NANYANG
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EEE RESEARCH NEWS

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SMART NATION
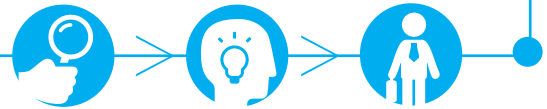
MEDICAL CENTRE

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School of Electrical and Electronic Engineering

Contents

From Research to Innovation to Enterprise

Established more than 30 years ago, the School of Electrical and Electronic Engineering (EEE) at Nanyang Technological University (NTU) has created, nurtured and provided the engineering talent and energy to help make Singapore what it is today. We have provided solutions to problems, helped to build a city envisioned by our leaders and realised the dreams of entrepreneurs.

With emerging challenges such as a shrinking workforce due to an ageing population and more selective immigration, we will continue to look for ways to improve people's lives and advance Singapore's interests. Our 12 research centres, equipped with sophisticated and state-of-the-art facilities and home to more than 50 laboratories and 140 faculty members, embrace this role and responsibility.

2016 has been a year of achievements and accolades for our school. The EEE was ranked fourth best in the field of electrical and electronic engineering in ShanghaiRanking's Global Ranking of Academic Subjects 2016. That makes NTU the top-ranked university in the field in Asia and Europe, and behind only the United States' University of California, Berkeley, Massachusetts Institute of Technology and Stanford University globally.

Professor Yoon Soon Fatt, Chair of the School of EEE, said: "Our latest ranking reflects positively on our commitment to teaching and research excellence, our focus on entrepreneurship and our ability to engage on a global stage."

Our professors, together with their colleagues from the School of Computer Science and Engineering, made up the formidable NTU College of Engineering's multi-disciplinary team that won the first National Research Foundation TRANS grant call. Professor Yuan Jun Song and his team did us proud too by winning the 2016 Best Paper Award of IEEE Transactions on Multimedia, for their work on hand gesture recognition using depth cameras.

We continue strengthening our partnerships with the private sector, we established two joint laboratories, with Taiwan's Delta Electronics and local rail operator SMRT respectively.

Our job is never done. We will continue to provide quality education to those interested in the field of electrical and electronic engineering, and build a culture of innovation that serves the interests of businesses, consumers, workers and societies.
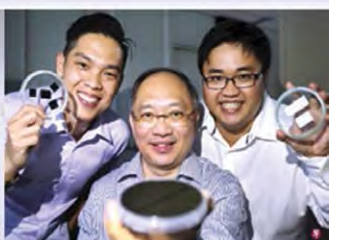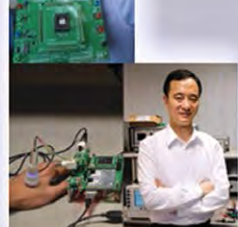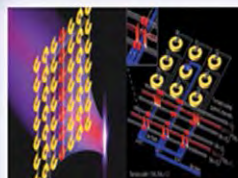
A "break" – Through Discovery

A new method to break down multi-material fibres and films could spell dividends for the medical, military and other fields.

Researchers from EEE's Centre for Optical Fibre Technology (*COFT*) and their collaborators in the U.S. have developed a novel way to fragment fibre-like materials into tiny, almost uniform internal segments or strips held in place within the fibre.

With their discovery, scientists could manipulate the materials to make them blend into the surroundings in a dynamic camouflage effect; increase their internal surface area for medical uses; and manufacture micro- and nano-particles of the materials more easily for various purposes.

The demonstrated method works on a variety of materials, including plastics, metals and glasses, and natural ones such as silk, ice and hair. It can produce particles ranging in size from nano-particles to ones that can be seen with the naked eye.

The innovation exploits a well-established process called cold-drawing, which has been used for almost a century to produce synthetic fibres such as polyester and nylon.

Prof Wei Lei from EEE and his collaborators discovered that, under some conditions, some materials within the fibres naturally break apart into almost uniform pieces as they are being cold-drawn.

Those conditions create a kind of wave that sweeps along the fibre's entire length as it is being cold-drawn. This wave breaks apart any brittle threads embedded in the fibre into short, almost uniform segments.

"The result can be a bundle of short rods kept in place within the polymer fibre, or the polymer can be dissolved to leave a collection of separated rods of precisely matched size and shape, which can be of a nanoscale size that would be difficult to manufacture by other methods," said Prof Wei.

With its ability to easily produce large quantities of nano-particles, nano-rods and nano-wires, this work could revolutionise disciplines ranging from optics to nano-technology. The research was published in scientific journal Nature in 2016.
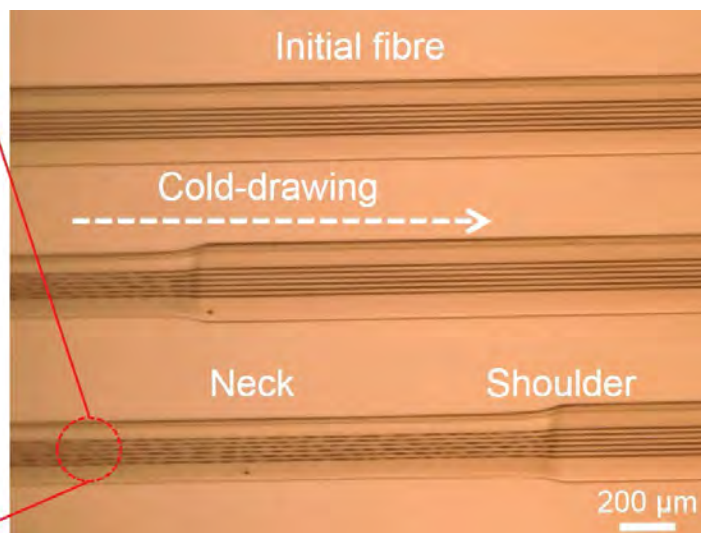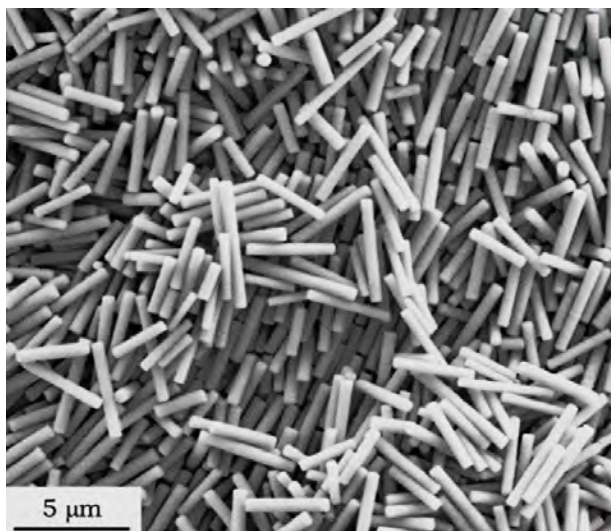
A Material Fit for Space
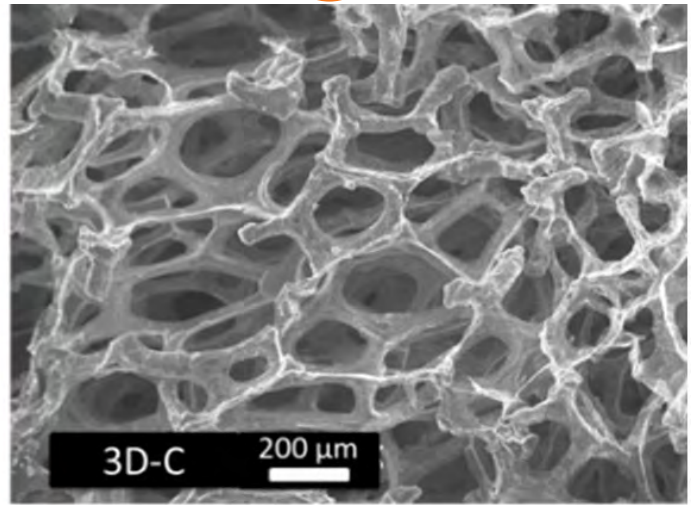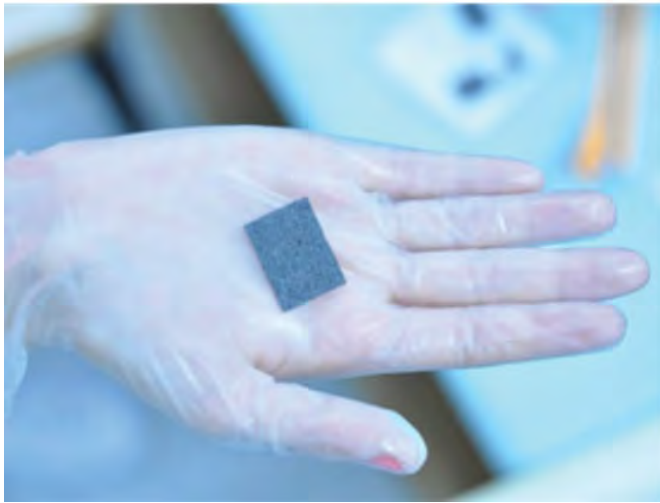
Satellites and other space vehicles have to endure extraordinarily harsh environments. An invention by Nanyang Technological University (NTU) could improve their chances of survival.

Scientists from EEE's Centre for Micro-/Nano-electronics (*NOVITAS*) have developed a new type of hybrid material that can better prevent the build-up of the electrostatic discharge found in space. This quality is crucial in materials to protect space vehicles as the discharge can damage on-board electronic systems, degrade their surfaces and cause other problems.

Only a few materials are space-qualified for use as thermal control blankets that protect space vehicles in the unforgiving space environment. These include polyimides, which are known for their low cost and high thermal stability, elasticity and tensile strength.

Polyimides' dielectric nature, however, makes them vulnerable to electrostatic discharge build-up.

Some researchers have added conductive nano-particles, such as graphene and carbon nanotubes as "nano-fillers" in the polyimides to improve on their properties. However due to the disconnected nature of these particles, a high percentage of materials have to be added to make any significant change. This in turns modifies the other useful properties of the polyimides degrading their overall performance.

The EEE team, led by Prof Teo Hang Tong, Edwin developed a new way to infuse a 3D interconnected graphene (termed 3D-C) into the polyimide creating a composite which uses less than 0.03% of new materials ensuring stability in the other properties.

When tested in ground-based simulated space environments, the EEE material improved on pure polyimide materials' thermal and electrical characteristics by 1,033 per cent and 10 orders of magnitude respectively.

The results showed that it can provide long-term and stable electrostatic discharge shielding protection for space vehicles.

Typical MLI outer layer

ITO conductive coating → ESD protection, AO protection

Polyimide → 50% absorptance of incoming solar radiation

Single layer of 3D-C/PI → ESD protection
UV radiation resistant
thermal spread
robustness
flexibility
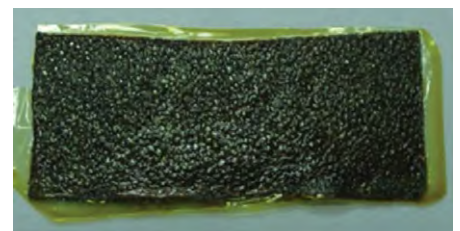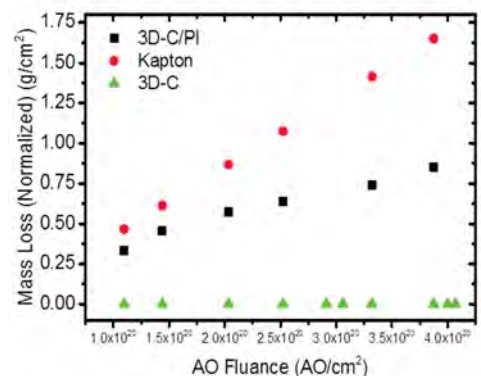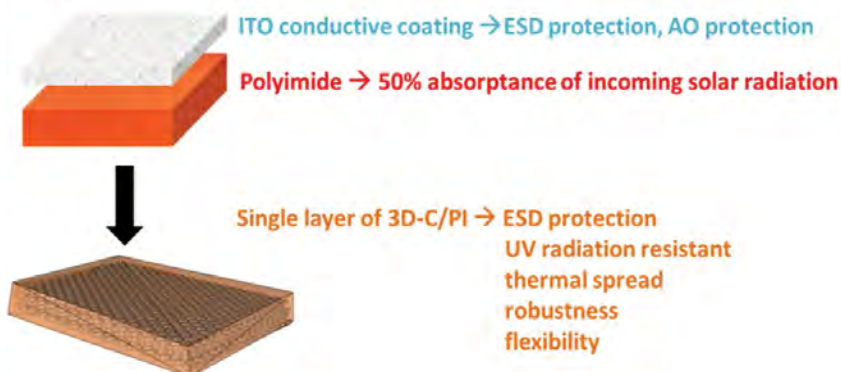
Satellite Successes

Two satellites launched by Nanyang Technological University (NTU) have completed their first space missions, further advancing the university's satellite programme.

The two satellites, developed by the Satellite Research Centre (*SaRC*) in EEE, conducted experiments in space and proved that several made-in-Singapore satellite technologies are commercially-viable.

These include precise Global Positioning System (GPS) based navigation system and hardware that can resist the impact of radiation in space.

VELOX-CI, a 123 kg microsatellite, has flown over Singapore more than eight months and tested several NTU inventions, including the GPS receivers and the navigation system, which allows satellites to determine their orientation just by looking at the stars in space.

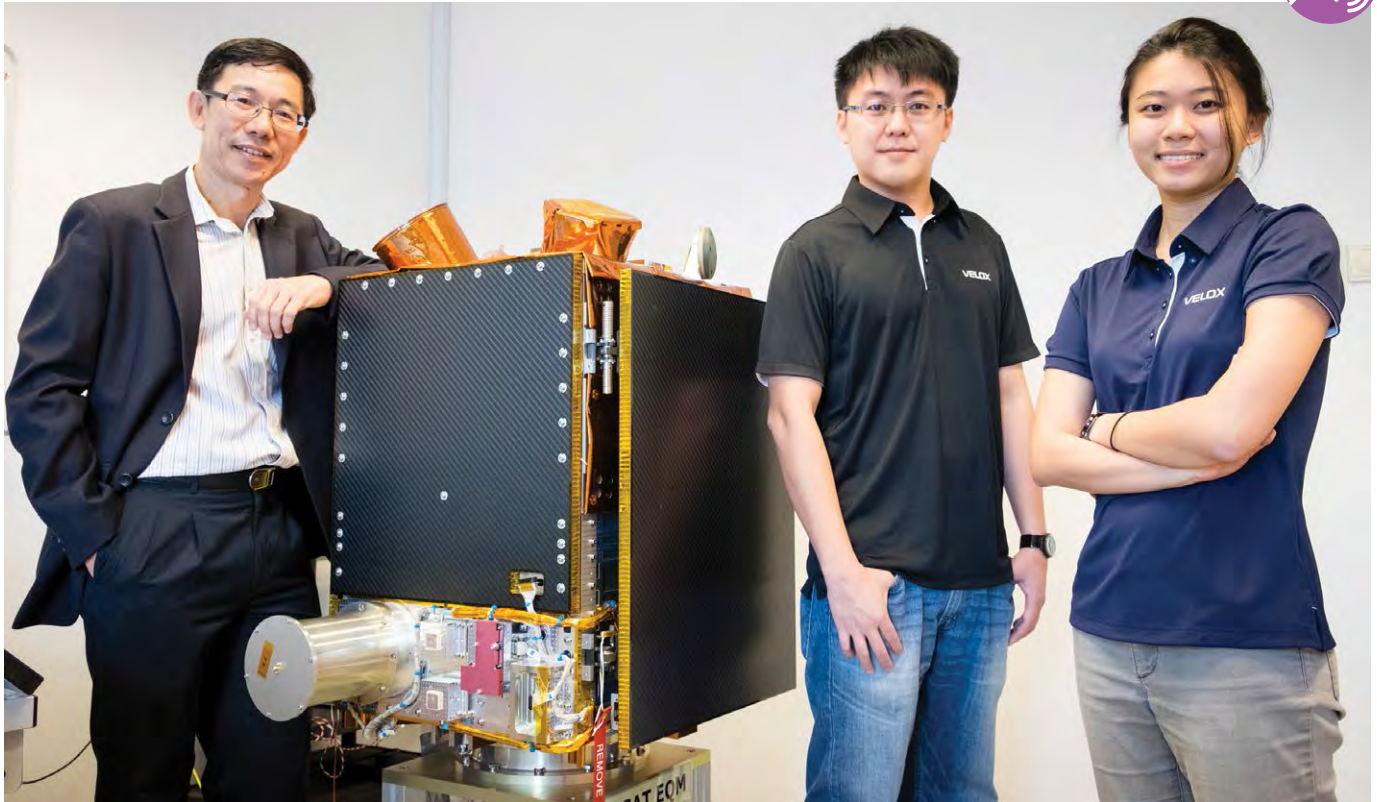Using the GPS receivers, EEE researchers also developed algorithms to study the ionosphere – a part of Earth's upper atmosphere – so that scientists can predict the impact of space weather on ground-to-satellite communications and satellite navigation.

VELOX-II, a 12 kg nanosatellite, was used to evaluate the on-demand communication system called the Inter-Satellite Data Relay System, developed by Singapore firm Addvalue Innovation; and a radiation-resistant chip that manages and stores the critical data in a satellite's memory.

Prof Low Kay Soon, director of the *SaRC*, said: "This success is a result of the rigorous testing of the satellites and the excellent team we have built over the years. Our next challenge is to design satellites that can carry advanced custom-built payloads."

NTU Provost Prof Freddy Boey added: "We have proven that NTU has what it takes to play a major role in supporting Singapore's leap into the space industry."

Jurong Lake Distinct (JLD) Urban Road Nextwork

Paving the Way for a Smoother Ride

A new traffic control system developed by School of Electrical and Electronic Engineering (EEE) could help to reduce travel time and congestions on urban roads in the future.

The EEE system was tested in the recent "Jurong Lake District – Smart Traffic Management System" project by Singapore's Land Transport Authority, Infocomm Development Authority and ST Electronics.
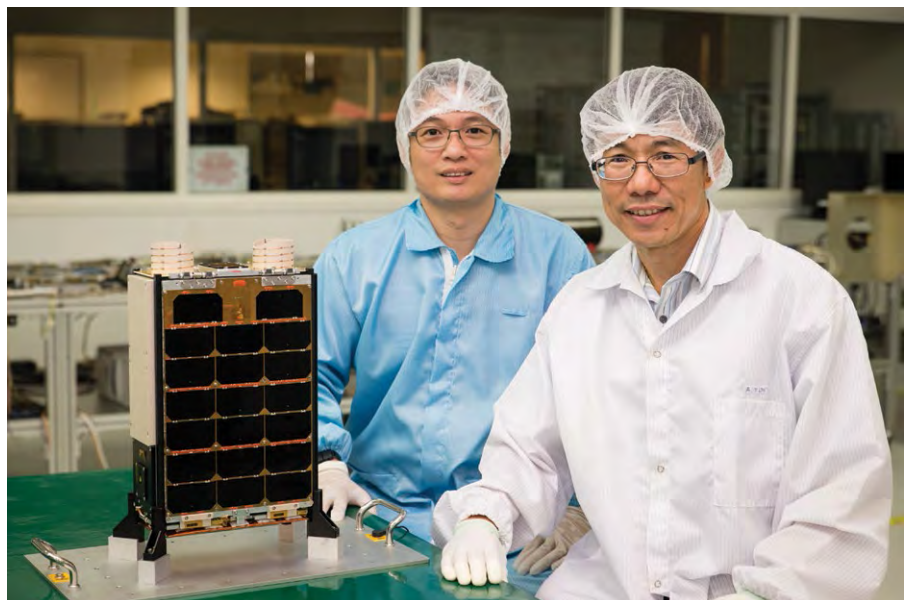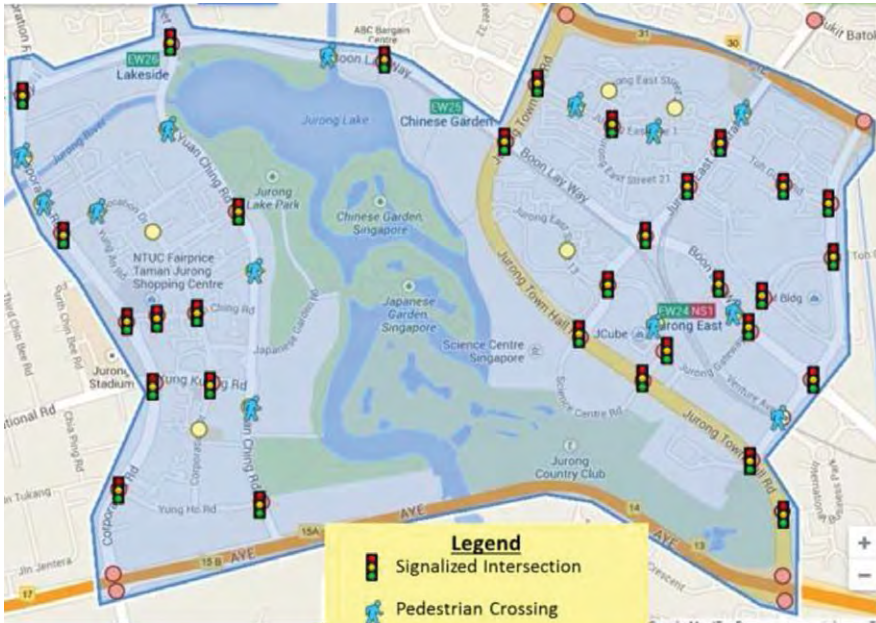
That project pitted the EEE system, as well as two other potential traffic control strategies, against a baseline, Australian urban traffic management system that synchronises traffic signals to optimise vehicular flow.

Traffic data from five months in 2014, from an area spanning 31 signalised junctions and 13 pedestrian crossings in the Jurong Lake district, was used to create realistic situations in a simulation program.

Each of the four traffic control systems was tested to see how it might improve the vehicles' time needed to travel in and out of the area, their average delay due to stops and the average number of stops.

The EEE system performed better than the baseline system in all three areas: By 29.34 per cent on average delays; 47.85 per cent on average delays due to stops; and 9.97 per cent on the average number of stops.

Prof Wang Danwei, director of the ST Engineering-NTU Corp Lab proposed a field test in Singapore in the near future to validate the encouraging results. "A smart urban transportation system would be a major achievement in Singapore's goal of becoming a Smart Nation to improve its people's lives," he said.

Realising that traffic flows are repetitive and usually have only small variations in rush hours. The researchers from EEE's Centre for System Intelligence and Efficiency (*EXQUISITUS*) created an "Iterative Tuning" system exploiting an area's historical traffic patterns to adjust its traffic lights' daily signal schedules. This could substantially reduce congestions and give commuters a smoother ride. An add-on predictive controller also fine-tunes the signals to compensate for variations in the traffic flows.

Simulation platform of JLD in Vissim
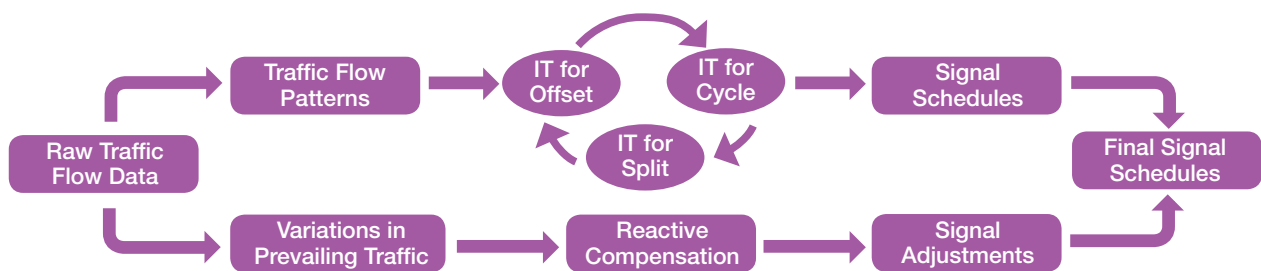
Schematic Diagram of Iterative Tuning Strategy

Speaking with Your Hands

As an important means of non-verbal communication, hand gestures are commonly used in our daily life. However, can we make machines to understand hand gestures too? For example, can we teach social robot human sign language so that it can communicate and interact with deaf people naturally and non-verbally? In the living room, can we control the TV remotely by using hand gestures only? In the virtual environment, can we manipulate virtual object with our hand and control the display using our hand gestures?

Although human can perform naturally well, analyzing and understanding human hand gestures is not easy for machines. Comparing with whole-body gestures, hands are much smaller objects with more complicated articulations, which easily subject to image sensing errors. Therefore, robust and efficient hand gesture recognition for real-life application is very challenging.

Prof Junsong Yuan's research group from EEE pioneers the works in robust hand gesture understanding and interaction using commodity depth cameras, such as Microsoft Kinect. Their work has been sponsored by Nanyang Assistant Professorship and Microsoft Company.

While prior work of Microsoft has utilized depth cameras to analyze whole-body motion, Prof Yuan's team is among the first to deal with hands using depth cameras. With their novel technologies for hand gesture analysis using a depth sensor, they have developed pattern recognition and machine learning methods to enable intelligent human-machine interaction using hand gestures. By accurately capturing the hand gesture, they have implemented prototypes for recognizing hand sign languages, interacting with social robot and virtual object with hands, and playing a virtual piano on a piece of white paper. Their work has also received the best paper award of IEEE Transaction on Multimedia in 2016.
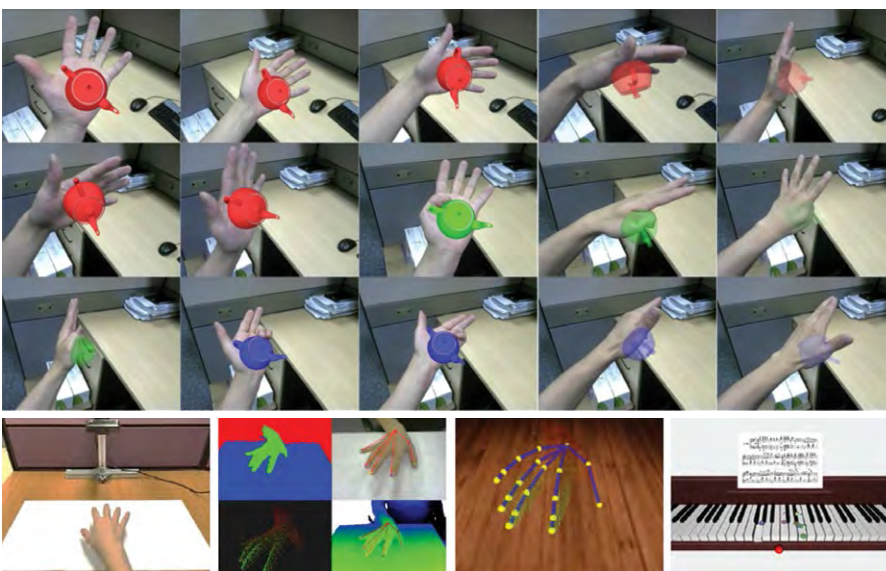
Powering Singapore

How do you keep Singapore's electricity flowing even as its economy and demand for energy continue to grow? Partly by keeping a close eye on the vast low-pressure pipe network (ca. 3000 km) that delivers the country's natural gas to utilities for power generation and other utilizations.

> The researchers from NTU's EEE have developed a research project to use sensors to monitor Singapore's underground gas pipeline network and alert operators to the need for repairs or preventive maintenance. This could help to ensure that Singapore continues to have interruption-free power generation.

The project is divided into three parts. Two of them focus on the use of sensors to monitor the temperature of the pipes and the flow-rate and pressure of the gas in the pipes. Any anomalies could indicate leaks, water in the pipes or other problems.

These sensors include distributed temperature sensors, which are optical fibres laid on the pipes' surface to pick up changes in their temperature profile. The use of different sensors in a comparative manner creates a more robust detection system.

The third project is centred on advanced data analytics that use the sensor data, radio frequency identification (RFID) technology and historical data to pinpoint the location of anomalies and equipment parts that are at risk of failure.

"The three projects are linked. The objective is to provide multi-sensor, real-time monitoring of the gas pipeline network, data analytics and preventive maintenance. All of this will help Singapore to enhance the resilience of its pipeline gas supply," said Prof Abhisek Ukil from EEE, who is leading the two sensor projects. Prof Justin Dauwels from EEE is heading the data analytics research.

The EEE teams will also work with two industry partners: Singapore utility SP PowerGrid - PowerGas, which will provide an underground pipeline test site, and global energy player ENGIE, France.

Technologies:	PROJECT **1** — Anomaly Detection using Distributed Temperature Sensing	PROJECT **2** — Anomaly Detection using Flow and Pressure	PROJECT **3** — Data Analytics for Localization, Predictive Maintenance in Gas Pipeline Network	

Temperature — Flow-rate — Pressure — Algorithm

Applications: Multi-sensor Real-time Monitoring → Predictive Maintenance

Objectives: Enhancing Resilience of Pipeline Gas Supply

Deployments: Demonstrated Technologies Transferred to Industrial Partner for Development & Field Trials

NANYANG TECHNOLOGICAL UNIVERSITY

SINGAPORE POWER

ENGIE
by people for people

A Hearing PAL

Watch a television show with your elderly parents and you could find it difficult to settle on a volume that works for you and them, as human hearing degrades with age.

The scientists from EEE's Centre for Infocomm Technology (*INFINITUS*), led by Prof Gan Woon Seng have come up with a Personal Assistive Listening (PAL) system that uses different types of loudspeakers to amplify sounds for the hard of hearing, while delivering normal sound to other people, all within the same room.

The system uses conventional electrodynamic loudspeakers and directional parametric loudspeakers to create two zones of hearing within a room, one for those with hearing losses and the other for people who can hear normally.
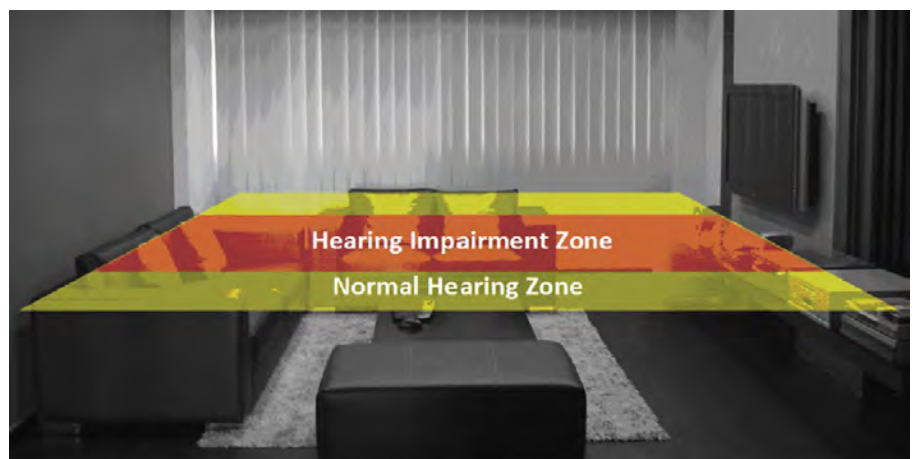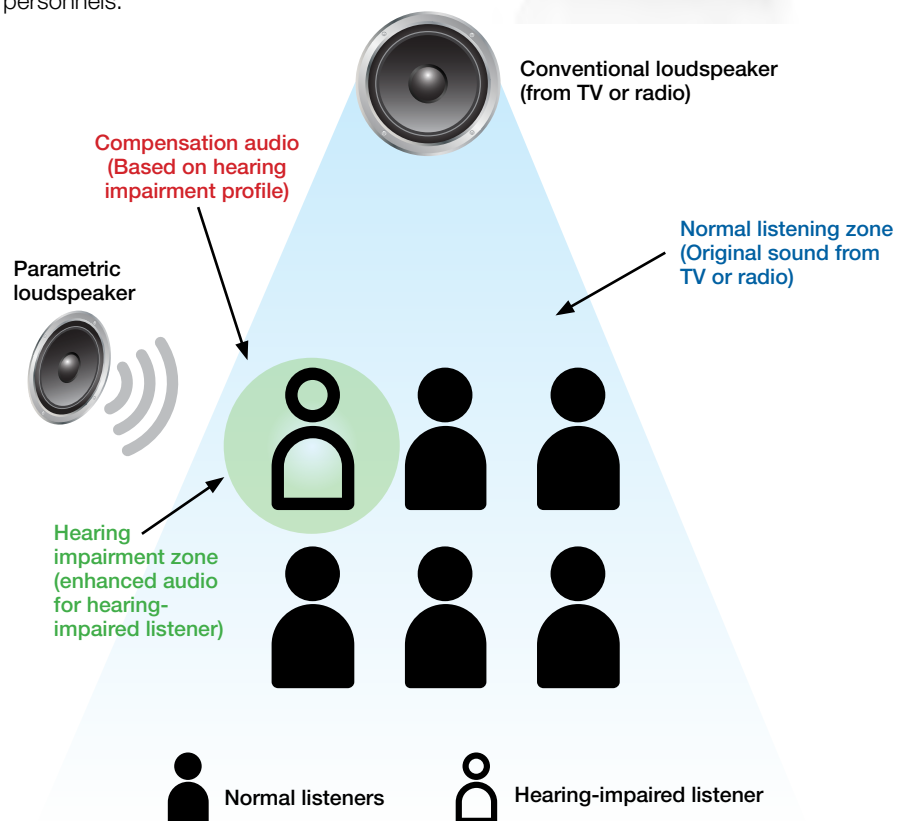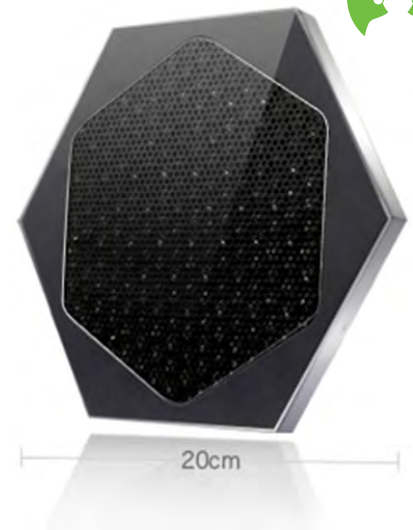
While conventional loudspeakers throw sound as clearly and wide as possible across a room, parametric ones focus their sounds into a relatively small area. Two people can be near each other with only one of them hearing the sounds from the parametric loudspeakers.

When the EEE researchers tested two variations of their system, PAL 1 and PAL 2, both were able to compensate for moderate hearing loss. PAL 1 performed better than PAL 2 at the lower frequency range, while the results were reversed at the higher frequency range.

The team said their system could work better in the home than hearing aids and other personal amplification devices. The latter can be uncomfortable to wear, and a study in 2009 found that the use of personal hearing aids did not significantly improve the recognition of televised speech.

Still, the system could help families to bond over watching television, said Prof Gan Woon Seng, director of the *INFINITUS*. He explained: "With the two different hearing zones, people of different age groups can enjoy television together even if they require different audio volumes."

The team is currently working with otolaryngologist and audiologists from the Tan Tock Seng Hospital to perform clinical trial on the effectiveness of the PAL system on hearing impaired personnels.

20cm

Conventional loudspeaker
(from TV or radio)

Compensation audio
(Based on hearing
impairment profile)

Normal listening zone
(Original sound from
TV or radio)

Parametric
loudspeaker

Hearing
impairment zone
(enhanced audio
for hearing-
impaired listener)

Normal listeners   Hearing-impaired listener

Hearing Impairment Zone
Normal Hearing Zone

Peace and Quiet

Living in the city shouldn't mean that you have to endure the noises of loud vehicles and traffic congestion. Researchers at Nanyang Technological University (NTU) have developed two new methods to tackle noise pollution and other problems to help make cities quieter.

The scientists from EEE's Centre for Infocomm Technology (*INFINITUS*) have created a noise-cancellation system that can be installed in home windows, as well as an automated monitoring system that could help government agencies to catch excessive noise offenders.

While some people deal with noise by shutting their homes' windows and switching on the air-conditioning, this is not an environmentally-friendly solution. The EEE noise-cancellation system relies on a technique called active noise control to mute sounds.

An array of small microphones and loudspeakers are placed near homes' windows. When the microphones detect incoming noise, the loudspeakers generate sounds that are the same in amplitude but opposite in phase – anti-noises, in effect – to cancel the incoming noise.

When the researchers tested two brands of speakers that could be installed with minimal obstruction to windows, they achieved noise reduction of more than 10 A-weighted decibels, about halve the perceived loudness reduction of typical traffic noise.

Separately, the researchers also created an automatic noisy vehicle detection and surveillance camera system, called NoivelCam, to track moving vehicles on roads and capture footage of those that exceed stipulated noise level thresholds.

Directional microphones are used to track vehicular noise on only the monitored lane. When the noise exceeds the stipulated level, a high-speed camera captures the offending vehicle's number plate. A video camera also continuously records footage to be used as proof, or to evaluate possible false triggers.

These inventions can help provide peace and quiet at home, and reduce noise-related health problems. The researchers hope that, through their work, urban dwellers can enjoy a better quality of life.
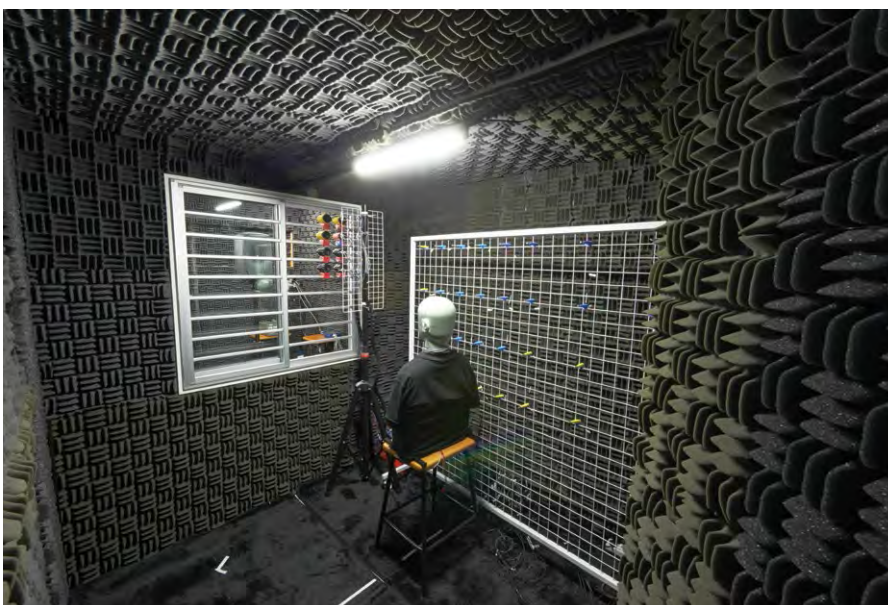
A Smarter Camera

The next generation of self-driving cars and unmanned aircraft could become more intelligent with a new invention from Nanyang Technological University (NTU).

Prof Chen Shoushun and his team from EEE have developed a camera system that tracks high-speed objects with little redundant data and at much lower cost compared to their commercial counterparts.

It could help autonomous vehicles to make split-second decisions about whether and how to avoid objects that pose a danger, and improve sectors such as manufacturing, defence and surveillance.

Traditional motion detection systems capture pictures at high frame rate, many times more than 500 images per second, to track fast-moving objects. Companies have to analyse all of the data, even though most of it – such as the images' background – does not change from picture to picture and is useless.

Instead of taking pictures, the EEE system analyses every pixel on view and records only those that show certain amount of change in light intensity. Static backgrounds are not captured. Moving objects, however, change the pixels' light intensity and are logged.

It monitors scenes at the equivalent rate of 100,000 frames per second, and generates 1000 times less data than commercial competitors for the same work, drastically reducing signal processing costs and expanding its potential applications.

Users set the threshold of light change in both of amount and slope which triggers the data collection, so the system can reject not just static backgrounds but also slower-moving ones, for example when it monitors traffic from a moving car or unmanned aircraft.

The processing software of the camera also differentiates between objects by looking at their light properties, and predicts each object's movement and speed by analysing the motion of the brightness patterns as it collects data. Such intelligence is crucial for autonomous vehicles to recognise and avoid potential collisions.

The researchers are improving their technology to make it even faster and use less power. They welcome academics, firms and government agencies to partner them to find new applications for their work.

Putting a Brain on a Chip
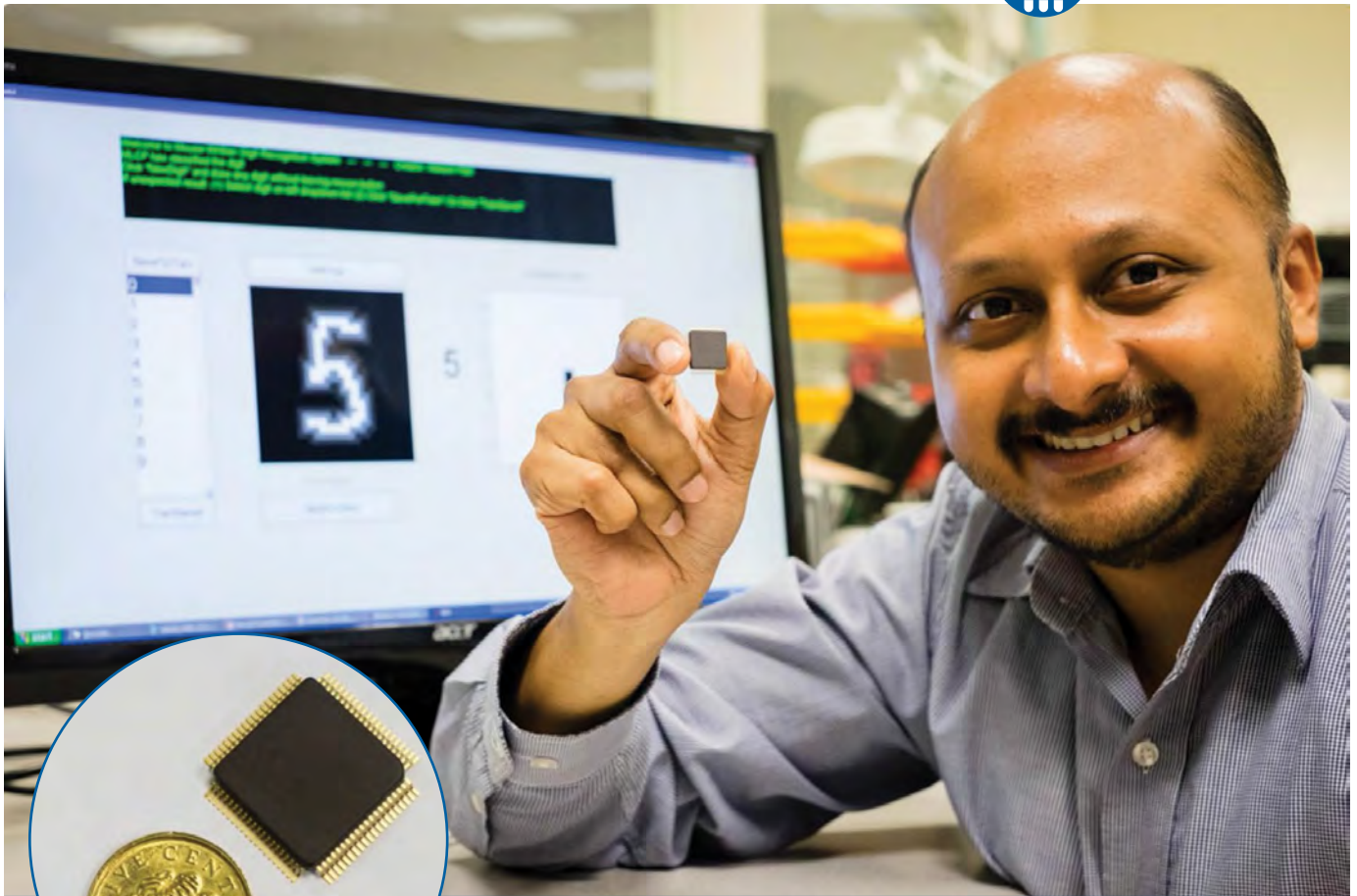
Portable and wearable devices such as health sensors could soon become smarter with a new invention by Nanyang Technological University (NTU).

The EEE researchers, led by Prof Arindam Basu have developed a smart chip that could imbue devices with artificial intelligence at minimal energy and cost.

The small and lightweight prototype, when mounted on a headgear, could help decode a monkey's brain waves and predict how it wanted to move its fingers with 99.3% accuracy. This could pave the way for implants and portable devices to help paralysed people regain use of their limbs.

The chip could also enable surveillance cameras and sensors to automatically identify intruders and alert security staff, and empower health-monitoring devices to recognise when a person is about to suffer a heart attack or epileptic seizure, and call for help.
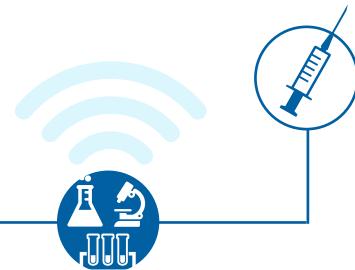
The invention taps on manufacturing imperfections that occur in the electronics sector. Transistors in electronics devices invariably deviate to some degree from the design and from one another due to manufacturing inconsistency.

The chip taps the resulting, unintended variations in the transistors' threshold voltage. It uses mathematical formulas that multiply input signals such as brain waves, temperatures, pressure, sounds and images using the transistors' varying threshold voltages. This fleshes out similarities and differences among the signals.

The chip can then better compare each signal to specified patterns. A doctor could study an epilepsy patient's brain activity and program the chip to recognise the signature of an impending episode, so that help can be activated when needed.

To achieve the same results, conventional smart chips have to use an additional component and more processes, so that their power usage is more than 100 times that of the EEE chip.

The scientists are developing an implant integrated with their chip for brain-machine interfaces. They have also received a $250,000 from the Singapore-MIT Alliance for Research and Technology to improve their prototype.

Putting a Lab in a Needle

Diagnosing diseases in the liver and other organs could soon become much faster and less expensive with a new invention from Nanyang Technological University (NTU) researchers and other scientists.

The scientists from EEE's *VIRTUS*, IC Design Centre of Excellence have invented a "lab in a needle" that collects tissue and blood samples, prepares them, amplifies and detects DNA or RNA sequences, and analyses them.

This novel diagnostic kit can test for liver toxicity in less than 30 minutes, allowing doctors to make on-the-spot decisions during surgeries. The low-cost and portable device can also be used in homes and remote areas to test various types of biological samples for diseases.

As the first organ to be damaged by chemicals, the liver is prone to diseases such as cirrhosis and liver cancer. While liver health is tested frequently, current methods such as tissue histopathology and blood tests for liver function require expensive clinical set-ups and can take several days to produce results.

Other scientists' solutions have had limited use. One recently-developed "lab on a chip" that extracts RNA sequences to test for chemical-induced liver damage, for instance, required extensive off-chip sample preparation and had other inherent limitations.

The "lab on a needle", on the other hand, carries out all the necessary steps in sample collection, preparation and analysis in one integrated, rapid and efficient process. "Our system features semi-automation, is relatively easy to use and has 'sample-in-answer-out' capabilities for multiplex gene expression analysis," said the researchers.
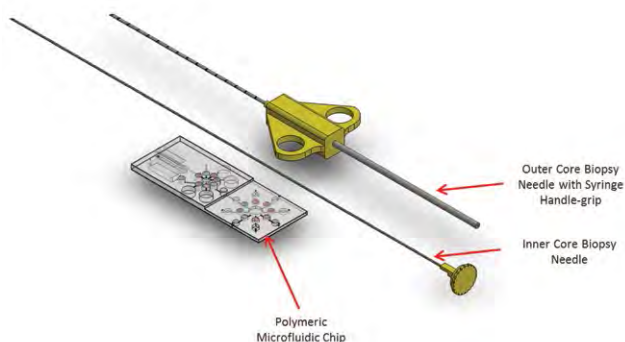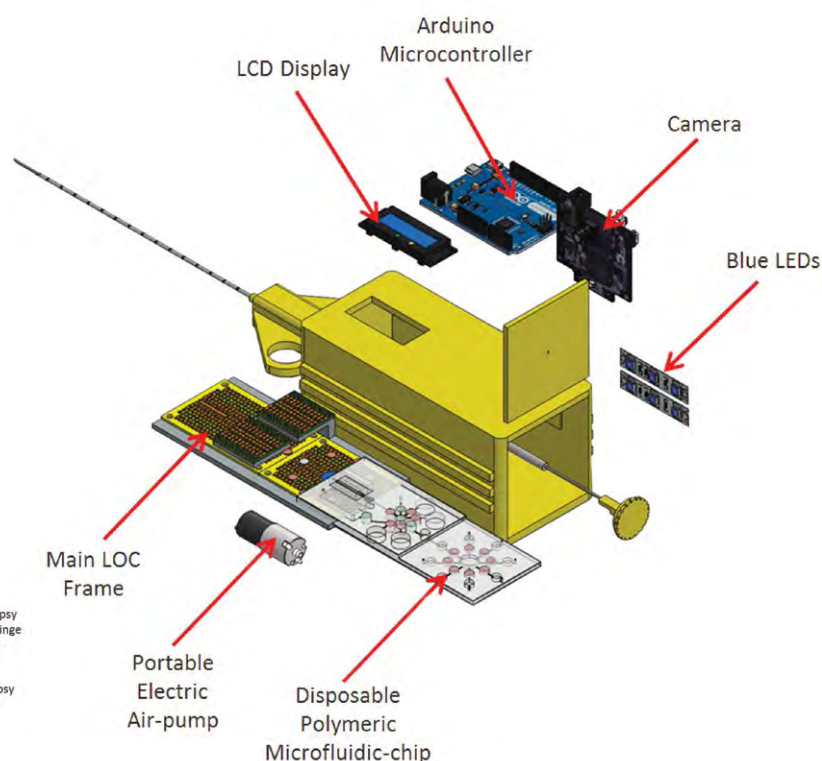
The work was done by an international group of scientists led by Prof Joseph Chang from EEE, Dr Wang Zhiping from the Singapore Agency for Science, Technology and Research's Singapore Institute of Manufacturing Technology, and Prof Stephen Wong from the Houston Methodist Hospital Research Institute at Cornell University in the United States.

Outer Core Biopsy Needle with Syringe Handle-grip

Inner Core Biopsy Needle

Polymeric Microfluidic Chip

LCD Display

Arduino Microcontroller

Camera

Blue LEDs

Main LOC Frame

Portable Electric Air-pump

Disposable Polymeric Microfluidic-chip

Diagnosis by Listening to the Sound of Light

Patients that suffer from stroke, shock and other brain diseases can benefit in the near future from POSTs (Photoacoustic Oxygen SaTuration sensor) – a new invention could help doctors to diagnose these brain disorders in the early stage for better treatment outcomes.

> The researchers from EEE's Centre for Bio Devices and Signal Analysis (*VALENS*) have created an iPhone size sensor to help doctors to detect shock in the early stage invasively. Their breakthrough could lead to more effective diagnosis that lead to better treatment of shock and other related brain diseases.

There are typical clinical features of shock, such as fast heart rates, low blood pressures, altered mental status and reduced urine output, but many patients may not exhibit these features.

Hemoglobin oxygen saturation of blood in the central veins (SvO_2), however, begins to fall *early* in shock even when blood pressures appear normal. The SvO_2 becomes lower than normal (<65%), reflecting a poor delivery of blood to oxygen-starved tissues, even when blood pressures appear normal. On the other hand, abnormally high levels of SvO_2 reflects a reduced ability of the tissues to metabolise oxygen. Thus, SvO_2 is an invaluable parameter for shock diagnosing.

Conventionally, SvO_2 can only be measured invasively using catheters in the right superior vena cava or in the jugular vein. The insertions of such catheters are by themselves risky, and only performed in selected patients.

POSTs, a novel portable sensor designed by the EEE researchers, which can detect SvO_2 accurately in a non-invasive manner. The sensor works by shining light of different colors into patients' neck and then "listening to" the resultant sound generated by the blood in the central vein to infer the SvO_2. The result is very accurate (~ 2%) since oxygenated and de-oxygenated hemoglobin show distinct signatures in absorbing different color of light and the generated sound waves could be accurately localized (<1 mm) with high signal to noise ratio.

Prof Zheng Yuanjin from EEE said: "The results demonstrate that POSTs has great potential in noninvasive SvO_2 measurement and could be used in the ICUs in the near future for early detection of shock, which reduces the onus of doctor and the pain of patients. Our ultimate goal is to get our POSTs device to penetrate to vast homecare market as well as for the Medicare."
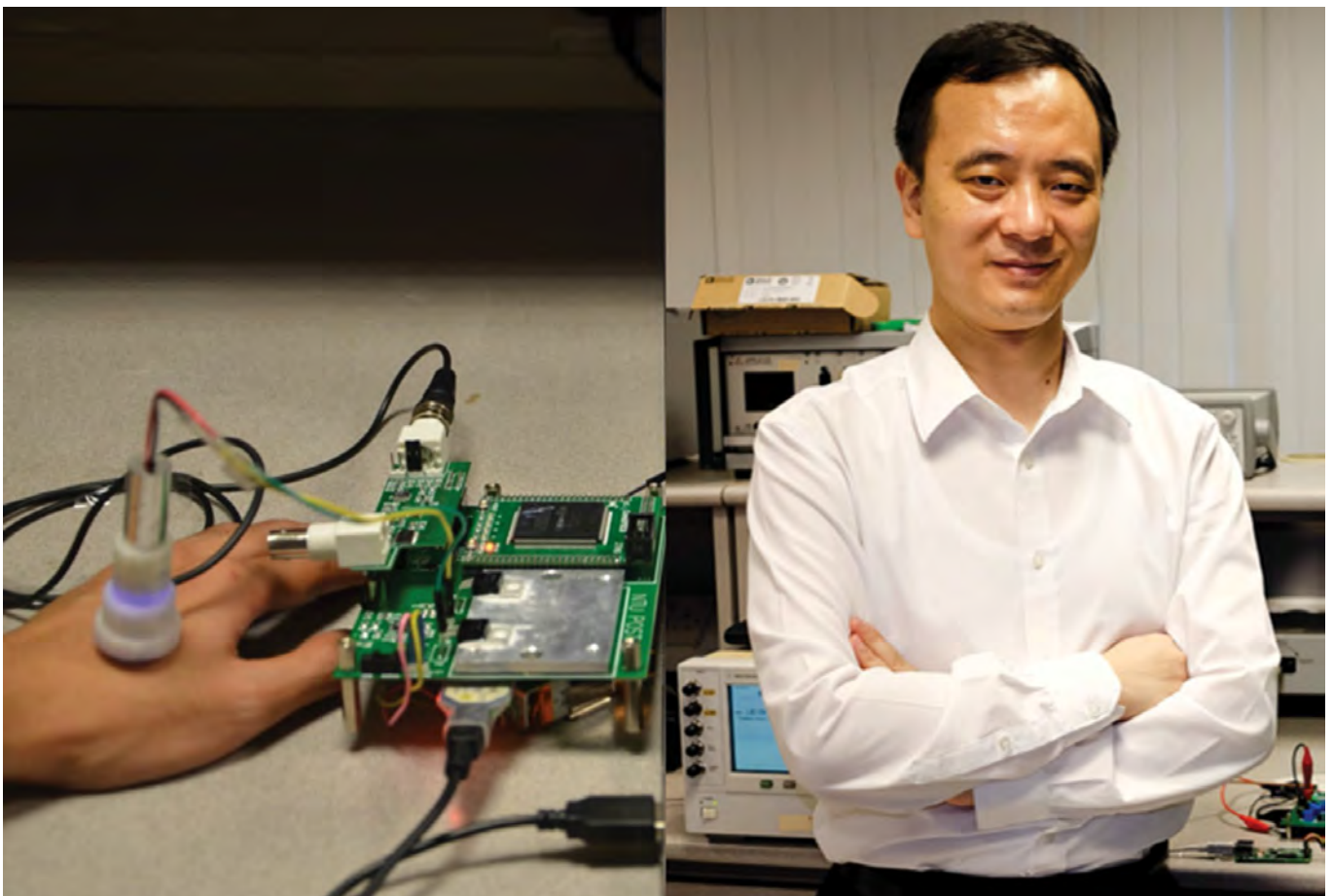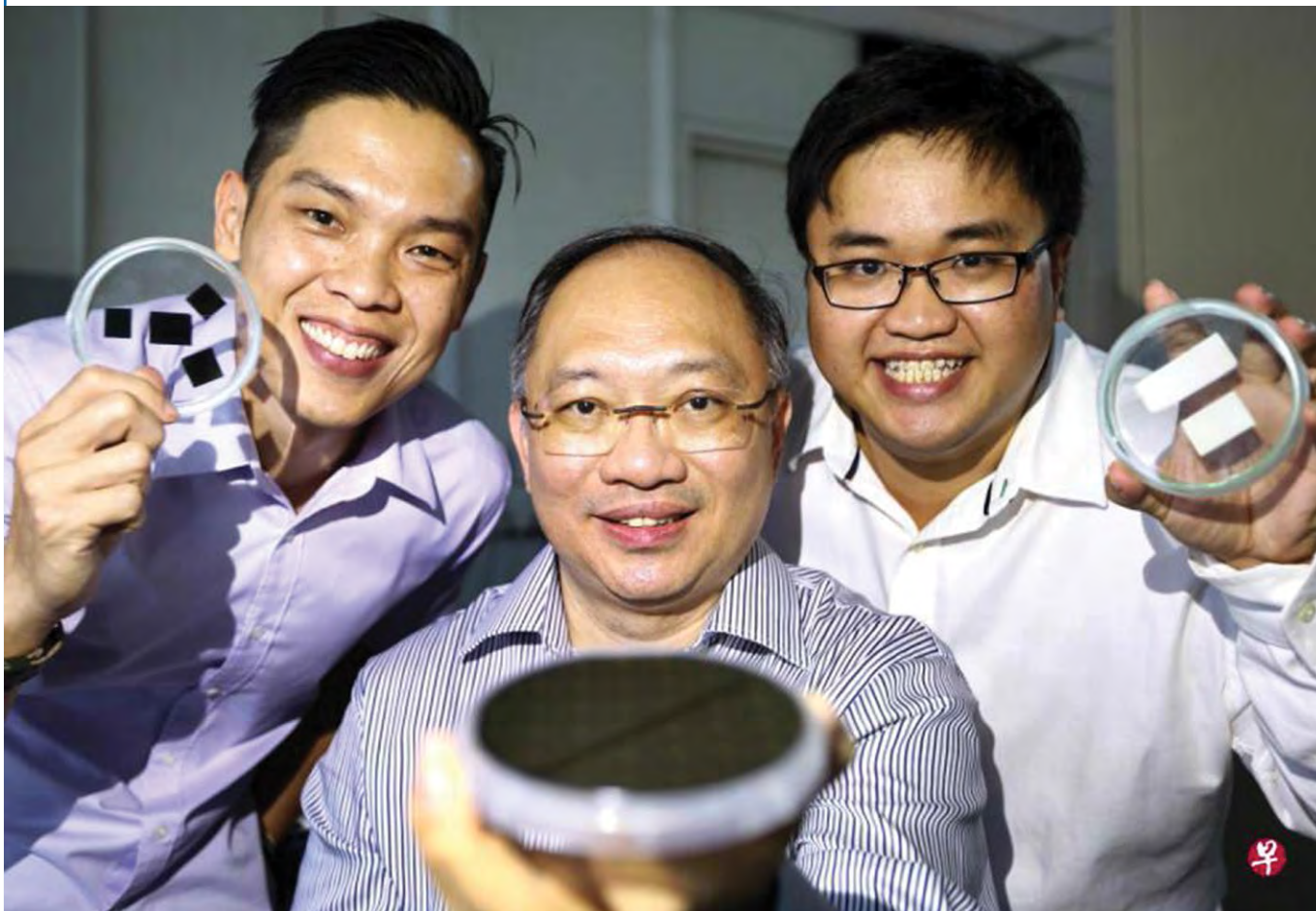
Smart Chip To Track Radioactive Substances
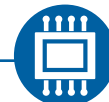
The Fukushima Daiichi nuclear disaster is a reminder of the far-reaching and irreversible impact of a nuclear crisis. Cleaning up radioactive material can be a complicated and expensive, estimated to last years or even decades. According to Prof Teo Hang Tong, Edwin, as many countries are growing interested in nuclear power and technology development, building a radiation monitoring network is a timely, proactive and necessary precaution to safeguard ourselves as well as monitor radiation levels in and around Singapore.

Integrating an advanced nano-material into the semiconductor chip fabrication, a smart chip that reads and monitors the radiation level in the environment had been conceptualized, and is being developed by a research team in the School of EEE. Prof Ng Geok Ing, who is leading the team explained that the smart chip will track the presence of neutrons that are released by the radioactive substances, generating electric signals that will be transmitted to the monitoring centres via wireless technology.

The cell prototype is expected to be ready in 1 to 2 years and will be nearly 600 times smaller than a 5-cent coin in size.

The current portable radiation detector works on helium, which is a finite, nonrenewable and declining resource. The new sensing smartchip is a promising alternative to this conventional detector model.

The team member, Prof Teo further visualized an assembly of high resolution radiation sensors, consisting of millions of miniaturized sensitive elements resembling high end camera image sensors that boast hundreds of megapixels. In addition to spotting the radiation source, the new radiation sensor plate will be able to generate the image of the radioactive substances.

The miniaturized smart chip can be deployed in diverse equipment such as unmanned vehicles or robots, sensor stations installed along borders, forming an extensive monitoring network to capture any trace of radiation.

Prof Ng highlighted a key usage of this technology in the anti-terrorism effort. The use of these smart chips will enable early detection of radioactive substances, commonly used as raw materials for dirty bombs.

A Smarter Way to Decode Brain Signals

Detecting and decoding brain signals is a crucial step in neuroscience research and neural prosthetics to help people with brain injuries and diseases. Researchers from Nanyang Technological University (NTU) have found a way to improve the process.

The scientists from EEE, working with other researchers, have developed a processing chip that uses less power to better detect brain signals and identify their neuron sources, a process called spike sorting. Their real-time processing, multi-channel chip is believed to be the first of its kind, and could lead to more compact neural implants.

The EEE-led scientists created algorithms for their on-chip sorter that strengthens the brain signals, filters out noisy data to better detect the relevant neural spikes, and cuts down on the information to classify the neural spikes.

"We can make the chip very compact because we've used the new algorithm to significantly reduce the power needed and the amount of data to be processed or sent outside of the brain," said Prof Tony Tae-Hyoung Kim from EEE.

The EEE-led scientists also developed another clustering algorithm that makes their chip "smarter" than its commercial counterparts. Traditionally, scientists have to input the mean values of neural clusters, with each cluster representing one neuron source, into a spike sorter's training engine component.

This means that the sorters can classify only pre-identified and programmed neural clusters.

The EEE-invented algorithm removes such limitations. It forms a new cluster for new data when the weighted distance of the new cluster to the existing clusters is larger than that between the existing ones.

The scientists fabricated a 0.414 millimetre square prototype of their chip, and verified its functionality using datasets. Prof Kim said: "To our knowledge, this is the first real-time, multi-channel spike-sorting chip that includes spike detection and alignment, feature extraction, dimensionality reduction and clustering." The developed spike sorting chip received Design Contest Award at IEEE/ACM International Symposium on Low Power Electronics and Design.
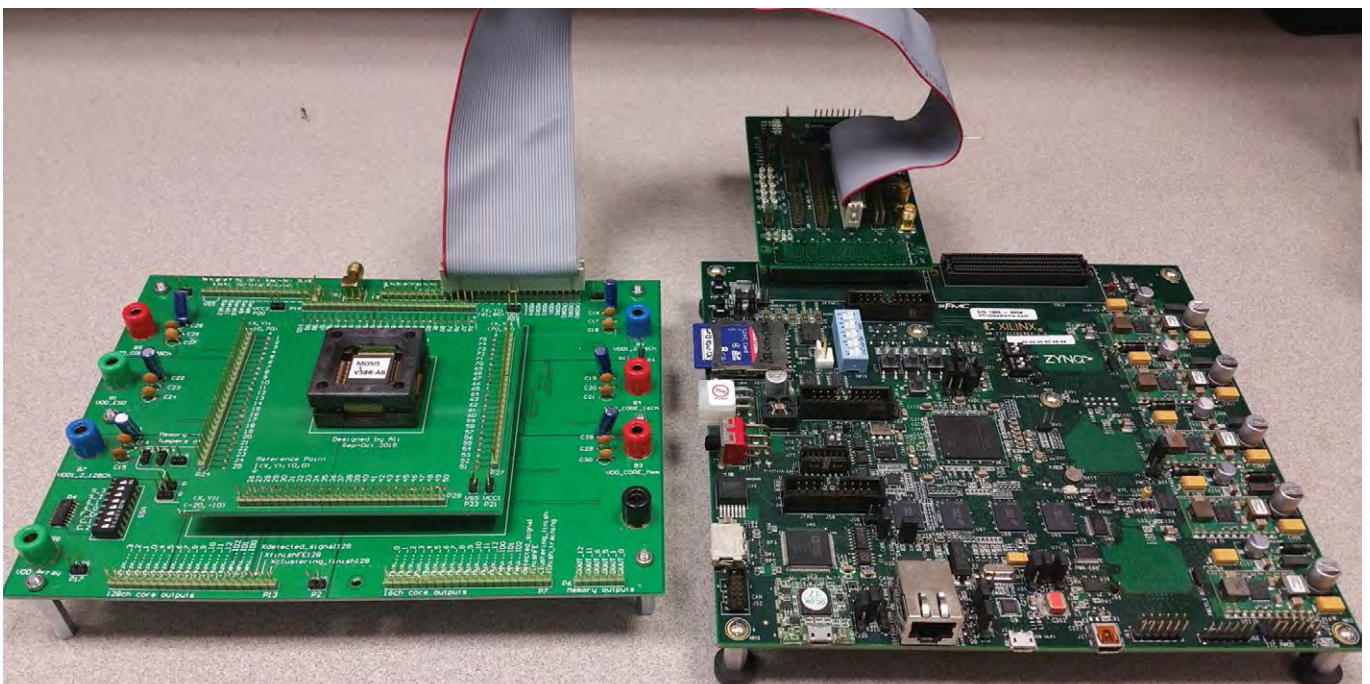
Industry Collaboration - Turn Ideas into Reality

In work, finding the right partner is everything. Over the years, Nanyang Technological University's School of Electrical and Electronic Engineering (EEE) has sought out the best firms in the world to help translate its research into products and services that can benefit not just Singapore, but also other countries near and far. Our collaborations with top-notch companies such as ST Engineering and NXP Semiconductors have yielded potential solutions to some of society's most pressing problems. In transport, we have launched a test-bed with NXP, on vehicle-to-everything (V2X) wireless communications technologies. These will lead to smarter vehicles that know how to avoid accidents and traffic congestion. The research will also bring EEE international visibility in 2019, when we showcase our work at the Singapore-hosted World Intelligent Transportation

Congress. Working with ST Engineering, Singapore-homegrown engineering group, we are close to producing smart robots and autonomous systems that can make airports more "intelligent", and survey disaster-stricken areas on their own and help save lives.

We continue strengthening our partnerships with the private sector, and established two joint laboratories, with Taiwan's Delta Electronics and local rail operator SMRT respectively.

The SMRT-NTU Smart Urban Rail Corporate Laboratory, a joint research facility to develop technology-driven solutions to build an urban rail system that is even more resilient and reliable as Singapore moves towards a car-lite future.

The Delta-NTU Corporate Laboratory for Cyber-Physical Systems will work on developing cyber-physical systems, ranging from large infrastructure systems such as water and power distribution to emerging consumer systems such as the Internet-of-Things (IoT), an ever-growing network of physical objects and systems connected to the Internet.

These outcomes would have not been possible without close partnerships between our faculties, research staff and their industry partners. By leveraging the School's scientific expertise and conglomerates' intimate knowledge of customer's need and requirements, we strive to become a powerful engine to turn ideas into reality.

Making Smarter Connections

From smartphones to air-conditioners that can be controlled remotely via the Internet, the world has never seen a greater proliferation of cyber-physical systems.

To help develop the next generation of smart technologies, Singapore's Nanyang Technological University (NTU) has partnered Taiwan's Delta Electronics to set up a $45 million, Delta-NTU Corporate Laboratory for Cyber-Physical Systems.

The joint laboratory will focus on physical systems that are connected through online networks. These can range from large infrastructure projects such as water and power distribution networks, to emerging, Internet-connected consumer products, such as advanced temperature and humidity sensors and "smart" lighting solutions.

When at full capacity, the laboratory will have more than 80 researchers and staff members, including NTU doctoral students. It will also collaborate with scientists from both NTU and the Delta Research Center, on its four key research areas: (1) Smart manufacturing, (2) Smart learning, (3) Smart living, and (4) Smart commercialisation.

Prof Xie Lihua from NTU's School of Electrical and Electronic Engineering (EEE), the laboratory's director, said: "Our vision is to be a world leader in cyber-physical systems (CPS) research and a solutions provider. To achieve this, we will build our core capabilities in advanced sensing and real-time analytics, CPS resilience and human-centric CPS design."

NTU President Prof Bertil Andersson added that the laboratory "brings together NTU's strong interdisciplinary research expertise and Delta's core competencies in power electronics and smart energy management, to create a unique research eco-system".

EEE and Delta Electronics had created another joint laboratory, focused on the Internet of Things, in November 2014. The new laboratory is supported by the Singapore National Research Foundation's Corporate Laboratory @ University Scheme, which funds key corporate laboratories set up through public-private partnerships.

EEE has three other Corporate Laboratories, set up with industry partners Rolls Royce, ST Engineering and SMRT respectively.

Keeping Commuters Moving

Cities that want to be car-lite, such as Singapore, will need an urban rail system that is reliable and resilient.

Now, Nanyang Technological University (NTU) has partnered transport operator SMRT to create a $60 million joint laboratory that will provide technology-driven solutions to keep rail systems moving quickly and efficiently.

Prof See Kye Yak from NTU's School of Electrical and Electronic Engineering, the laboratory's director, said: "The SMRT-NTU Corporate Laboratory has two research tracks: Developing better monitoring and detection systems to fix potential problems; and devising prediction methods and analytical tools to aid in preemptive maintenance."

With real-time data from sensors that monitor critical rail equipment, operators can make timely and accurate decisions to fix faults before they result in service delays.

Researchers in the laboratory will study various sensors, such as thermo-acoustic ones that detect temperature fluctuations within materials. These can be used to find cracks and defects that lie deep within rail components such as rail foots and joints.

Through 3D printing, the sensors can be customised to fit in previously inaccessible spots. The goal is to repair or replace faulty components on the same day that they are discovered.

With more advanced prediction and analytical tools, operators can also better assess the lifespan of their train components and systems, and optimise maintenance schedules.

Data analytics could tell operators how vibration and structural stresses could affect the longevity of various parts in the rail system. The laboratory's work could ensure that train and track components are performing at their best.

The laboratory will also provide training opportunities for more than 100 undergraduates, 35 graduate students and 60 researchers across a broad range of specialties. It hopes to nurture engineering specialists in the rail industry who will create solutions that are used globally.

The laboratory is supported by the National Research Foundation Singapore's Corporate Laboratory@ University Scheme, which funds key corporate laboratories set up through public-private partnerships.
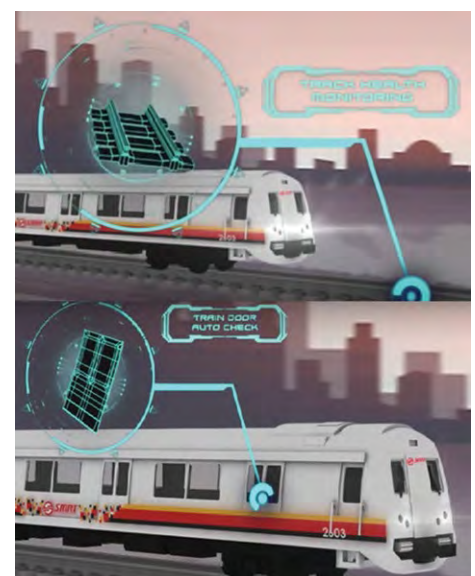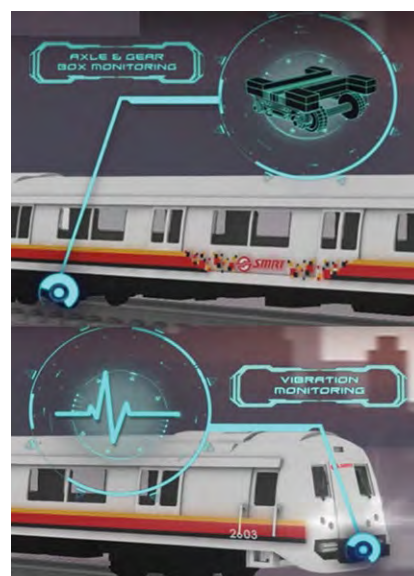
A Hub for Trailblazing Research

Underlying our research philosophy is the focus of translating innovative concepts into reality with commercial value. The listing of the 12 research centres are as follows:

Centre for Infocomm Technology (INFINITUS)

Information and communication engineering are priorities at *INFINITUS*, which has pioneered research in communications and network systems, sensors, cyber security, data analytics and other fields. Its recent projects include a test-bed for vehicle-to-everything wireless communications technologies, which will transform vehicles and create smarter transport systems. Its partners span local and international research and educational institutions and firms, such as Singapore Economic Development Board, the Asian Office of Aerospace Research and Development, and NXP.

www.infinitus.eee.ntu.edu.sg

Centre for Bio Devices and Signal Analysis (VALENS)

Striving to uncover the human body's workings and improve people's health, *VALENS* has four research priorities: lab-on-a-chip; bio-imaging; e-Health, which includes wearable devices to monitor health; and neurotechnology, where scientists develop methods to detect and predict neurological disorders. A recent collaboration with Massachusetts General Hospital and Harvard Medical School, for instance, resulted in a computer program to help doctors quickly diagnose epilepsy and predict seizures. *VALENS* also works with many Singaporean hospitals and international institutions.

www.valens.eee.ntu.edu.sg

LUMINOUS! Centre of Excellence for Semiconductor Lighting and Displays

How can cities be lit more efficiently to reduce their contribution to climate change? At *LUMINOUS!*, researchers aim to improve artificial lighting's energy use, to transform a sector that now makes up one-fifth of all electricity demand in the world. The scientists will investigate, for instance, excitons, which are particles that emit light as they decay. They are also developing high-efficiency LED lighting through innovative materials and fabrication. *LUMINOUS!*'s partners include Stanford University and the California Institute of Technology.

www.luminous.eee.ntu.edu.sg

Centre for Micro-/Nano -electronics (NOVITAS)

NOVITAS, Centre of Micro-/Nano-electronics, conducts research and development in micro/nanoelectronics. Its 32 faculty members, 36 researchers and more than 50 PhD students' research interests cover electronic material syntheses and characterizations, micro-/nano-electronic device design and fabrication, device performance evaluation, simulation and physical mechanism study, etc. *NOVITAS* collaborates extensively with local and global academic and industrial partners and it holds 52 on-going research projects with a total fund of S$40 million.

www.novitas.eee.ntu.edu.sg

Centre for OptoElectronics and Biophotonics (OPTIMUS)

The science of light, and how to control it for various uses, is at the heart of *OPTIMUS*. Its research areas include optoelectronics which studies of electronics and light converge through semiconductor technologies, and biophotonics which uses light to image, detect and manipulate biological materials. One project, for instance, could give users a point-of-care compact device for non-invasive inspection of adulteration and contaminations for food safety and healthcare. *OPTIMUS* has also partnered many organisations such as Harvard, MIT, Imperial College London, ASTAR, and various companies.

www.optimus.eee.ntu.edu.sg

VIRTUS, IC Design Centre of Excellence

An integrated circuit (IC, 'microchips') usually embodies millions of transistors and functions as the 'brain' of the myriad of electrical and electronic devices in our modern society – the major driver in humanity's third wave of invention and economic disruption. Research at the *VIRTUS*-IC Design Centre of Excellence encompasses most areas in IC design, ranging from contemporary areas to emerging areas, including organic/printed electronics on flexible substrates, the Internet-of-Things, Terahertz circuits-and-systems, satellite electronics, III/V-on-CMOS, Point-of-Care devices, etc. *VIRTUS* collaborates with major research universities, including MIT, Caltech, Cornell, etc., and with major industry players, including NXP, Infineon, Huawei, Mediatek, etc.

www.virtus.eee.ntu.sg

Centre for System Intelligence and Efficiency (EXQUISITUS)

Engineering systems among us are advancing to a level with high intelligence and efficiency. Urban traffic control, building air-conditioning systems, power grids, renewable energy systems, unmanned systems, are example of such complex engineering systems under research in the centre. *EXQUISITUS* develops core technologies to make these systems smarter and improve their performances. Main research areas include smart grids, power system control, renewable energy technologies, green cooling and air-conditioning technology, autonomous systems, machine learning, optimization, data analytics etc. Over the years, *EXQUISITUS* has worked with many universities and organisations including MIT, UC Berkeley, Cambridge University, Technological University of Munich, Rolls-Royce, Singapore Power, ST Engineering, Land Transportation Authority of Singapore, et al.

www.exquisitus.eee.ntu.edu.sg

Electromagnetic Effects Research Laboratory (EMERL)

Though invisible to the naked eye, electromagnetic fields are all around us and can interfere with electronic devices. *EMERL* – short for the Electromagnetics Effects Research Laboratory – researches and measures electromagnetic effects on military and commercial electronic systems. Spearheaded by NTU and Singapore's defence organisation DSO National Laboratories, *EMERL*'s goal is to achieve the safe and innovative use of electromagnetic fields in new technologies. Its research could lead to increasingly compact electronic systems with high immunity to electromagnetic fields.

www.emerl.eee.ntu.edu.sg

Satellite Research Centre (SaRC)

The Satellite Research Centre or *SaRC*'s high-flying research includes putting into space Singapore's first locally-built satellite, the X-SAT, in 2011. Since then, it has developed and deployed five more satellites. Its researchers are also pushing the frontiers of satellite technology with innovations such as a fault-tolerant electronic system, precision navigation hardware, sensors, advanced control and electric propulsion system etc. In 2009, it started training students in various fields including advanced payload and satellite development from pico- to micro-satellites. Its goal is to become a centre of excellence in small satellite technology.

www.sarc.eee.ntu.edu.sg

Centre for Optical Fibre Technology (COFT)

Optical fibres as thin as human hair can transmit vast quantities of data from one place to another. The Centre for Optical Fibre Technology (COFT) gathers fibre-based technology and applications in Singapore under one roof hosted by the school of EEE, NTU. *COFT* has also partnered the overseas universities and research groups to develop ways to manufacture special optical fibres and related technologies. *COFT*'s goal is to become a hub for optical fibre fabrication and fibre-based devices research.

www.coft.eee.ntu.edu.sg/

Rapid-Rich Object Search Lab (ROSE)

In Internet searches, a picture could be worth a thousand words. The Rapid-Rich Object Search or *ROSE* Laboratory is a collaboration between NTU and China's Peking University to boost the efficiency and effectiveness of image-enabled search from mobile devices or over the Internet. In particular, the lab is focusing on the classification, recognition, retrieval, and tracking of visual objects in images and videos. The *ROSE* Lab is also constructing a large structured object database, which will contain millions of images in domains related to tourism, e-commerce, humans and lifestyle and hobbies. It will work with Internet giants and industry leaders to commercialise its research.

rose.ntu.edu.sg

Silicon Technologies, Centre of Excellence (Si-COE)

Silicon is found in virtually all electronics and has transformed every aspect of our economy, including information technology, transportation, energy production, and national security. The Silicon Technologies, Centre of Excellence or *Si-COE* aims to find new uses for it in sectors from multi-purpose healthcare wearables to energy efficient sensors for Internet of Things. Its four research focuses are the use of silicon in advanced sensors, new silicon chips intermixed with compound semiconductors, three-dimensional integrated circuits, and innovative solutions to dissipate heat in microchips. It has established research partnership with multinational corporations like GLOBALFOUNDRIES, Infineon, Hewlett Packard as well as Institute of Microelectronics in Singapore.

www.sicoe.ntu.edu.sg

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