Inspiring Innovators

By Sharon Aschaiek, Nicole Axworthy, Jennifer Coombes and Michael Mastromatteo

Innovation and entrepreneurship are continually emphasized as avenues for professional engineers to make lasting contributions to the development of safer, sustainable, resilient and more robust communities. Engineers, in turn, are encouraged to tell better stories to celebrate the profession and demonstrate the ongoing relevance of the P.Eng. licence. The outstanding examples of engineering featured here are just a small sampling of vital innovation in action.

Cutting edge takes on new meaning with safety system

At first blush, it's difficult to see how a cutting device with precisely angled, multiple blades slicing through an aluminum frame would enhance human safety. But for William Altenhof, PhD, P.Eng., the proof is all there on the drawing board.

Altenhof is a professor of mechanical, automotive and materials engineering at the University of Windsor, who has made car passenger safety and child restraint systems the hallmark of his research.

The winner of an Engineering Medal in the young engineer category at the Ontario Professional Engineers Awards in 2008, Altenhof recently scored another triumph with the development of his axial cutting device system, which better protects vehicle passengers from the often devastating forces unleashed from collisions and high-speed impacts.

A product of materials engineering research, the device is an energy dissipating system that eliminates much of the guesswork about how materials crush and deform under strain.

In some ways, the axial cutting device is an enhancement of the crumple-zone passenger protection system developed by Mercedes Benz in the 1950s, and adopted by most auto manufacturers since. But where the crumple-zone technology dissipates energy more or less randomly, Altenhof's system adds an element of predictability to the process.

"We observed that some materials would fracture and then would actually cut through each other," Altenhof says. "And while they were cutting, we noticed that the load was quite constant. We said, 'Well, that's actually what you want. You want a constant force during the deformation.' So we came up with this whole concept of, rather than buckling a tube or folding it, we are slicing through it. And once we saw that, we opened the door to an incredible field."

Altenhof and his research team further experimented to reveal that cutting forces tend to proceed at constant rates, rather than haphazardly as with traditional energy dissipation. The discovery allows Altenhof to control more variables, such as thickness of the material, blade geometry and other factors, in designing the system to withstand specific loads.

"So, now the beauty is, if you come to me with a certain application and you say, 'I have this situation where I know that the force can be no greater than 20 kN,' I can design an energy absorber where the load will never exceed 20 kN, and will generally remain constant throughout all the deformation," he says.

William Altenhof, PhD, P.Eng., holds a cut aluminum extrusion illustrating the deformation of his energy absorber. Variation in the wall thickness of the extrusion is one method of "programming" the force/displacement and energy absorbing characteristics of the device.

Furthermore, if the thickness or other system parameters are wisely adjusted, a desired force/displacement or energy-dissipation response can be "programmed" into the system. This represents a passive, adaptive, energy-dissipation system.

Another benefit of the system, Altenhof adds, is that it's "strain rate insensitive," meaning that whatever the rate of the cutting action, the forces remain generally the same. Current energy-dissipation systems in automobiles are the opposite, or strain rate sensitive. "If you hit them at 100 kilometres an hour, or 50 km an hour or 20 km an hour, the actual force response will vary," Altenhof says. "And that's a problem because the designers need to know how to design the system. They know forces are going to change as a function of the impact velocity." Eliminating this variation in system performance is also appealing in dynamic loading conditions.

The axial cutting system was patented in January 2013 and Altenhof is negotiating with suppliers and the University of Windsor to commercialize the product.

Although its primary appeal is in the automotive sector, Altenhof sees how his device can be used in personal protective equipment, fall-arrest mechanisms, even sporting equipment.

He is especially enthusiastic about the breakthrough's potential as an active energy absorber/dissipation system, especially for the next generation of automobiles. Altenhof foresees ways to integrate the axial cutting device into all aspects of a vehicle's operation.

"For example, as you're driving, the vehicle will sense your speed," he says. "It will acknowledge what's around you. It will sense other conditions and the (safety) system will change as your driving conditions change. Envision your vehicle transforming and behaving in a certain way that's optimal for your kind of crash conditions." He believes an active, adaptive energy absorber could become the next generation of the system he is rolling out right now.

Given his track record of research into better protective devices, it's no surprise Altenhof sees safety as within the purview of innovative engineers. "It's amazing how we take safety for granted," he says. "The simplest activities in life really require engineering innovation to mitigate or completely eliminate the possibility of physical harm resulting from the chaos associated with these common daily activities–traveling in a car, working at heights, skating on ice, riding a bike, competing or playing in sporting activities, and so on."

He says innovation is key to ensuring engineers understand and identify mechanisms that would compromise safety and then develop devices to mitigate or eliminate such conditions "…so that we can all return home just as we left, in the same or better state."

Says Altenhof: "I think this is critically important as the fundamental role associated with our profession–to protect and enhance our society and its safety–is simply the purpose of these devices by ensuring safer environments during transit, work, employment, or other living and leisure activities."

Seeing is believing in image processing enhancement

There was once an advertisement for stereo speakers claiming the speakers' sound reproduction quality was "as good as you hear." A related advertising campaign might have described the image quality of cameras, TV screens, videos or computer monitors as "as good as you see."

The notion of exploiting technology to better approximate how the human eye perceives and appreciates image clarity is of special interest to Zhou Wang, PhD, P.Eng., associate professor of engineering at the University of Waterloo and the recipient of an EWR Steacie Memorial Fellowship from the Natural Sciences and Engineering Research Council of Canada.

The Steacie award recognizes Wang's work predicting "human visual perception" of image quality and providing more sensory-based ways of improving image quality in image processing and signal transmission applications.

The key plank of Wang's work is his development of the Structural Similarity Index (SSIM), described as a method for measuring the similarity between two images.

Wang can be considered a true innovator because his work initialized a paradigm shift in how to predict perceptual quality of images.

Zhou Wang, PhD, P.Eng., is working on how the human eye perceives the quality of digital images and video.

A member of the Institute of Electrical and Electronics Engineers' (IEEE's) Multimedia Signal Processing Technical Committee, Wang can be considered a true innovator because his work initialized a paradigm shift in how to predict perceptual quality of images.

In essence, the SSIM sheds more light on how the human eye perceives the quality of digital images and videos, based on how the data captured in the image is recorded and reassembled.

"It shows it's possible to have a conceptually and computationally simple model that can provide accurate predictions of image quality across a wide range of image content and distortion types," Wang says. "It also has a number of desirable mathematical features that allow researchers to use it in the design and optimization of various image-processing algorithms and systems."

Wang's work is considered an advance in the kinds of image-quality measurement systems used previously. "Most people in the field typically use mathematically convenient approaches, such as mean squared error, to measure image quality," he says. "Starting in the 1970s or earlier, a number of researchers realized the importance of developing perceptually meaningful measures for image quality, but existing measures were not widely adopted in practice due to low accuracy and high complexity."

Wang says SSIM helps identify the distortions or defects at every location in an image and predicts how annoying these defects are to the human visual system. "Repairing" an image is not what SSIM does, but the literature indicates significant follow-up work to design SSIM-motivated approaches to repair problematic images and better process,

enhance, compress and transmit images so as to avoid or reduce perceptual quality degradations.

"Since almost all images are eventually meant to be viewed by humans, perceived image quality is a critical issue in almost all image processing applications," Wang adds. "Therefore, a better perceptual quality predictor like SSIM can penetrate to essentially all such applications. It explains why our original paper has been cited more than 9000 times and accelerating in the past 10 years.

"Naturally, a number of large organizations, including Google, Netflix, Intel and Comcast, have exploited SSIM in their work, and its impact has spread into industries such as Internet TV, HDTV, video sharing, video conferencing, mobile video and image reproduction in the social media, entertainment, educational and even health sciences areas."

Among the innovator's upcoming objectives is improving the public's visual experience when watching videos transmitted via multiple networks and channels. "One particular application we are currently trying to push very hard on is to stabilize and improve the quality of network transmissions of video content, which will occupy over 80 per cent of Internet traffic in a few years," Wang says. "We have already developed an even more advanced tool named SSIMplus, and we believe it will make a major impact in the industry in the next few years."

A side view of one of Thermalfrost's chillers, which uses heat to generate cooling. It's currently being used for industrial and commercial purposes like fishing vessels and refrigerated trucks and could one day replace mechanical vapour compression refrigeration, which consumes electricity and uses pollution-causing refrigerants.

Electricity-free, thermally activated cooling technology has potential to revolutionize refrigeration

By harnessing waste heat that would otherwise pollute the atmosphere, Ottawa-based Thermalfrost International Inc. has developed and commercialized a cooling and refrigeration technology that its founders consider the world's most efficient thermal chiller.

Using heat to cool results in an approximately 90 per cent reduction in energy consumption for that cooling and is changing the way people and industry think about cooling. Waste heat, solar, biomass, geothermal and so on can all be used to provide freezing, air conditioning or refrigeration for industrial processes, commercial and residential buildings, or transportation applications. In fact, Thermalfrost's technology could be modified to satisfy most of the world's refrigeration needs, from fish refrigeration to running refrigerated trucks.

"We're striving to eliminate energy consumption for cooling, which accounts for 15 per cent of the world's energy," explains Thermalfrost President and CEO Steven Donaldson. "Lack of cooling greatly impacts food availability in developing countries where, in some cases, more than 30 per cent of food is lost due to spoilage."

These new systems are designed to replace mechanical vapour compression refrigeration systems that consume electricity and use pollution-causing refrigerants. The most compelling advantage of Thermalfrost's technology is the system's capability to harness low-grade heat (as low as 70 C) to generate low-temperature cooling (as low as -30 C) with unprecedented COP (coefficient of performance)–a ratio of cooling provided to energy consumed.

Developed by Carleton University engineering professor Junjie Gu, PhD, P.Eng., Thermalfrost's technology uses absorption refrigeration processes. With a good foundation of work from previous engineers and refrigeration experts to build upon, Gu's research focuses on the chemical bonding of the technology's unique sorptive pair (NH_3 and salts) and then on creating prototypes with improvements to the heat exchangers, design of the circulation system and efficiencies within the generator. "Doing so required research on each component of the chiller, and to improve the system by better understanding the heat and mass transfer within," Gu explains. His team's work at Carleton led to commercial potential for the company, where Gu remains as a senior technical advisor.

Since its inception in 2007, Thermalfrost has operated according to the philosophy that collaborating and consolidating new ideas and technology can improve the outcome of common market-driven goals. "Thermalfrost is a small company with a big vision," Donaldson says. "We recognized early that in order to reach our goals, we needed to collaborate with many to succeed and accelerate our time to market."

The Ontario Centres of Excellence and the Ontario Power Authority invested in early-stage research that enabled Thermalfrost to develop the technology and create a prototype. The company has also received investments from the National Sciences and Engineering Research Council of Canada and Sustainable Development Technology Canada, and has partnered with numerous fishing companies, yacht and ship builders, manufacturers like Hyundai Mechatec and Hyundai Industrial Machinery, renewable energy companies, engine manufacturers, utility companies, and governments.

While Thermalfrost must still obtain certification and regulatory approval to sell its products to various markets, it is well on its way to revolutionizing refrigeration worldwide. Donaldson says the company is always looking to improve upon its current designs to stay ahead of the competition. Although mainly focused on building better products for its industrial partners, the company last year created an Ottawa-based subsidiary to focus on product development for commercial and residential applications, which demand lower cost, smaller form factors and versatility to harness different forms of heat and air cooling. New products from this initiative include highly efficient air-conditioners and refrigerators. "We never seem to have enough resources to keep up with demand, so we are always looking for money and ways to stretch our dollar," he says.

The company's ultimate aims, Donaldson says, are to curtail climate change by reducing energy consumption and to create a billion-dollar, Canadian-headquartered clean energy company: "I want to see our competition try to provide a similar solution. As they do, it will force us to innovate faster. Collectively, these efforts will bring better solutions to the marketplace, reducing energy consumption for cooling, thereby reducing green house gas emissions and bringing cooling to where it is otherwise unavailable."

Nationwide warning system to strengthen Canada's response to flooding

It may surprise you to learn that, unlike the US, UK and some other developed countries, Canada has no national flood warning system. But that's about to change, thanks to a bold new strategy being championed by hydrologic modelling and forecasting expert Paulin Coulibaly, P.Eng. Coulibaly is the principal investigator behind FloodNet, a comprehensive nationwide strategy that is bringing together the most advanced expertise and tools in the field to improve how floods are handled in Canada.

"With FloodNet, our main desire is to enhance the Canadian capacity for dealing with floods, in terms of forecasting and estimating, and in terms of their impact, and that any decisions made will be based on sound science," says Coulibaly, a professor in McMaster University's department of civil engineering and school of geography and earth sciences.

In Canada, floods are the most common and largely distributed hazard to life, property, the environment and the economy. The flood of June 2013 in southern Alberta, which cost approximately $1.7 billion in damage, is now considered the costliest natural disaster in Canadian history and that's only the worst of several examples of the high economic cost of flooding, which has been increasing in frequency and intensity over the last 20 years, mainly because of climate change.

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Forecasting and managing floods is a provincial responsibility, and so the infrastructure and techniques to do so vary widely from province to province. This patchwork approach makes it difficult for provinces to coordinate their flood response if the need arises. What's more, individual provinces typically lack the resources to access the most sophisticated tools and knowledge in flood forecasting, which can result in less-than-optimal success rates. For example, Coulibaly says, most provincial systems don't have the ability to consider how specific landscape features affect flooding in their regions.

Paulin Coulibaly, P.Eng., is the principal behind FloodNet, Canada's first national flood warning system.

Coulibaly is confident that with its emphasis on studying and implementing best practices, and using state-of-the-art tools in the field, FloodNet can go a long way in addressing Canada's flood woes. Because it draws on diverse expertise from both engineering and science, and leverages flood-related experience, knowledge, equipment and facilities at universities, industry and government all across Canada, the network will make it easier to proactively address the threat of flooding, he says.

FloodNet is funded by a five-year (2014-2019), $5-million grant from the Natural Sciences and Engineering Research Council of Canada through its Strategic Network Program, which supports projects in which researchers partner with companies over the long term in areas of importance to Canadians. It is being facilitated by 30 public and private partners, including agencies from all levels of government, 12 universities, provincial hydro companies, engineering firm SNC Lavalin, and Deltares, a Netherlands-based company that is a leading expert in flood forecasting.

A primary component of the initiative is knowledge generation through research initiatives that are investigating the processes and impact of floods in Canada. The research is being conducted by a multi-disciplinary team of 21 academic investigators and more than 30 engineers or scientists. The resulting information will be used to make improvements in such areas as infrastructure design, flood forecasting, and minimizing the impact of floods on people, society and the environment.

A key objective of the researchers is to develop a Canadian flood forecasting and early warning system that will deliver accurate and reliable forecasts with an appropriate lead time, to allow for better flood mitigation in the country's flood-prone regions. For this initiative, Coulibaly and some of his partners are evaluating and comparing current flood forecasting tools in Canada's provinces, and in other jurisdictions, such as the US and Europe. Use of the resulting system will be optional, meaning provinces can choose whether to use it exclusively or in parallel with their own systems.

FloodNet research will also yield new methods for updating the intensity-duration-frequency (IDF) curves of heavy rainfall. These insights will be used to develop a standard flood estimation manual and software, which Coulibaly says will be useful to engineers involved in designing such hydraulic infrastructure as bridges, urban drainage systems and culverts. As well, engineers will learn how to improve operation of hydropower reservoirs to reduce incidents of downstream flooding.

Says Coulibaly: "Floodnet will provide engineers with access to well-researched and widely agreed-upon guidelines, so that when they are designing new structures, they will be based on the best information out there regarding flood prevention."

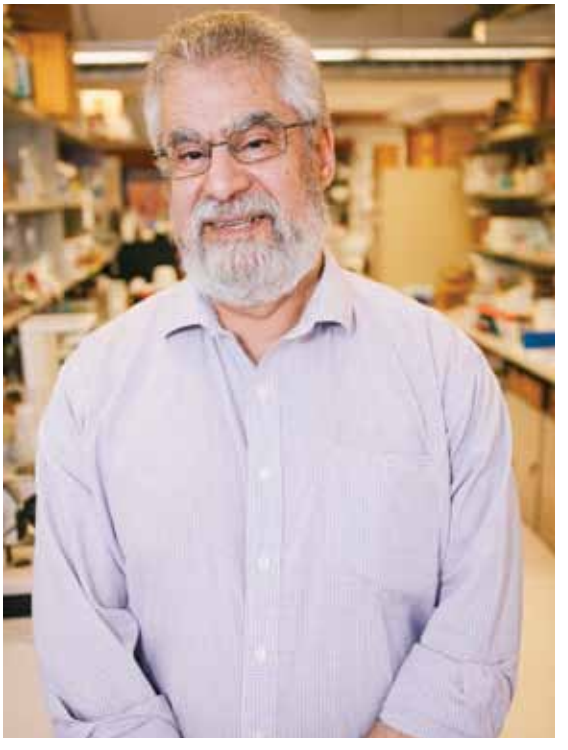
Will organ donations soon be a thing of the past?

University of Toronto (U of T) biomedical engineer Michael Sefton, ScD, P.Eng., believes so. For over 40 years, he has been working toward a single goal: to one day grow replacement organs and other body parts to treat a host of human diseases and conditions.

One of the world's foremost authorities in tissue engineering, regenerative medicine and biomaterials, Sefton was the first to recognize the potential of combining living cells and synthetic polymer materials to create new tissue structures that could one day act as functional equivalents of the body's organs and tissues.

Part of his research at U of T's Institute of Biomaterials and Biomedical Engineering involves taking live cells–pancreatic insulin-producing cells, for example–encapsulating them in collagen gel modules coated in endothelial cells and implanting them under the skin of test animals. Each module's ingenious membrane protects the fragile cells from the body's response, while allowing two-way diffusion: oxygen and nutrients needed for cell metabolism in, and waste products out.

The goal is to have these collections of cells take over the function of the organ they're intended to replace. Sefton's team is looking at



Michael Sefton, ScD, P.Eng., an award-winning biomedical engineer, was the first to combine living cells and materials to create new tissue structures that could one day act as functional equivalents of human organs and tissues.

Photo: Calvin Thomas

producing solutions that are functionally equivalent but not necessarily structurally equivalent to a particular organ like a liver or pancreas.

"What's promising is, at this point, when we put islets [insulin-producing cells] in these modules they are able to stay alive and are able to maintain normal blood sugars in a diabetic mouse," he says. In the not-so-far future, this approach is expected to be applicable to whatever organ or tissue requires replacement.

Implanting the cells is one thing. Keeping them alive is the challenge. One of the limiting factors to the viability of these cellular implants is vascularization. For cells to live they must be within 100 microns of a blood vessel, so a major focus of Sefton's research is getting blood vessels to grow to supply these implanted cell modules with oxygen and other necessities for cellular metabolism.

One of Sefton's most exciting discoveries was the observation about 15 years ago that a particular polymer–based on methacrylic acid (MAA)–almost magically promoted the growth of new blood vessels. "If there are blood vessels, the cells will work. We know that's the limiting step," says Sefton. "With MAA, we know we get blood vessels, but now we're trying to understand why. What is it about this material? What is it about the biological response of the material that causes blood vessels?"

In the intervening years, these mysteries, for the most part, have remained unsolved. "It's like a 1000-piece jigsaw puzzle and we have, maybe, 15 pieces identified. The question is always whether we have pieces in the sky or pieces in the actual picture. We never know whether they are important pieces or are things that are just happening anyway. We don't have anywhere near a complete picture yet."

It's Sefton's hope that within the next decade he and his team will have more answers, which will allow them to develop tissues with strong vascular functions. This, in turn, will bring his research a few steps closer to the goal of making replacement organs readily available.

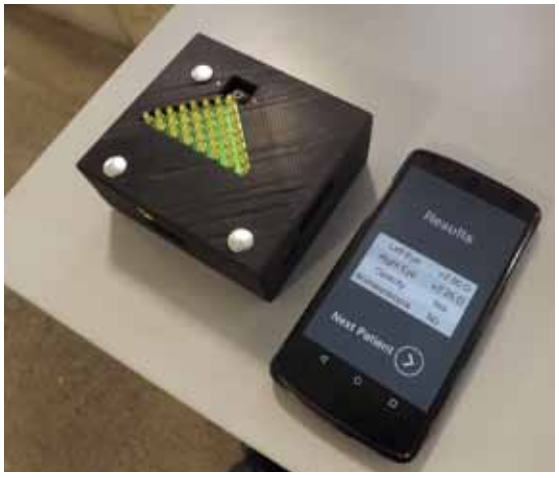
Sefton's tremendous contributions to the field of tissue engineering have not gone unnoticed. He has received a long list of awards and accolades in his four decades of research, including the Killam Prize in Engineering from the Canada Council for the Arts in 2008, the Ontario Professional Engineers Gold Medal in 2013, and the Engineers Canada Gold Medal in 2014. In 2003, he was named a University Professor, a rare status at U of T that recognizes unusual scholarly achievement and pre-eminence in a particular field of knowledge. Sefton's most recent honour, in October 2014, was one very few Canadians have received–an induction into the United States Institute of Medicine (IOM), the health arm of the National Academy of Sciences, which advises the US government on scientific and medical matters.

Apart from the considerable advancements he has made to tissue engineering over his long career, Sefton says he is also particularly proud of the department he has built at U of T. Included among the world-class researchers he has helped recruit are Molly Shoichet, PhD, LEL, who is the tier 1 Canada research chair in tissue engineering, and an expert in the study of polymers for drug delivery and regeneration, and Milica Radisic, PhD, P.Eng., a cardiac tissue engineering and regenerative medicine specialist. "It's a lead department now in medicine and engineering and there are often many initiatives that get built out of biomedical engineering now because of the kinds of people we have here," says Sefton.

Student start-up brings vision care to the developing world

Two recent University of Waterloo engineering grads, Daxal Desai and Ashutosh Syal, are building a fast and easy way for people in developing countries to have their eyes checked–in hopes of providing accessible, low-cost vision care to millions of people currently underserved by care in their regions.

EyeCheck was born out of an idea to create a smartphone app that could be used to replace traditional equipment for eye exams and make exams quicker and easier than ever before. During their third year at the University of Waterloo, Desai's and



The EyeCheck two-stage solution for eye exams is portable and easy to use.

Ashutosh Syal (not pictured) and Daxal Desai demonstrate how the EyeCheck camera is used.

An EyeCheck-equipped smartphone takes a quick picture of a person's face and tells the user right away whether they are nearsighted or farsighted.

Syal's professor of systems design engineering, John Zelek, PhD, P.Eng., challenged them to come up with a mobile phone-based solution to assess myopia (near-sightedness) in the developing world.

In these regions, temporary "eye camps" are held, where hundreds of people line up to get their vision checked by volunteers. It takes time to examine each individual, and the very young and elderly are often excluded because they can't make it to the camps or wait in the long lines. Knowing that so many people remain only a prescription away from clear vision and a new level of comfort, the co-founders resolved to find a solution.

In fall 2013, the students decided to make the problem the focus of their fourth-year design project. "This time, the project goals were more grand, with an aim to build a complete solution to be used in a mobile eye-care setting," explains Syal. "By the end of the capstone project, our team had set up the groundwork for the mobile screening app."

Their vision soon turned into a two-stage solution. As they learned through their research, the smartphone app is a valuable tool for screening a large number of people quickly, but a hardware component, such as a standalone camera, is also necessary because it allows doctors to take a detailed image of the eye for a more accurate prescription. The two devices work by shining different light into the eyes and analyzing the reflections coming back.

The benefits of the EyeCheck equipment are that it is automatic, portable and easy to use.

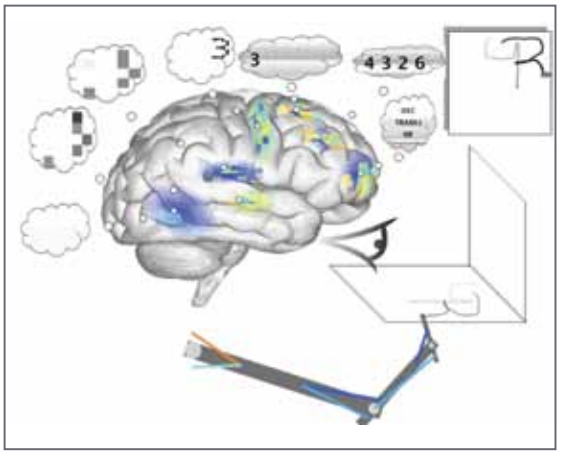
The exam process is simple: an EyeCheck-equipped smartphone takes a quick picture of a person's face and tells the user right away whether they are nearsighted or farsighted, and whether they have an opacity–a more serious problem like glaucoma or cataracts–in their eyes. If the app detects vision problems, the EyeCheck stand-alone camera takes a new image and provides a prescription for eyeglasses. According to Syal, the prescription is surprisingly accurate: "In a small experiment to determine how accurate our software was in identifying where a refractive error was present, the accuracy was well over 90 per cent," he says. "Based on early results, we are very excited and optimistic for this summer's testing."

Based in the Velocity Foundry in downtown Kitchener, a free co-working space where University of Waterloo students and alumni can develop, test and implement their start-up ideas, EyeCheck is working on developing a field-ready app and validating both its technology and business model. It is funding research and development efforts with the $50,000 the students have received from various awards and sources, including University of Waterloo Engineers of the Future Trust, Velocity Fund Finals competition, CDMN Soft Landing program, Communitech Business Development Fund, and the University of Waterloo alumni pitch night event, and hopes to be generating revenue within six months.

Last year, EyeCheck was named one of the top 20 inventions of the year by the James Dyson Foundation. "They are very determined and have invested their own time at their own cost over the last two years trying to make this work," says Professor Zelek, who has been involved in the project since the very beginning. "They probably need some investment to get them over the next hurdle. I think if they can get the interest of a large corporation, they will be successful. Without investment and a large corporation helping, the process will be slower; however, I admire their stamina and sticking to their cause."

Being a member of the Velocity program has granted Desai and Syal access to mentorship from other teams in the program, as well as alumni powerhouses like Kik, Thalmic Labs, Viyard, MappedIn and BufferBox. "This powerful group has guided us through countless obstacles, while also preventing us from succumbing to some amateur start-up pitfalls," says Syal. "The Velocity program has also given us access to coaches who support the teams... and a fixed place for development, complete with a well-stocked workshop."

Today, EyeCheck has a working prototype of both hardware and software solutions, with an immediate priority of developing the smartphone app to be field-ready by June. Says Syal: "Taking lessons from our last trip [to India], we are confident that we can get the data we need to create a market-ready solution."



Professor Chris Eliasmith, PhD, P.Eng., has combined engineering, neuroscience and philosophy to design the world's largest computer model of the human brain.

SPAUN is illustrated as a single eye with a mechanical arm attached. The eye absorbs information, the brain processes it and, in turn, triggers the arm to write out its findings or solutions.

Virtual neurons used as building blocks for model of functional brain

Perhaps it's not surprising that an educator with a specialty in systems design engineering *and* philosophy would have insights into how the brain works and how data is perceived, transmitted, thought about and stored.

But it's that sort of approach that animates the work of Chris Eliasmith, PhD, P.Eng. A University of Waterloo professor of systems design engineering and computer science, with a joint appointment to the philosophy department, Eliasmith is in the midst of potential-laden research about neurons and their relationship to brain function, and how these can be simulated by computer modeling.

The Canada research chair in theoretical neuroscience is also head of the university's Computational Neuroscience Research Group and director of the Centre for Theoretical Neuroscience, all within the University of Waterloo. He is also author of the engaging and accessible 2013 publication *How to Build a Brain*.

In February, Eliasmith was named the winner of the Natural Sciences and Engineering Research Council of Canada John C. Polanyi Award for outstanding achievement in natural sciences or engineering.

His key achievement to date is the Semantic Pointer Architecture Unified Network or SPAUN–the world's largest functional model of the human brain. Although similar models exist in various research centres throughout the world, SPAUN, with its 2.5 million "virtual neurons," is the first to replicate some of the flexibility of human behaviour.

"Our project is the first large-scale, brain-level simulation that was able to reproduce a lot of behaviours all within one model," Eliasmith says.

Having biologically realistic neurons interconnected is important to the project's success, Eliasmith says: "In the [human] brain, the data and memory are stored in the same location where the processing is occurring, so it's a very different kind of structure, but, nevertheless, it's a lot of simple

components that are hooked up in some sophisticated manner to give rise to something much more complicated than what you'd be able to get out of one simple component."

Central to SPAUN is its assembly of virtual neurons. Natural neurons, between 86 and 100 billion in a normal human brain and nervous system, are what transmit electrical and chemical signals throughout the body to allow movement, sensing and other sentient activity. By building and connecting a large number of virtual neurons in SPAUN, Eliasmith and his team are gaining insights into the relationship between neural activity and brain function.

"The brain is for controlling a body, so it's really important to understand how neurons, which seem like things we can understand, are organized to give rise to the sort of control and behaviour we observe in people and animals," he says.

Although SPAUN is the world's largest model of the functional brain, it doesn't have a physical size. "Effectively, it's a computer program," Eliasmith says. "We write down some equations that simulate how each neuron works and then we write equations that describe how any two neurons communicate with each other and then we run it in a computer."

SPAUN is illustrated as a single eye with a mechanical arm attached. The eye absorbs information, and then the brain processes it and triggers the arm to write out its findings or solutions.

SPAUN's accomplishment lies in the combination of millions of neurons working together to perform more complex tasks. Eliasmith and his team have shown that SPAUN can solve problems like those on standard intelligence tests, with the same accuracy as a person with an average IQ. In addition, SPAUN uses biologically realistic neurons to think about patterns it encounters to make things happen in its environment.

While SPAUN's functionality is impressive, it's still a far cry from what a real brain can accomplish. Nevertheless, it works more like a brain than most digital computers.

"It's actually a fairly different kind of story you have in the case of a brain than in the case of a digital computer," Eliasmith says, "because with the brain, each of the components is sort of wired uniquely in the circuit, but in the case of digital components, they are often generic. They can hold any data or any program, or do multiple [things] depending exactly on what's been demanded by the user."

Eliasmith believes SPAUN-related work will further the efforts of "neuromorphic (brain-like) hardware" designers who develop computer chips to mimic human brain function. And as SPAUN and its complementary hardware grow in sophistication, it could yield new insight into how the human brain works, and how neural activity is affected by brain injury or diseases such as Alzheimer's.

Eliasmith and his team have shown that SPAUN can solve problems like those on standard intelligence tests, with the same accuracy as a person with an average IQ.

Although it's rare that NSERC would award its Polanyi prize to a philosopher (albeit one who is a P.Eng.), Eliasmith notes a certain logic between the two disciplines.

"I did engineering first and it gave me lots of useful technical tools. I went more into the philosophical issues to try to understand how people theorized about how the brain works at the cognitive level," Eliasmith recalls. "I wrote my PhD on the semantics of mental representations. When I came to the University of Waterloo, I was hired as a philosopher and later jointly appointed to systems design engineering. I'm also cross-appointed to computer science. All of these are relevant disciplines for trying to build mechanistic, biologically plausible models that actually address human cognition."

Paralysis treatment taps into the power of electricity

A new engineering innovation that uses the power of electricity to fight paralysis is transforming patients' lives.

MyndMove harnesses the capabilities of functional electrical stimulation (FES) to promote recovery and restore voluntary movement in people experiencing upper-limb paralysis as a result of a stroke or spinal cord injury. This non-invasive neurorehabilitation therapy stimulates the entire arm in a way that allows for the return of such functions as reaching, grasping and pinching. The mind behind MyndMove is Milos Popovic, PhD, P.Eng., a Toronto-based mechanical engineer who says the technology will help patients live more independently.

MyndMove therapy has the potential to recover a full range of voluntary motion in patients suffering from upper limb paralysis.

"The more you can recover, the less you need to rely on others for help with things such as tying your shoes, opening your wallet or going to the bathroom. It's about improving people's quality of life," says Popovic, the Toronto Rehab chair in spinal cord injury research, and a professor at the University of Toronto's Institute of Biomaterials and Biomedical Engineering.

MyndMove is the first therapy to harness FES in a way that can revive the ability of muscles to perform functional movements. The treatment involves a physiotherapist or occupational therapist guiding a patient to try to engage their upper-limb muscles in a desired movement. As that happens, the MyndMove device delivers electrical stimulation to these muscles, which then sends a signal to the brain. This coordinated effort leads to the creation of a new pathway between the muscles and undamaged motor control regions of the brain, which lets patients improve voluntary control of their movement.

MyndMove therapy evolved after more than a decade of scientific and clinical research led by Popovic, and with support from partners such as University Health Network, University of Toronto, Ontario Centres of Excellence and the federal government. Developing the technology involved accessing the expertise of biomedical, electronic, software and systems engineers. One challenge they faced was creating a device that could quickly and easily program different muscle movement protocols. In the beginning, it took weeks to program these protocols, but they've now shortened that process to minutes.

This coordinated effort leads to the creation of a new pathway between the muscles and undamaged motor control regions of the brain.

They also had to build hardware that could match the device's software capabilities, with an electric stimulator that could produce the right mix of electrical amplitudes and frequencies. Another key task was eliminating the pain caused by the level of electricity the device delivered. Popovic and his team eventually learned how to manage that problem by changing the shape of the electrical pulses.

"Designing a system that allows you to do complicated movements of the body, and do that using simple programming tools, was not trivial," says Popovic about overcoming the technical obstacles.

The resulting machine can elicit more than 30 different

Popovic says a large majority of patients who receive the therapy experience clinically significant improvements, and a substantial number achieve full recovery.

reaching and grasping movements, and features an eight-channel stimulator that can target up to eight different muscle groups in a single stimulation protocol. In numerous clinical studies, including randomized controlled trials in both stroke and spinal cord injury populations, the device was found to significantly help patients improve their ability to perform such tasks as picking up an object, and reaching forward or sideways. Popovic says a large majority of patients who receive the therapy experience clinically significant improvements, and a substantial number achieve full recovery.

MyndTec, the medical technology company Popovic co-founded in Mississauga, and which now has eight, full-time employees, launched MyndMove in October, and the therapy is being delivered at several physiotherapy clinics in Ontario. The company is now trying to further expand into the neurorehabilitation market across Canada and, eventually, the US.

Popovic sees big possibilities for MyndMove, and his optimism is borne out by statistics from the Heart and Stroke Foundation, which reports that about 50,000 people in Canada have a stroke each year. In the US, the figure is about 800,000 a year, according to the Centers for Disease Control and Prevention, and, according to recent international studies, stroke rates among younger people (ages 24 to 64) will double in the next 15 years. In Canada, strokes cost the Canadian economy $3.6 billion a year in physician services, hospital costs, lost wages and decreased productivity.

"If a person recovers their hand function, they don't have to have an attendant or need long-term care, which saves them and the health-care system a lot of money. Second, they may go back to work, which means they will pay taxes, which is good for everybody," Popovic says. "So this technology is not only good for patients, but for society."

Professor's FES invention sparks student's idea

U of T student Kramay Patel used Milos Popovic's FES technology as a jumping-off point for his own invention.

A breakthrough by Milos Popovic, PhD, P.Eng., in using functional electrical stimulation (FES) to reverse upper-limb paralysis inspired one of his students to invent a new technology that uses the technique to promote trunk stability in people with spinal cord injuries (SCIs).

SCI patients who use power wheelchairs lack the ability to control their trunk muscles, which requires them to wear belt straps and chest harnesses to avoid being jerked back and forth by their chair's movements. But such restraints can interfere with their ability to perform the tasks of daily living.

Kramay Patel, who is entering his fourth year of the biomedical systems engineering program at U of T, conducted research under the supervision of Popovic and a PhD student to investigate how FES might improve trunk posture among members of this population. The result was a first-of-its-kind, wheelchair-based, neural prosthetic device that achieved promising results in clinical tests and, earlier this year, won the Sunnybrook Research Prize.

Patel, 20, who also does engineering research for Toronto Rehabilitation Institute and last year established Kreaate Corp., his own design engineering company, plans to further test and refine his innovation with the goal of commercializing it in the near future.

"We're hoping this can become a useful rehabilitative tool that can improve the quality of life of SCI patients," Patel says.

Lindsay Brock (second from right) and capstone project team members (from left) Ioana Craiciu, Roy Lee and Farzi Yusufali have developed a thermally reflective roof coating material that they plan to commercialize.

Nano-based initiative uses light reflection to better heat and cool roofs

One of the earliest science lessons imparted to elementary school students is that lighter colours reflect light while dark colours absorb it. Countless kids over the years have tested it out on sunny days, placing their hands on the roofs of black or white cars, and taking note of the temperature difference.

But a University of Waterloo engineering graduate has combined this basic property of light reflection with nano-materials to come up with a roof coating material that could save home- and commercial building owners big money in heating and cooling costs.

Lindsay Brock, a graduate of Waterloo's nanotechnology engineering program, was a member of a capstone project team that developed a two-phase, thermally reflective roof coating material, alternatively known as "roof coating with a temperature dependent reflectance."

The resulting company, Grayscale Coatings, was one of the winners in the university's 2014 Norman Esch Entrepreneurship Awards for Capstone Design.

"The idea for Grayscale Coatings came when we were brainstorming ideas for our capstone project at the University of Waterloo," Brock says. "We came across the idea of energy-efficient reflective roofs, and wondered if that could be tailored to the Canadian climate. Our background in nanotechnology engineering provided us with a solid understanding of both the fundamental science and engineering design principles we ended up basing our final design on."

Hany Aziz, PhD, P.Eng., a professor at the university's Waterloo Institute for Nanotechnology, is not surprised with the success of former student Brock and her capstone project team. He says the Grayscale Coatings effort showed true innovative and entrepreneurial spirit by taking a well-known principle of light movement, and combining it with chemical and electrical engineering, nano-materials, nano-electronics, nano-biotechnology, and nano-instruments to create a new product specially suited for use in Canadian climates.

Brock says previously developed roof coatings have been unstable at lower outside temperatures.

"The idea is novel and it can certainly have some energy-saving advantages," Aziz said in an interview. "Lindsay and her team's work is quite interesting and worth at least examining to see if it can be commercialized."

The coating consists of small particles inside a polymer matrix, Brock explains. By studying the refractive indices of two different components, the research team came up with a coating material permitting absorption of sunlight when it's cold and the reflection of sunlight when it's hot.

"At low temperatures, the coating looks clear," she says. "When we put it on a dark surface, such as roofing shingles, light can pass through the coating and be absorbed. As the temperature increases, the refractive indices of the component materials start to diverge. This means at high temperatures, light will hit particles with a different refractive index than the rest of the coating and scatter, resulting in a white coating with increased reflectivity."

The tricky part is finding the best application method for the roof coating, whether the material should be sprayed on, brushed, painted, or applied by some other cost-effective method.

Brock says previously developed roof coatings have been unstable at lower outside temperatures and lack overall robustness. In fact, robustness and a firm appreciation of Canadian weather conditions were top of mind to Brock and her team in developing Grayscale Coatings.

"The innovative part of our work was in creating a design that was more robust and easier to integrate with current roofing solutions. A large part of this was selecting our materials carefully," she says.

Brock and her team are already involved with potential partners to bring their innovative product to market. "We're at the prototype stage and entering into commercialization," she says. "We're currently looking for partners interested in helping us further develop the product. In terms of commercialization, the next big challenge I see is figuring out the best manufacturing path to take and adapting the product to work with existing coating processes. Ideally, we would also like to further increase the reflectance at high temperatures because we think it's possible to improve upon our current prototype." Σ