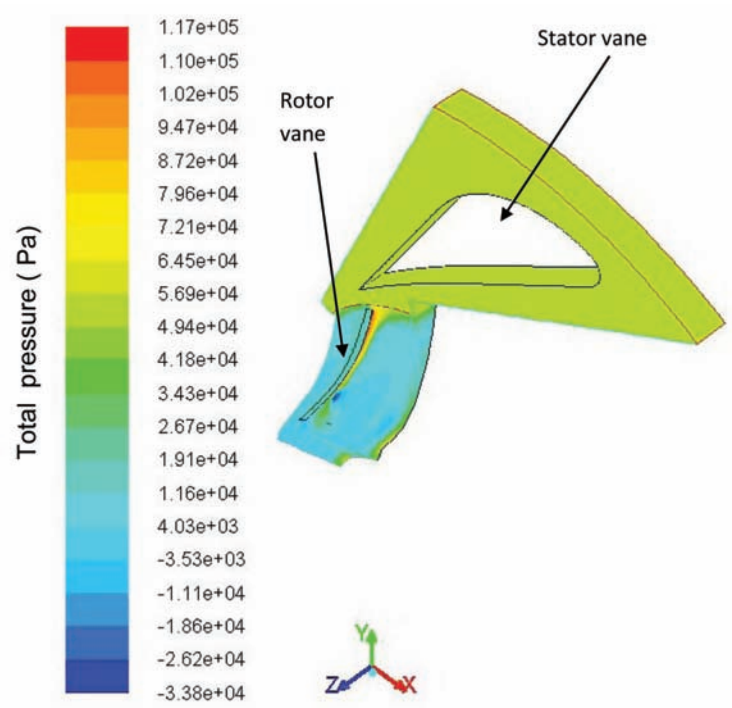


Figure 3. Total pressure distribution

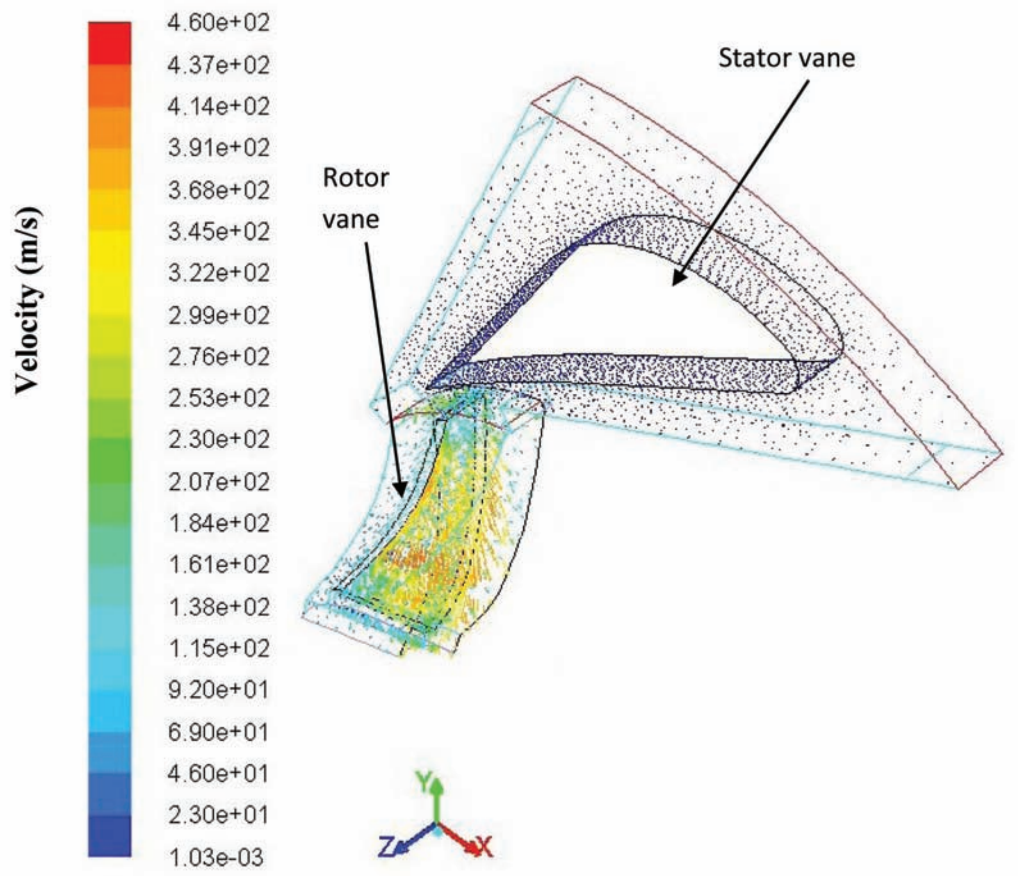


Figure 4. Velocity Vectors

The Test Rig

An experimental set-up consisting of a turbine coupled with a compressor was developed to conduct the experiments. The IRF turbine was operated by supplying compressed air of pressures 8, 6 and 4 bar to the inlet; consequently the turbine rotor rotated at speeds of 40000, 20000 and 15000 rpm. The air to the IRF turbine is supplied by a screw compressor. The inlet and outlet temperature and the pressure for both the turbine and the compressor have been measured by Honeywell sensors. The flow rate is measured by an orifice plate connected to a Honeywell differential pressure transmitter. The flow rate to the turbine can be varied by controlling a ball valve in the inlet pipe. The compressor performance has been varied by regulating the discharge valve and experiments on the surging phenomenon was conducted by regulating a bypass valve at the discharge line. The temperature drop, pressure drop, mass flow rate of the fluid flowing across the turbine and operating speed have been measured and necessary data logged on to a PC to evaluate turbine performance mapping. The team is also engaged in the investigation of the internal flow characteristics of both the turbine and the compressor through appropriate experiments.

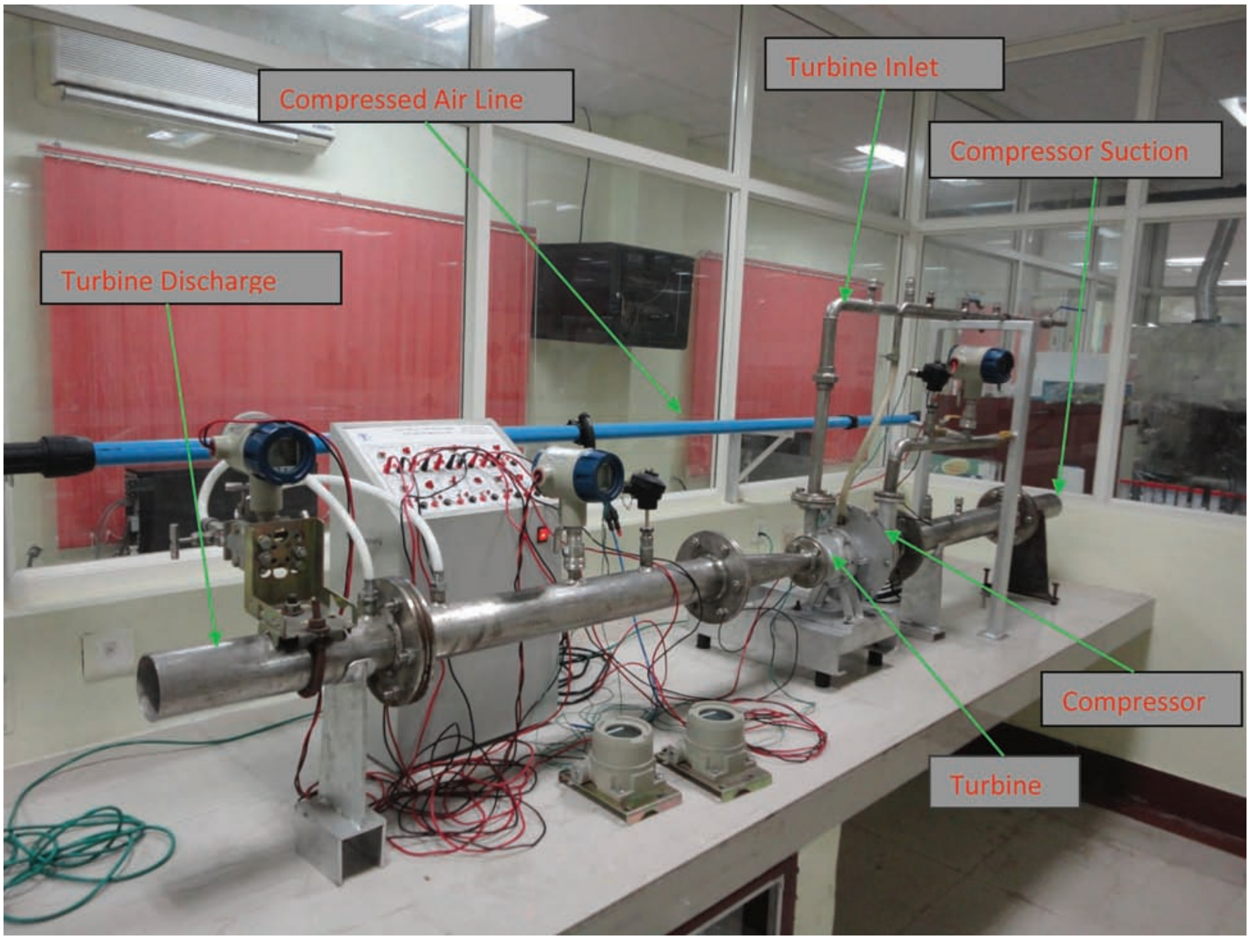


Figure 5. Test Rig

Conclusion

The turbo-expander is the most important mechanical device in an Environment Control System. A turbo-expander coupled with a centrifugal compressor suitable for an Environment Control System has been developed which is now under extensive experimental study. Detailed study on the effect of some important parameters like pressure ratio, rotor-shroud clearance, rotor inlet, outlet width ratio, Reynolds number and operating speed, etc. on the performance characteristics of the turbine has emerged as issues of significant impact. Effort is also being made to explore the internal flow characteristics of the turbine and the coupled centrifugal compressor with a view to further design optimization.

Looking Ahead

Sliding Mode Control

Necessity

Control System Theory has evolved gradually as a mathematical tool for engineers and scientists alike to enhance the performance of different types of systems – be it electrical, mechanical, hydraulic, pneumatic, electro-mechanical, biological, chemical or of any other type. Though different control techniques were developed to solve specific problems, the task of all these algorithms has been the same since the primary goal consisted of designing an optimal, effective and robust control algorithm. Optimality of any control algorithm design always pertains to the system under consideration and so does the effectiveness of the algorithm. However, robustness is one property which troubled control engineers for a long time till the theory of Robust Control evolved. Any control algorithm designed for a particular set of parameters and providing effective control performance is called a Robust Control algorithm if the effectiveness of the algorithm does not vary significantly for a change in parameters of the system or if disturbances do not affect the system. Sliding mode control, which found mention initially in Soviet literature in the early 1950's, has come to the fore in the past decades as one of the control techniques which provides a robust performance, especially for a special class of systems called Variable Structure Systems.

A 'structure' refers to a path traced out in space by the state of a system. In case of nonlinear systems, which have discontinuities, time dependency, etc. the state trajectory is not defined. In such cases the control action becomes difficult as at a particular time instant the state may follow a particular path but may trace out a different trajectory altogether in the next instant. The situation becomes more complex when more than one state is involved. Individual structures can be defined based on the trajectories of the state. Such a system, which consists of more than one structure for its states, is known as a Variable Structure System. Since the properties of the states keep changing, hence the controller designed for the entire system has also to change as per the behavior of the state to provide a controlled output.

Ideal Sliding Mode

Sliding Mode Control is a special category of Variable Structure Control (VSC) resulting in a non-linear robust control algorithm. Sliding Mode Control (SMC) evolves from a combination of the concepts of switching surface design, characterization of different phases of sliding mode theory and control law formulation. SMC originated as a special class of VSC where the state trajectories of the system were driven from any initial condition to a stable switching surface by satisfying a reaching condition and then moved along the surface to a stable equilibrium point complying with the existence and stability constraints in the process. In the ideal case for perfect Sliding Mode control operation, it is necessary that any kind of disturbance affecting the system or any parametric uncertainty of the system is rejected. Such a Sliding Mode operation is achievable theoretically only and that too if all the conditions of reaching, existence and stability are complied with as the system switches at an infinite frequency. With an infinite DC gain the system has precise tracking, zero regulation error and very fast dynamic response along with the best robustness property. In such cases Sliding Mode is the best control action possible for Variable Structure Systems.

Sliding Surface

The sliding surface originates from the switching surface which is a function of the states to the system to be controlled. This switching function is represented as,

$\sigma = f\{x_1, x_2 \ldots\ldots\ldots x_n\}$ Where $x_1, \ldots x_n$ are the states

The sliding surface is then given as, $\sigma = 0$

Considering a second order system with two states to be controlled, the VSS property of the system is shown when under particular conditions the states follow different paths leading to different phase portraits as shown below.

In such a case a switching surface arises as the point of intersection between the individual structures. Being a part of the combined Variable Structure, this switching surface is a function of the states of the system. At the same time, since it is formed by intersection of two second order systems and passes through the origin, its representative equation is that of a line. This fact proves that the order of the sliding surface (which in this case is a line) is less than that of the original system. Extending this concept to a higher order system, the fact evolves that the dimensions of the switching surface is always less than the dimension of the original system. However, the existence of a sliding mode is not guaranteed for every switching surface. A switching surface that passes through or contains the equilibrium point origin must satisfy the condition that for any initial position of the state trajectory that lies on the switching surface there must exist a defined position of the state trajectory

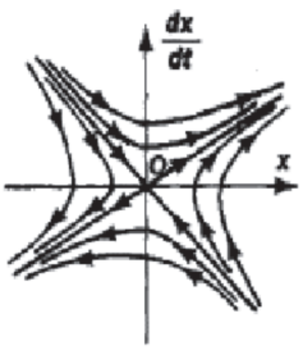


Figure 1. Structure A

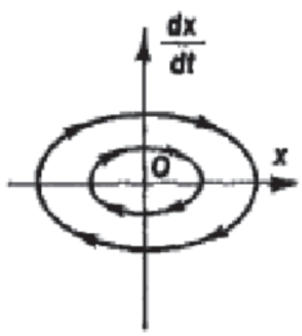


Figure 2. Structure B

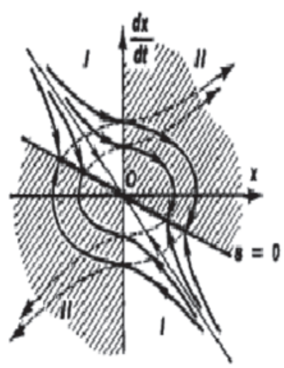


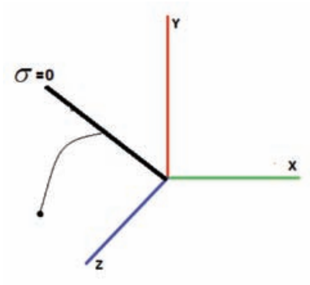
Figure 3. VSS with sliding mode

on the same switching surface for all times greater than the initial time. In other words, it can be stated that the state trajectories starting from either side of the switching surface must be able to approach the surface after the initial time instant irrespective of the initial conditions. Only in such a case is the switching surface called a sliding surface. For higher order systems the sliding surface is often referred to as the sliding manifold or the sliding hyper plane. The number of switching functions and the surfaces which a particular system can have is decided by the number of control inputs in the system. The number of switching surfaces possible for a system with 'm' inputs of 'n^{th}' order is given as $(2^m - 1)$.

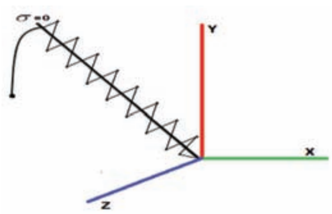
Reaching Phase, Sliding Phase and Stability

Reaching Phase is the transient phase of Sliding Mode operation that gets affected by disturbances and uncertainties easily. During the reaching phase, the state trajectory is forced to reach the stable sliding plane regardless of the initial conditions. The designer has to ensure that the reaching phase dynamics is very fast. The state trajectory is thus forced to reach the sliding plane within the minimum possible time such that the control action is least affected by uncertainties. The Sliding mode control scheme is designed and developed on this critical time limit which ensures that the time taken by the state trajectory to reach the sliding mode should be as minimum as possible. For this critical time limit to be obeyed, the reaching condition must be obeyed.

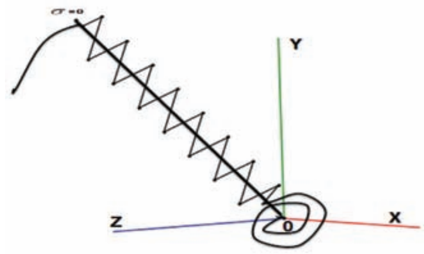
Issues of robustness to parametric uncertainties and disturbances are handled during the Sliding phase. It is this phase which is affected by the severe oscillatory problems called chattering. The state trajectory after having satisfied the reaching conditions is forced onto the sliding plane. The sliding phase starts once on the sliding plane. In the sliding phase the state trajectory is controlled by a series of switching actions occurring at a very high frequency such that it is always maintained in the vicinity of the sliding surface and forced to move towards the equilibrium point. The control process thus tracks the sliding surface as a reference path which must be followed to reach the stable equilibrium point. To maintain the state trajectory on or in the vicinity of the sliding surface the existence condition must be satisfied. The reaching condition and the existence condition are both derived from Lyapunov's second theorem of stability. By defining the switching surface as a function of all the states of the system it can be established that Lyapunov's stability criterion is achieved if $\sigma\dot{\sigma} < 0$. Then the state trajectory starting from any initial condition will ultimately reach the sliding plane defined as $\sigma = 0$. This concept is then employed in the local sense to ensure the compliance of the existence condition. In a physical sense, the existence condition can be understood as the requirement for the state trajectory and its time derivative to have opposite signs in the vicinity of a sliding surface. Thus with any sign of the state trajectory it is always forced back to the sliding surface which is a stable surface. The behavior of the state trajectory once it approaches the equilibrium point determines the stability aspect of the system and chattering consequences which is collectively called the steady state mode. For stability purposes if the Eigen values of the system are negative then the system under consideration is said to be asymptotically stable with the trajectory converging to the equilibrium point exponentially. In ideal cases, for stable operation a system controlled under sliding mode will have its state trajectory slide



Reaching Phase



Sliding Phase



Sliding Mode Control

along the sliding plane and then come to rest at the origin, which acts as the equilibrium point. However, in practical or non-ideal cases where physical systems are considered, delays and offsets play a major role in determining the stability and convergence of the state trajectory to the equilibrium point. For systems with associated offsets the trajectory never comes to rest at the origin, but oscillates periodically about it. Similarly for a system with finite time delays the problem of chattering comes into picture which can prove dangerous for the system. It is due to this reason that in practical implementation of Sliding mode control there always exists some definite steady state error. Combining the Reaching phase, Sliding phase and Stability results in Sliding Mode Control.

Control Law

The control law relates the state variables of the system to the control input in terms of differential equations and other mathematical modifications forming a guideline for the control designer to control the performance of the system. The main objective in designing a control law for any VSS is to satisfy a particular reaching condition. For any switching surface 'σ', out of the several existing free structure approaches the most popular ones that are employed are:

i. The Direct Approach $\sigma\dot{\sigma}<0$

ii. Lyapunov Function Approach $\dot{V}=\frac{d(\sigma\dot{\sigma})}{dt}<0$

iii. Reaching Law Approach $\dot{\sigma}=-q\,\mathrm{sgn}(\sigma)-kf(\sigma)$

Of the above mentioned approaches, the most popular approaches are the Lyapunov approach and the more recent Reaching law approach, which have been dealt with earlier in this article. The pre-assigned control structures are employed where the controller gains are fixed such that a desired reaching condition is satisfied.

Robustness of System

The sliding phase is characterized by robustness to parametric uncertainties and disturbances affecting the system. In compliance with the existence criterion, once the state trajectory enters the sliding manifold it is always confined on the sliding plane where it slides along or moves till the equilibrium point is reached. The state trajectory once on the sliding plane is always characterized by the equation; $\sigma = 0$. This expression for the state trajectory is always true till the existence condition is met with. Any sort of parametric variations or operating condition changes that affect the system during this phase cannot force the state trajectory to move out of the vicinity of the sliding plane. If that happens, then the criterion of existence is violated and sliding mode control no longer applies. Hence the dynamics of any system which obeys the existence condition and is controlled by sliding mode principle is unaffected and constant during the sliding phase. In such a case the robustness of the system in the sliding phase is always assured. It is noteworthy that the reaching phase is affected by operating condition changes and is typically very fast in comparison to the time taken to complete the sliding phase. Thus by having a system that has a sliding phase that takes considerably longer time to be completed in comparison to the reaching phase, robustness against parametric uncertainties and disturbances can be assured.

Application Base of Sliding Mode Control

1. Motion control systems

In motion control systems the usual tasks are trajectory tracking, velocity control, along with control of the force exerted on the system by the environment. In such systems the torque or force acts as the control input. These control inputs are obtained from actuators (usually electrical) which themselves have very complex dynamics. The entire system thus becomes highly non-linear for which SMC acts a viable control scheme.

2. Automobile engineering

In specific areas of automobile engineering such as automotive alternators, control of air-to-fuel ratio in combustion engines, anti-lock brake control, etc. the systems to be controlled are very complex, non-linear and consist of states that are unattainable directly. In most cases these systems require knowledge of states which are internal to the system and thus observers have to be designed. For such complicated, high performance driven systems complex controllers and observers are required. Here variable structure control plays an important role.

3. Power electronics

Power converters used in power electronic applications employ switching for better energy efficiency and can be effectively modeled as Variable Structure Systems. By managing the switching frequency (usually done using PWM) best possible energy efficiency of the converter is obtained. It can thus be concluded that the power converter has two structures which provide variable outputs. One is when the switch is on while another is when the switch is off. The use of specific converters that involve very high specific, fast and precise switching tasks necessitates complex control algorithms ideally suited for the application.

Apart from the abovementioned areas, Sliding Mode Control finds use in very specific and complex areas of industries, robotics and automobiles such as in aerospace related control, missile control, underwater robotics control, highly precise machining operations, etc. With such widespread use, SMC forms an algorithm that has and is rapidly developing as a solution to the problems of robustness faced in different control problems.

Looking Ahead

CSIR–CMERI Participation in FAIR Project

A large international accelerator center – the Facility for Antiproton and Ion Research (FAIR) - is being built at GSI (Helmholtzzentrum für Schwerionenforschung), Darmstadt (Hesse), Germany (Figure-1). FAIR was formed by an International treaty on October 4, 2010 with an investment proposal of the order of 250 billion Euro by the participating countries and will be realized in stages. The Republic of India signed the FAIR convention on October 4, 2010 in Wiesbaden, Germany and India's in-kind contribution to the FAIR Project is of the order of 36 million Euro. India is the third largest shareholder in the FAIR project and is represented by the Indo Fair Coordination Committee (IFCC) formed by Department of Science and Technology (DST) and the Department of Atomic Energy (DAE), Government of India. India is involved in the design and development of magnets, detectors and beam stoppers.

Figure 1. Existing GSI and proposed FAIR facility at GSI, Darmstadt, Germany. Courtesy-GSI

The heart of the facility is a double ring synchrotron with a circumference of 1200 m. A system of cooler-storage rings for effective beam cooling at high energies and various experimental halls will be connected to the facility. The existing GSI accelerators would serve as injectors for the new facility. The double ring synchrotron will provide ion beams of unprecedented intensities as well as of considerably increased energy as compared to the existing GSI facility (Figure-2), thereby producing intense secondary beams of unstable nuclei or antiprotons. The system of storage-cooler rings will enormously improve the quality of these secondary beams i.e. their energy spread and emittance. Moreover, four parallel experimental programs can be realized simultaneously utilizing the double ring synchrotron.

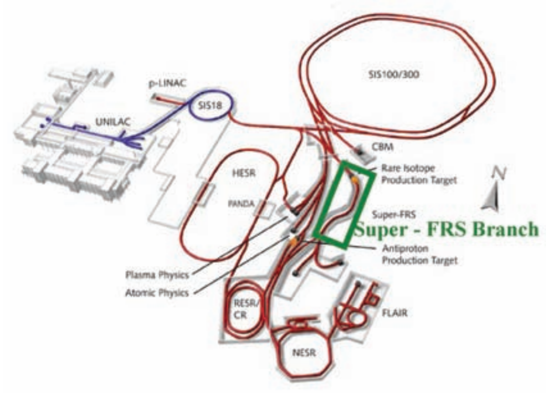


Figure 2. Proposed FAIR accelerator complex – red line and its Super-FRS branch (green box). Courtesy-GSI.

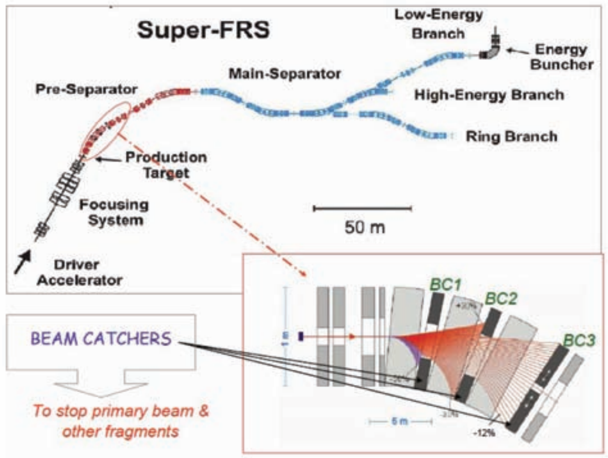


Figure 3. Schematic showing the position of beam stoppers (BC1,2 and 3) in the Super-FRS line. Courtesy-GSI.

The Variable Energy Cyclotron Center, Kolkata, (VECC-DAE) has sought collaboration with CSIR-CMERI in the engineering design of the beam stoppers. The collaborative venture would be carried out by an expert team comprising scientists from the VECC (DAE), CSIR-CMERI and GSI Darmstadt involving expertise in the fields of ion beam optics, mechanical engineering and control systems for the design and development of beam stoppers in the in pre-separator beam-line of Super-FRS accelerator facility at GSI, Germany *(*Figure-3*)*. The beam stoppers are essentially required to stop the primary beam particles and unwanted secondary particles after the production target. The primary beam is of ^{238}U of high intensity (~10^{12} pps) & high energy (1.5 GeV/u). The Super-FRS needs stoppers after each of the first three dipole magnets. The stoppers must withstand the high-power deposition when operated in the "Fast Extraction" mode. *The major challenge is to ensure that the absorber in the stopper sustains the huge thermal shock and that the cooling system is designed for quick heat removal.* In addition, the ion optical elements downstream are protected from radiation damage. The stopping of such high intensity & high-energy heavy-ion beams needs state-of-the-art design. A design with layers of graphite followed by iron for shielding has been envisaged at the moment for the stopper.

The beam stopper serves two purposes: firstly it absorbs the main part of the primary beam energy and secondly shields the subsequent parts of the separator from a high level of secondary radiation. The main aim is to solve the technical problems due to the specific energy deposition of the heavy ions up to uranium *for fast and slow extraction modes*. Most of the kinetic energy of the heavy ions has to be absorbed by the beam stopper system, whereas in the production target only about 10% is lost. The deposited beam power of up to 57 kJ is deposited in one pulse of 50-100 ns for fast extracted uranium ions at 1.5 GeV/u. The maximum beam energy is limited to 1.5 GeV/u for the heaviest ions at the maximum intensity, whereas for light ions one can safely go up to 2.7 GeV/u. For the minimum operating energy, one has to consider staying within the favorable ratio of the atomic and nuclear interaction lengths, which considerably reduces the effective Bragg peak in the stopping power.

Engineering design activity related to this project primarily deals with material selection; design of ultra high vacuum cavity and associated pumping; heat transport; analysis of thermo-mechanical stress fields, its propagation and shock wave generation; mechanism and motion control (online and offline) of stoppers and associated instrumentation. The primary challenge comprises enabling the release of ~57kW energy in the absorbing medium (Graphite) almost instantaneously (50-100 ns) over a volume which is to be estimated by (μx:σx), (μy:σy) and Bragg's law along the Z direction. This pulsed energy deposition will generate propagating thermo-mechanical stress field with shockwave formation, which on reflection at the boundary may damage the absorbing medium. The phenomenon needs to be investigated and experimentally validated. The typical snapshot of energy release for particular instance has been depicted in the figure [Figure-4(a), (b)].

The thermo-mechanical analysis results depend on the material properties like elastic modulus, yield stress and strength, which are functions

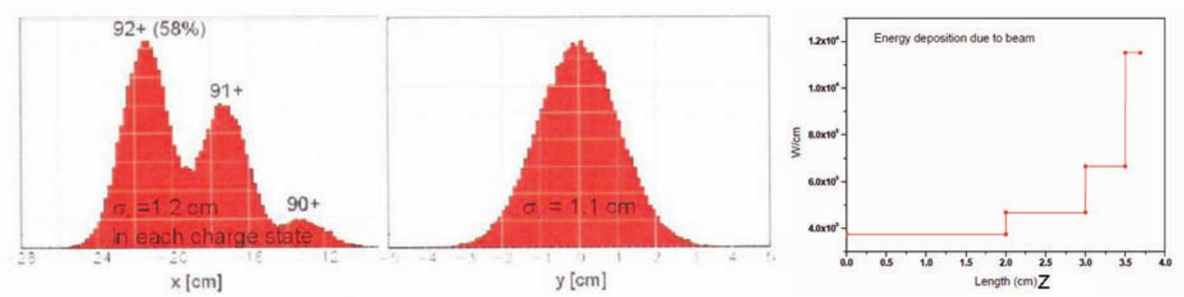


Figure 4(a). Energy distribution snapshot in the beam stopper of a particular species of ion, which is the input for thermo-mechanical analysis of the absorber medium.

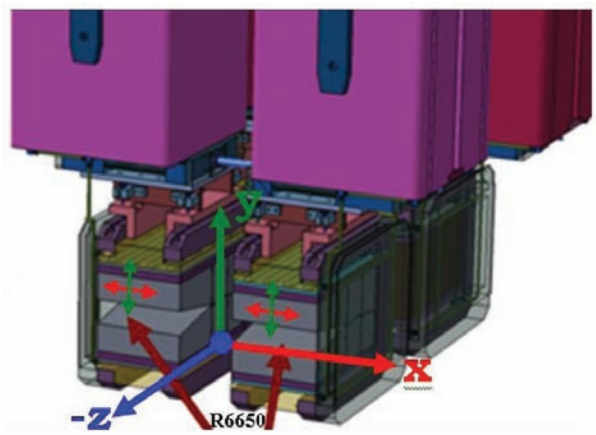


Figure-4(b). Schematic design of beam stopper-3, showing the reference axes, online motion directions from remote control and envisaged cooling arrangement.

of composition, heat treatment, temperature, pressure, rate of deformation, and even the history of deformation. Hence the problem is highly non linear. It is simply impossible to consider all these factors.

In the above analysis, only the dependence of material properties on temperature can be included. Therefore, a fresh investigation will be required to measure the changes in the material properties after in-beam testing of the prototype model for incorporation in the final design.

As the energy deposition is inhomogeneous throughout the stopper, with most of the energy deposited in the Bragg's peak region, some difficulties in estimating the volume of heating, localized melting, etc. are encountered. Moreover, the state right after the energy deposition is highly unstable as the region with higher pressure tends to expand into its surrounding region and tends to set the material mass into motion, and hence convert part of the energy into mechanical energy that is responsible for wave motion. The pressure pulse may reflect back from the boundary, and at certain regions there may be resonant superposition with the original pressure pulse of the next beam cycle leading to very high amplitude pressure wave that might result in rupture of the stopper material.

The detailed study of shock wave propagation through the material can be quite involved and even intractable, since different models describing different wave phenomena must be incorporated to describe the whole wave propagation process, and numerical techniques are indispensable to get final result such as stress, strain and particle velocity distribution both in time and space. To understand the shock wave phenomena, its interaction with target boundaries, interaction of reflected wave from the boundary with the fresh wave due to next beam pulse, experimental verification is required. The detailed picture – both thermal and mechanical – of such a high energy density is not clear at the present stage and needs to be investigated further.

The effects of radiation on structural materials and high radioactivity of the system makes the design process more complicated (Figure-5).

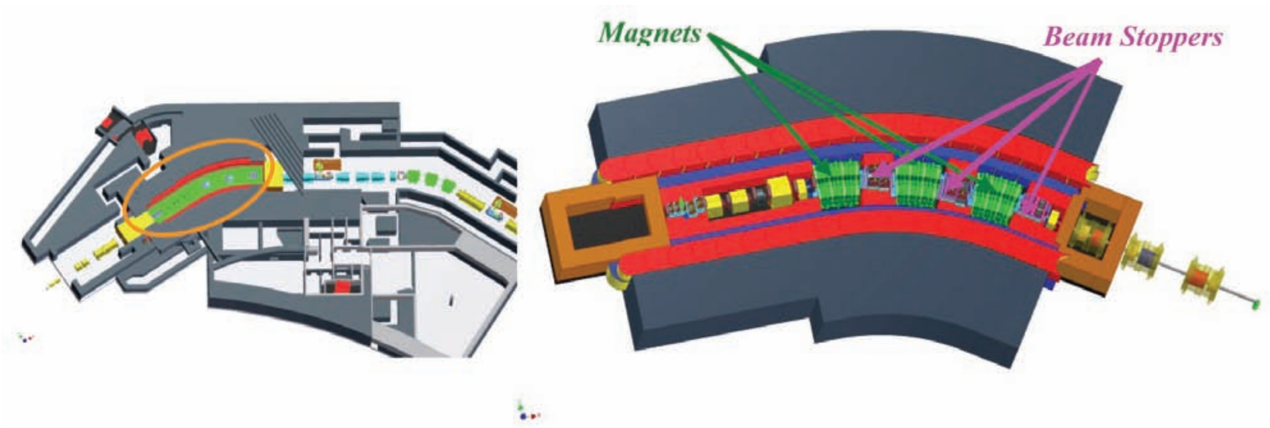


Figure 5. Radioactive shielding of the Super-FRS line showing the location of magnets and beam stoppers. Red is the iron shield and Grey is the concrete shield. Courtesy-GSI

Radiation effects on materials like dislocation pinning, Frenkel defects (pairs of lattice vacancies and interstitial atoms) are well known. The result is the increase of both yield and tensile strength and also at times the embrittlement of the material. In this case, the uranium beam intensity is very high and the interaction of stopper material with the incident beam and secondary particles is very strong, and the effect on the mechanical properties of material might be quite severe. Moreover, the cooling water may be affected by radiation and produce tritium. The cooling channels must be located at a sufficient distance away from the primary beam and fission fragments to avoid the interaction. On the other hand, this reduces the cooling efficiency of the system. Optimization is therefore required in this region though quantitative description is difficult at the moment.

The design of beam stoppers involves an international collaborative effort among the scientific community, starting form beam optical design to calculate the deposition energy density (by physicists), FEM simulation to study the temperature rise, shock wave propagation and structural integrity and scaled-down prototype fabrication for in-beam testing at the Super-FRS for verification of the design parameters and finalization of the design. High radioactivity introduces additional challenges in the engineering design, sensing and motion control, with the additional requirement of modularity so that disassembly, transportation and re-assembly can be done within the shielded enclosure only through remote manipulation over a limited access window as human intervention is permissible only during the initial installation.

Other Activity Facets

- Erudite Lectures by Eminent Faculty & Scientists
- Foreign Deputations of CSIR-CMERI Personnel
- Outside Training Schedules Attended by CSIR-CMERI Personnel & HRDC Ghaziabad Training Programme
- Workshops / Seminars / Conferences Attended by CSIR-CMERI Personnel
- In-house Training Programmes Organised for CSIR-CMERI Personnel
- Higher Qualification Attained
- Awards / Recognition
- List of Publications
- Dateline CSIR-CMERI
- CSIR-CMERI Celebrates International Year of Chemistry
- One day Workshop on Computational Transport Phenomena
- International Conference on Microactuators and Micromechanisms
- Scientific Manpower Profile
- Showcase

Other Activity Facets

Erudite Lectures by Eminent Faculty & Scientists

SL.	Name	Topic	Date
1	Prof. Sudip Chattopadhyay, J.C. Bose National Fellow, NIT, Durgapur	Light-Controlled Arabidopsis Seedling Development	18.04.2011
2	Dr. Sanjay Kumar, IHBT, Palampur	Plant processes that need technological interventions	18.04.2011
3	Dr. Debasish Bhattacharya, IICB, Kolkata	Application of Bio-inspired engineering in snake bite management	18.04.2011
4	Dr. Sudit Mukhopadhyay, NIT, Durgapur	Introduction of life and life engineering	18.04.2011
5	Prof. Amitabha Chattapadhyay, CCMB, Hyderabad	Current excitements and challenges in membrane biology	19.04.2011
6	Prof. Ranga Narayanan, University of Florida	Separation of species via oscillating flow	19.04.2011
7	Prof. Ron Kopito, Stanford University, California	Quality control in the protein assembly line	19.04.2011
8	Prof. Ajoy Kumar Ray, Vice Chancellor, BESU, Shibpur	Recent advances in diagnosis of diseases	11.05.2011
9	Prof. Gautam Biswas, Director, CSIR-CMERI	Enhancement of Heat Transfer using Streamwise Longitudinal Vortices	08.06.2011
10	Prof. Debjyoti Banerjee, Mechanical Engineering Department, Texas A & M University	Nano-devices for enhanced thermal energy storage, cooling and sensing	09.06.2011
11	Prof. Debopam Das, Aerospace Engineering Department, Indian Institute of Technology, Kanpur	Experimental Study of Flapping Flight Aerodynamics using PIV	13.06.2011
12	Mr. Partha Sarathi Banerjee, Sct, CSIR-CMERI, Durgapur	Spinal problems and their biomechanical remedies	22.06.2011
13	Prof. P. Seshu, Sct.-in-charge, CMMACS, Bangalore	Computational Mechanics of Mechanical Systems	19.07.2011
14	Prof. Alok Chakraborty, Variable Energy Cyclotron Centre, Kolkata	Our Cosmic Connection	27.07.2011

SL.	Name	Topic	Date
15	Prof. Krishna Shenai, University of Toledo, USA	Large-Scale Sensor Networks and Robotic Surgery	28.07.2011
16	Prof. Rajiv M Bhatnagar, Defence Academy of United Kingdom, Cranfield University, UK	Modelling of Hydraulic and Smart Fluid based Dampers for Low Speed and High Speed Applications	11.08.2011
17	Prof. Bidyut Baran Saha, Mech. Engg. Department, Kyushu University, Japan	Possibility and Constraints of Working Pairs for Adsorption Cooling and Desalination Systems	12.08.2011
18	Dr. R. K. Bhandri, Director, VECC, Dept. of Atomic Energy, Government of India	Charged Particle Accelerators: Wonderful Machine for Research & Applications	26.09.2011
19	Prof. Rudra Pratap, Dept. of Mechanical Engineering, IISc, Bangalore	Understanding the Dance of Micro & Nano Scale Mechanical Structures	26.09.2011
20	Prof. J. N. Moorthy, Lalit M Kapoor Chair Professor, Dept. of Chemistry, IIT, Kanpur	Rational Molecular Design for Amorphous Organic Light Emitting Diodes (OLEDs) & Ordered Functional Mimics of Inorganic Zeolites	26.09.2011
21	Prof. Mihir Sen, University of Notre Dame	Synchronization in Thermal And Mechanical Oscillations	17.11.2011
22	Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur.	Free Surface Flows with a Focus on Bubble Formation and Detachment in Film Boiling.	21.11.2011
23	Prof. Sakir Amiroudine & Prof. Michael Bouderon, University of Bordeaux 1, France	Thermovibrational instabilities in supercritical fluids & Mixing of miscible fluids by Faraday instability	19.12.2011
24	Prof. Animesh Chakravorty, Indian Association for the Cultivation of Science, Kolkata	The Times, Life and Work of Acharya Prafulla Chandra	21.12.2011
25	Prof. Sourav Pal, Director, National Chemical Laboratory, Pune	Chemistry in shaping materials for the future	21.12.2011
26	Prof. Sabyasachi Sarkar, Department of Chemistry, Indian Institute of Technology, Kanpur	Learning Earth's Aptness in Harvesting Solar Energy	21.12.2011
27	Prof. Chaitali Mukhopadhyay, Department of Chemistry, University of Calcutta, Kolkata	Simulation of the Dynamics of Biomolecules	21.12.2011
28	Prof. Dipak K. Palit, Radiation & Photochemistry Division, Bhabha Atomic Research Centre, Mumbai	Ultrafast Dynamics of the Excited States using Time-Resolved Absorption Spectroscopy	21.12.2011

SL.	Name	Topic	Date
29.	Prof. Tarasankar Pal, Department of Chemistry,Indian Institute of Technology, Kharagpur	Coinage Metal Nanoparticles: Fabrication of Mono- and Bi- Metallic Architecture for Enhanced Raman Signals	21.12.2011
30.	Dr. Aniruddha Mukhopadhyay, ANSYS Inc.,USA	Simulation Driven Engineering in the Industry	03.01.2012
31.	Prof. Gautam Biswas, Director, CSIR-CMERI.	Simulation of Free Surface Flow: Special focus on Falling drops.	03.01.2012
32.	Prof. Achintya Mukherjee, Dept. of Mech. Engg., JU-Kolkata	Modelling of Multi-phase flow	03.01.2012
33.	Dr. Pradeep Rebala, Asian Institute of Gastroenterology, Hyderabad	Robotic Surgery	19.01.2012
34.	Prof. Victor Petuya & Prof. Mikel Diez, Department of Mechanical Engineering, Bilbao Alameda de Urquijo, Spain	Protein Motion Simulation Algoritham for Dihedral Angle Rotation Implementing Variable Speed	19.01.2012
35.	Prof. Brian Jensen, Department of Mechanical Engineering, Brigham Young University	Investigation of Unique Carbon Nanotube Cell Restraint Compliant Mechanisms	19.01.2012
36.	Prof. Shantanu Bhattacharya, Department of Mechanical Engineering, IIT, Kanpur	Bio MEMS and Microfluidics for Clinical Diagnostics and Detection	19.01.2012
37.	Prof. Sunil Kumar Agrawal, Department of Mechanical Engineering, University of Delaware	Novel Robots for Functional Training of Neural Impaired Adults and Children	19.01.2012
38.	Prof. Anupam Saxena, Department of Mechanical Engineering, IIT, Kanpur	Contact Aided Compliant Displacement delimited Gripper-Manipulators	19.01.2012
39.	Dr. Tuhin Subhra Santra, Institute of Nano Engineering and Micro System, National Tsing Hua University, Taiwan	Localized Electroporation and Molecular Delivery into Single Living Hela Cell by ITO Based Transparent Electrode Chip	19.01.2012
40.	Dr. Silka Grimske & Dr. Benny Rohlig, Dept. of Micro Fabrication, Institute of Production Engg. Holstenhofweg 85, 22043 Hamburg	Square Foot Manufacturing - A Modular & Mutable Desktop Machine Tool System	19.01.2012
41.	Prof. Ashok Kumar Mallik, INSA Senior Scientist, S.N. Bose National Centre for Basic Sciences, Kolkata	Mathematical Black Holes, Chaos and Fractals	19.01.2012

SL.	Name	Topic	Date
42.	Mr. S. Kanmani Subbu, Department of Mechanical Engineering, IIT, Kanpur	Micro-electric discharge plasma: characterization and applications	19.01.2012
43.	Rizuwana Parveen, Sanjay Sane & Prof. Rudra Pratap, Centre for Nano Science and Engineering, IISc, Bangalore	Vibratory gyroscopes: a study in contrast of cranefly halters and MEMS Dual mass gyros	20.01.2012
44.	Dr. I. Ivanov & Prof. B. Corves, Department of Mechanism Theory and Dynamics of Machines, Eilfschornsteinstrae 18, 52062 Aachen, Germany	Stiffness oriented design of flexure hinge based parallel manipulator	20.01.2012
45.	Dr. Prem Pal, MEMS & Micro/Nano Systems Laboratory, Department of Physics, IIT, Hyderabad	DRIE vs Wet Sillicon Bulk Micromachining in MEMS	20.01.2012
46.	Prof. Suhas Joshi, Department of Mechanical Engineering, IIT, Bombay	Development of a low-cost, vision-based microassembly system	20.01.2012
47.	Prof. Ashitava Ghosal, Department of Mechanical Engineering, IISc, Bangalore	Design and development of enhanced laparoscopic surgery tools	20.01.2012
48.	Dr. Ashok Kumar Pandey, Department of Mechanical Engineering, IIT, Hyderabad	Optical Tuning of the Dynamic Characteristics of Micromechanical Device	20.01.2012
49.	Dr. M. Sekar & Prof. Yang Seung Ha, Department of Mechanical Engineering, Karunya University	Design and Implementation of high performance Realtime Free from NURBS Interpolator in Micro CNC Machine Tool	20.01.2012
50.	Mr. Gautham Srinivas Baichapur & Prof. G.K. Ananthasuresh, Dept. of Mechanical Engineering, IISc, Bangalore	Micro Newton Force Sensor using a Displacement-amplifying Compliant Mechanism	20.01.2012
51.	Mr. Srijjan Bhattacharya & Prof. S. Bhowmik, Arospace Engg. & Applied Mechanics, BESU, Shibpur	IPMC Actuated Compliant Mechanism Based Multi-functional Multi-finger Micro-gripper	20.01.2012
52.	Mr. Sambuddha Khan & G.K. Ananthasuresh, Dept. of Mechanical Engineering, IISc, Bangalore	Micromechined Accelerometers with Mechanical Amplifiers	20.01.2012
53.	Dr. Dipankar Chatterjee, Simulation & Modelling Group, CSIR-CMERI, Durgapur	Thermohydrodynamic simulation of a DC magnetohydrodynamic (MHD) micropump	20.01.2012

SL.	Name	Topic	Date
54.	Mr. R.K. Jain, Design of Mechanical System Group / Micro Robotics Laboratory, CSIR-CMERI, Durgapur	Bio-mimetic behavior of IPMC using EMG signal for micro robot	20.01.2012
55.	Dr. Amaresh Dalal, Asst. Professor, Dept of Mechanical Engineering, IIT Guwahati	Course on “Solution of 3D Navier Stokes Equation for arbitrary geometry”	10-11.02.2012
56.	Prof. Kornel Ehmann, Northwestern University, USA	Micro Structured Engineered Surfaces	13.02.2012
57.	Prof. Shiv G. Kapoor, University of Illinois Urbana-Champaign, USA	Aerostatic Lead Screw Design	13.02.2012
58.	Prof. Kalyanmoy Deb, IIT-Kanpur	Evolution’s Niche in Practical Problem Solving	26.02.2012
59.	Prof. S.K. Brahmachari, Director General, CSIR	Foundation Lecture	26.02.2012
60.	Dr. Soumen Sen, Dr. Sambhunath Nandi & Dr. Sudipta Dey, CSIR-CMERI, Durgapur	Presentation by Young Scientists	26.02.2012

Other Activity Facets

Foreign Deputations of CSIR-CMERI Personnel

SL.	Name	Deputation To	Duration
1.	Mrs. Abhilasha Saksena, Sct.	Tohoku University, Japan	10/04/2010 to 10/03/2011 to 10/10/2012
2.	Dr. Debabrata Chatterjee, Sr. Principal Sct.	Visiting the UCI, Irvine	03/04/2011 to 16/04/2011
3.	Dr. Debabrata Chatterjee, Sr. Principal Sct.	Visiting the University of Maine, Orono, USA	01/05/2011 to 15/05/2011
4.	Dr. Ranajit Ghosh, Sct.	UIC, USA, Indo-US Centre	15/05/2011 to 15/08/2011
5.	Ms. N.S. Lakshmiprobha, QHF (Trainee)	Vancouver, Canada	01/06/2011 to 03/06/2011
6.	Dr. Sarita Ghosh, Sct. Fellow	University of California, Irvine, USA	01/06/2011 to 01/09/2011
7.	Dr. Debabrata Chatterjee, Sr. Principal Sct.	Erlangen University, Erlangen-Nurnberg, Germany	05/06/2011 to 10/06/2011
8.	Mr. Atanu Maity, Principal Sct.	Tallinn, Estonia	20/06/2011 to 23/06/2011
9.	Prof. Gautam Biswas, Director, CSIR-CMERI	Saint Petersburg, Russia	01/07/2011 to 05/07/2011
10.	Ms. Rekha. J, QHF (Trainee)	Las Vegas, Nevada, USA	18/07/2011 to 21/07/2011
11.	Mr. Atanu Maity, Principal Sct.	Kuala Lumpur, Malaysia	26/07/2011 to 28/07/2011
12.	Mr. Dip Narayan Ray, Sct.	Kuala Lumpur, Malaysia	26/07/2011 to 28/07/2011
13.	Mr. Samik Dutta, Sct.	Indonesia	04/08/2011 to 04/08/2011
14.	Mr. S. Nandy, Principal Scientist	Bejing, China	07/08/2011 to 10/08/2011
15.	Mr. Srinivas Reddy N, QHF Trainee	Bejing, China	07/08/2011 to 10/08/2011

SL.	Name	Deputation To	Duration
16.	Ms. Shikha Jain, QHF Trainee	Bejing, China	07/08/2011 to 10/08/2011
17.	Mr. Amit Jyoti Banerjee, Sr. Principal Sct.	Bevilard, Switzerland	29/08/2011 to 09/09/2011
18.	Mr. Pranabendu Saha, T.O.	Bevilard, Switzerland	29/08/2011 to 09/09/2011
19.	Mr. Himadri Roy, Sct.	University of Bayreuth, Germany	29/08/2011 to 28/08/2012
20.	Shri Biplab Chowdhury, Principal Sct.	Adsorption Cooling Laboratory of Kyushu University, Japan	01/09/2011 to 31/10/2011
21.	Dr. Satya Prakash Singh, Sr. Sct.	Dalian, China	05/09/2011 to 07/09/2011
22.	Mrs. Anjali Chatterjee, Principal Sct.	Soest, Germany	05/09/2011 to 08/09/2011
23.	Prof. Gautam Biswas, Director, CSIR-CMERI	China	05/09/2011 to 07/09/2011
24.	Dr. Atanu Maity, Principal Scientist	Qingdao, China	17/09/2011 to 19/09/2011
25.	Mr. N.C. Murmu, Sr. Scientist	USA	10/10/2011 to 09/02/2012
26.	Dr. Sudip Kr. Samanta, Principal Scientist	New Taipei City, Taiwan	06/11/2011 to 09/11/2011
27.	Dr. Ranajit Ghosh, Sct.	Japan	17/11/2011 to 16/11/2013
28.	Dr. Soumen Sen, Principal Scientist	Phuket, Thailand	07/12/2011 to 11/12/2011
29.	Sri Dip Narayan Roy, Scientist	Phuket, Thailand	07/12/2011 to 11/12/2011
30.	Dr. Atanu Maity, Principal Scientist	Phuket, Thailand	07/12/2011 to 11/12/2011
31.	Dr. B. N. Mondal, Chief Scientist	Biopolis, Singapore	09/01/2012 to 11/01/2012
32.	Dr. Debabrata Chatterjee, Sr. Principal Sct.	Queensland University of Technology, Brisbane, Australia	04/03/2012 to 10/03/2012
33.	Sri Nilrudra Mandal, Scientist	Phuket, Thailand	12/03/2012 to 13/03/2012

Other Activity Facets

Outside Training Schedules Attended by CSIR-CMERI Personnel

SL.	TRAINING PROGRAMME ON	PARTICIPANTS
1.	Protein sequence analysis & structure prediction	1
2.	Vibration Analysis – Level 1 Certification Course	2
3.	Service life assessment for missile system	1
4.	Innovation Management & Technology Valorization	1
5.	Co-ordinate Measuring Machine & its application	2
6.	Computational Fluid Dynamics	1
7.	Introduction of Nano Metrology	1
8.	National Training Programme on IPR & WTO issues	2
9.	Intensive Course on Noise & Vibration	1
10.	Training Programme on Vibration Analysis-Level II Certification Course	2

HRDC Ghaziabad Training Programme

Sl.	Training On	Duration	Participants
1.	Emotional Intelligence for Managerial Efficiency	July 18-20, 2011	2
2.	Training Programme on S&T Communication and Presentation Skill	Feb. 15-17, 2012	2

Other Activity Facets

Workshops / Seminars / Conferences Attended by CSIR-CMERI Personnel

Sl.	NAME OF THE PROGRAMME	PARTICIPANTS
1.	Electronics Computer Technology (ICECT-2011)	1
2.	Design & Manufacturing (NaCoMM 2011)	1
3.	Ocean Society of India Conference (OSICON'11)	1
4.	Sustainable Energy & Intelligent System (SEISCON-2011)	1
5.	Advances in Lithium Batteries	1
6.	Information Processing (ICIP-2011)	1
7.	Chemical Research in the First Decade of 21st Century	1
8.	5th Renewable Energy Conference India 2011 EXPO	1
9.	Corrosion Conference & EXPO 2011	1
10.	Tissue Engineering & Regenerative Madicine (ICTERM-2011)	2
11.	International Journal of Computer Science & Information Technoloies (IJCSIT)	1
12.	Advance in Civil Engineering (ACE-2011)	1
13.	International Journal of Computer Trends & Technology	1
14.	Image Information Processing	2
15.	Advances in Environmental Chemistry	2
16.	Industry Academia Linkages	2
17.	Frontiers in Electronics Communication & Instrumentation Technology (FECIT 2011)	1
18.	Microstructure Across Length Scales & Material Properties (Microstructure-2011)	1
19.	Miniature Specimens for Evaluation of Mechanical Properties of Structural Materials (MEMP-2011)	1
20.	10th International Heat Pipe Symposium	1
21.	Fluid Machinery & 3rd Fluid Power Technology Exhibition	1
22.	11th Asian International Conference on Fluid Machinery & 3rd Fluid Power Technology Exhibition	2

Sl.	NAME OF THE PROGRAMME	PARTICIPANTS
23.	Workshop on Fuzzy Sets, Rough Sets, Uncertainty Analysis & Applications	1
24.	Practical Thermal-Fluid System Simulation	3
25.	15th National Conference on Machine & Mechanisms (NaCoMM-2011)	2
26.	National Instruments Technical Symposium 2011	1
27.	Conference on NDESAI 2011	1
28.	4th Bangalore Nano	1
29.	3rd IEEE International Conference on Trends in Information Science & Computing, (TISC 2011)	1
30.	National Tribology Conference (NTC-2011)	1
31.	International Conference on Advances in Materials & Materials Processing (ICAMMP-2011)	1
32.	International Conference on Precision, Meso, Micro and Nano Engineering (COPEN-7)	2
33.	International Conference on Precision, Meso, Micro and Nano Engineering (COPEN-7)	2
34.	IUTAM Symposium on Bluff Body Flows (BLUBOF2011)	3
35.	SERC School on Nonlinear Programming & Soft Computing Techniques for Chemical Engineering	2
36.	"Quality Function Deployment"	3
37.	International Congress of Environmental Research (ICER-11)	1
38.	Advanced Computing, Networking & Security (ADCONS 2011)	1
39.	26th Indian Engineering Congress 2011	2
40.	IEEE Indian Annual Conference INDICON 2011	2
41.	21st National & 10th ISHMT-ASME Heat & Mass Transfer Conference	4
42.	3rd International Conference on Sensors & Related Networks (SENNET-2012)	1
43.	6th Asian Conference on Electrochemical Power Sources	2
44.	Industrial Fuel Switching	1
45.	International Conference on Nano Science & Technology (ICONSAT 2012)	2
46.	International Conference on Engineering Coatings: Processes, Controls and Applications (EnggCoat – 2012)	1
47.	International Conference on Technological Advancements in Civil Engineering (ICTACE-2012)	1
48.	National Seminar on Challenges in Library Management System (CLMS-2012)	1
49.	International Conference on Computer, Communication, Control & Information Technology	1
50.	Workshop on Surfaces Engineering of Metals & Alloy (SEMA-2012)	2
51.	60th Indian Foundry Congress	2

Sl.	NAME OF THE PROGRAMME	PARTICIPANTS
52.	8th International Symposium on Fuels & Lubricants (ISFL-2012)	2
53.	IEEE International Conference on Devices, Circuits and Systems (IEEE-ICDCS 2012)	1
54.	Regional Cost Conference, 2012	2
55.	IEEE International Conference on Advances in Engineering, Science and Management (ICAESM-2012)	2

Other Activity Facets

In-house Training Programmes Organised for CSIR-CMERI Personnel

SL.	TRAINING PROGRAMME ON	PARTICIPANTS
1.	Engineering Mechanics of Solids	5
2.	Computational Fluid Dynamics	4
3.	ANSYS Software – (Phase I)	10
4.	Finite Element Methods & Related Applications	33
5.	Course on communication and writing skill in English	50
6.	Course on Solution of 3D Navier Stokes Equation for arbitrary geometry	20

Other Activity Facets

Higher Qualification Attained

Sl. No.	Qualification	Awardee
1	M.Tech. from NIT, Durgapur **A Systematic Study & Comparative Analysis of Rotors for Micro-Aerial Vehicle**.	**Shri Suman Kumar Char,** Technical Assistant
2	Ph.D. from IIT, Kharagpur **Monotonic and Cyclic Fracture Behaviour of AISI 304LN Stainless Steel**	**Dr. Himadri Roy,** Scientist
3	Ph.D. from IIT, Kharagpur **Analysis of Some High-speed Compressible Flow Problems Using Flux Algorithms**	**Dr. Pabitra Halder,** Scientist
4	Ph.D. from NIT, Durgapur **Studies On Influence Of Alloy Microstructure And Superficial Coating Of Reactive Oxides on The High Temperature Corrosion Behavior of 2.25 Cr - 1 Mo and 9 Cr - 1 Mo steels in SO_2 + O_2 Atmospheres**	**Dr. Debashis Ghosh,** Principal Scientist
5	Ph.D. from NIT, Durgapur **Serpentine Robot Locomotion: An Implementation Through Joint Orientation Function**	**Dr. Atanu maity,** Principal Scientist
6	M.Tech. from NIT, Durgapur **Mathematical Modelling and FE Based Software Simulation & Modelling (using ABAQUS CAE 6.1.1). Behaviour of Pile Foundation & Pile Groups at Liquified Soil Layers under Dyamic Seismic Forces and Drift Responses of Slender Stack Like Structures (Tall RCC chimneys) under Dynamic Wind Vortex (using STAAD Pro & FE based ABAQUS softwares)**.	**Shri Sumit Guha,** Senior Technical Officer (2)
7	Ph.D. from Banaras Hindu University **Experimentation and Modeling on fatigue and residual life estimation of ball bearing**	**Dr. Naresh Chandra Murmu,** Principal Scientist
8	Ph.D. from BESU **Dynamic State Estimation in Presence of Uncertainty**	**Dr. Arpita Mukherjee,** Senior Scientist
9	Ph.D. from NIT, Durgapur **Predictive Embedded System in Safety Critical Application**	**Dr. Joydeb Roy Chowdhury,** Senior Principal Scientist

Other Activity Facets

Awards / Recognition

1. Prof. Gautam Biswas, Director, CSIR-CMERI was invited to join the **Editorial Advisory Board** of the journal **Heat Transfer - Asian Research.**
2. Prof. Gautam Biswas, Director, CSIR-CMERI delivered the **Second Prof. B.R. Seth Memorial Institute Lecture** at **IIT, Kharagpur**
3. Prof. Gautam Biswas, Director, CSIR-CMERI was nominated a member of the **Working Group** on **S&T Human Resource Development** of the Planning Commission, Government of India
4. Dr. Debabrata Chatterjee was elected as a **Fellow** of the **National Academy of Science, India**

Other Activity Facets

List of Publications

SN	AUTHOR	TITLE	JOURNAL	DETAILS
1.	M.K. Karmakar A.B. Datta	Generation of hydrogen rich gas through fluidized bed gasification of biomass	Bioresource Technology	102(2),2011, PP 1907-1913
2.	Debabrata Chatterjee Ujjwal Pal Sarita Ghosh Rudi van Eldik	Redox reactions of a RuIII-edta complex with thioamino acids. Kinetic and mechanistic studies	Dalton Transactions	40, 2011, 1302-1306
3.	Debabrata Chatterjee E. Ember S. Ghosh U. Pal Rudi van Eldik	Kinetics and mechanism of the [RuIII(edta)(H_2O)]- mediated oxidation of cysteine with H_2O_2	Dalton Transactions	40, 2011, PP 10997-11004
4.	Debabrata Chatterjee E. Ember U. Pal S. Ghosh Rudi van Eldik	Remarkably high catalytic activity of the RuIII(edta)/ H_2O_2 system towards degradation of the azo-dye Orange II	Dalton Transactions	40, 2011, PP 10473-10480
5.	Chanchal Loha H. Chattopadhyay Pradip K. Chatterjee	Thermodynamic analysis of hydrogen rich synthetic gas generation from fluidized bed gasification of rice husk	Energy	36(7),2011, PP 4063-4071
6.	D. Chatterjee Sarita Ghosh U. Pal	Kinetics and mechanism of NO production in the Ru(III)-(edta) mediated oxidation of L-arginine with H_2O_2	Dalton Transactions	40, 2011, PP 683-685

SN	AUTHOR	TITLE	JOURNAL	DETAILS
7.	Dipankar Chatterjee Sakir Amiroudine	Lattice Boltzmann simulation of thermofluidic transport phenomena in a DC magnetohydrodynamic (MHD) micropump	Biomedical Microdevices	13, 2011, PP 147-157
8.	T. Gangopadhyay D. K. Pratihar I. Basak	Expert system to predict forging load and axial stress	Applied Soft Computing	11(1),2011, PP 744-753
9.	Prosenjit Das R. Jayaganthan T. Chowdhury I.V. Singh	Fatigue behavior and Crack Growth rate of Cryorolled Al 7075 alloy	Materials Science and Engineering: A	Vol 528, Iss 24 15 Sep 2011, PP 7124-7132
10.	I. Chakraborty G. Biswas P.S Ghoshdastidar	Bubble generation in quiescent and co-flowing liquids	International Journal of Heat and Mass Transfer	54 , 2011, 4673-4688
11.	Chanchal Loha P.K.Chatterjee H. Chattopadhyay	Performance of fluidized bed steam gasification of biomass – Modeling and experiment	Energy Conversion and Management	Vol 52, Iss 3, March 2011, PP 1583-1588
12.	Debabrata Chatterjee A. Sengupta Rudi van Eldik	Kinetics and mechanism of the reaction of [RuII(tpy)(pic)(H_2O)]+ with $KHSO_5$ in oxidative cleavage of DNA	Journal of Coordination Chemistry	64, 2011, PP 30-37
13.	Nilrudra Mandal B. Doloi B. Mondal	Development of flank wear prediction model of Zirconia Toughened Alumina (ZTA) cutting tool using response surface methodology	International Journal of Refractory Metals and Hard Materials	29(2),2011, PP 273-280
14.	S. Basu S.K.M. Hossain D. Chakravorty M. Pal	Enhanced magnetic properties in hydrothermally synthesized Mn-doped $BiFeO_3$ nanoparticles	Current Applied Physics	11(4),2011, PP 976-980
15.	Sudip K. Samanta H. Chattopadhyay M. M. Godkhindi	Thermo-physical characterization of binder and feedstock for single and multiphase flow of PIM 316L feedstock	Journal of Materials Processing Technology	Vol 211, Iss 12, Dec 2011, PP 2114-2122

SN	AUTHOR	TITLE	JOURNAL	DETAILS
16.	Dipankar Chatterjee Gautam Biswas	Effects of Reynolds and Prandtl numbers on flow and heat transfer across tandem square cylinders in the steady flow regime	Numerical Heat Transfer A	59, 2011, PP 421-437
17.	Prakash Chandra V. V. Satyamurty	Non-Darcian and Anisotropic Effects on Free Convection in a Porous Enclosure	Transport in Porous Media	Vol 90, No. 2, PP 301-320
18.	B. Roy B. Karmakar P. M. G. Nambissan M. Pal	Mn substitution effects and associated defects in ZnO nanoparticles studied by positron annihilation.	NANO	Vol 6, PP 173, 2011
19.	B. Roy O. Mondal A. Deb S. P. Sengupta P. Chaterjee M. Pal	Preparation and Microstructural Characterization of Nanocrystalline Mn-doped ZnO	NANO	Vol 6, PP 379, 2011
20.	R. Bardhan S. Mahata B. Mondal	Processing of natural resourced hydroxyapatite from egg shell waste by wet precipitation method	Advances In Applied Ceramics	110(2), 2011, PP 80-86
21.	D. Chatterjee	Reactivity of Ru-edta complexes with DNA fragments and thioaminoacids: Kinetic and mechanistic studies	Indian Journal of Chemistry -Section A	50A(01), 2011, PP 38-40
22.	Saptarshi Das Suman Saha Shantanu Das Amitava Gupta	On the selection of tuning methodology of FOPID controllers for the control of higher order processes	ISA Transactions	50(3), 2011, PP 376-388
23.	Nilrudra Mandal B. Doloi B. Mondal Reeta Das	Optimization of flank wear using Zirconia Toughened Alumina (ZTA) cutting tool: Taguchi Method & Regression Analysis	Measurement	Vol 44, Iss 10, Dec 2011, PP 2149-2155

SN	AUTHOR	TITLE	JOURNAL	DETAILS
24.	Sudipta De Murugan Thangadurai	Numerical simulation of shock tube generated vortex: effect of numerics	International Journal of Computational Fluid Dynamics	Vol 25 (6), 2011 PP 345–354,
25.	Pabitra Kumar Paul Syed Arshad Hussain Debajyoti Bhattacharjee Mrinal Pal	Adsorption of a Cationic Laser Dye onto Polymer/ Surfactant Complex Film	Chin. J. Chem. Phys.	Vol 24, PP 348, 2011
26.	Atanu Saha D. K. Mondal Joydeep Maity	An Alternate Approach to Accelerated Spheroidization in Steel by Cyclic Annealing	Journal of Materials Engineering and Performance	Vol 20(1), 2011, PP 114-119
27.	A.K. Lohar B.N. Mondal S.C. Panigrahi	Effect of Mg on the Microstructure and Mechanical Properties of Al0.3Sc0.15Zr-TiB_2 Composite	Journal of Materials Engineering and Performance	Vol 20, No. 9, 2011, PP 1575-1582
28.	Arpita Mukherjee Aparajita Sengupta	A recursive maximum a posteriori estimator	Asian Journal of Control	13(3),2011, PP 465–469
29.	Debashis Das Abhijit Chatterjee	A Comparison of Hardened Properties of Flyash based Self-Compacting Concrete and Normally Compacted Concrete under Different Curing Condition	Magazine of Concrete Research	Vol 64, Iss 2, Dec 2011, PP 129 –141
30.	P. Halder K.P. Sinhamahapatra N. Singh	Numerical investigation of supersonic wake of a wedge using AUSM+ scheme on unstructured grid	Journal of Applied Mathematics and Mechanics	Vol 7(11): 2011, PP 46-48
31.	S.R. Debbarma S. Saha	In-situ investigation of thermal gradient and growth of strain in long-span PSC box Girder Bridges due to atmospheric temperature and its effects in profile of girders	International Journal of Earth Sciences and Engineering	Vol 4, No. 6, 2011, PP 709-715

SN	AUTHOR	TITLE	JOURNAL	DETAILS
32.	R. K. Jain S. Datta S. Majumdar A. Dutta	Two IPMC Fingers based Micro-gripper for handling	International Journal of Advanced Robotics Systems	8(1), March 2011, PP 1-9
33.	O. Mondal M. Pal	Strong and unusual violet blue emission in ring-shaped ZnO nanocrystals.	J Mater Chem	Vol 21, Iss 45, 2011, PP 18354-18358
34.	O. Mondal SK. M. Hossain B. Roy M. Pal	Unusual Magnetic Properties of Nanocrystalline $GdFeO_3$ Prepared By Solid State Reaction Route at Lower Temperature	Func. Mater. Lett.	Vol 4 (3), 2011, PP-249
35.	B. Mondal K.Usha Shrabani Mahato	Synthesis and Characterization of nanocrystalline TiO_2 thin films for use as photoelectrodes in Dye Sensitized Solar Cell Application	Transactions of Indian Ceramic Society (TICS)	Vol 70 (3) , 2011, PP 71- 77
36.	Dipankar Chatterjee Bittagopal Mondal	Effect of thermal buoyancy on vortex shedding behind a square cylinder in cross flow at low Reynolds numbers	International Journal of Heat and Mass Transfer	Vol 54, Iss 25–26, Dec 2011, PP 5262-5274
37.	M. Goswami R. Ghosh G. Chakraborty K. Gupta A. K. Meikap	Optical and Electrical Properties of Polyaniline-Cadmium Sulfide Nanocomposite	Polymer Composites	Vol 32, Iss 12, PP 2017–2027, Dec 2011
38.	A. K. Nandi C. Cingi S. Datta J. Orkus	Experimental investigation on equivalent properties of particle reinforced silicone rubber: Improvement of soft tooling process	Journal of Reinforced Plastics And Composites	Sep 2011, Vol 30, 17, PP 1429-1444

SN	AUTHOR	TITLE	JOURNAL	DETAILS
39.	S. Patra S. Sarkar S. K. Bera G. K. Paul R. Ghosh	Influence of surface topography and chemical structure on wettability of electrodeposited ZnO thin films	Journal of Applied Physics	Vol 110, Iss 3, 2011, 3615932 (1 page)
40	S. Sarkar A. Dalal G. Biswas	Unsteady wake dynamics and heat transfer in forced and mixed convection past a circular cylinder in cross flow for high Prandtl numbers	International Journal of Heat And Mass Transfer	Vol 54, Iss 15–16, Jul 2011, PP 3536–3551
41.	S. Mukherjee S. Manju	An improved parametric formulation for the variationally correct distortion immune three-noded bar element	Structural Engineering And Mechanics	Vol 38, No. 3, May 2011, PP 261–281
42.	D. Ghosh S. K. Mitra	High Temperature Corrosion Problem of Boiler Components in presence of Sulfur and Alkali based Fuels	High Temperature Materials And Processes	Vol 30 no.1 PP 81-86, 2011
43.	T. Gangopadhyay R. K. Ohdar D. K. Pratihar I. Basak	Three-dimensional finite element analysis of multi-stage hot forming of railway wheels	International Journal of Advanced Manufacturing Technology	Vol 53, No. 1-4, 2011, PP 301-312
44.	S. K. Samanta H. Chattopadhyay M. M. Godkhindi	Modelling the powder-binder separation in injection stage of PIM	Progress In Computational Fluid Dynamics	2011 - Vol 11, No. 5, PP 292 - 304
45.	A. K. Nandi S. Datta K. Deb	Investigating the Role of Nonmetallic Fillers in Particulate-Reinforced Mold Composites using EAs	Materials And Manufacturing Processes	Vol 26, No. 3, Mar 2011, PP 541-549
46.	A. K. Nandi K. Deb S. Datta J. Orkas	Studies on effective thermal conductivity of particle-reinforced polymeric flexible mould material composites	Proceedings of The Institution of Mechanical Engineers Part L-Journal of Materials-Design And Applications	Vol 225, 2011, PP 149-159

SN	AUTHOR	TITLE	JOURNAL	DETAILS
47.	Stephen Sproules Priyabrata Banerjee Thomas Weyhermüller Yong Yan James P. Donahue Karl Wieghardt	Monoanionic Molybdenum and Tungsten Tris(dithiolene) Complexes: A Multifrequency EPR Study	Inorganic Chemistry	2011, 50 (15), PP 7106–7122
48.	Sucheta Joy Tobias Krämer Nanda D. Paul Priyabrata Banerjee John E. McGrady Sreebrata Goswami	Isolation and Assessment of the Molecular and Electronic Structures of Azo-Anion-Radical Complexes of Chromium and Molybdenum: Experimental and Theoretical Characterization of Complete Electron-Transfer Series	Inorganic Chemistry	2011, 50 (20), PP 9993–10004
49.	Dipankar Chatterjee	Computational modeling of transport phenomena in high energy materials processing application: Large Eddy Simulation and Parallelization	International Journal of Computational Materials Science and Surface Engineering	4(1), 2011, 1-22
50.	Tapas Sarkar Asit Kr. Batabyal	Evaluation of customer satisfaction in R&D organization: a conceptual framework	Asian Journal on Quality	12(1), 2011, 20 - 29
51.	Manisha Pal Baishakhi Roy M. Pal	Structural Characterization of Borate Glasses Containing Zinc and Manganese Oxides	Journal of Modern Physics	Vol 02 No. 9, PP 1062-1066, Sep 2011
52.	Suprabhat Mukherjee Sudip Mondal Rajashree Bardhan B. Mondal	Stem Cells in Tissue Engineering- An Interface between Biology and Engineering	International Journal of Biological Science and Engineering	Vol 02, (01), PP 49- 55, 2011
53.	Sudip Mondal Rajashree Bardhan Suprabhat Mukherjee B. Mondal	Synthesis of Hydroxyapatite Biomaterial from Different Bio Sources for Tissue Engineering	International Journal of Biological Sciences and Engineering	Vol 02, (01), PP 17- 24, 2011

SN	AUTHOR	TITLE	JOURNAL	DETAILS
54.	Prosenjit Das Samik Dutta H. Roy R. Jayaganthan	Characterization of Impact Fracture Surfaces under Different Processing Conditions of 7075 Al Alloy using Image Texture Analysis	International Journal of Technology And Engineering System(IJTES)	Jan –March 2011, Vol 02, No. 2, 143-147
55.	Sudip K. Samanta H. Roy D.P.Chattopadhyay S. Kumar S. S. Roy A. K. Chowdhury S. Majumder	Scrap Polymer as a Partial Replacement of Graphite for Cast Iron Production	Indian Foundry Journal	Vol 57, No. 1, January 2011, 23-28
56.	J. Bhattacharya S. Majumder G. Sanyal	A Modeling of Shape Descripting Approaches using Local Patterns of High Gradient Points	International Journal of Computer Trends and Technology	Sep-Oct 2011, Vol 02, Iss 1, PP 86-91, ISSN: 2231-2803
57.	J. Bhattacharya S. Majumder	Visual Odometric Navigation: the Generalized Feature Vector Way	Journal of Communication and Computer	Vol 08, No. 3, 2011, ISSN:1548-7709
58.	A. Ganguly P. K. Chatterjee A. Dey	Studies on Ethanol Production from Water Hyacinth- A Review	Renewable & Sustainable Energy Reviews	Vol 16, Iss 1, January 2012, Pages 966-972
59.	Arup Kumar Nandi Kalyanmoy Deb Subhas Ganguly Shubhabrata Datta	Investigating the role of metallic fillers in particulate reinforced flexible mould material composites using evolutionary algorithms	Applied Soft Computing	Vol 12, Iss 1, January 2012, Pages 28-39
60.	Himadri Chattopadhyay Arindam Kundu Binod K. Saha Tapas Gangopadhyay	Analysis of flow structure inside a spool type pressure regulating valve	Energy Conversion and Management	Vol 53, Iss 1, January 2012, Pages 196-204

SN	AUTHOR	TITLE	JOURNAL	DETAILS
61.	Debabrata Chatterjee Sarita Ghosh Ujjwal Pal Sudit Mukhopadhyay	Redox reactions of a [RuIII(hedtra)(pz)] complex with biochemically important reductants. Kinetic, mechanistic and anti-microbial studies	Eur.J. Inorg. Chem.	Vol 2012, Iss 4, Pages 678–683, February 2012
62.	T. Murugan S. De C. L. Dora D. Das	Numerical simulation and PIV study of compressible vortex ring evolution	Shock Waves	2012, Vol 22, Number 1, Pages 69-83
63.	Debabrata Chatterjee Rudi van Eldik	Mechanism of –O-O- bond activation and substrate oxidation by Ru-edta complexes	Journal of Molecular Catalysis A: Chemical	Vol 355, March 2012, Pages 61-68
64.	S. Mahata M. M. Nandi B. Mondal	Preparation of high solid loading titania suspension in gelcasting using modified boiling rice extract (MBRE) as binder	Ceramic International	Vol 38, Iss 2, March 2012, Pages 909-918
65.	S. Mahata M. M. Nandi B. Mondal	Preparation of high solid loading titania suspension in gelcasting using modified boiling rice extract (MBRE) as binder	Ceramics International	Vol 38, Iss 2, March 2012, Pages 909-918
66.	Nilrudra Mandal H. Roy B. Mondal N. C. Murmu S. K. Mukhopadhyay	Mathematical Modeling of Wear Characteristics of 6061 Al-Alloy-SiCp Composite Using Response Surface Methodology	Journal of Materials Engineering and Performance	2012, Vol 21, Number 1, Pages 17-24
67.	Ujjwal Pal Sarita Ghosh Debabrata Chatterjee	Effect of sacrificial electron donors on hydrogen generation over visible light–irradiated nonmetal-doped TiO_2 photocatalysts	Transition Metal Chemistry	2012, Vol 37, Number 1, Pages 93-96

SN	AUTHOR	TITLE	JOURNAL	DETAILS
68.	Anurup Datta Samik Dutta Surjya K Pal Ranjan Sen Sudipta Mukhopadhyay	Texture Analysis of Turned Surface Images using Grey Level Co-occurrence Technique	Advanced Materials Research	Vol 365 (2012), PP 38-43
69.	S. Dutta A. Das K. Barat H. Roy	Automatic characterization of fracture surfaces of AISI 304LN stainless steel using image texture analysis.	Measurement	Vol 45, PP 1140 - 115
70.	S. Dutta A. Datta N. Das Chakladar S. K. Pal S. Mukhopadhyay R. Sen	Detection of tool condition from the turned surface images using an accurate Grey level co-occurrence technique	Precision Engineering	Vol 36(3), PP 458 - 466
71.	H. Roy S. Sivaprasad S. Tarafder K. K. Ray	Cyclic fracture behavior of 304LN stainless steel under load and displacement control modes	Fatigue & Fracture of Engineering Materials & Structures	Published online : 2 JUN 2011, DOI: 10.1111/j.1460-2695. 2011.01596.x
72.	Biswajit Ruj Pradip Kumar Chatterjee	Toxic release of chlorine and off-site emergency scenario – A case study	Journal of Loss Prevention in the Process Industries	In Press, Available online 20 January 2012
73.	T. Murugan S. De	Numerical visualization of counter rotating vortex ring formation ahead of shock tube generated vortex ring	Journal of Visualization	Online First™, 11 October 2011, DOI: 10.1007/s12650-011-0110-1
74.	Debabrata Chatterjee P. Banerjee J. C. Bose K S. Mukhopadhyay	Peroxydisulfate activation by $[RuII(tpy)(pic)(H_2O)]^+$. Kinetic, mechanistic and anti-microbial activity studies.	Dalton Transactions	DOI : 10.1039/C2DT11821A in press

SN	AUTHOR	TITLE	JOURNAL	DETAILS
75.	Vijay Kumar Meena Man Singh Azad	Grey Relational Analysis of Micro EDM Machining of Ti-6Al-4V alloy	Journal of Materials and Manufacturing Process	**DOI:** 10.1080/ 10426914.2011.610080 Available online: 28 Sep 2011
76.	Abhijit Banerjee Soumitra Patra Mahuya Chakrabarti Dirtha Sanyal M. Pal Swapan K. Pradhan	Microstructure, Mossbauer and optical characterizations of nanocrystalline Fe_2O_3 synthesized by chemical route	ISRN Ceramics	DOI.10.5402/ 2011/406094
77.	Vijay Kumar Meena Man Singh Azad Souren Mitra	Effect of flushing condition on deep hole micro EDM drilling	International Journal of Machining and Machinabilty of Materials	2012, 12(4), PP 308
78.	Debashis Das Abhijit Chatterjee	Assessing Concrete Quality in Structure through Statistical Interpretation of Ultrasonic Pulse Velocity Measurements	Magazine of Concrete Research	2012, 64(8), PP 717
79.	N. S. Lakshmiprabha J. Bhattacharya S. Majumder	Identity, Expression and Age Information using Active Appearance Model Features	International Journal on Information Processing	Accepted
80.	Dipankar Chatterjee	A lattice Boltzmann model for high energy materials processing application	International Journal for Multiscale Computational Engineering	2012, 10(3), PP 229
81.	Bittagopal Mondal Dipankar Chatterjee	Lattice Boltzmann simulation of heat conduction problems in non-isothermally heated enclosures	Heat Transfer-Asian Research	2012, 41(2), PP 127
82.	Dipankar Chatterjee Bittagopal Mondal	Forced convection heat transfer from tandem square cylinders for various spacing ratios	Numerical Heat Transfer A	2012, 61, PP 381

SN	AUTHOR	TITLE	JOURNAL	DETAILS
83.	Dipankar Chatterjee Bittagopal Mondal	Effect of Thermal Buoyancy on the two-dimensional Upward Flow and Heat Transfer around a Square Cylinder	Heat Transfer Engineering	2012, 33(12), PP 1063
84.	Dipankar Chatterjee Bittagopal Mondal	On the vortex shedding mechanism behind a circular cylinder subjected to cross buoyancy at low Reynolds numbers	Computational Thermal Sciences	2012, 4(11), PP 23
85.	Dipankar Chatterjee Bittagopal Mondal	Forced Convection heat transfer from an equilateral triangular cylinder at low Reynolds numbers	Heat and Mass Transfer	2012, 48, PP 1575
86.	Dipankar Chatterjee Sakir Amiroudine Gautam Biswas	Mixed convection heat transfer from an in-line row of square cylinders in cross-flow at low Reynolds number	Numerical Heat Transfer A	2012, 61, PP 891

BOOK

1. **Biomass Gasification- Thermo Chemical Fluidized Bed Gasification of Biomass**, Malay Karmakar, Dr. P.K.Chatterjee, Dr. Abhi Bhusan Datta , ISBN: 9783843375773, January 2011

Book Chapter

1. **Braille Character Recognition Using Generalized Feature Vector Approach,** Bhattacharya J. and Majumder S., Communications in Computer and Information Science, 1, Volume 157, Computer Networks and Intelligent Computing, Part 3, Pages 171-180
2. **Age Estimation Using Gender Information,** Lakshmiprabha N.S., Bhattacharya J. and Majumder S., Communications in Computer and Information Science, 1, Volume 157, Computer Networks and Intelligent Computing, Part 3, Pages 211-216
3. Sanjay K. Biswas and Rashmi R. Sahoo (2011) **Tribology of MoS_2 nanoparticles in the ambient and in liquid suspension** in "Molybdenum: Characteristics, Production and Applications" Ed.: Matías Ortiz and Thiago Herrera, Nova Publisher, NY, Ch - 9.
4. **Lattice Boltzmann Modeling for Melting/Solidification Processes**, Dipankar Chatterjee, Hydrodynamics - Optimizing Methods and Tools, ISBN 978-953-307-712-3 Edited by: Harry Edmar Schulz, André Luiz Andrade Simões and Raquel Jahara Lobosco Publisher: http://www.intechweb.org/, October 2011
5. **Polyaminecarboxylateruthenium(III) Complexes on the Mosaic of Bioinorganic Reactions: Kinetic and Mechanistic Impact.** Debabrata Chatterjee and Rudi van Eldik, Advanced in Inorganic Chemistry, Book Chapter. 2011. In press.

Other Activity Facets

Dateline CSIR-CMERI

SL.	DATE	PROGRAMME NOMENCLATURE
1.	April 18-19, 2011	Workshop on “Biology Leading to Bio-inspired Engineering”
2.	May 4-5, 2011	Hindi Workshop
3.	11-05-2011	National Technology Day Celebration
4.	12-08-2011	Inauguration of Central Research Facility (CRF) in CSIR-CMERI
5.	15-08-2011	Flag Hosting Ceremony on the Independence Day
6.	19-08-2011	Observation of Sadhbhavana Diwas
7.	30-08-2011	Opening of State Bank Of India at CMERI Colony
8.	Sept 7-14, 2011	Hindi week
9.	26-09-2011	CSIR Foundation Day Celebration
10.	Oct 31 - Nov 5, 2011	Observation of Vigilance Awareness Week - 2011
11.	11-11-2011	26^{th} Management Council Meeting
12.	Nov 19-25, 2011	Fund Raising Week for Communal Harmony Campaign
13.	30-11-2011	45^{th} Research Council Meeting
14.	21-12-2011	Celebration of International Year of Chemistry & 150^{th} Anniversary of Acharya Prafulla Chandra Ray
15.	Jan 19-20, 2012	International Conference on Microactuator and Micromechanisms (MAMM - 2012)
16.	Jan 24,25,27, 2012	Hindi Typing Workshop on Computer through UNICODE
17.	26-01-2012	Flag Hosting Ceremony on Republic Day
18.	03-02-2012	Management Review Meeting
19.	Feb 4-5, 2012	CMERI Annual Sports - 2012
20.	26-02-2012	55^{th} CMERI Foundation day celebration
21.	09-03-2012	DG-CSIR Visit to CSIR-CMERI
22.	12-03-2012	46^{th} RC meeting
23.	11-05-2012	National Technology Day Celebration

Other Activity Facets

CSIR-CMERI Celebrates International Year of Chemistry

CSIR-Central Mechanical Engineering Research Institute (CSIR-CMERI), Durgapur celebrated the International Year of Chemistry and 150th anniversary of Acharya Prafulla Chandra Ray– guru of the first research school of chemistry in the country on December 21, 2011. The galaxy of the dignitaries present on the occasion were Professor Animesh Chakravarty, Indian Association for Cultivation of Science, Kolkata and Chief Guest of the Programme; Professor Saurav Pal, Director, CSIR-National Chemical Laboratory, Pune; Professor Sabyasachi Sarkar, IIT Kanpur; Professor Dipak Palit, Bhabha Atomic Research Centre, Mumbai; Professor Chaitali Mukherjee, University of Calcutta, and Professor Tarasankar Pal, IIT, Kharagpur. A number of eminent professors, teachers, students and research scholars from various academic, engineering institutions and schools congregated in M.M. Suri Hall at CSIR-CMERI, Durgapur to participate in this lecture-cum-interactive programme.

In his inaugural address, Prof. Gautam Biswas, Director, CSIR-CMERI welcomed the august gathering and extended warm and hearty greetings to the dignitaries and the distinguished gathering. Subsequently, Prof. Biswas emphasized on the importance of chemistry in the 3rd industrial revolution which demands a seam-less frontier of molecular and materials science by bringing together under a common umbrella chemists, physicists, biologists and mechanical engineers, dovetailing multi-pronged experimental and theoretical probes.

In his epitomizing lecture, Prof. Animesh Chakravarty, Chief Guest of the programme, illustrated the seminal chemist in Acharya Prafulla Chandra Ray negating the portrayal of Acharya as a philanthropist clad in run-of-the-mill attire. Tracing the evolution of science in India, Prof. Chakravarty observed that Chemistry was just not a subject, but a way of life to the Acharya. While commenting on the impact of the scientific contribution of Acharya Prafulla Chandra Ray on the society, Prof. Chakravarty added that chemistry was instrumental for many societal transformations.

Prof. Sourav Pal, Director, CSIR-NCL engrossed the whole audience by his enthralling talk on "Chemistry in Shaping Materials for the Future". While narrating the history of evolution of chemistry, he portrayed chemical science as a central science. He also highlighted the role of chemistry in materials like opto-electronic materials, hydrogen energy storage materials, fuel cell materials, catalytic materials and solar energy harvesting materials, smart and functional materials with different response characteristics, which will play a significant role in shaping our future. He reiterated that the design and evolution of future materials will be dictated by chemistry along with knowledge of other science disciplines.

Prof. Sabyasachi Sarkar, Indian Institute of Technology Kanpur delivered a stimulating presentation on the topic 'Learning Earth's Aptness in Harvesting Solar Energy'. In his thought provoking speech, Prof. Sarkar mentioned that nature started photochemical fixation of carbon dioxide to formate, which can be assimilated by acetogens to produce sugar. He also stressed on the necessity of modeling of bacteriochlorophyll and the reaction center of Photosystem-I for understanding their role in the search of a relatively simple cycle to harvest solar energy as chemical energy.

Prof. Chaitali Mukherjee, University of Calcutta, enumerated on the topic 'Simulation of the Dynamics of Biomolecules'. In her eloquent presentation, she emphasized that the need of awareness of Molecular Dynamics is to probe the relationship between molecular structure, movement and function by using numerical methods.

Professor Dipak Palit, Radiation & Photochemistry Division, Bhabha Atomic Research Centre, Mumbai, deliberated on the use of Ultrafast Dynamics of the Excited States using Time-Resolved Absorption Spectroscopy for investigating the fundamental processes in chemistry of breaking and forming chemical bonds, geometrical change or configurational relaxation and transfer of electrons and protons in ultrafast time scale by using visible pump - IR probe, IR pump – IR probe and electron pulse pump – optical probe transient absorption spectroscopic techniques.

Prof. Tarasankar Pal, Department of Chemistry, Indian Institute of Technlogy, Kharagpur, delivered the lecture on 'Coinage Metal Nanoparticles: Fabrication of Mono– and Bi–

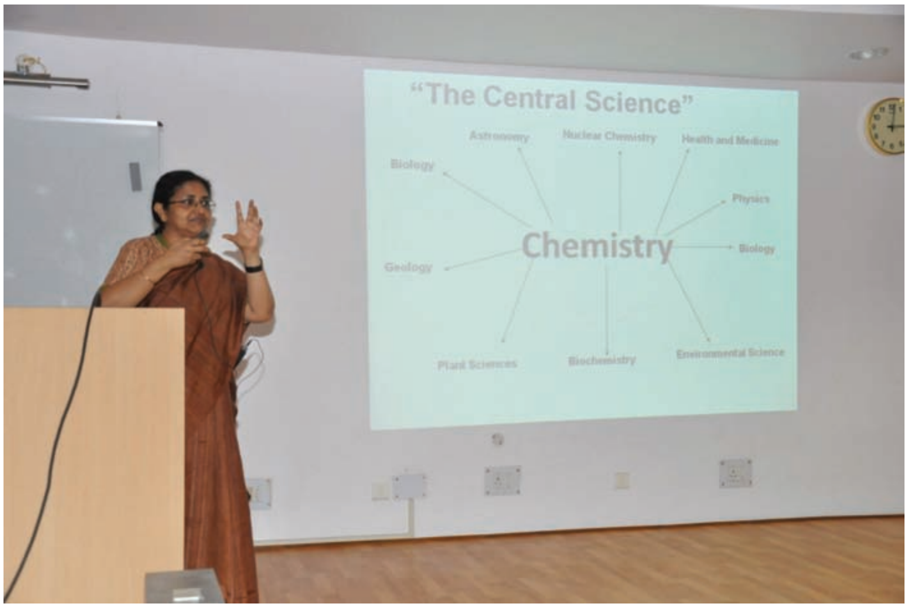
Professor Animesh Chakravorty, Indian Association for Cultivation of Science (IACS), Kolkata speaking on the theme "The Times, Life and Work of Acharya Prafulla Chandra"

Metallic Architecture for Enhanced Raman Signals'. While discussing the amazing chemistry of coinage metals at nano-domain, he remarked that gold, which have advantages over other coinage metals, is still best in nano-regime.

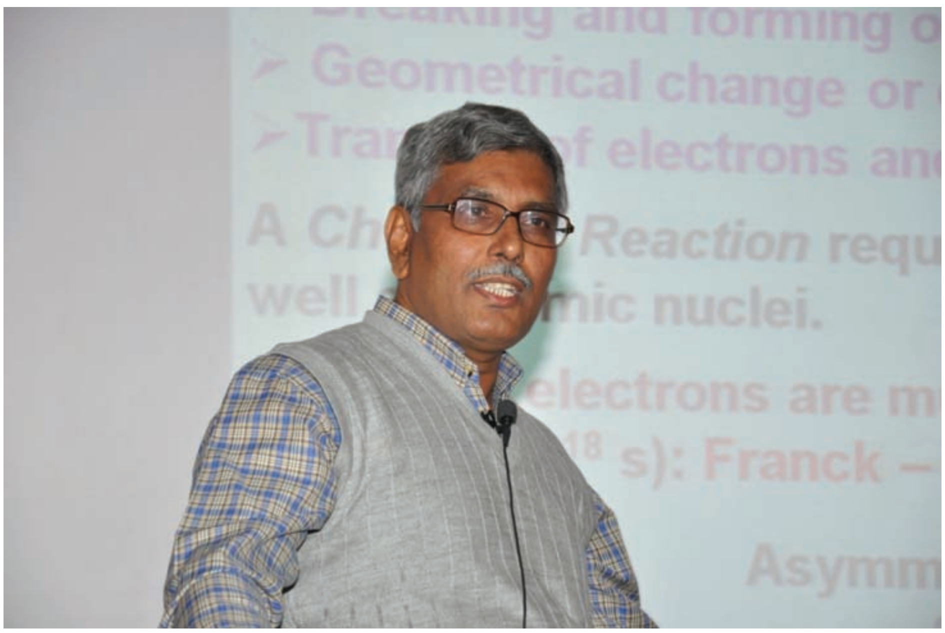
Dr. Debabrata Chatterjee, Head, Chemistry & Biomimetics group of CSIR-CMERI, finally proposed the vote of thanks concluding the programme.

Professor Sourav Pal, Director, CSIR-NCL delivering the lecture on "Chemistry in Shaping Materials for the Future"

Professor Sabyasachi Sarkar, Department of Chemistry, IIT, Kharagpur enumerating on "Learning Earth's Aptness in Harvesting Solar Energy"



Professor Chaitali Mukhopadhyay, Department of Chemistry, University of Calcutta, during the lecture on "Simulation of the Dynamics of Biomolecules"



Professor Dipak K. Palit, Radiation & Photochemistry Division, Bhabha Atomic Research Centre, Mumbai, speaking on the theme "Ultrafast Dynamics of the Excited States using Time-Resolved Absorption Spectroscopy"

Professor Tarasankar Pal, Department of Chemistry, IIT, Kharagpur, delivering the lecture on “Coinage Metal Nanoparticles: Fabrication of Mono- and Bi- Metallic Architecture for Enhanced Raman Signals”

Professor Gautam Biswas, Director, CSIR-CMERI delivering the Inaugural Speech

Professor Sourav Pal, Director, CSIR-NCL lighting the Inaugural Lamp during the Inaugural Programme of International Year of Chemistry and the 150th Anniversary of Acharya Prafulla Chandra Ray

Other Activity Facets

One day Workshop on Computational Transport Phenomena

The CSIR-Central Mechanical Engineering Research Institute, Durgapur organized a workshop on **Computational Transport Phenomena** on 3rd January 2012. The workshop focused on the recent developments on applications of principles of heat transfer and computational fluid dynamics (CFD) to solve different physical problems related to phenomena such as water droplet transport, frees surface flows, multiphase flow, flow analysis in aerospace valves, fluidized bed hydrodynamics and manufacturing processes like semisolid processing of alloys, etc. and was conceived to serve as a forum for exchange between the initiated Scientists.

The workshop was inaugurated by Prof. Gautam Biswas, Director CSIR-CMERI with a lecture on **Simulation of free surface flow: Special focus on falling drops**, which is an important phenomenon with wide engineering applications such as industrial cooling towers.

Subsequently, **Dr. Aniruddha Mukhopadhyay** who is currently heading the North American Technical Team of FLUENT-ANSYS, USA delivered the keynote lecture on **Application of transport phenomena** in various fields of engineering such as heat pipes, materials processing including casting-solidification, sensors & actuators, etc. and the availability of CFD software to solve various problems

related to the above fields. 35 delegates including researchers of CSIR-CMERI, CSIR-CGCRI and faculty members of Jadavpur University, Kolkata attended the workshop; some of them presented results of their current research on related topic. The workshop ended with a brainstorming session. The workshop also highlighted the recent developments on transport phenomena and their impacts in the related fields.

Other Activity Facets

International Conference on Microactuators and Micromechanisms

CSIR-CMERI organized an International Conference on Microactuators and Micromechanisms (MAMM-2012) at CSIR-Central Mechanical Engineering Research Institute, Durgapur during January 19-20, 2012 with joint patronage from the International Federation for the promotion of Mechanism and Machine Science (IFToMM), the Council of Scientific and Industrial Research (CSIR) and the Indian Association of Machines and Mechanisms (MAMM 2012)

The aim of this conference was to bring together scientists, experts from industry and students and to provide to them an opportunity for forging new connections and collaborations in various disciplines related to microacturators and micromechansims. This conference was attended by more than 80 delegates including leading experts from Germany, USA, Spain, Taiwan and India.

The conference was inaugurated by Prof. Burkhard Corves, Prof. Amitabha Ghosh, Prof. Gautam Biswas and Prof. Ananthasuresh. In his welcome address, Prof. Biswas, Director, CSIR-CMERI, Durgapur stressed on the importance of the conference in the context of the incipient third industrial revolution. Thereafter, Prof. Amitabha Ghosh presented a brief history of industrial revolution and predicted that micro-nano systems engineering will play a pivotal role in the future and will be accelerated further with mechanical engineering systems operating on the basis of biological principles. Prof. Corves dwelt on the history of MAMM conference and outlined its importance against the backdrop of a growing scope and space for micro systems engineering. Prof. Anathasuresh discussed in detail different microactuators and micromechanisms for different applications. Finally Dr. Nagahanumaiah, Convener of the conference, introduced the theme of the MAMM-2012 and welcomed the delegates for effective scientific deliberations.

The Conference, spanning two days saw the presentation of 25 research papers. The key speakers included Prof. Rudra Pratap and Prof. Ashitava Ghoshal from the IISc, Bangalore; Prof. Brian Jenson and Prof. Sunil Agrawal from USA; Prof. Suhas Joshi from IIT, Bomnbay; Prof. Victor Petuya from Spain and Dr. Pradeep Rebala from the Asian School of Medical Science, Hyderabad and many more. This event was special in the sense that more than 50% of the delegates were research students including 12 research scholars from the IISc, Bangalore alone. A wide gamut of topics and themes related to microactuators, micromechanisms, micro machines, and processing technologies were discussed during the course of the Conference. CSIR

Scientists presented their achievements made under NWP-30 network project on Modular and Reconfigurable Micro Manufacturing Systems during the poster presentations. The selected papers are scheduled to be published in a special issue of the International Journal of Mechanics Based Design of Structures and Machines published by Taylor & Francis.

The Technical Sessions were extremely lively where all the delegates participated with full fervor. In the evenings, special lectures and cultural programmes were organized for the edification and entertainment of the delegates. A general talk on MathemaGical Black Holes, Chaos and Fractals was delivered by Prof. Ashok Mallik on the first evening mesmerized the audience with the magic of numbers. Smt. Amraboti Biswas, and exponent of Indian classical music enthralled the delegates with the rendition of enriched Hindustani Music, while trainees and teachers of the Uday Shankar School of Dance presented the different Indian traditional dances during the second evening.

Other Activity Facets

Scientific Manpower Profile

Sl. No.	Name	Group Affiliation
Junior Scientists		
1.	Satanand Mishra	Information Technology
2.	Abhijit Das	Surface Robotics
3.	Srinivasan A	Cybernetics
4.	Priyabrata Chattopadhyay	Advanced Design & Optimisation
5.	Pradyumna Kr. Sahu	Electronics & Instrumentation
Scientists		
1.	Nilrudra Mondal	Centre for Advanced Materials Processing
2.	Dr. Ranajit Ghosh	Centre for Advanced Materials Processing
3.	Dr. Priyabrata Banerjee	Chemistry & Biomimetics
4.	Dr. Swarup Kr Laha	Condition Monitoring
5.	Amon Arora	Cybernetics
6.	Hanumath Prasad Ikkurti	Drives & Control Group
7.	Suman Saha	Drives & Control Group
8.	Sumit Kumar	Drives & Control Group
9.	Rudra Prasad Chatterjee	Electronics & Instrumentation
10.	Santu Kumar Giri	Electronics & Instrumentation
11.	Prosenjit Das	Foundry & Heat Treatment
12.	Rajesh Prasad Barnwal	Information Technology
13.	Dr. Debashis Das	Material & Structural Evaluation Group
14.	Dr. Pradipta Basu Mandal	Mechanics & Stress Analysis & Product Design; Simulation Division
15.	Samik Dutta	Metrology
16.	Abhiram Hens	Microsystem Technology Laboratory
17.	Henal Shah	Microsystem Technology Laboratory

Sl. No.	Name	Group Affiliation
18.	Dr. Himadri Roy	NDT & Metallurgy
19.	Dr. Lal Gopal Das	Process Plant Engineering
20.	Manoj Kumar Rawat	Process Plant Engineering
21.	Dr. Siva Prakash S	Process Plant Engineering
22.	Binod Kumar Saha	Product Design & Simulation Division
23.	Virendra Kumar	Robotics & Automation
24.	Dibyendu Pal	Robotics & Automation
25.	Subhra Kanti Das	Robotics & Automation
26.	Shikha	Robotics & Automation
27.	S. Reddy	Robotics & Automation
28.	Shikha Jain	Robotics & Automation
29.	Dr. Pabitra Halder	Simulation and Modelling Laboratory
30.	Dr. Bittagopal Mondal	Simulation and Modelling Laboratory
31.	Dr. Pranab Samanta	Surface Engineering and Tribology
32.	P.K. Mallisetty	Surface Engineering and Tribology
33.	Dip Narayan Ray	Surface Robotics
34.	N.S. Lakshmiprabha	Surface Robotics
35.	Rekha Jayprakash	Surface Robotics
36.	Man Singh Azad	Technology Innovation Centre
37.	Vineet Kumar Saini	Technology, Publication & Patent
38.	Dr. Malay Kumar Karmakar	Thermal Engineering
39.	Chanchal Loha	Thermal Engineering
40.	Dr. T. Murugan	Thermal Engineering
41.	Abhijit Mahapatra	Virtual Reality & Virtual Prototyping
42.	Amit Kumar	Virtual Reality & Virtual Prototyping
43.	Ajay Yadav	CMERI-COEFM, Ludhiana
44.	Ravi Kumar Arun	Microsystems Technology Laboratory
Senior Scientists		
1.	Dr. Arup Kr. Nandi	Advanced Design & Optimization; Cybernetics
2.	Subrata Kr Mondal	Advanced Design & Optimization
3.	Dr. Ujjwal Pal	Chemistry & Biomimetics
4.	Dr. Sarita Ghosh	Chemistry & Biomimetics
5.	Kamalkishor J Uke	Condition Monitoring
6.	US Patkar	Design of Mechanical Systems
7.	RK Bharilya	Design of Mechanical Systems

Sl. No.	Name	Group Affiliation
8.	Ravi Kant Jain	Design of Mechanical Systems
9.	Dr. Arpita Mukherjee	Electronics and Instrumentation
10.	Abhilasha Saksena	Embedded System Lab
11.	Dr. Aditya Kr. Lohar	Foundry & Heat Treatment
12.	Ashok Kr Prasad	Manufacturing Technology Group
13.	Palash Kumar Maji	Manufacturing Technology Group; Product Design & Simulation
14.	Rajpal Singh	Manufacturing Technology Group
15.	Swapan Barman	Metrology
16.	Atanu Saha	NDT & Metallurgy
17.	Anupam Sinha	Product Design & Simulation Division
18.	Bibhuti Bhusan Ghosh	Product Design & Simulation Division
19.	SR Debbarma	RPBDG
20.	Dr. Ranjit Ray	Robotics & Automation
21.	Siva Ram Krishna Vadali	Robotics & Automation
22.	Dr. Dipankar Chatterjee	Simulation and Modelling Laboratory
23.	Dr. Sudipta De	Simulation and Modelling Laboratory
24.	Dr. Satya Prakash Singh	Simulation and Modelling Laboratory
25.	Dr. Rashmi Ranjan Sahoo	Surface Engineering & Tribology
26.	Kalyan Kumar Mistry	Surface Robotics
27.	Dilip Kumar Biswas	Technology Innovation Centre
28.	Dr. Krishnendu Kundu	CMERI-COEFM, Ludhiana
29.	Dr. Pradeep Rajan	CMERI-COEFM, Ludhiana
Principal Scientists		
1.	Dr. Atanu Maity	Advanced Design and Optimization
2.	Dr. Mrinal Pal	Centre for Advanced Materials Processing
3.	Dr. Sudip Kr. Samanta	Foundry & Heat Treatment
4.	Anjali Chatterjee	Cybernetics
5.	Manju Singh	Foundry & Heat Treatment
6.	Uday Sankar Ghosh	HRD & Library
7.	Partha Sarathi Banerjee	HRD & Library; Product Design & Simulation
8.	Sankar Karmakar	Manufacturing Technology Group
9.	G.S. Reddy	Material & Structure Evaluation Group
10.	Dr. Surendra Kumar	Mechanics & Stress analysis
11.	B.N. Singh	NDT & Metallurgy

Sl. No.	Name	Group Affiliation
12.	Pankaj Kumar Roy	NDT & Metallurgy
13.	Dr. Debasish Ghosh	NDT & Metallurgy
14.	Mow Nandi Sarkar	Process Plant Engineering
15.	Tapas Gangopadhyay	Product Design & Simulation Division
16.	Dr. Asit Kr Batabyal	ISO
17.	Dr. Arup Kumar Mitter	RPBDG
18.	Sambhunath Nandi	Robotics & Automation
19.	Dr. Soumen Sen	Robotics & Automation
20.	Dr. Naresh Chandra Murmu	Surface engineering & Tribology
21.	Sarbari Datta	Surface Robotics
22.	Dr. Biswajit Ruj	Thermal Engineering
23.	Dr. Reeta Das	Thermal Engineering
24.	Aswani Kumar Kushwaha	CMERI-COEFM, Ludhiana
25.	B. D. Bansal	CMERI-COEFM, Ludhiana
26.	Rajesh Kumar Chak	CMERI-COEFM, Ludhiana
Senior Principal Scientists		
1.	Dr. Biswanath Mondal	Centre for Advanced Materials Processing; PPD
2.	Dr. Debabrata Chatterjee	Chemistry & Biomimetics
3.	Dr. Partha Bhattacharjee	Cybernetics
4.	Soumya Sen Sharma	Technology, Patent & Publication; Drives & Control
5.	Uma Datta	Electronics & Instrumentation
6.	Joydeb Ray Chaudhury	Embedded System Lab
7.	Ashish Kr. Chowdhury	Foundry & Heat Treatment
8.	Amit Jyoti Banerjee	Manufacturing Technology Group
9.	Abhijit Chatterjee	Material & Structural Evaluation Group
10.	Dr. Somnath Mukherjee	Mechanics & Stress Analysis
11.	Dr. Nagahanumaiah	Microsystems Technology Laboratory
12.	Awadhesh Kr. Shukla	NDT & Metallurgy; RPBDG
13.	Prasanta Kumar Sen	Process Plant Engineering
14.	Tapas Sarkar	ISO; Product Design & Simulation Division
15.	Avik Chatterjee	Virtual Reality & Virtual Prototyping
16.	Rabin Kr. Biswas	Condition Monitoring
17.	Tapan Kr. Paul	Condition Monitoring
18.	Debojyoti Banerji	Robotics & Automation
19.	Syd. Salman Mojiz	CMERI-COEFM, Ludhiana

Sl. No.	Name	Group Affiliation
Chief Scientists		
1.	Dr. Somjyoti Majumder	Surface Robotics, Design of Mechanical Systems; Information Technology
2.	Sankar Nath Shome	Robotics and Automation
3.	Dr. Pradip Kumar Chatterjee	Thermal Engineering
4.	Dr. Sibnath Maity	Technology Innovation Centre
5.	Dr. Ranjan Sen	Metrology
6.	Cdr. V.R. Dahake	CMERI-COEFM, Ludhiana
Quick Hire Scientists		
1.	Praveen Kumar Singh	CMERI-COEFM, Ludhiana
2.	Mrs. Sarika Bharilya	Advanced Design and Optimisation

Other Activity Facets

Showcase

Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur delivering the Welcome Address on the occasion of the CSIR Foundation Day Celebration on September 26, 2011

Prof. Rudra Prathap of Indian Institute of Science, Bangalore delivering the Eminent Lecture on **Understanding the Dance of Micro & Nano Scale Mechanical Structures** on the occasion of the CSIR Foundation Day Celebration on September 26, 2011

Prof. J. N. Moorthy, IIT, Kanpur delivering the Eminent Lecture on **Rational Molecular Design for Amorphous Organic Light Emitting Diodes (OLEDs) and Ordered Functional Mimics of Inorganic Zeolites** on the occasion of the CSIR Foundation Day Celebration on September 26, 2011

Dr. R. K. Bhandari, Director, Variable Energy Cyclotron Centre, Kolkata delivering the **CSIR Foundation Day Lecture on Charged Particle Accelerators: Wonderful Machine for Research and Applications;** September 26, 2011

Prof. S.K. Brahmachari, Director General, CSIR inaugurating the CSIR-CMERI Foundation Day Celebration by lighting the inaugural lamp; February 26, 2012

Prof. Kalyanmoy Deb speaking on **Evolution's Niche in Practical Problem Solving** on the Occasion of the CSIR-CMERI Foundation Day; February 26, 2012

Prof. S.K. Brahmachari, Director General, CSIR delivering the Foundation Day Lecture on the occasion of the CSIR-CMERI Foundation Day Celebration; February 26, 2012

Prof. S.K. Brahmachari, Director General, CSIR during his visit to the School of Mechatronics; February 26, 2012

Prof. S.K. Brahmachari, Secretary, DSIR, Government of India during the TUC Review Meet & 110th Meeting of the TSC; February 26, 2012

Prof. S.K. Brahmachari, Director General, CSIR interacting with young scientists during his visit to Cybernetics Group; February 26, 2012

Prof. S.K. Brahmachari, Director General, CSIR being demonstrated the working prototype of the Voice Controlled Wheel Chair during his visit to the Surface Robotics Group; February 26, 2012

Prof. S.K. Brahmachari, Director General, CSIR during his visit to the Foundry Group; February 26, 2012

Prof. S.K. Brahmachari, Director General, CSIR immediately before the inauguration of the Aerosystems Laboratory; February 26, 2012

Prof. Vani Brahmachari during her visit to Microsystems Laboratory; March 09, 2012

Prof. Vani Brahmachari during her visit to the Surface Robotics ; March 09, 2012

Prof. Vani Brahmachari addressing the Women Scientists of CSIR-CMERI, Durgapur; March 09, 2012

Prof. Vani Brahmachari during her visit to the Robotics & Automation Group; March 09, 2012

Prof. B. Corves inaugurating the **International Conference on Microactuators and Micromechanisms (MAMM-2012)**; January 19 –20, 2012

Prof. Amitabha Ghosh, Prof. B. Corves and Prof. G.K. Ananthasuresh during the inaugural programme of the **International Conference on Microactuators and Micromechanisms (MAMM-2012)**; January 19 –20, 2012

Smt. Amarabati Biswas, and exponent of Indian classical music enthralling the delegates with the rendition of enriched Hindustani Music on the occasion of the **International Conference on Microactuators and Micromechanisms (MAMM-2012)**

सी. एस. आई. आर – केन्द्रीय यान्त्रिक अभियान्त्रिकी अनुसंधान संस्थान, दुर्गापुर

CSIR - CENTRAL MECHANICAL ENGINEERING RESEARCH INSTITUTE, DURGAPUR