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KERNEL

Editorial

The Indian Institute of Science (IISc) has a rich history of contributing to nation-building. Apart from fundamental research, its faculty members have also led large-scale programmes with the goal of transforming industries and leaving a lasting impact on society. One such programme, featured in this second issue of *Kernel*, is the country's first indigenous Smart Factory initiative. This issue also spotlights interdisciplinary research on micro and nano robotics with wide-ranging biomedical and sensing applications.

THE FUTURE OF MANUFACTURING

Photo: Ayush Ranka

A SMART FACTORY PLATFORM ESTABLISHED AT THE INSTITUTE SEEKS TO SHOWCASE HOW DATA-DRIVEN AUTONOMOUS SYSTEMS CAN TRANSFORM TRADITIONAL MANUFACTURING TO IMPROVE SAFETY, QUALITY AND PRODUCTIVITY

Advances in data analytics, machine learning and robotics are changing the way manufacturing works, leading many to believe that the world is on the brink of the fourth industrial revolution. Factories of the future will see a marked shift from automated machines that carry out programmed tasks to autonomous systems that can make intelligent decisions, according to Amaresh Chakrabarti, Chair of the Centre for Product Design and Manufacturing (CPDM).

A few years ago, Chakrabarti, along with colleagues Dibakar Sen and B Gurumoorthy, led the establishment of IISc's – and India's – first indigenous Smart Factory platform, a model factory

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An international conference on Industry 4.0 held in IISc in June 2019 (Photo courtesy: Amaresh Chakrabarti)

that would incorporate sensing and data analytics, and provide a springboard for testing new ways to improve productivity, safety and sustainability, before they are adopted by industries. It was born out of a strategic partnership with The Boeing Company, which provided seed funding. “They wanted us to create what used to be called a network-enabled manufacturing facility, which is essentially a smart factory, but a very scaled-down version,” says Chakrabarti.

In a smart factory, data is collected at every level – from temperature sensors that track machine wear and tear to air quality sensors for noxious gases, and gesture sensors that evaluate workers’ postures. This data is then consolidated and analysed in near real-time using cutting-edge software and algorithms for faster decision-making. “The people, the products, the tools, the environment and the processes that are happening – all of them are connected,” says Chakrabarti.

In 2017, additional funding was committed by the Department of Heavy Industries (DHI), Government of India, to expand this project into a Common Engineering Facility Centre (CEFC) under the government’s Samarth Udyog Bharat 4.0 programme. Out of the Rs 25 crore funding sanctioned, Rs 20 crore comes from the government, while the remaining Rs 5 crore is raised from industry partnerships.

The CEFC’s mandate is multifold. The first is to operate as a demonstration centre to showcase what a smart factory would look like. Two types of platforms are being tested. One replicates an entirely automation-driven factory, with sensors, robots, and data analytics. Another focuses on incorporating some smart elements and technologies into a completely manual set-up, typical of Micro, Small and Medium Enterprises (MSMEs). For example, a sensor system using cameras and algorithms has been deployed in a small shoe manufacturing company to check materials for defects before they are manually assembled. This can substantially reduce material wastage and cost. “We are testing about 20 such platform technologies that can change the way individual companies work,” says Chakrabarti.

The second goal is research on new manufacturing technologies. In 2019, with support from Wipro 3D and DHI, IISc researchers from various departments came together to develop the first prototype of an indigenous metal additive manufacturing machine, touted as a metal 3D printer. This machine uses a high power electron beam to melt metallic powders in a vacuum and build complex objects such as biomedical implants and aircraft components faster and more efficiently. New types of robots and cobots – machines that work alongside humans – are also being developed and tested. “The aim is to go beyond buying stuff and showing it off. We want to create our own capability in the country for all these technologies,” says Chakrabarti.

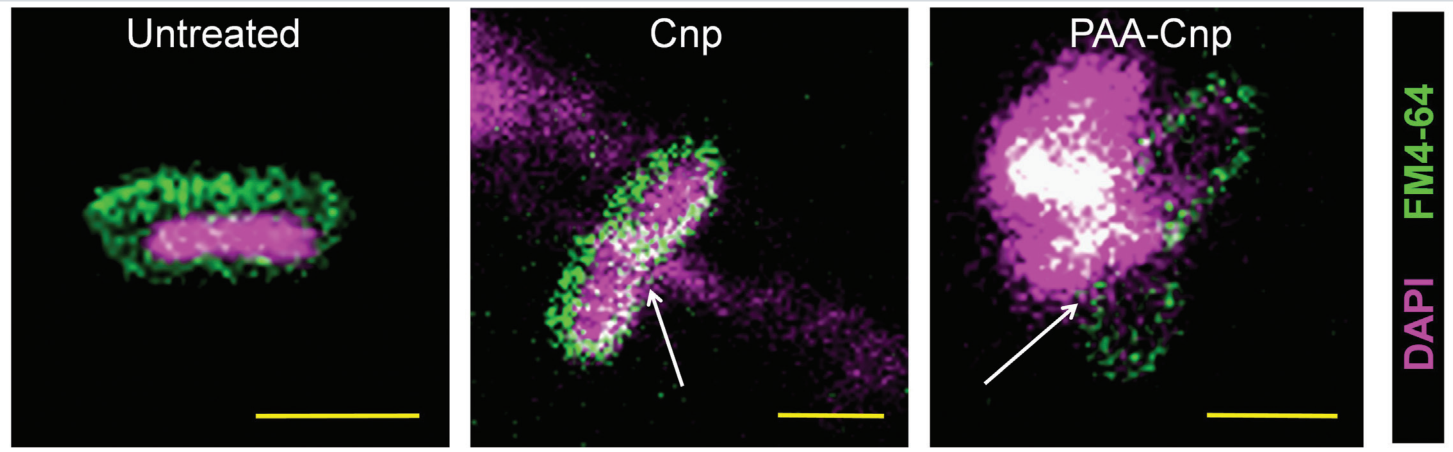
Another goal is to foster industry R&D. Several products and techniques are being developed with current partners Ashok Leyland, TCS, Toyota Kirloskar Motor, Faurecia and Yaskawa. These include smart wearables for worker safety, imitation learning approaches to train robot arms, smart imaging systems for surveillance, and real-time air quality monitoring systems. The facility also aims to nurture new and existing startups.

Education and training is another goal of the centre. Several workshops, training programmes and visits have been organised for industry professionals, academic researchers, MSMEs and school children. An MTech degree programme in smart manufacturing and a PhD programme in advanced manufacturing have also been initiated at IISc.

- *Ranjini Raghunath*

Metal additive manufacturing machine prototype at IISc
(Photo courtesy: Thulasi Raman)

Image: Kritika Khulbe and Kapudeep Karmakar



NANOMATERIALS AS BROAD-SPECTRUM ANTIBACTERIAL AGENTS

AN IISc TEAM HAS SYNTHESISED A NANOZYME THAT CAN BREAK UP THE CELL MEMBRANES OF PATHOGENIC BACTERIA AND REDUCE BIOFILM FORMATION IN URINARY CATHETERS

In a significant breakthrough in the battle against antibiotic resistance, a research team from IISc has synthesised a nanomaterial that mimics an enzyme and can disintegrate the cell membranes of a range of disease-causing bacteria. The study, published in the journal *ACS Applied Bio Materials,* is a collaboration between researchers from the Department of Inorganic and Physical Chemistry (IPC) and the Department of Microbiology and Cell Biology (MCB).

The discovery of antibiotics revolutionised the field of medicine. By the 1960s, many health experts even believed that the fight against infectious diseases was in its final stages. However, recent decades have seen a new challenge – the evolution of resistance to antibiotics in pathogenic bacteria.

Antibiotics typically work by interfering with the cellular activities of the bacteria. Over many generations, owing largely to the misuse and overuse of antibiotics, several strains of bacteria have developed resistance to antibiotics by producing their own enzymes that target the drugs.

The cell membranes of all organisms, including bacteria, have two layers of lipids containing phosphate molecules. “Phospholipid is an essential component of the cell membrane,” explains Kapudeep Karmakar, a former PhD student at MCB and the joint first author on this paper along with Kritika Khulbe, former PhD student at IPC.

Therefore, the researchers decided to target these phospholipids with the help of nanomaterials that would break the bonds holding the membrane bilayer together. These nanomaterials are known as nanozymes. According to the authors, since the nanozymes directly target the chemical integrity of the phospholipids to destroy the cell membrane, bacteria are less likely to be able to develop resistance against them.

To develop this novel compound, the team synthesised a cerium oxide-based nanozyme using what is known as a chemical co-precipitation method. In the next step, they carried out a reaction between cerium oxide and sodium polyacrylate in a basic solution to coat the nanoparticles with polymers. The polymer coating allows the nanozyme to disperse onto any surface or material and boosts its activity.

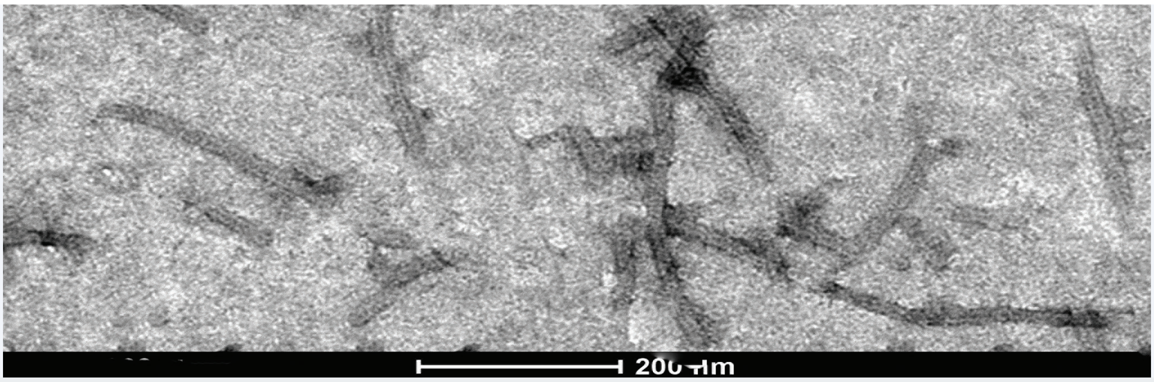
The nanomaterial was then tested in the lab on several potentially pathogenic bacteria such as *Salmonella* Typhi, *Shigella flexneri, Escherichia coli, Vibrio cholerae* and *Klebsiella pneumoniae,* which cause typhoid, gastroenteritis, dysentery, cholera and pneumonia respectively. What the team found was that the nanozyme stopped their growth and subsequently inhibited the formation of biofilm – a densely packed community of bacteria.

“Most antibiotics are not able to penetrate through biofilms. Our nanomaterials were able to penetrate even a 10-day old, well-developed biofilm and showed anti-bacterial activity inside the biofilm because of their small size,” says Khulbe.

The researchers also tested the nanozyme on urinary catheters. These medical devices are vulnerable to formation of pathogenic biofilm on their surfaces, leading to infections in patients. In a laboratory setting, the team found that the bacterial attachment to the catheter surface significantly reduces on treatment with the nanozyme. Because the nanozyme does not distinguish between human and microbial cells, the researchers strategically coated only the inner surface of the catheter to kill the microbes. In order to use their nanomaterial in other medical devices, more research would be required to ensure that there is no contact between human cells and the nanozymes.

- Priti Bangal

Image: Pallavi Sabharwal



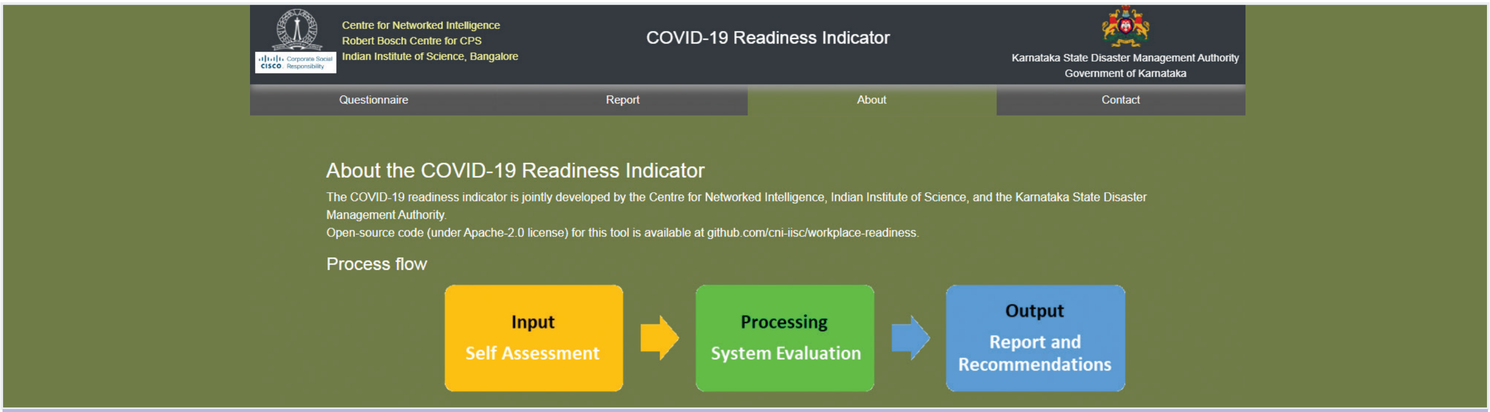
PLANT VIRUS-LIKE PARTICLES TO DELIVER THERAPEUTIC ANTIBODIES

Monoclonal antibodies are used in immunotherapy to target diseased cells and treat psoriasis, cancer and autoimmune disorders. Delivering them inside a cell, however, requires a vehicle that can cross the cell membrane. Virus-Like Particles (VLPs) have this ability. VLPs have the structural components of a virus but not the genetic material, which makes them non-infectious.

Researchers led by HS Savithri in the Department of Biochemistry have now developed a VLP of a plant virus called the pepper vein banding virus (PVBV) to use as a possible vehicle. They genetically engineered the VLPs by adding the antibody-binding domain of a bacterial protein to an exposed region of the VLP's coat protein, resulting in what is called a chimeric VLP. This chimera, when exposed to the antibodies that need to be transported, can recognise and bind to them to form a stable complex. These antibody-bearing chimeric VLPs can enter mammalian cells and deliver the antibody inside, where it can neutralise the target molecule.

- *Anoushka Dasgupta*

Image courtesy: https://covid.readiness.in/



A COVID-19 WORKPLACE READINESS TOOL FOR ORGANISATIONS

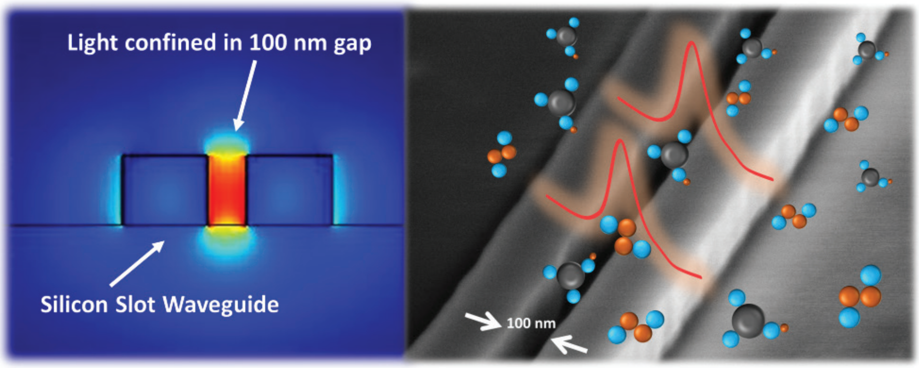
An online self-assessment tool known as the COVID-19 Workplace Readiness Indicator has been developed by a team of researchers led by Rajesh Sundaresan at the Department of Electrical Communication Engineering, in collaboration with the Karnataka State Disaster Management Authority. It was designed as part of research efforts at the new Centre for Networked Intelligence established at IISc with CSR support from Cisco.

The tool takes into account broad epidemic factors and social objectives, and suggests a simple readiness threshold that organisations need to meet or exceed in order to operate effectively, while managing their pandemic response. An organisation can enter information about their workplace and current level of operation into the website, which will then calculate their readiness level using ten specific indices, each with a maximum score of 100, and provide a consolidated report. It also provides targeted suggestions if specific weaknesses are identified.

The Government of Karnataka has recommended this tool to various organisations in the state, as they reopen operations.

- *Ranjini Raghunath*

Image courtesy: Shankar Kumar Selvaraja lab

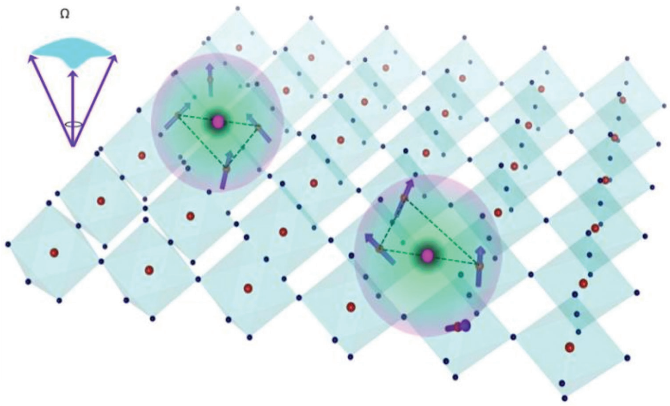


SILICON PHOTONICS SENSOR FOR ULTRA-LOW VOLUME MEASUREMENTS

Optical sensors use light-matter interaction to help us understand the world around us. Photonic integrated circuits offer a platform to miniaturise such sensors. They enable sub-wavelength confinement of light in micrometre scale volume in a photonic waveguide. However, less than 10 percent of light is available for interacting with the environment, which limits the sensing ability.

Researchers in the lab of Shankar Kumar Selvaraja at the Centre for Nano Science and Engineering (CeNSE) have now developed a compact on-chip optical sensor based on a slot-waveguide that increases the light interaction volume to 50 percent. In collaboration with Shell India, the team demonstrated an on-chip chemical reaction at the nanoscale, and detected changes in chemical concentrations in a microlitre sample. Such sensors can help probe chemical reactions that were earlier impossible to track using conventional techniques. They can be easily manufactured on a large scale using microelectronics fabrication tools. The team is also exploring ways to detect low volumes of biomarkers and pathogens.

Image courtesy: Srimanta Middey/Advanced Quantum Technologies



ACHIEVING NONTRIVIAL SPIN TEXTURES IN QUANTUM MATERIALS

Data storage technology using conventional magnetic systems is reaching its limits, and researchers across the world are intently searching for alternatives. Materials having nanoscale non-coplanar spin configurations are a promising platform for ultra-dense, low-power memory applications. Realising such non-coplanar spin textures in new materials and through new routes is of great interest. However, till date, this has been restricted only to magnetic materials which already possess localised magnetic moments.

In a recent study, a research team led by Srimanta Middey in the Department of Physics has successfully demonstrated a new route to realise non-coplanar spin configuration in a non-magnetic system. They achieved this by deliberately creating oxygen vacancies (OVs) in a non-magnetic band insulator called $KTaO_3$. Creation of OVs turns pristine insulating $KTaO_3$ into a metal. It leads to the formation of a non-coplanar network of magnetic moments around the OV, resulting in a phenomenon called topological Hall effect. These design principles could be utilised to engineer more complex and stable spin structures in various quantum materials.

Photo: Vinay Krishna Sharma

A ROBOTIC ARM CONTROLLED BY EYE-GAZE FOR THE SPEECH AND MOTOR IMPAIRED

ROBOTIC ARM MANIPULATED BY EYE MOVEMENT USING A WEBCAM AND COMPUTER INTERFACE CAN HELP PEOPLE WITH SEVERE SPEECH AND MOTOR IMPAIRMENT

People with Severe Speech and Motor Impairment (SSMI) – a condition caused by disorders such as cerebral palsy – find it difficult to physically operate devices such as a joystick, mouse or trackball, or use speech recognition systems.

To help people with SSMI, a research team at the Centre for Product Design and Manufacturing (CPDM) has designed a robotic arm that can be manipulated by eye movement using a computer interface. This interface is non-invasive since it is through a webcam and a computer, unlike other eye gaze-tracking devices that use head-mounted systems.

The team worked with young adult students who have SSMI at Vidya Sagar (formerly The Spastics Society of India) in Chennai, an institution for individuals with disabilities. "Many of these students [with cerebral palsy] are not able to precisely focus at a single point in their visual field, due to uncontrolled gaze movement. They are also not comfortable to look at all portions of the visual field equally," says project lead Pradipta Biswas, Assistant Professor at CPDM.

Biswas and his team used computer vision and machine learning algorithms to analyse live feeds of facial video from the users, and were able to estimate where they were looking. The team coupled this with an Augmented Reality application to allow users to use a robotic arm for tasks like picking up and dropping objects, and placing them where they desire, as long as it was within reach of the robotic arm.

One of the main applications of this eye gaze-controlled robotic arm is to rehabilitate young adults with SSMI through tasks such as fabric printing. They usually require assistance in doing such tasks, as they can only do a small part of it by themselves. Using the robotic arm designed by the researchers, people with SSMI can use their eye gaze to perform mechanical tasks that can help them work on handicrafts independently.

This eye gaze-controlled interface has been deployed at Vidya Sagar and is in regular use. "This validation and evaluation [of the interface and robotic arm] with end users is a major contribution of the study," says Biswas.

The students with SSMI are able to use the robotic manipulator almost as well as their non-disabled counterparts.

This technology can also be used by younger individuals with SSMI to move toys like cars. "We are using play as a medium to teach new technologies, which they can use for the rest of their lives," adds Biswas. According to the researchers, the tool could also be adapted for e-learning.

The authors believe that this interface is an important step towards designing technologies that would help those with physical impairments resulting from SSMI learn better and become skilled professionals. Biswas also says that such a system could be useful for automotive and aeronautical applications, as well as for developing collaborative robots used in smart manufacturing.

- Anoushka Dasgupta

MICRO AND NANO ROBOTICS RESEARCH AT IISc

Microbots driven by light and magnetic field

New class of robots that can selectively pick up, transport, and release tiny objects with great speed and accuracy in fluids, with applications in drug delivery and quantum sensing

Ambarish Ghosh (CeNSE)

Circuits that can self-heal

Smart interconnects that automatically heal open circuit failures using a dispersion of conductive particles in an insulating fluid, making it a useful innovation for flexible electronic systems

Sanjiv Sambandan (IAP)

Culturing biological cells on microbots

Microrobots on which biological cells can be cultured, with the eventual goal of facilitating onsite assembly of tissue fragments inside the body

GK Ananthasuresh (ME)

Modeling bacterial swarms

Experimentally validated models for collective motility in large bacterial swarms, which can be extended to the control of artificial micro and nano robots

Manoj Varma (CeNSE)

Enhanced coupling between nanoresonators

Enhancing coupling between two modes of a nanoresonator, leading to improved sensitivity of nano-mechanical sensors, for use in mechanical logic circuits and quantum limited measurement

Akshay Naik (CeNSE)

Automated AFM tip replacement

Automated tip replacement modules that can be retro-fitted into commercial Atomic Force Microscopes, greatly cutting down cost and time

GR Jayanth (IAP)

Microfluidic interfaces for cell manipulation

New microfluidic techniques to study mechanical properties of cells by probing electrical signatures and fluorescent signals from individual cells

Prosenjit Sen (CeNSE)

Ultrafast Fourier Transform of sensor outputs

Inspired by the human ear, a platform for carrying out ultrafast low power Fourier Transform of the output from any arbitrary sensor, to interface with artificial neural networks

Saurabh Chandorkar (CeNSE)

Photo courtesy: Sai Siva Gorthi lab

MOBILE LABS FOR COVID-19 TESTING

The gold standard for COVID-19 testing, called RT-PCR, requires expensive equipment and trained personnel. Besides, only a limited number of centralised laboratories and large hospitals can conduct these tests. The current testing infrastructure is overwhelmed, and people often have to wait for more than a day to get their test results.

To ramp up testing and reduce turnaround time, the country's first ICMR-approved mobile COVID-19 diagnostic lab has been developed by an IISc team led by Sai Siva Gorthi at the Department of Instrumentation and Applied Physics. It has been developed in collaboration with Deepak Saini at the Department of Molecular Reproduction, Development and Genetics, and Shanmukha Innovations, an IISc-incubated start-up, and with support from the SBI Foundation, Toyota Kirloskar Motor and Tata Motors.

The mobile labs consist of a fleet of four vehicles – a container truck and three vans – that can travel to, and operate in remote areas. Of the three vans, one is a sample collection lab, the second is a sample processing lab, and the third is the actual RT-PCR testing lab. The container acts as a nodal hub and stays parked at a central location. It has facilities for storage of consumables and Personal Protective Equipment (PPE), and for bio-waste disposal.

Each fleet, named as an MITR (Mobile Infection Testing and Reporting) lab, can handle up to 6,000 samples per month. This fleet is now ready to be deployed, and will soon be handed over to the Karnataka government.

This innovation can increase the reach of public healthcare services significantly, and in the future, be used to test for other infectious diseases as well.

- *Samira Agnihotri*

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