Chemical and Biomolecular Engineering

Getting the most out of the sun

NUS CDE researchers combine perovskite and organic semiconductors to create next-generation thin-film photovoltaic cells.

Photovoltaic cells, fundamental components of solar panels, continue to be a cornerstone in the renewable energy sector and are poised to surpass coal as the world's largest source of power capacity in the next few years.

At the College of Design and Engineering (CDE), National University of Singapore (NUS), researchers such as Assistant Professor Hou Yi from the Department of Chemical and Biomolecular Engineering continue to innovate at the forefront of solar technology, designing photovoltaics that are more efficient at converting sunlight into electricity.

Image above was created with the assistance of DALL·E 2

Some of Asst Prof Hou's inventions include solar cells composed of perovskite and organic semiconductors, which complement each other to offer both flexibility and efficiency that leapfrog conventional counterparts. These advancements are a crucial cog in the engine steering the world toward a greener and more sustainable future, unlocking more of the sun's potential to provide a clean and abundant source of power.

Mix and match

While conventional, silicon-based solar panels have become a common means of harvesting the sun's energy, they are also quickly nearing their theoretical maximum efficiency, known as the Shockley-Queisser limit.

An approach to work around this barrier involves employing a different material, such as perovskite, which excels at absorbing light compared to silicon. It also exploits untapped regions of the solar spectrum. By integrating thin perovskite layers with other solar cell technologies, in a configuration known as tandem solar cells (TSCs), researchers have exceeded the efficiency limits of single-material solar cells.

At NUS CDE, researchers are exploring the use of organic semiconductors in place of silicon, and in tandem, which could lead to more adaptable and flexible ultra-thin solar cells for applications like vehicle- and building-integrated photovoltaics.

"Perovskite/organic TSCs offer a blend of flexibility and efficiency that surpasses traditional solar technology with their tuneable chemical composition and bandgap," says Asst Prof Hou. "However, their performance still lags behind other thin-film technologies."

These TSCs face issues like open-circuit voltage losses, impacting the cell's efficiency in converting solar energy into electricity. Additionally, their performance is further impeded by inefficiencies in the layers that connect different parts of the cell.

Rolling out efficient ultra-thin solar cells

Asst Prof Hou's research team implemented two key strategies to address these challenges. Firstly, they used benzylphosphonic acid to passivate the nickel oxide hole-transport layers (HTLs) — the 'highway' for moving positive charges towards the metal electrode. This modification reduced surface recombination losses,

enhancing the open-circuit voltage in the perovskite layer, and thus the power conversion efficiency of the cell.

The second strategy involved engineering a four-nanometre-thick interconnecting layer of iridium zinc oxide (IZO), sandwiched between organic bathocuproine and molybdenum oxide. With its excellent electrical and optical properties, the layer improved electrical conductivity and boosted near-infrared light absorption.

Together, the passivated nickel oxide and IZO layers enabled the perovskite/organic TSC to achieve an impressive power conversion efficiency of 23.60%, with high stability maintained over 20 days of continuous use.

Additionally, Asst Prof Hou's research revealed crucial insights into the design of interconnecting layers in perovskite-based TSCs. Discussing the complex interplay between the surface coverage of the layers, the directional movement of charge carriers and the lifespan of electron-hole recombination processes, the team's findings provide a blueprint for optimising interconnecting layers to enhance the overall efficiency of TSCs.

"We are excited by the outcomes of our research, which shows the great potential of perovskite/organic TSCs to rival or even surpass the performance of other existing thin-film TSCs in module sizes," says Asst Prof Hou. "Further innovation in narrow-bandgap organic materials, improving the stability of HTLs and suppressing phase segregation in wide-bandgap perovskites are vital next steps for advancing these solar cells."

The team's findings were published in *Nature Energy* on 20 January 2022. ◆

Industrial Design

Serving innovation on a ceramic platter

Innovative ceramic wares with built-in electronic circuits are capable of responding to touch, temperature and moisture, blending technology with everyday items to create convenience and connection.

Sometimes, innovation hides in plain sight. Or in items you'd least expect. Such as the breakfast china used to hold scrambled eggs or the porcelain bowl cradling a comforting serving of ramen or the decorative vase brightening up a living room.

Image above was created with the assistance of DALL·E 2

All these items share a common denominator: ceramic. It's ubiquitous — yet often overlooked and underutilised. Assistant Professor Clement Zheng from the Division of Industrial Design (DID) at the College of Design and Engineering, National University of Singapore, sees untapped potential in glazed ceramics and has infused these common objects with his ingenious touch — by integrating electronic circuits to bring them to life.

Assistant Professor Clement Zheng embedded interactive circuits into ceramic wares, transforming everyday objects into human-computer interfaces and smart devices.

Asst Prof Zheng's research introduces a fresh approach to embedding interactive circuits into ceramics. By carving traces on the ceramic surfaces and filling them with conductive ink, his work has transformed everyday objects into human-computer interfaces and smart devices that can participate in daily activities — from touch-sensing tableware to temperature-sensitive tiles to moisture-aware flowerpots.

This approach was published in a paper presented at the 2023 CHI Conference on Human Factors in Computing Systems.

When craft and computing collide

In 'ubiquitous computing', computational technology disappears and weaves itself into the fabric of everyday life. This concept guided Asst Prof Zheng and his team as they explored the potential of interactive circuits on glazed ceramic ware. Drawing inspiration from smart textiles and touch-sensitive surfaces led to the eureka moment where they imagined a future in which everyday ceramic objects could be transformed into interactive interfaces.

Bringing together a unique blend of expertise, involving professional designers and builders of interactive systems, the multidisciplinary team "aimed to entangle the materiality of the investigated craft with the physical and computational materiality of tangible interfaces and interactive electronics."

The process began with masking the ceramic surfaces using adhesive vinyl film cut into intricate patterns. Using an adaptation of resist-blasting, a technique developed by Associate Professor Hans Tan from DID, the team then sandblasted these masked surfaces to carve out the circuit traces on the surfaces. Once the masking was removed, the recessed areas formed the foundation for the circuits.

Next, they adorned these recessed traces with conductive inks, creating functional — and aesthetically pleasing — electronic traces. This meticulous process transformed ordinary ceramics into smart devices capable of sensing a range of parameters, from touch to temperature to moisture.

Applications galore

Integrating interactive circuits into glazed ceramics opens up a world of practical — and intriguing — applications. Take tableware, for instance. Like the bashful touch-me-not plant, plates and bowls embedded with circuits can respond to touch, controlling ambient music or lighting during meals, as part of an overarching smart-home system. Or imagine a colour-shifting plate that senses the temperature of the food it holds, adding a new dimension to culinary presentation.

Temperature-sensitive tiles can monitor the heat levels of kitchens and bathrooms in real-time, providing visual feedback and enhancing occupant safety. For instance, sensors on the back wall of a kitchen stove can indicate if a stove is in use, or if there is a fire. In the bathroom, sensors can point out if there is a leak, or if the floor is wet.

Smart ceramics can also cultivate better plant owners. Moisture-aware plant pots can monitor soil hydration levels and alert users when plants need watering — a clever blend of technology with gardening for improved plant care.

Reciprocating warmth and conviviality

The researchers' smart ceramics also unlock new avenues for expression. One of Asst Prof Zheng's creations, *Reciproco*, conceived together with independent designer and artist Genevieve Ang, was proudly showcased at Future Impact 2, an exhibition of new works by a select group of Singaporean designers who were commissioned by Design Singapore Council.

Reciproco comprises a pair of interactive ceramic pieces coated in glaze formulated with glass waste and enhanced with

"*Reciproco* is about presence and how materials and technology can support communication between two people."

thermochromic paint. The piece changes colour when the surface is activated. It is also heated with circuits embedded into the ceramic body that are triggered when touched.

"If someone places their hand on one, the other — whether it's across the room or on the other side of the world — will heat up in response," says Asst Prof Zheng. "*Reciproco* is about presence and how materials and technology can support communication between two people."

Crafting ceramics of the future

Asst Prof Zheng is keen on addressing larger infrastructural needs to integrate smart ceramics into homes. "For example, while acrylic placements were a clever way to connect ceramics to a microcontroller, everything has to be carefully placed so that the conductive pads align with the pins of the placemat," adds Asst Prof Zheng.

This includes developing specialised hardware components and collaborating with interior designers, builders and electricians to explore how ceramic interfaces — and the required electronics infrastructure — can be threaded into living spaces more seamlessly. Additionally, other future work being considered includes developing new computational design algorithms and digital fabrication processes to further enhance interactive ceramic systems. ◆

Biomedical Engineering

The biomedically engineered biomedical engineer

Harnessing digital devices to monitor the progress of health regimens reveals the potential of gamification to enhance adherence and optimise health.

Recall the last time you decoded a seemingly impossible riddle, claimed victory over the 'final boss' in Super Mario Bros., or got out of a tight situation in an Escape Room at the very last minute. You likely breathed a pleasurable sigh of relief — one charged by dopamine, a hormone secreted in a specific area of our brain known as the reward centre — and subsequently experienced an arcane rush of motivation. *Game on*, you uttered to yourself.

Image above was created with the assistance of DALL·E 2

Professor Dean Ho revealed the potential of gamification to enhance adherence to health regimens and optimise health.

The appeal of gameplay is anything but a mystery, and the 'feel-good' hormone is the invisible character pulling the strings. An expert game designer pours a lot of thought into crafting challenges that consider player agency, flow, goals, preferences, motivation and rewards — all to engage the players' dopaminergic system, inducing a sense of motivation and perseverance, ultimately engendering behavioural change.

Beyond the gaming lexicon, this strategic process is known as gamification. Astute businesses apply it to train employees and boost customer engagement. Educators use it to nudge disinterested students to complete their coursework. When gamification is harnessed judiciously, benefits abound.

Indeed, one might consider that healthcare is poised to reap the bountiful rewards of gamification. This is especially pertinent against a backdrop of global ageing, where healthcare resources struggle to meet the demand for long-term, centralised care. As older adults become increasingly digitally savvy, gamification offers an opportunity, through technology, to strengthen intervention design and reach older populations with more health initiatives.

Professor Dean Ho, Head of the Department of Biomedical Engineering, College of Design and Engineering, National University of Singapore (NUS), has personally experienced the positive effects of gamification in healthcare. In his first-of-its-kind study, in which he was the sole subject, Prof Ho essentially became a biomedically engineered biomedical engineer. He explored how the marriage of data and digital technology could sustain intermittent fasting and improve health outcomes. He found that keeping an eye on vital biomarkers could in turn become a source of motivation for him to stick to his health regimens, leading to significant health improvements — an insight that could inform strategies to help older persons manage their health more effectively.

The findings were published in the journal *PNAS Nexus* on 30 May 2024.

Through a gaming lens

A fitness enthusiast, Prof Ho, who's also the Director of both the Institute for Digital Medicine (WisDM) at the NUS Yong Loo Lin School of Medicine (NUS Medicine),

and the NUS N.1 Institute for Health, grounded his work in studying the process of ketosis and its health benefits. Ketosis flicks the body's metabolic switch to burn fat for energy instead of glucose, and is linked to weight loss and better management of type 2 diabetes. The ability to achieve this energetic switch declines during the ageing process. As such, the measurement of metabolic flexibility served as a surrogate marker for Prof Ho's metabolic health during this study.

Prof Dean Ho with a glucose monitor patch on this arm, and meals that he consumed, consisting of leafy greens, nuts, chicken breast, salmon and avocado. (Credit: Prof Dean Ho)

From May to November 2023 Prof Ho documented his journey on his regimen. He fasted for at least 20 hours daily and started each day religiously with strength or cardiovascular training. Leafy greens, lean proteins, seeds, olive oil and other Mediterranean staples formed his diet. He drank only water, black coffee and black tea, without milk or sugar. Sensors and wearables monitored his health metrics, such as blood ketone levels, blood glucose, blood pressure and body weight.

The health outcomes were remarkable. Prof Ho shed about 7.5 kilograms, gained 20% more grip strength and could lift weights 10% heavier than before. He also achieved the impressive feat of completing 1,000 push-ups in under 40 minutes. These results highlight the potential of combining intermittent fasting with a disciplined fitness and dietary regimen.

"Using digital health technologies to monitor my progress represents a shift towards more personalised and engaging health management."

Above all, the gamification aspect of Prof Ho's regimen was salient. "Using digital health technologies to monitor my progress represents a shift towards more personalised and engaging health management," says Prof Ho. "By observing the dynamics in health responses to different interventions, sticking to a health regimen can be converted into a game-like experience."

Akin to the ups and downs a player experiences in heart-thudding gameplay, Prof Ho's ketone levels followed a discernible, repeatable pattern as he adhered to his regimen every day: high in the morning, plummeting after his workouts and soaring again before breaking fast in the evening. While this demonstrated that ketone levels fluctuate according to various activities such as fasting and exercise, it also indicates that the metabolic switch can serve as a clear and measurable 'target' for participants to reach.

"This means health management can be *dynamically* personalised at the individual level," adds Prof Ho. "For instance, visualising how various biomarkers change and progress during a health programme can make the process more engaging — encouraging the participant to stick to the plan and achieve improved health outcomes over time."

Data-driven incentives for healthy ageing

While Prof Ho's regimen required a lot of discipline, the approach can be tailored to an individual's preferences and habits for sustained user engagement. "Initiating small habits is a good way to build towards a more comprehensive health regimen," advises Prof Ho. "It is key to enjoy the process, and not jump right into an intense fasting regimen."

As global ageing unfolds, managing concomitant disorders such as metabolic diseases and frailty will be an increasingly essential component of the demographic shift. New approaches to promote healthy behaviours at the population level will therefore be key. This study raises a question: can personalised health interventions infused with digital technology be effectively implemented on a large scale?

Gamification, the welcome byproduct of digital transformation in healthcare, may address the psychological aspects of health management, and may therefore provide better — as well as far-reaching — strategies for health promotion, prevention and self-management of chronic conditions. This could alleviate the already-strained health system — by encouraging non-critical patients to complete assigned tasks and reducing paperwork, clinic visits and other administrative tasks. Perhaps weaving an element of fun into healthcare could be the next winning strategy for health optimisation. ◆

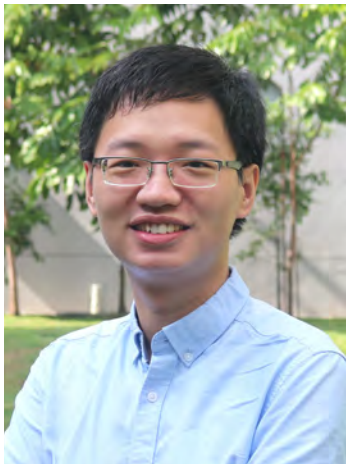
Materials Science and Engineering

Learning from the platypus's 'sixth sense'

By integrating triboelectric and visuotactile sensing, a novel bionic electro-mechanosensory finger achieves both remote control and tactile perception, mimicking the platypus's ability to sense electronic signals in murky waters and respond to physical stimuli.

If Mother Nature had a wonderfully weird child, it would very well be the platypus. This duck-billed, otter-footed, beaver-tailed, egg-laying mammal has an assemblage of traits like no other. And if its appearance alone somehow fails to impress, the Australian native has another trick up its furry sleeve: a so-called 'sixth sense', based on electro- and mechano-reception.

Image above was created with the assistance of DALL·E 2



Associate Professor Wu Changsheng invented a novel bionic finger capable of both touchless and tactile perception.

The platypus's bill comes adorned with specialised nerve endings that detect faint electrical signals generated by the muscular contractions of its prey. Meanwhile, push-rod mechanoreceptors on the bill sense changes in pressure and motion. This evolutionary adaptation is particularly crucial as the animal often feeds on bottom-dwelling invertebrates like shellfish and worms.

Flipping the biomimicry manual open, can the monotreme teach us a thing or two about sensing? Assistant Professor Wu Changsheng from the Department of Materials Science and Engineering at the College of Design and Engineering, National University of Singapore, believes so. Inspired by the platypus's super-sensory organ, Asst Prof Wu led a team to develop a bionic finger capable of both touchless and tactile perception, taking human-robot interaction (HRI) to a whole new level. Whether operating in the air or underwater, the team's innovation could improve how robots interact with their surroundings, and more importantly, with humans.

The team's work, which was an international, academia-industry collaboration involving Tencent Robotics X and Tsinghua University, was published in *Nano Energy* on 19 August 2023.

It makes sense

As the globe experiences rapid ageing, the need for healthcare solutions tailored to the elderly arises. Robots that can safely interact with humans are a key enabler in this context, from assisting with daily tasks to delivering healthcare services in hard-to-reach areas. Crucially, the effectiveness of these robots hinges on their ability to sense and interpret their surroundings adeptly.

"Creating sensors that can do so is challenging — as human-friendly robots need to sense remotely and tactilely," says Asst Prof Wu. "In that regard, traditional sensors often struggle to detect non-contact stimuli, such as the presence of objects in the environment, and lack the resolution needed for precise tactile feedback."

Drawing inspiration from nature, Asst Prof Wu's team assembled an electro-mechanosensory finger (EM-Finger) — a bionic device that emulates the platypus's extraordinary sensing abilities. The device is designed with a triboelectric sensor

array and a finger-shaped visuotactile sensor — all housed within a structure that resembles a human finger. The triboelectric sensor, made from a liquid-metal-polymer conductive layer, serves as the electrode for the sensor array while also acting as a reflector in the visuotactile sensor system. The entire structure is encapsulated in a dielectric layer, protecting it from environmental wear and enabling its amphibious capabilities.

"Sensors that operate both in air and underwater are crucial for ageing populations and healthcare, particularly for ensuring continuous and safe interactions in different environments."

Together, these components enable the EM-Finger to encode both touchless and tactile interactions into voltage signals — effectively enabling it to 'feel' its environment — much like a platypus does. In particular, the triboelectric sensor responds to electrical stimuli in air and underwater without the need for contact, while the visuotactile sensor captures detailed information about the surfaces with which it comes into contact.

"Sensors that operate both in air and underwater are crucial for ageing populations and healthcare, particularly for ensuring continuous and safe interactions in different environments. Elderly individuals often face higher risks of falls or accidents in wet environments, like bathrooms," Asst Prof Wu adds. "Amphibious sensors allow robotic systems to reliably assist in these conditions — whether handling slippery objects or providing support — reducing the risk of injury and ensuring safer, more dependable care in critical situations."

With the help of a deep-learning algorithm, which fuses data from both sensors, the EM-Finger operates in complex and unstructured environments with ease. In an experiment, it successfully classified 18 different materials, from acrylic to glass to resin, with an accuracy of 94.4% (the triboelectric sensor alone achieved only 67.4%).

Sensing a step change

The team's EM-Finger taps into a whole new world of possibilities for real-world applications, enhancing HRI to improve quality of life, particularly in healthcare and eldercare.

"Going forward, more practical applications can be realised by bridging the interface between the EM-Finger and robotic systems, particularly in healthcare for ageing populations," adds Asst Prof Wu. "The EM-Finger's ability to perform both touchless and high-resolution tactile sensing could enhance assistive robotics, enabling remote patient monitoring and delicate object manipulation. We envision the finger's design as the key that unlocks truly intelligent robots capable of intuitively perceiving and interacting with their environment, improving care delivery through precise, non-invasive assessments." ◆

Accelerating the discovery of spine issues with AI

Developed by the Department of Diagnostic Imaging at NUH, Spine AI slashes the time needed for radiologists to interpret MRI scans by more than half, enabling faster diagnosis and treatment of lumbar spinal stenosis.

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Singapore's population is ageing rapidly. By 2030, one in four Singaporeans will be over 65, compared to one in 10 in 2010 — a demographic shift that will lead to an increase in age-related health conditions. Among these, lumbar spinal stenosis, a narrowing of the spinal canal in the lower back that leads to nerve compression, is common among older persons. It can cause significant discomfort, limiting mobility and quality of life.

This condition, which typically presents with pain and cramping in the legs and buttocks, relies on MRI scans for diagnosis. Against the backdrop of an ageing population, the volume of scans is expected to surge. This places greater pressure on radiologists to interpret these scans efficiently while maintaining diagnostic accuracy.

This has spurred healthcare professionals to turn to artificial intelligence (AI) technologies, such as Spine AI developed by the Department of Diagnostic Imaging at the National University Hospital (NUH). The AI-driven tool improves the consistency, accuracy and objectivity of MRI scan assessments, reducing the interpretation time by more than 50 per cent.

A better view of the spine

Diagnosing lumbar spinal stenosis is a tedious process.

> *"After an MRI of the lumbar spine, a radiologist will manually assess five spinal segments, each with five potential sites for stenosis, resulting in 25 regions that require analysis, which can take 10 minutes or more," shares Dr Andrew Makmur, Consultant, Department of Diagnostic Imaging, NUH. "Reporting can be repetitive and time-consuming too. There are multiple grading systems for lumbar spinal stenosis, with a lack of standardisation."*

Spine AI streamlines this process. Trained on lumbar MRI studies from 446 patients and comprising over 18,000 images, the tool uses deep-learning algorithms to automatically detect areas of stenosis in the lumbar spine and grade their severity.

> *"It overlays colour-coded boxes along each site, enabling radiologists to verify the findings quickly, and even auto-generates a report," says Dr James Hallinan, Senior Consultant, Department of Diagnostic Imaging, NUH.*

Efficiency gains

Spine AI brings a step change in diagnostic efficiency — reducing the time it takes to interpret a scan from 10 minutes to just three. A seven-minute reduction may appear modest; but it adds up quickly — NUH handles about 4,000 lumbar MRI scans annually, translating to approximately 466 hours saved. This frees up valuable hours for radiologists to focus on more complex cases.

Promisingly, Spine AI's potential extends beyond Singapore's shores. NUH has partnered with a leading medical technology company to optimise the tool's user interface and user experience, aiming to bring it to the global market as a more efficient solution for managing spinal imaging at scale.

Banking on stool as a tool to treat diseases

Southeast Asia's sole stool bank taps into the potential of gut microbiome to treat a myriad of conditions, from inflammatory bowel disease to irritable bowel syndrome to *Clostridioides difficile* infections.

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Tucked away in the Singapore Science Park, a hub for research, development and technology in Queenstown, lies a rather unconventional 'bank'. Here, you won't find gold or money secured behind vaults, but rather something unusual.

Operated by a local start-up, this bank stores stool samples, from which gut microbiome is harvested for faecal microbiota transplantation (FMT). The sole stook bank in Southeast Asia, of which Dr Jonathan Lee Wei Jie, Senior Consultant, Division of Gastroenterology and Hepatology, Department of Medicine, National University Hospital (NUH) is a co-founder, has pioneered FMT in Singapore. By introducing healthy gut bacteria into patients, this technique has shown immense potential in managing and treating a variety of conditions, such as *Clostridioides difficile (C. diff)* infections and inflammatory bowel disease.

One person's poop, another's life-saving potion

The gut microbiome is a diverse ecosystem of microorganisms, spanning fungi, bacteria and viruses, that reside within the gastrointestinal tract. Whether extracting energy from what we eat or creating crucial compounds such as neurotransmitters, enzymes and vitamins, these microscopic critters play a key role in regulating many physiological processes, from blood sugar regulation to immune system support and even mood modulation.

Maintaining a healthy, balanced gut microbiome is vital for overall well-being. Disturbances in this microbial community can often lead to a host of health issues, ranging from gastrointestinal disorders and obesity to impacts on mental health.

> *"This is where FMT steps in to mitigate disease," says Dr Lee. "Currently, FMT is primarily used to treat severe, recurrent C. diff infections — a condition characterised by watery, and sometimes bloody, diarrhoea, severe dehydration, fever and nausea."*

This condition, which can be life-threatening, often arises after a course of strong, broad-spectrum antibiotics, which indiscriminately kill most gut bacteria, leaving only the most resistant strains behind. These surviving bacteria can wreak havoc on the patient's microbiome, bringing about serious infections.

> *"By injecting healthy gut microbiota into a patient affected by C. diff infections via endoscopy, a 15-minute process, we've seen remarkable success in treating the disease," says Dr Lee. "Last year, 19 out of 20 patients who received this therapy experienced no recurrence of C. diff infection after a single microbiota infusion, with only one requiring a second infusion ten months later."*

Promising poop potential

For FMT to be effective, stringent protocols govern the collection and processing of gut microbiota to ensure the final liquid remains potent. For instance, careful attention must be paid to the rewarming process to prevent oxidation, which could reduce the treatment's effectiveness.

> *Dr Lee emphasises the importance of a reliable source of healthy gut microbiota, which hinges entirely on stool donations from volunteers. "Only the healthiest individuals meet the strict criteria, with fewer than two out of 100 donors qualifying," he notes.*

The gut microbiota has, in recent years, been thrust into the scientific limelight, with researchers probing its potential in developing biomarkers for various neurological disorders such as autism, depression and Alzheimer's disease, as well as metabolic conditions such as diabetes and fatty liver disease.

In Singapore, Dr Lee is leading two clinical trials at NUH, one of which focuses on treating irritable bowel syndrome (IBS), a chronic condition that causes unpleasant abdominal symptoms, including constipation, diarrhoea, gas and bloating. This year, 110 patients will take part in Singapore's first clinical trial using locally sourced faecal microbiota, fashioned into pills, for IBS treatment.

> *The second trial targets inflammatory bowel disease (IBD), another chronic condition that triggers painful flare-ups in the gastrointestinal tract. This trial explores the incorporation of FMT into existing therapies, with preliminary results showing improvement in four out of six participants. "As IBD cases rise in Singapore, with NUH's patient numbers doubling over the past five years, exploring this promising treatment modality is particularly timely," adds Dr Lee.*

These investigations will be part of NUH's new National University Centre for Digestive Health (NUCD), which will spearhead efforts in research, clinical practices and the development of new technologies to enhance the early detection, diagnosis, treatment and prevention of gastrointestinal-related diseases.

Navigating the complex terrain of cancer with AI

Researchers at NUH are harnessing machine learning to map cancers, offering a clearer view of how cells within tumours behave to design and develop more effective treaments.

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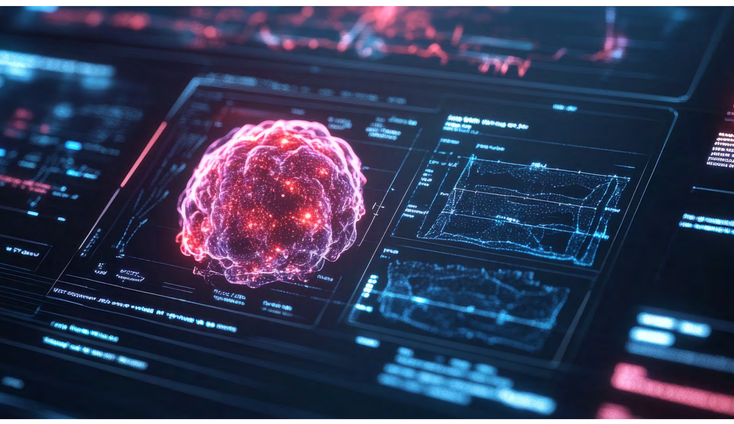

What if, like a tourist effortlessly traversing unfamiliar terrain with the help of a reliable navigation app, we could map every cell within a tumour — enabling us to visualise and understand not just which cells are present, but also their precise locations and how they 'talk' to one another?

Researchers call this approach 'spatial biology'. Dr Anand Jeyasekharan, Senior Consultant, Department of Haematology-Oncology, National University Cancer Institute, Singapore, is leveraging the technique to battle cancer, where advanced imaging equipment is used to analyse cancer with high molecular detail.

Mapping the future of cancer care

Spatial biology strips down biological systems to their key components, such as gene and protein expression, analysing them in three dimensions. It explores how cells and molecules are distributed within and interact across a tissue, what their environment indicates about their behaviour, and where they are located and why.

Consider embryonic development — a process in which humans and other organisms grow from a single cell. By deciphering how various cell types organise into complex tissue architectures, and subsequently, into a final form, scientists can decode the mechanisms through which embryos develop, uncovering insights into organ and tissue formation.

In the context of oncology, tumours are dynamic ecosystems composed of malignant and non-malignant cell types — cancer cells, stromal cells and immune cells — that evolve rapidly in response to various internal and external factors.

"Studying the body's reaction to cancer cells is like observing a battlefield where two armies are programmed to annihilate each other," says Dr Jeyasekharan. "Examining cells in their natural context and understanding cell-to-cell communication within tumours could help us detect tumours faster, deliver more accurate diagnoses and identify key targets for personalised anti-cancer drugs."

AI provides a shot in the arm

Artificial intelligence (AI) is a crucial enabler in Dr Jeyasekharan's spatial biology approach. "AI algorithms can process and analyse vast quantities of imaging data, identifying subtle patterns and correlations that might elude the human eye," he adds. "It is indeed turning the traditional way of interpreting complex molecular data on its head, driving our understanding and treatment of cancer forward."

Dr Jeyasekharan also underscores the significance of clinical research in advancing cancer treatment, from clinical trials to historical data analysis that helps to understand and improve healthcare delivery. "We're never satisfied with delivering standard treatment because it simply isn't good enough. Some patients are cured, while others are not — we're committed to increasing the chances of curing more people," he says.

Advancing genomic testing for individualised cancer treatment

NUH formalises commitment to increase patient access to affordable genomic testing for cancer in Singapore and the region.

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No two cancers are the same. Even in those of the same type, each possesses a unique array of genetic nuances that influences how tumours grow, spread and respond to treatment.

Traditional treatments, such as chemotherapy and radiation therapy, eliminate cancer cells with drugs and high-energy beams, respectively. However, the indiscriminate nature of these treatments means they also inadvertently play havoc with healthy cells, causing patients to experience a range of unpleasant side effects.

Eschewing the one-size-fits-all approach, genomic testing offers a more personalised solution: it zooms in on specific genes within tumours to help doctors identify targeted treatments that will work best against the cancer-causing culprits.

The National University Hospital (NUH), together with Singapore-headquartered RNA technology company, MiRXES, and the world leader in serving science, Thermo Fisher Scientific, signed a Memorandum of Understanding agreement to formalise their commitment to jointly develop and clinically validate next-generation sequencing (NGS) genomic testing solutions and further cancer research.

Bringing genomic testing to a broader population

Access to affordable genomic testing for cancer remains limited in many Southeast Asian countries. Enhancing the local availability of rapid NGS genomic testing, which can profile multiple genes concurrently, enables healthcare providers to match patients with the most suitable therapies quickly.

NGS testing pinpoints genetic alterations in tumours that may respond well to targeted therapies. By focusing on specific molecular targets, these therapies block cancer growth while minimising damage to healthy cells.

"With NGS, we can detect a wider range of mutations that can be targeted by drugs, including rarer ones that would have been missed by traditional single-gene testing," says Dr Kenneth Sooi Wei Xiong, Associate Consultant, Department of Haematology-Oncology, National University Cancer Institute, Singapore. "This broadens treatment options, which improves the patient's prognosis, while drastically reducing side effects."

Singapore's first public-private partnership centre for specialty molecular testing

In collaboration with MiRXES, NUH offers NGS testing at the NUH Diagnostic Molecular Oncology Centre (DMOC) @ Biopolis, co-located with M-Diagnostics, a wholly-owned subsidiary of MiRXES, bringing together expertise and resources from both public and private sectors.

NUH DMOC @ Biopolis offers the APEX (Actionable, Personalised, Express) cancer treatment selection test, a state-of-the-art 50-gene targeted NGS panel. Currently, the laboratory provides NGS testing for four common cancers: non-small cell lung cancer, breast cancer, colorectal cancer and gastrointestinal stromal tumour. This list is expected to expand as new treatments become available.

"Not only does the NGS test detect actionable mutations that determine if the tumour is suitable for targeted therapy, but it also identifies most, if not all, of the resistant mutations that indicate the patient will not benefit from targeted therapy," says Associate Professor Tan Soo Yong, Head & Senior Consultant, Department of Pathology, NUH.

From the lens of health economics, identifying when a targeted therapy may be less effective is just as crucial as determining the most suitable one — as it conserves valuable healthcare resources while directing patients to more effective alternatives.

"Our deep clinical expertise, combined with research and development in biotechnology, will empower us to improve early detection methods and deliver even more precise diagnoses and treatments," adds A/Prof Tan.

Blood-based biomarkers improve the screening and treatment of liver cancer

Researchers at NUH harness the pinpoint precision of blood-based biomarkers for the early detection and treatment of hepatocellular carcinoma, one of the world's deadliest cancers.

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Hepatocellular carcinoma (HCC), the most common type of primary liver cancer, is the third-leading cause of cancer-related death worldwide — yet its detection remains challenging. Predominantly caused by chronic liver conditions such as severe scarring (cirrhosis), fatty liver disease and hepatitis B, HCC often presents no symptoms in its early stages. This frequently leads to late-stage diagnoses, in which the prognosis is grim, with fewer than 20 per cent of patients surviving beyond five years.

While hepatitis B is currently the leading cause of HCC in Singapore, Dr Daniel Huang, Consultant at the Division of Gastroenterology and Hepatology, Department of Medicine, National University Hospital (NUH), and his team have shed light on an emerging trend. Fatty liver disease is rapidly becoming a significant contributor to HCC, with Southeast Asia experiencing the highest prevalence. "In Singapore, the incidence of fatty liver-related liver cancer is projected to increase by 100 per cent between 2020 and 2030," says Dr Huang.

Current detection methods are struggling to keep pace with the evolving landscape of HCC aetiology — underscoring the urgent need for a shift in screening strategies. To this end, Dr Huang and his team are developing blood-based biomarkers that offer a more effective, personalised approach to screening, which could ultimately improve outcomes for those at risk.

Personalised care for early detection

Personalisation is at the core of the team's approach. "The traditional focus on cirrhosis as the primary indicator for HCC screening is increasingly inadequate, especially given the rising incidence of HCC linked to fatty liver disease," says Dr Huang. "Nearly 40 per cent of HCC cases associated with fatty liver occur in the absence of cirrhosis — this means many patients are at risk of being overlooked."

To address this, Dr Huang is turning to blood-based biomarkers, which refine the screening process by enabling the stratification of patients based on their risk level for developing liver cancer. "Specific molecular signatures in the blood that risk stratify people with fatty liver disease into those with a high risk of developing liver cancer and those without will help to save lives and healthcare costs" says Dr Huang. "This will allow us to identify high-risk individuals more precisely, facilitating earlier intervention and potentially curative treatments."

The shortcomings of the current screening process extend beyond an over-reliance on cirrhosis. The limited visibility provided by ultrasound imaging, particularly in patients with fatty liver disease, has prompted Dr Huang's team to explore the use of simplified MRI, which has proven more accurate and cost-effective.

In addition to improving the screening process, Dr Huang's team has also uncovered substantial risks of HCC among individuals who do not meet the current hepatitis B treatment criteria. By expanding the eligibility for antiviral treatment, his team demonstrated a 70 per cent reduction in HCC risk — this work contributed to an expansion of the World Health Organisation's guidelines on hepatitis B treatment in 2024.

Tech-enabled digestive centre supercharges early cancer detection

The new National University Centre for Digestive Health rides the artificial intelligence wave to enhance the early detection, diagnosis, treatment and prevention of gastrointestinal-related diseases.

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Gastrointestinal (GI) cancers rank among the most prevalent cancers worldwide—accounting for one in four cancer cases and one in three cancer deaths.

In Singapore, GI cancers constitute one-third of male cancer cases and about one-fifth of females, according to the latest Annual Report from the Singapore Cancer Registry, with colorectal cancer emerging as the most common GI cancer in the city-state.

These diseases are also on the rise among the youth. One study indicated that rates of GI cancers in younger adults may be rising faster than other cancers. This uptick coincides with dietary shifts across many countries, with rising obesity rates and diets rich in processed foods—which upset the gut microbiome, the complex community of intestinal microbes intimately linked to GI cancers—as likely culprits.

Overcoming these formidable challenges requires some systems-level, out-of-the-box thinking. Harnessing innovative technology is one. To this end, the National University Hospital (NUH) is establishing the National University Centre for Digestive Health—expected to be operational by mid-2025. The use of artificial intelligence (AI) and advanced technology will be a major underpinning for the centre, spearheading efforts in research, clinical practices and the development of new technologies to enhance the early detection, diagnosis, treatment and prevention of GI-related illnesses.

Data-driven detection and diagnostics

"The new centre will be a one-stop shop for gastroenterology and hepatology services, where specialised care, from diagnostic to therapeutic procedures, is augmented by AI and other state-of-the-art technologies," says Adjunct A/Prof Lee Guan Huei, Head and Senior Consultant, Division of Gastroenterology and Hepatology, Department of Medicine, NUH.

One of the areas in which the centre will provide significant value is the early identification of GI lesions. These abnormalities in stomach tissues may be a precursor to cancer, so detecting and diagnosing them earlier—and in real time—can translate to improved patient outcomes.

Three AI-powered systems—Computer-assisted detection (CADe), Computer-assisted diagnosis (CADx) and Computer-assisted quality control (CAQ)—work hand-in-hand to enable this medical capability. The Centre is the only one in Singapore to deploy these three systems simultaneously to boost diagnostic precision.

Improving the early detection of stomach and colorectal cancers is high on the centre's radar. "Our team at NUH is jointly developing a blood-based diagnostic test for stomach cancer called GASTROClear, which identifies high-risk individuals while reducing the need for invasive endoscopies for those at low risk," adds Adjunct A/Prof Lee. "We are looking into novel biomarkers to enhance colorectal cancer detection, as well as new assays for pancreas and liver cancers."

Tech-enabled surgical interventions

Surgery at NUH is also undergoing a significant transformation—with technology at the forefront. Since August 2023, the NUH Endoscopy Centre has implemented a high-performance X-ray-based visualisation system, the first-of-its-kind in Southeast Asia, which harnesses 3D imaging to enhance the precision of surgical interventions. The clarity and depth provided by the technology enable surgeons to accurately pinpoint, address and remove diseased tissues, which are often challenging to discern with traditional 2D imaging. This not only slashes procedure times but optimises surgical outcomes.

Robots too are getting increasingly 'hands-on'. Another practice-changing innovation is a robotic-assisted endoscopic surgery system that removes gastric and colon tumours through natural orifices, such as the mouth. This is a markedly less invasive approach whereby patients are more comfortable during the process and recover quicker. What is more, complication rates are lower—less than five per cent as demonstrated by clinical trials—and hospital stays are shortened to less than a day.

"The impact of integrating new technologies into our surgical practices cannot be overstated," says A/Prof Asim Shabbir, Head & Senior Consultant, Department of Surgery, NUH. "From enhancing early detection and streamlining patient services to implementing more effective, less invasive intervention strategies, our goal is to meet the unique needs of our patients as we continue to expand our infrastructure and adopt new technologies."

A keen AI to enhance the early detection of breast cancer

An AI-powered radiological computer-assisted detection software, co-developed by A/Prof Mikael Hartman, improves the speed and accuracy at which breast cancer is diagnosed.

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The World Health Organisation reported that breast cancer was the most prevalent cancer in women across 157 countries out of 185 in 2022. Early detection remains a cornerstone in combating this disease—as most patients exhibit no symptoms in the initial stages.

Despite the importance of screening, fewer than 40% of Singaporean women (aged 50 to 69) had gone for a mammography in the past two years, according to the National Population Health Survey 2022. The inherent limitations in existing technology disincentivise them from doing so.

Mammograms, which paint a monochromatic picture where both dense breast tissues and potential anomalies register as similar shades of white, often make tell-tale signs of breast cancer indiscernible. This can complicate detection, delaying diagnostic reports for weeks. Mammograms also risk missing 20% of breast cancers present at the time of screening. Such delays and uncertainties fan anxiety among women.

Against this backdrop of diagnostic challenges, A/Prof Mikael Hartman, Head & Senior Consultant, Division of General Surgery (Breast Surgery), Department of Surgery, NUH, has been intimately involved in the development of FxMammo, an artificial intelligence (AI)-enabled tool designed to enhance the accuracy and efficiency of breast cancer screening through advanced image analysis.

The keen AI of FxMammo

"Unlike traditional methods, today's mammogram images are digital, which opens up new possibilities for more efficient analysis," says A/Prof Hartman. "With advanced AI tools and some powerful number-crunching, coupled with a sea of data for training, we developed FxMammo with the hope that this technology would give us an edge in beating breast cancer."

Think of FxMammo as an experienced assistant who pores over mammogram images with a very keen eye—or rather, AI. Detecting subtle variations is no sweat for this assistant. Picking up anomalies in dense breast tissue, often overlooked by the human eye, is a walk in the park. Once the assistant identifies suspicious areas, its binary-coded brain generates a detailed report, highlighting these concerns clearly and succinctly for further review by a (human) radiologist.

The benefits of FxMammo are manifold. It significantly shortens the diagnosis time, reducing the waiting period from weeks to mere minutes. This rapid turnaround is crucial for early intervention—which in turn alleviates the anxiety associated with prolonged waiting times for results. The AI-powered technology has also been proven to reduce the rate of false positives by over 20% and decrease false negatives by more than 38%. These improvements not only enhance patient outcomes but also build crucial trust in breast cancer screening processes, which could encourage higher participation rates among the target demographic.

Moving from bench to bedside

FxMammo is currently undergoing rigorous research at NUH, ensuring it meets—and exceeds—the stringent requirements of clinical efficacy before implementation in in-patient services.

When it comes to adopting new technologies, A/Prof Hartman says that "initial resistance is understandable as past experiences with earlier computer-assisted diagnosis systems were frequently marred by high rates of false positives and diagnostic noise."

The developers of FxMammo have designed this technology with those past challenges in mind. It is engineered to seamlessly augment the current mammogram process without disrupting established workflows.

"The initial scepticism from radiologists has begun to dissipate as they recognise the tool's ability to discern features in mammograms that previously went unnoticed," says A/Prof Hartman. "I look forward to seeing FxMammo prove its worth in NUH's clinical trials and eventually aid in the global fight against breast cancer."

“The pharmaceutical industry relies on many separation processes, many of which guzzle huge amounts of energy. Our lab’s new technique shortens the time needed to produce energy-efficient COF membranes that remain stable and resistant to organic solvents,” says Xu.

Xu and her team envision a future where sustainable COF membranes play a key role in driving industrial efficiency and environmental responsibility across various sectors. “In particular, we are keen to take our R&D further and explore the large-scale fabrication of COF membranes to help build a more sustainable pharmaceutical industry,” says Xu.

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Nature-inspired pressure sensing technology aims to transform healthcare and surgical robots

NUS researchers take a leaf out of nature's book to develop 'eAir' — an aero-elastic sensor that revolutionises the way pressure is detected

Researchers at the National University of Singapore (NUS) have developed a novel aero-elastic pressure sensor, called 'eAir'. This technology can be applied to minimally-invasive surgeries and implantable sensors by directly addressing the challenges associated with existing pressure sensors.

The eAir sensor promises increased precision and reliability across medical applications. It can potentially transform laparoscopic surgeries by enabling tactile feedback for surgeons, allowing more precise manipulation of patient tissues. In addition, the sensor can improve patient experiences by offering a less invasive means of monitoring intracranial pressure (ICP), a key health metric for individuals with neurological conditions.

Led by Associate Professor Benjamin Tee from the **NUS College of Design and Engineering < https://cde.nus.edu.sg/>** and **NUS Institute for Health Innovation & Technology < https://ihealthtech.nus.edu.sg/>** , the research team's findings were recently published in scientific journal ***Nature Materials*** **< https://www.nature.com/articles/s41563-023-01628-8>** on 17 August 2023.

From lotus leaf to laboratory: Harnessing nature's design

Conventional pressure sensors frequently struggle with accuracy. They have trouble delivering consistent readings, often returning varying results when the same pressure is applied repeatedly and can overlook subtle changes in pressure — all of which can lead to significant errors. They are also typically made from stiff and mechanically inflexible materials.

To address these challenges in pressure sensing, the NUS team drew inspiration from a phenomenon known as the 'lotus leaf effect' — a unique natural phenomenon where water droplets effortlessly roll off the leaf's surface, made possible by its minuscule, water-repelling structures. Mimicking this effect, the team has engineered a pressure sensor designed to significantly improve the sensing performance.

"The sensor, akin to a miniature 'capacity meter', can detect minute pressure changes — mirroring the sensitivity of a lotus leaf to the extremely light touch of a water droplet," explained Assoc Prof Tee.

Employing an innovative 'air spring' design, the eAir sensor houses a trapped layer of air, forming an air-liquid interface upon contact with the sensor's liquid. As external pressure increases, this air layer compresses. A surface treatment results in a frictionless movement of the interface within the sensor, triggering a change in electrical signals that accurately reflects the exerted pressure. Using this design, the natural water-repelling capabilities of the lotus leaf have been reimagined as a simple yet elegant pressure-sensing tool.

The eAir devices can be made relatively small – at a few millimetres in size – and this is comparable to existing pressure sensors.

Potential game-changing advancement for minimally invasive surgeries

The real-world applications of this novel technology are wide-ranging. For instance, in laparoscopic surgeries where precise tactile feedback is indispensable, incorporating eAir sensors could lead to safer surgical procedures, ultimately enhancing patient recovery and prognosis.

"Conducting surgeries with graspers presents its unique challenges. Precise control and accurate perception of the forces applied are critical, but traditional tools can sometimes fall short, making surgeons rely heavily on experience, and even intuition. The introduction of soft and readily integrable eAir sensors, however, could be a game-changer," said Assoc Prof Tee, who is also from the **NUS Department of Materials Science and Engineering < https://cde.nus.edu.sg/mse/>** .

"When surgeons perform minimally-invasive surgery such as laparoscopic or robotic surgery, we can control the jaws of the graspers, but we are unable to feel what the end-effectors are grasping. Hence, surgeons have to rely on our sense of sight and years of experience to make a judgement call about critical information that our sense of touch could otherwise provide," explained Dr Kaan Hung Leng, Consultant, Department of General Surgery at the National University Hospital, Ng Teng Fong General Hospital and **NUS Yong Loo Lin School of Medicine < https://medicine.nus.edu.sg/>** .

Dr Kaan, who is not involved in the research project, elaborated, "The haptic or tactile feedback provided by smart pressure sensors has the potential to revolutionise the field of minimally-invasive surgery. For example, information about whether a tissue that is being grasped is hard, firm or soft provides an additional and important source of information to aid surgeons in making prudent decisions during a surgery. Ultimately, these intra-

operative benefits have the potential to translate into improved surgical and patient outcomes."

Additionally, eAir presents an opportunity to improve the process of monitoring intracranial pressure — the pressure within the skull that can influence brain health. Similarly, by offering a minimally invasive solution, the technology could transform patient experiences in the management of brain-related conditions, ranging from severe headaches to potential brain damage.

Unfolding the future of smart sensing

The NUS team is laying the groundwork for collaborations with key players in the medical field. At the same time, they have filed a patent for the eAir sensor technology in Singapore, and aims to translate the technology for real-world applications.

"We want to further refine the eAir sensor to enhance its performance by exploring various new materials and microstructural designs," shared Assoc Prof Tee.

The team envisions the eAir technology being weaved into a diverse tapestry of applications for liquid environments.