ROBERT BOSCH CENTRE for CYBER-PHYSICAL SYSTEMS
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EDITORIAL

In his recent speech at the Indian Science Congress, Prime Minister Modi called out the importance of Cyber Physical Systems as "huge opportunity by research, training and skilling in robotics, artificial intelligence, digital manufacturing, big data analysis, deep learning, quantum communication and Internet of Things". In hindsight, the setting up of the Robert Bosch Centre to focus on Cyber Physical Systems at IISc about five years back, now looks visionary. With the launch of a slew of new research and academic activities for this year, it promises to be very exciting times ahead! Read about these and more in this issue.

Best regards,

Prof Bharadwaj Amrutur

Chairman, Robert Bosch Centre for Cyber-Physical Systems

IN THIS ISSUE

News @ RBCCPS

New research projects started

The Centre has launched new research projects in the areas of **Smart Cities, Health Systems, Smart Manufacturing, Smart Grids and Autonomous Systems.** These projects offer enormous opportunities for developing and applying Cyber-Physical Systems concepts to solve problems of great societal and industrial impact.

Autonomous systems and robotics

Prof Chiranjib Bhattacharyya of CSA dept. is leading this effort to develop technologies for autonomous drone navigation in urban environments. They are looking at a specific use case of delivering small packages within the campus autonomously. These environments are challenging in terms of obstacles like trees, overhanging cables, pedestrian and vehicular traffic etc. They aim to address these by developing new algorithms for navigation by fusing information from a diversity of sensors including on-board cameras. With expertise in drone construction, the team is also looking to create custom drones that are robust to collision and can carry significant payloads efficiently.

Prof Manoj Varma of CeNSe is leading a multi-disciplinary team to equip robots with the sense of smell. They are inspired by the acute sensitivity of olfaction in the animal kingdom and would like to study its mechanisms and incorporate it in robots. They envision these

robots to be of great use in search and rescue missions, sniffing out landmines or chemical weapons etc.

Smart Grids

Dr Ashish Joglekar of RBCCPS is leading an effort to develop technologies for remote monitoring of solar photovoltaic panels. Large Solar PV plants can have lakhs of panels and it becomes essential to be able to monitor each of these and more critically, undertake preventive maintenance. He is also working with a team from EE department, led by Prof Gurunath, to develop a new IED (Intelligent Electronics Device), which is a critical component of Smart grid systems.

Prof Shalabh Bhatnagar of CSA dept., who is an expert in distributed reinforcement learning, is a possible user of this new IED as these devices will run his distributed algorithms to better integrate local microgrids with the main grid.

Smart Cities

With the Indian government announcing an investment of about 80,000 Crores in Smart Cities, this is an area great interest in the country. Prof Bharadwaj Amrutur of RBCCPS is leading an effort set up a test bed in Electronics City – a large township in South Bangalore, to experiment with various technologies that will allow efficient, low cost solutions to many of the cities requirements. Distributed video analytics and semantic internetworking are two of the many research questions which are being pursued through this test bed.

Smart manufacturing systems

With Industry 4.0 gaining in momentum, its application to improve manufacturing, especially in Indian context is of tremendous relevance. Prof Amaresh Chakraborthy of CPDM is leading an effort to look at how to use Industrial IoT technologies to improve manufacturing lines – especially for biomedical devices.

Prof Rajesh Sundaresan of ECE dept. has recently secured funding under the central government's UAY scheme to study how to improve energy costs in manufacturing lines, in collaboration with India's leading software services company, TCS.

Health systems

Prof G K Ananthasuresh of Mechanical Engineering dept. is leading a multidisciplinary team of biologists and engineers to gather fundamental understanding of the human digestive system, especially with a view to address the many diseases of the system which is commonly prevalent in India. Both bio-chemical and mechanical properties play a significant role in the operation of the system. The team is attacking the problem across different scales from the genetic to the organ level via extensive data analysis, modeling and experimental techniques.

In related work, Dr. Venkatesh Sheshadri of RBCCPS is leading an effort to develop a low-cost sensor for detecting E.Coli and other fecal coliform contamination in water. The emphasis is to develop a real-time and low cost sensor to rapidly detect contamination so that quick action can be taken to prevent spread of Gastro-intestinal diseases.

For more detailed information on all projects, please visit the "Project" section of our website.

New team members

We have four new team members who have recently joined the Robert Bosch Centre:

Dr Ashish Vasant Joglekar, an alumnus of College of Engineering, Pune, finished his PhD thesis from IISc on "Design and practical implementation of novel, low cost, commercially viable Active EMI filters for mitigation of conducted EMI in switched mode power converters" and has joined as a Member of Technical Staff in October 2016. His interests are broadly in Electronics Systems Engineering with a special interest in topics like high voltage, power electronics and design aspects for EMI and EMC.

Dr Abhay Sharma, who joined the Centre in November 2016 as a Member of Technical Staff, comes from the Systems team at Qualcomm India. Abhay is an alumnus of BITS Pilani and did his PhD at IISc. Abhay's expertise is in embedded signal processing with special interests in sparse signal processing, wireless communications and video analytics.

Stefan Ipach joined the Centre in November 2016 as Manager of Research and Academic Programs after working for seven years as Senior Research Advisor at the Friedrich-Schiller-University of Jena.

Dr Atreyee Kundu started as a Member of Technical Staff at the Centre in January 2017. She graduated with a PhD degree from IIT Bombay and spent a year at University of Lorraine, France as a post-doc researcher. Her specialization is in networked control systems.

New PhD research program

The Centre has been granted permission to start a new research training program for doctoral students for PhD degrees in Cyber-Physical Systems, starting August 2017. The admissions website will open in February and we encourage students from around the world to apply for a position. Interviews for selection will held in the first week of June. Please visit the IISc and Centre websites to keep updated about this program.

Key highlights from past project

During the first phase of the RBCCPS, 28 research projects have been completed and we would like to highlight some of RBCCP's success stories. In this issue we will have a closer look at two projects that resulted not only in scientific publications, patent applications and posters at prestigious national and international conferences, but in start-up companies that are bringing the cutting-edge research results to market.

Decentralized low power filtration via field effect – A water bottle for desalination

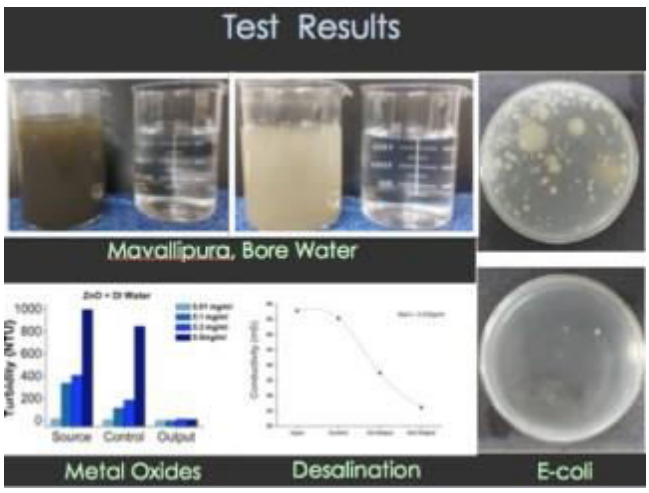
Dr Sanjiv Sambandan, faculty in the Department of Instrumentation and Applied Physics of IISc, undertook a research project in 2012 to study the possibility of using oscillating electric fields to help in water filtration, with funding support from the Centre. Such fields, if carefully tuned, lead to aggregation of fine particles into larger clusters, which can then be filtered out using very low cost filters. His proof of concept worked exceedingly well and since then he and his team have been working on developing and refining it further to improve the throughput for various practical applications.

From an initial throughput of one microliter per minute, to a prototype that filters one milliliter per minute and then achieve six liters of water per hour – with an energy consumption of 100 Milliwatts, they have come a long way. With an additional grant from the Department of Biotechnology, extensive field trials could be initiated and the current system is now able to filter 1,000 liters of water per day!

Dr Sanjiv's idea has the potential to revolutionize Indian water treatment: "Bangalore city, for example, consumes 1.35 BLD (billion liters per day) of water and puts out 1.2 BLD of waste water. All the centrally installed sewage treatment plants total a capacity of 0.7 BLD. Despite the large number of apartment complexes, decentralized, i.e. apartment level, recycling and reuse of water is poor and contributes only about 10 to 15% of the recycling effort. With our system, we provide a zero waste solution, and it is affordable for every apartment.", states Dr Sanjiv.

This is exactly the problem in the Indian context: The regulations that require apartments to treat their waste water are not enforced, resulting in the low compliance. Furthermore, traditional water treatment requires either membranes or chemicals to clean the water. Both are not produced in India and are therefore expensive, hard to maintain and also hard to store. Sanjiv's method of using electrical fields to clean the water, on the other hand, is able to reliably filter out fluoride, arsenic, reduce around 70% of the hardness, remove e.Coli bacteria and other floating particles and is now certified by independent NABL accredited labs. There are no maintenance requirements and only the filters have to be scrubbed every few months. In addition to that, the waste can be used a biofuel, essentially making contaminated water a source of fresh water and energy.

Dr Sanjiv was so convinced of his idea that he started his own company – Openwater.in – to further develop his system. Initially alone, he was joined in 2013 by one of his students, Karthik, and in 2016 by two engineers for designing a marketable version of his water treatment system. The Centre has provided additional funding support towards his R&D efforts in 2016. "Without the support of IISc and its many entities – the Chairman of the Department of Instrumentation and Applied Physics, the Chair of the Division of Physical and Mathematical Sciences, the Robert Bosch Centre for Cyber-Physical System, the Society for Innovation and Devel



Test results of the filtration effect and prototype of the portable water bottle as presented for Google Zurich

opment (SID) and the Centre for Infrastructure, Transportation and Urban Planning, none of this would have been possible.", opines Dr Sanjiv.

Openwater.in is currently focusing on the water treatment of apartment complexes and hopes to considerably lower the burden of wasted water. It has already won several awards, the Google Zurich Award in 2015, and it was listed amongst the top 10 of start-ups of F6s and the top 10 out of 1,000 world-wide start-ups at GEN in 2016.

The most challenging task so far, however, has been the search for investors: "People think longer to fund hardware start-ups as compared to software start-ups", Dr Sanjiv states. "But we're optimistic to use our momentum to overcome this barrier. And already, two major apartment builders are interested in our treatment system."

The next steps are to use the incubator space at IISc to further refine the business model and develop a marketable version of the treatment system within the next twelve months. In addition to that, a hand-held version – a water treatment bottle – will also be developed. It uses the same principles, but the necessary power will be provided by a crank, making it ideal for rural areas.

For more information, please visit the Openwater.in website or write to Dr Sanjiv directly at sanjiv@iap.iisc.ernet.in.

Endoscopic simulator

The sub-project of Prof G.K. Ananthasuresh, Department of Mechanical Engineering of IISc was part of the larger project "Cyber surgery and remote patient care", led by Prof. Ashitava Ghosal, Department of Mechanical Engineering. It had been funded by the Robert Bosch Centre and ran for three years until August 2015. Prof. Ananthasuresh's work focused on the development of a model of the gastrointestinal tract that can be used in endoscopy and minimally invasive surgery training and resulted in several scientific publications and two patent applications.

Dr Shanthanu Chakravarthy, a member of the project team, just finished his PhD in Mechanical Engineering in August 2016 and wants to take the project even further: He started his own company, MIMYK and is currently developing the endoscopic simulator prototype, that had been built at the end of the project, towards a market-ready version by the end of 2017. Shanthanu has a true engineering and entrepreneurial spirit: "I became an engineer to develop new solutions and products and I love working in a team setting to do that, so for me it has been an easy step to bring the endoscopic simulator to the next level."

While there are already two companies, one in the US and one based in Israel, who are currently building endoscopic simulators, his device will have two distinctive advantages: Its haptic interface provides realistic feedback for the training doctor on the use of the endoscope and furthermore, he can provide it at only one-fifth of the cost.

This is an especially important point for teaching hospitals in emerging countries, where most of the training is still done with either animal or plastic models. Those suffer severe drawbacks, however: The animal models are not very durable and both lack any variety, resulting in a training experience that basically only teaches on how to put the endoscope into the esophagus. Shanthanu's simulator, on the other hand, can be programmed for any kind of disease or imaginable situation, offering a wide, realistic variety in training young doctors.

Several hospitals already expressed their interest in the development and Shanthanu is working closely with the Asian Institute of Gastroenterology, Hyderabad. In close collaboration with the medical experts there, the simulator is getting refined from an end user's perspective. His target market is India and Asia/Pacific but he plans to sell his product eventually on a global scale.

Shanthanu is currently raising funds for MIMYK and already has successes: He was awarded a grant under the Biotechnology Ignition Grant Scheme (BIG) with a seed funding of 50,00,000 Rs., additionally the Society for Innovation and

Shanthanu Chakravarthy in front of the prototype of the Endoscopic simulator

Development (SID) of IISc is supporting MIMYK by providing office space in the Entrepreneurship Building and mentoring Shanthanu. The MIMYK team also put around 70 lakh rupees of their own money into the endeavor. They estimated that around three crore rupees will be needed in total. MIMYK is also looking for engineers and designers to complement the team, so if you are interested in joining or in supporting the team, please visit their sway-sheet for more information or write to Shanthanu directly at sc@mecheng.iisc.ernet.in.

Research focus: Smart Cities

Smart cities have been identified as a high priority, national mission by the Government of India. India is undergoing rapid urbanization and the only way city infrastructures can keep up is to rethink and apply technological advances to enable rich and satisfying environments for the city denizens. Cities are perfect examples of complex interacting systems, with multiple subsystems working in semi-independant yet collaborative manner.

Our current approach to cities is largely reactive and we are unable to keep pace with their staggering growth. This can only be mitigated via application of Information and Communication Technologies (ICT) for not only data driven management of these systems but also do new science to develop deep understanding of these systems. The scale of Indian cities, with many having 10-20 million citizens, and the need for being extremely cost-effective, offers exciting opportunities for both fundamental research as well as technology innovation. With data being the key raw material for smartness, we need to develop technologies and policies to harvest, manage and mine this data for public good, while maintaining data integrity, privacy yet enable openness. Since this is an emerging area, there is not enough experience, especially in the Indian context, to decide on choices of various technologies, approaches and policies.

We are specifically looking at energy, water and mobility systems and their interplays along with research on systems engineering issues in IoT communications, security and distributed analytics.

To this end, the Robert Bosch Centre is funding two projects, heads the IoT for Smart Cities Task force and co-organizes a workshop on Smart Cities in March.

Smart Campus IISc

The interdisciplinary project is headed by Yogesh Simmhan, Assistant Professor at the Department of Computational and Data Sciences of IISc and also involves faculty, staff and students from the Department of Electrical Communication Engineering and the Department of Civil Engineering. It started in June 2015 for a two year period and is funded by the Robert Bosch Centre and the Ministry of Information and Communication Technologies (MeitY).

The project aims to develop an open, integrated and extensible Internet of Things (IoT) technology stack for Smart Management of campus utilities. The IoT stack brings together hybrid sensing, diverse networking, Big Data analytics and science-driven utility management, and will be validated through affordable and intelligent water resource management for a sustainable campus environment.

The project researches, reuses, develops and integrates the four critical layers essential to an IoT technology stack: (1) **hybrid physical and crowd-sourced sensing**; (2) **reliable and adaptive networking**; (3) **Big Data management and analytics in realtime on clouds**; and (4) **online science-driven decision making for optimal resource usage**.

About 30 buildings on campus are expected to be instrumented with IoT networking and water sensors. The initial target domain is intelligent water management for a sustainable campus environment, and can be extended to other domains like energy and environment monitoring. The outcome will lead to lower energy use through optimal pump operations, improve water quality through online prediction and detection, and reduce the water usage through knowledge sharing and citizen-science within a campus eco-system. The project will also bring visibility to campus members of their water usage and the quality.

To this end, the team investigates innovative techniques on combining affordable physical sensors with crowd-sourced open data gathering; data collection over diverse networking technologies to respond to ongoing sensing needs; stream and event processing engines to enable Big Data analytics over distributed data on clouds for forecasting and visualization; and (in the context of water management) hydrological modelling for active decision making on pumping/ storage, and leakage/ contamination detection/ correction.

For more information, please visit the project website.

Smart City test bed

The project started on 1 November 2016 and is headed by Prof Bharadwaj Amru-

tur, Chairman of the Robert Bosch Centre and Professor at the Department of Electrical Communication Engineering.

The Indian Government has identified Smart Cities as a priority area for development in the coming years. Information and communication technologies will play a key role in supporting smart city solutions and more specifically, IoT technologies will be a key enabler for providing the "smarts". The requirements from citizens in cities is diverse and cuts across many different verticals like transportation, water management, solid waste management, smart parking etc. Typically, each vertical will be addressed by a different vendor, who will provide an end-to-end solution. However it has been recognized of late, that a better approach might be to have a horizontal approach where in sensors, and other data are made available across different silos – in order to foster new, cost effective solutions to various city related problems and citizen needs. A simple example is that of a camera sensor which can aid in not only in surveillance but also in crowd management, smart parking, transit operations management etc. applications. Hence there is a need to develop smart city ICT/IoT framework as a generic platform that will support a diverse set of applications.

The main thrust of this work will be to develop an instrumented test bed in Electronic City, which will consist of a collection of sensors, gateways, middleware and server side software, supporting a few candidate applications of energy monitoring, water monitoring and solid waste management. The testbed will be a hybrid of real and virtual components. Being able to support such a hybrid system will enable us to test concepts at scales of real cities with thousands of gateways and tens of thousands of sensors, while the real world portion of the testbed will still be small and low cost. The scaling limits will be determined via analysis of current and future requirements for Indian Smart Cities in terms of:

- Data base size, query latency, IO/second, availability
- Communication throughput, latency, loss tolerance
- Gateway performance (throughput), memory, storage
- Sensor density per square kilometer and its data bandwidth

Finally the test bed will be validated via the physical portions instantiated in Electronic City as well as the virtual portions instantiated to mimic a city of the scale of Bangalore. The concept of using light poles as smart city infrastructures will also be incorporated in the test bed via instrumenting several light poles with the gateways and sensors.

IoT for Smart Cities Task Force

The Robert Bosch Centre is managing the "IoT for Smart Cities Task Force", which is funded by the Ministry of Information and Communication Technologies (MeitY). The task force is organized in three working groups – (1) Usage Scenarios, (2) Architecture, and (3) RFP Framework – and serves as an open forum of experts across academia, government, industry, start-ups and professional bodies collaborating to help efficient and effective IoT technology enablement of Indian Smart Cities.

The Indian Government has launched the Smart Cities Mission that aims to convert 100 Indian cities into modern, hyper-connected entities with a coherent plan of infrastructure development, service delivery and information transparency. IoT technology can provide a seamless inter-connect between the physical entities with the cyber world and will be the key to success for the deployment of smart city solutions. Some early examples of using IoT based smart solutions are in the areas of smart parking, intelligent transportation system, smart grids, smart urban lighting, smart waste management, and smart water management.

IoT deployments are still at a nascent stage across the world, and for it to be adopted at a large scale by Indian cities there is a need for an ecosystem to develop that can enable government agencies to mobilise rapid scalability of deployment of embrace agile innovation that can translate to sustainable technology solutions appropriate for India.

The task force aims at building multi-disciplinary and multi-organisational technical capabilities, and a culture for partnerships and collaboration – which is going to be the key to the success of India's Smart City initiative.

Over 120 members from industry, academia, startups, professional institutions, and consulting bodies have come together and meet every week to discuss the various technological aspects of smart city development.

The aim of this project is to enabling the Indian Smart Cities Challenge by providing:

1. Recommendation and guidelines for Smart City RFPs related to IoT specific technologies: (1) driven by an "India specific" use case analysis (2) emerging technology adaptation methodology
2. India appropriate reference architecture for IoT enabled Smart Cities through a collaborative platform of domain experts from industry, academia, government, start-ups, professional bodies and user-agencies.

For more information please visit the website of IoT for Smart Cities Task Force.

Workshop on Smart Cities

The Symposium on Smarter Cities is being organized jointly by Ramaiah Institute of Technology, Bangalore and the Robert Bosch Centre under TEQIP-II (Technical Education Quality Improvement Programme). The symposium will be held at Ramaiah Institute of Technology on 10-11 March 2017.

Smarter Cities act as a catalyst for economic growth and improve the quality of life of their citizens by developing and implementing area-based technologies and solutions to today's challenges. The goal of the symposium is to provide a platform for domain experts, researchers, practitioners, and students to exchange ideas on technologies and practical experiences related to Smarter Cities. It will cover various aspects of Smarter Cities such as energy, transportation, water, healthcare, education, pollution, tourism and governance with a focus on state-of-the art technologies, methodologies, and best practices.

The Symposium will be accompanied by an "Ideathon", open to students of engineering colleges all over India. All ideas are welcome that are **novel, practical and of an interdisciplinary nature for solutions to problems related to Smarter Cities**. The Ideathon will provide an opportunity to students to interact with experts and present their ideas for solving real-world problems. The top three ideas will win cash awards worth a total of Rs. 1,50,000 (First prize – Rs. 75,000, second prize – Rs. 50,000, third prize – Rs. 25,000).

Relevant topics include but are not limited to:

1. Mobile apps for citizen participation in sensing, reporting, crowd management, e-governance, e-commerce, e-help, mobility & traffic management etc.
2. Novel sensors and actuators for smarter management of water, energy, waste, roads, parks, public spaces and public utilities
3. Big data analytics for e-governance and smarter management of city
4. Novel video and image analytics of data from security cameras for enabling a host of smart city applications
5. Novel applications of autonomous systems technologies like drones and robots for effective surveillance and delivery of other city services like waste pickup, drain cleaning, road maintenance, tourist guides etc.
6. Novel uses of ICT for solving the traffic and mobility problem of Indian cities
7. Novel mobile apps and IT solutions to foster community spirit and enrich cultural life through enablement of people interactions via sports, arts and entertainment

Registration for the Symposium is open, the **last day of registering is 28 February**. As the number of participants is limited to 150, an **earlier registration is advised.** Please visit the Symposium website for more details.

Publications

In the last year, 34 publications resulting from projects executed through the Centre or from the Centre's Faculty Steering Group have been published. The total number of publications reached 149. You can find the complete list here: https://www.rbccps.org/publications/.

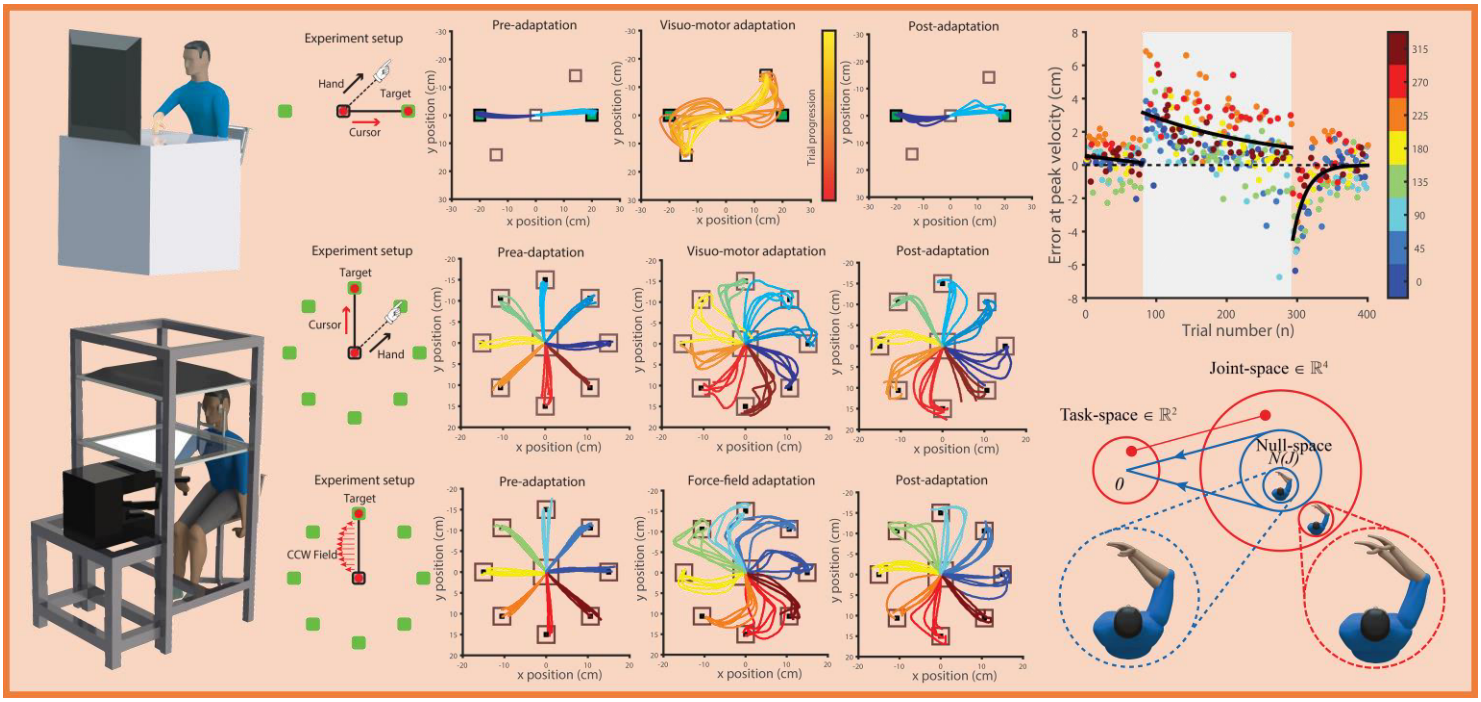
One of the publications, "**Exploration of joint redundancy but not task space variability facilitates supervised motor learning**" by Puneet Singh (Phd student at the Centre for Biosystems Science and Engineering), Sumitash Jana (PhD student at the Centre for Neuroscience), Ashitava Ghosal (Professor at the Department of Mechanical Engineering) and Aditya Murthy (Professor and Chairman at the Centre for Neuroscience) we want to present in more detail.

The article was published in PNAS, resulting from the RBCCPS project "Cyber surgery and remote patient care" and focuses on the role of variablity in motor learning:

The number of joints in a human arm is more than what is required for reaching the desired point in three-dimensional space. How the nervous system control and utilizes this redundancy and how the reaching task is achieved reliably and repeatedly in the presence of motor variability are unsolved problems in motor control. In this work, we explore redundancy and investigate its significance and effect on motor learning. We propose that some part of motor variability arises out of the redundancy. We show that greater uses of redundancy lead to faster learning across subjects. We observed this when a force was applied perpendicular to the hand trajectory or when the cursor motion on a screen, representing the hand trajectory, was rotated by 45 degrees. Interestingly, we also found differences in the use of redundancy between the dominant hand and non-dominant hand, suggesting that the nervous system actively controls the redundancy. The results provide experimental support for the hypothesis that the exploration of redundancy aids in learning and that the redundancy component of the motor variability is not noise. In the future, we plan to use these results for enhancing motor skills

and motor skill rehabilitation from injury.

The following figure shows the experimental setup (left panel), the trajectory of the hand when there is no perturbation, with perturbation and when the perturbation is removed for different reaching tasks (middle panel), and motor learning (right panel). The right most bottom figure shows graphically the concept of redundancy. More details of the experiments and results are available in the published paper at PNAS (DOI 10.1073/pnas.1613383113).



Figures above shows the experimental setup (left panel), trajectory of the hand when there is no perturbation, with perturbation and when the perturbation is removed for different reaching tasks (middle panel), and motor learning (right panel). The right most bottom figure shows graphically the concept of redundancy.

Upcoming events

10 - 11 March 2017: Symposium on Smarter Cities

19 - 21 July 2017: International Symposium on Cyber-Physical Systems

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