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DEFTECH Update

August 2018

Dear Reader,

Welcome for this fourth 2018 release of the DEFTECH (Defence Future Technologies) Update.

You have now the opportunity to access all the releases here: https://deftech.ch/updates using the regular login and password.

This document summarizes emerging technology signals related by Strategic Business Insights' (SBI) Scan and Explorer services that the Technology Foresight Research Program from armasuisse Science + Technology subscribes to.

For each trend, we try to anticipate what could be the implications for the armed forces. Each trend is also related to the original signal of change elaborated by SBI that the interested reader finds at the end of this document.

The intent is to stimulate strategic technology forward thinking in a form that is pleasant and quickly readable.

If you desire to learn more about a specific topic or would like to access the SBI platform directly (Swiss government readers only!), please don't hesitate to contact me.

I hope you enjoy the journey!

Best regards,

Dr. Quentin Ladetto
Research Director – Technology Foresight

P.S. For question and suggestion, please contact me here: quentin.ladetto@armasuisse.ch

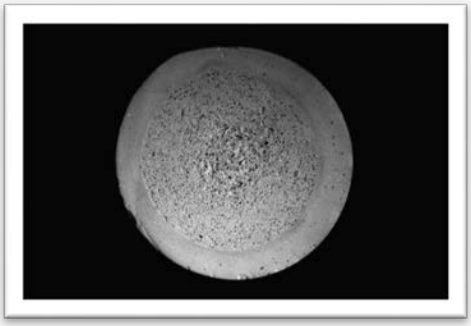

Image source: MIT Media Lab

Functionally Graded Materials: Functionally graded materials (FGMs) are materials that have a gradual variation in their structure or composition. Such physical variations lead to variations in the materials' properties, including strength, chemical reactivity, thermal conductivity, and density. With FGMs, engineers can create unique components that have nonuniform material properties. Researchers are studying how additive manufacturing could enable commercial use of FGMs.

Implication for Defense and Security*: The ability to vary the composition and structure of a material dramatically changes how engineers can design parts for military applications. FGMs could potentially allow engineers to create new complex components and replace many individual parts with a single component. Initial defense applications will likely focus on aerospace and jet engine components. Other potential applications could include components for ground vehicles and firearms.*

Timing of Implication: *now/5 years/**10 years**/15 years*

Image source: Roam Robotics

Smart Suits: Companies continue to explore new concepts for smart clothing, exosuits, and exoskeletons. Start-up Xenoma is developing a durable, machine-washable smart shirt that monitors the wearer's body temperature, breathing, and movements. Roam Robotics is developing an exoskeleton that uses pneumatic muscles to reduce the loads on wearers' knees while they are skiing. Researchers from Harvard University developed a machine-learning algorithm that optimizes parameters for assistive wearables according to the wearer's physiological signals.

Implication for Defense and Security*: Continued progress in smart fabrics and garments will eventually allow for low-cost smart uniforms and clothing for soldiers (for example, monitoring vitals and physical exertion). In addition, soft exosuits potentially offer a compelling alternative to bulky and power demanding hard exoskeletons. Future exosuits could consist of fabric actuators that provide mild assistance over a long period, allowing soldiers to operate with less fatigue.*

Timing of Implication: *now/**5 years**/**10 years**/15 years*

Image source: MIT

Energy-Harvesting Foams: Researchers are making progress in the development of energy-harvesting ceramic and metallic foams. Researchers at the Pennsylvania State University developed a piezoelectric ceramic foam that they claim could have up to ten times more energy-harvesting capacity than conventional piezoelectric composites have. Researchers at the Massachusetts Institute of Technology developed a thermoelectric metallic foam that generates electricity from changes in air temperature.

Implication for Defense and Security*: Defense and security organizations may be able to utilize new energy-harvesting foams in applications including remote sensing, drones, and robotics. Implantable healthcare devices may also benefit from energy-harvesting foams. New foams offer a high strength-to-weight ratio and improve on the energy efficiency of earlier attempts at developing the technology.*

Timing of Implication: *now/**5 years**/**10 years**/15 years*

Image source: World Econ. Forum website

Steps toward Neural Interfaces: As new neuroscience-based treatments emerge, researchers take small steps toward sophisticated brain–machine interfaces. Researchers at the Ohio State University recently conducted trials of a form of deep-brain stimulation for Alzheimer's patients. BrainQ Technologies is using a non–surgically embedded EEG machine to collect data about patients who have suffered strokes or spinal injuries, Neurolutions is using EEG technology to restore movement to paralytic patients.

Implication for Defense and Security*: Initial applications of neural interfaces will target individuals with neurological conditions and injuries—and potentially help wounded soldiers. In particular, multiple studies have identified neurological degeneration in some soldiers exposed to combat explosions. After the development of treatment-focused neural implants, researchers will likely explore the development of implants to augment human's capabilities to control equipment and communicate with others.*

Timing of Implication: *now/5 years/10 years/**15 years***

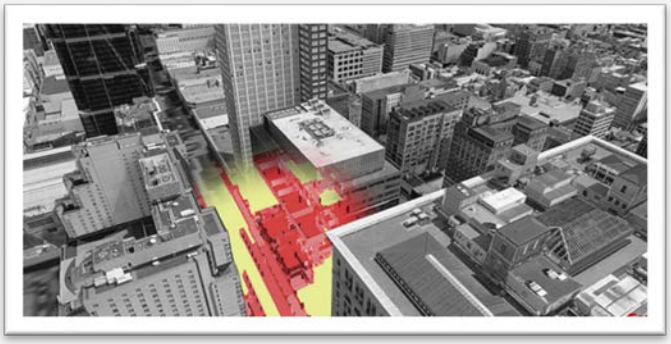

Image source: GCN.com

Cartography in Urban Environments: New technologies are enabling a widening range of urban maps with increasingly fine details and features. Emerging maps make use of mobile and energy data, and employ new sensor technologies and emerging projects—particularly those that relate to self-driving vehicles and their mapping needs. In addition, the US Defense Advanced Research Projects Agency is exploring subterranean mapping and navigation.

Implication for Defense and Security*: The development of low-cost mapping technologies—including solid-state lidar—will enable detailed 3D mapping of battlefields and urban environments. Militaries could create detailed 3D maps by equipping low-cost sensors to vehicles, soldiers, and drones. Additionally, availability of detailed urban maps will aid city-based operations and allow autonomous vehicles and robots to better navigate the environments.*

Timing of Implication: *now/**5 years**/**10 years**/15 years*

Image source: Festo

Cyberattacks on Infrastructure: Malicious groups are increasingly targeting cyber-physical systems and critical infrastructure. For example, the US Department of Homeland Security and the Federal Bureau of Investigation recently published an alert that describes state-led attacks against US government entities and energy infrastructure.

Implication for Defense and Security*: Defense and security organizations need to ensure that critical infrastructure is protected against malicious groups. Systems require constant surveillance, frequent updates, and potentially exploratory assaults from friendly groups. Additionally, defense and security organizations need to collaborate with the private corporations that operate many important cyber-phsyical systems.*

Timing of Implication: *now/**5 years**/10 years/15 years*

Image source: Courtesy company

Oceans of Things: Research groups are exploring sensor networks for oceans. The US National Oceanic and Atmospheric Administration deployed two semiautonomous sensor-equipped sailboat drones that spent eight months collecting-data in the Pacific Ocean. The US Department of Defense's Defense Advanced Research Projects Agency (DARPA) is working on the Oceans of Things program that aims to create a "persistent maritime situational awareness over large ocean areas by deploying thousands of small, low-cost floats that could form a distributed sensor network." Another DARPA project is looking at speculative approaches to analyzing ocean data through the use of living organisms.

Implication for Defense and Security*: Oceans are extremely challenging environments for accurately tracking submarines, ships, and other objects of interest to defense and security organizations. Development of low-cost devices and autonomous marine vessels could allow militaries to create robust sensor networks to improve tracking of vessels and other threats.*

Timing of Implication: *now/5 years/**10 years**/15 years*

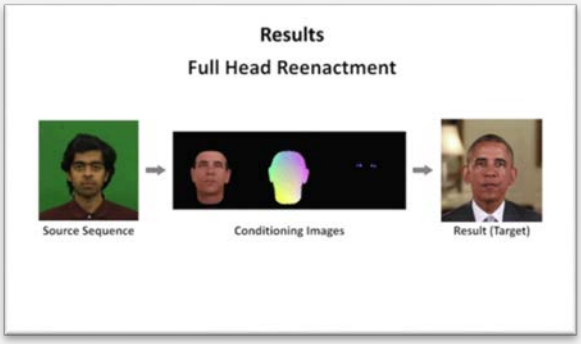

Image source: TechCrunch website

Deep Fakes: Developers are creating software that puts high-end artificial-intelligence (AI) tools into the hands of novice users. Some tools allow novice users to create deep fakes—digital manipulations of images, audio, or video that give the appearance that someone is doing something or saying something that he or she did not do.

Implication for Defense and Security*: Military intelligence depends on reliable and factual information. As video and editing tools become better and easier to use, trusting information sources could become much more complicated for military intelligence. Additionally, low-level insurgents could weaponize fake video and audio to persuade public opinion in a region. Militaries would benefit from software tools to analyze video and audio to detect signs of digital manipulation.*

Timing of Implication: *now/**5 years**/10 years/15 years*

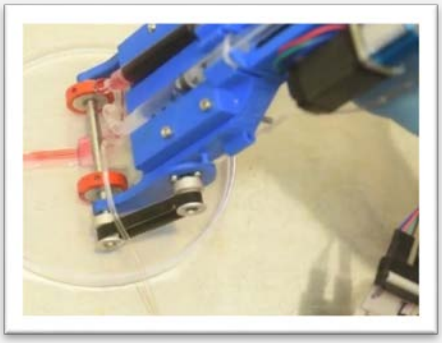

Image source: University of Toronto

Advanced Tissue Bioprinting: Researchers are driving advances in bioprinting. Advanced bioprinting systems may enable the printing of complex tissues, bone, and artificial organs that could transform health care and medical procedures. For example, researchers at the University of Toronto have developed a new handheld skin-bioprinting system that can print layers of tissue in deep skin wounds.

Implication for Defense and Security*: Bioprinting of tissue, such as skin, cartilage, and bone, could help soldiers recovering from wounds. If bioprinters become compact, easy to use, and fast, then they could help quickly seal wounds in the field. Advanced bioprinters could also create functional organs quickly for wounded soldiers—removing the requirement of finding a donor organ.*

Timing of Implication: *now/5 years/**10 years**/15 years*

Image source: MIT Website

Advanced Onboard Computing: The functionality and efficiency of portable electronic devices is advancing. Researchers from the Massachusetts Institute of Technology have developed a new chip and software that can perform public-key encryption faster and more efficiently than conventional techniques. Arm Holdings recently introduced two new processor designs using new architectures optimized for AI applications. Google recently introduced a software-framework that will bring augmented-reality features to mobile devices.

Implication for Defense and Security*: Novel computing hardware and software designs could equip soldiers and basic equipment with advanced computing systems. Advanced wearable computers could support many capabilities including facial recognition, real-time language translation, secure communications, 3D mapping, and navigation overlays for augmented-reality headsets. Better device level security (such as the MIT chip) could enable secure IoT environments.*

Timing of Implication: *now/**5 years**/10 years/15 years*

Image source: Butterfly Network

Enabling Remote Health Care: Developments in technology are bringing once-expensive healthcare equipment to new users. Butterfly Network's Butterfly iQ is a low-cost handheld ultrasound scanner that works with an Apple iPhone. Researchers from the University of Washington have developed a smartphone app that assesses brain injuries by looking for changes in a person's pupil response to light.

Implication for Defense and Security*: Militaries could potentially use advances in consumer electronics technology to create low-cost and lightweight medical devices to assess and treat battlefield injuries in the field. The technologies could aid soldiers in remote regions and those that become cutoff from others during operations.*

Timing of Implication: *now/**5 years**/10 years/15 years*

Image source: Gilles Sabrie for The New York Times

China's Technology Initiatives: A number of technology initiatives from the Chinese government aim to improve the orderliness of Chinese society. Initiatives include digital currencies, extensive use of facial recognition, and a social-credit system. China's global influence could encourage other governments or international companies to adopt similar technologies

Implication for Defense and Security*: Although some of China's initiatives raise privacy issues, they also advance surveillance capabilities. Technology similar to the kind China is developing could help military and security operations monitor large populations and assist in identifying potential threats.*

Timing of Implication: *now/**5 years**/10 years/15 year*

STRATEGIC BUSINESS INSIGHTS

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June 2018

P1214

AI Tools in Amateur Hands

By Guy Garrud (Send us feedback.)

Developers are creating software that puts high-end artificial-intelligence (AI) tools into the hands of relatively untrained users.

Abstracts in this Pattern:

SC-2018-05-02-066 on data analytics
SC-2018-05-02-093 on deep-fake technology
SC-2018-05-02-020 on deep-fake-porn creation
SC-2018-05-02-056 on deep-fake removal

Novel platforms offer relatively untrained individuals tools that enable them to use AI to extract useful insights from large data sets; however, these individuals can fail to understand the results of AI-based analyses or use such tools to manipulate content.

Self-service analytics platforms are one example of an expanding set of platforms that are placing high-end machine-learning tools into the hands of relatively unskilled individuals. Such platforms enable employees to make sense of data that businesses generate and store so they can extract knowledge without the aid of expert data scientists, who are in short supply; however, industry observers caution that nonexperts have a limited capability to understand AI-based analyses.

A more controversial type of software enables relatively unskilled users to create *deep fakes*—digital manipulations of images, audio, or video that give the appearance that someone is doing something that he or she did not do. The most recent versions of the software combine machine-learning technology with traditional sound and video editing and can see use to create very convincing images and video. For example, a user could generate video clips of politicians making statements that they did not make. Perhaps unsurprisingly, one of the early uses of deep-fake technology is to generate *deep-fake porn*—pornographic content in which the faces of public figures or celebrities replace the features of the original performers. Many social-media platforms and websites have banned deep-fake porn. Ironically, one such website is Reddit (Reddit; San Francisco, California), which had hosted online communities that focus on improving the quality and accessibility of deep-fake AI.

Policing malicious AI-generated content is nontrivial, because this fake content is of high quality. This matter has driven the creation of new tools that enable the identification and removal of such content. For example, Gfycat (Palo Alto, California), which hosts short user-generated video content, is using AI algorithms to detect and remove deep-fake content. The company's systems look for subtle imperfections that are indicative of a doctored image.

Signals of Change related to the topic:

SoC1002 — Recognizing and Analyzing Faces
SoC994 — Video Analytics…
SoC985 — …Alien Intelligence

Patterns related to the topic:

P1193 — Expanding Digitalization
P1187 — …Humans and AI
P1131 — Digital Transformation…

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June 2018

P1215

Advanced Onboard Computing

By Sean R. Barulich (Send us feedback.)

Dedicated hardware and software solutions are improving the functionality of consumer electronics.

Abstracts in this Pattern:

SC-2018-05-02-017 on MIT
SC-2018-05-02-034 on Arm
SC-2018-05-02-068 on Canon
SC-2018-05-02-045 on Google

Researchers are producing hardware that may improve the security of Internet of Things devices. For example, Massachusetts Institute of Technology (MIT; Cambridge, Massachusetts) researchers recently developed a new chip that can perform public-key encryption. The chip uses elliptic-curve protocols that enable the encryption process to work faster and use less energy than conventional encryption techniques do.

Companies are also designing hardware that brings artificial intelligence (AI) out of the cloud and directly into consumer electronics. For example, Arm Holdings (SoftBank Group Corp.; Tokyo, Japan) has introduced two new processor designs that it based on completely new architectures and optimized for AI applications. The design of the Arm Machine Learning Processor accelerates the execution of machine-learning models, which see use in AI applications such as machine translation and facial recognition. And the company optimized the design of the Arm Object Detection Processor for visual-data processing and object and people detection. Other companies are also integrating machine-learning features into devices. For example, Canon (Tokyo, Japan) recently introduced the Speedlite 470EX-AI—a camera flash module that can automatically change its orientation to optimize photograph quality. The module leverages AI to determine the distance from the camera to a subject and to the ceiling to determine the best flash angle for a photograph and uses built-in motors to move itself into the ideal orientation.

Companies are also developing software that improves the accessibility of augmented-reality (AR) and computer-vision features on devices. For example, Google (Alphabet; Mountain View, California) recently rolled out its ARCore AR software framework into wide release. ARCore enables more than 100 million Android smartphones to run AR applications. Additional research, development, and investment in the field of computing will enable the advance of consumer devices and the introduction of new computing functionality.

Signals of Change related to the topic:

SoC926 — Quantum Computing's Security…
SoC857 — Guesswork Computing
SoC022 — Cognitive Computing

Patterns related to the topic:

P1206 — Investing in Novel Computing
P1128 — Moore's Law Extends
P1126 — Hot Computing

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June 2018

P1216

China's Technology Initiatives

By David Strachan-Olson (Send us feedback.)

A number of technology initiatives from the government of China aim to improve the orderliness of Chinese society, but technologies from these initiatives could find adoption outside China.

Abstracts in this Pattern:

SC-2018-05-02-044 on digital currency
SC-2018-05-02-013 on facial recognition
SC-2018-05-02-052 on social credit
SC-2018-05-02-087 on software platform

China's government is spurring a number of technological innovations to improve the orderliness of Chinese society, thereby providing stability and maintaining economic growth. The People's Bank of China (Beijing, China) has been working on a cashless monetary system since 2016. The bank intends to create a digital currency that integrates seamlessly with existing services and financial-management systems. Unlike transactions with decentralized cryptocurrencies, transactions with this digital currency will see processing through centralized clearinghouses. China's government is also testing the use of facial-recognition technology to help police identify criminals. Officers wear smart glasses developed by LLVision Technology Co. (Beijing, China) and scan crowds. The glasses feature a camera and facial-recognition technology that can, according to the company, identify people from a database of 10,000 criminal suspects in as little as 100 milliseconds. China's government is also developing a social-credit system that uses machine learning, online databases, municipal records, and smartphone data to generate a social-trustworthiness score for individuals. The government believes that the system will help bring order to the complex social interactions in urban areas by guiding people's behavior. People with a high score will receive benefits such as discounts on products and services, and people with low scores could face restrictions on the products and services they can purchase.

Although individuals may label some of China's ambitions as dystopian, China clearly believes that technology can help bring order to the complexities of society. Because China's government is backing the above technologies, they will see very rapid development. In addition, China's global influence could encourage the governments of and companies from other countries to adopt the same or similar technologies. Such an outcome is already occurring with autonomous-vehicle technology. China's government recently designated Baidu's (Beijing, China) Apollo—an integrated software platform for guiding self-driving road vehicles—as the "national autonomous driving platform" of China. This action creates a significant market for hardware and software that function with Apollo and encourages adoption of the Apollo platform outside China.

Signals of Change related to the topic:

SoC1000 — Losing the Fight for…Privacy
SoC933 — Snooping Technologies
SoC930 — Trust(ed) Systems

Patterns related to the topic:

P1213 — China's Automotive Adventures
P1107 — …Pervasive Surveillance
P1064 — Data and…Safety, and Security

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July 2018

P1226

Evolving Cybersecurity Threats

By Sean R. Barulich (Send us feedback.)

Cybersecurity vulnerabilities continue to increase in number as more systems gain connectivity and researchers discover flaws in legacy software.

Abstracts in this Pattern:

SC-2018-06-06-060 on CPUs
SC-2018-06-06-100 on Russia
SC-2018-06-06-073 on China
SC-2018-06-06-078 on Saudi Arabia

New vulnerabilities in computing hardware are enabling more powerful exploits for hackers. For example, cybersecurity firm CTS-Labs (Tel Aviv, Israel) recently published a report about flaws in central processing units (CPUs) from Advanced Micro Devices (AMD; Santa Clara, California). The report describes 13 vulnerabilities that affect multiple lines of AMD processors and enable hackers to infect systems at the secure-boot level—albeit only if attackers have administrator access. The flaws could allow hackers to install persistent malware that would be undetectable by security software on infected systems.

Flaws in hardware often introduce serious threats to cybersecurity, but governments and hackers also threaten cybersecurity. For example, the US Department of Homeland Security (DHS; Washington, DC) and the Federal Bureau of Investigation (FBI; Washington, DC) recently published an alert that describes state-led attacks against US government entities and energy infrastructure. The DHS and FBI claim that Russian-state-led actors used tactics such as spear phishing and malware staging to target multiple commercial facilities. Ultimately, the attackers gained access to systems and extracted data about industrial control systems—data that could see use in future attacks. Countries other than Russia have made efforts to advance their abilities in the cybersecurity space. For example, the government of China is reportedly preventing groups of Chinese *white-hat hackers*—ethically motivated hackers and computer-security experts who identify and safely disclose the security vulnerabilities of systems to improve the systems' security—from joining international competitions to discover and publicize flaws in operating systems and popular software. Although cybersecurity professionals typically compete to improve the security of systems, China appears intent on using its cybersecurity experts to stockpile rather than share vulnerabilities.

Cyberattacks by hacking groups continue to advance and become increasingly dangerous. In August 2017, an advanced cyberattack targeted a petrochemical plant in Saudi Arabia and would have caused an explosion if not for an error in the hackers' computer code. Investigators believe that hackers designed the attack primarily to sabotage the plant's operations. This attack is similar to recent state-led attacks that often target critical infrastructure.

Signals of Change related to the topic:

SoC1000 — Losing…Privacy
SoC963 — Hacking: Now…Pervasive
SoC946 — Diffusion of Hacking…

Patterns related to the topic:

P1214 — AI Tools in Amateur Hands
P1202 — Smartphone-Data Surprises
P1190 — Cryptocurrency Issues

July 2018

P1230

Smart Suits

By David Strachan-Olson (Send us feedback.)

Companies continue to explore new concepts for smart clothing, exosuits, and exoskeletons that wrap individuals in sensors and actuators.

Abstracts in this Pattern:

SC-2018-06-06-034 on Xenoma
SC-2018-06-06-097 on Roam Robotics
SC-2018-06-06-058 on Harvard University
SC-2018-06-06-053 on L. L. Bean

Electronics components have become cheaper and more capable, and companies are showing an increasing interest in creating wearable electronics. Most companies are focusing on smartwatches and fitness trackers, but some are developing smart clothing and smart suits. For example, start-up Xenoma (Tokyo, Japan) is developing a durable, machine-washable smart shirt that monitors the wearer's body temperature, breathing, and movements. The shirt includes sensors that cover more than a dozen sections of the upper body, and "as the shirt expands and contracts, the sensors transmit signals to a nearby smartphone or PC via a small Bluetooth device on the chest." Xenoma believes its smart shirt could find use in areas such as athletics and fitness, preventative health care, and video games.

Companies are also developing exosuits and exoskeletons that use motors and actuators to provide wearers with active assistance. Roam Robotics (San Francisco, California) is developing an exoskeleton that uses pneumatic muscles to reduce the loads on wearers' knees while they are skiing or snowboarding. The company claims that the system will enable users to ski or snowboard better and for longer periods with less fatigue. Adapting to a wearer's capabilities and body mechanics is a key requirement for exosuits and exoskeletons. Researchers from Harvard University (Cambridge, Massachusetts) recently developed a machine-learning algorithm that optimizes the control parameters for assistive wearable devices on the basis of real-time measurements of the wearer's physiological signals. The researchers' algorithm-based optimization method was able to reduce the metabolic expenditure of people using an exosuit that provides walking assistance.

Traditional-clothing manufacturers may face difficulties in developing smart clothing and smart suits because they often lack an understanding of the technology and of consumer attitudes toward technology. For example, L. L. Bean (Freeport, Maine) recently called off a "data collection and analytics project that would have tested the use of a blockchain ledger and sensors attached to coats and boots" after a misunderstanding about the type of data the clothing would collect led to a public backlash. The project aimed to collect data about how consumers use the clothing and how the clothing performs, but the media incorrectly reported that the company aimed to track customers' locations, creating privacy concerns.

Signals of Change related to the topic:

SoC938 — …Human Augmentation
SoC928 — Wearables…
SoC865 — Wearable Robotics

Patterns related to the topic:

P0968 — Fashionable High Tech
P0923 — Sensing Skin
P0515 — Robots for Help…

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July 2018

P1234

Steps toward Neural Interfaces

By Guy Garrud (Send us feedback.)

As new neuroscience-based treatments emerge, researchers will take small steps toward developing sophisticated brain–machine interfaces.

Abstracts in this Pattern:

SC-2018-06-06-072 on implanted electrodes
SC-2018-06-06-076 on EEG
SC-2018-06-06-103 on prostheses

Researchers at the Ohio State University (Columbus, Ohio) recently conducted trials of a form of deep-brain stimulation for Alzheimer's patients. The researchers implanted into patients' frontal lobes electrodes that act as a form of pacemaker for the brain to help reduce cognitive decline in Alzheimer's sufferers. As researchers gain a better understanding of neurostimulation, implants capable of affecting brain activity could find use in interface technologies.

Other research groups are exploring noninvasive forms of neurological health care. Several companies are looking at non–surgically embedded electroencephalography (EEG) for use in a range of applications. For example, BrainQ Technologies (Jerusalem, Israel) is using a non–surgically embedded EEG machine to collect data for use in improving treatments for patients who have suffered strokes or spinal injuries, Neurolutions (Saint Louis, Missouri) is using EEG technology to restore movement to paralytic patients, and NeuroPace (Mountain View, California) is using EEG technology to treat patients suffering from seizures. In addition to providing treatment options, EEG technology may eventually provide a way for users to interact with computer systems—in fact, some video games already use an EEG headset as a control device.

Meanwhile, systems that enable interactions between the brain and a device are under development and seeing progress. For example, researchers at the Cleveland Clinic (Cleveland Clinic Foundation; Cleveland, Ohio) Lerner Research Institute have developed a system that provides wearers of advanced prostheses with a sense of how their prostheses are moving through space. Although advanced prostheses can move in response to electrical signals from the body that occur when users think about moving their missing limbs, they do not provide users with feedback about their movement, so users must watch their prostheses to move them properly. The system uses a device to vibrate muscles that contain rerouted nerves from amputees' missing limbs, replicating the sensation of joint movement and enabling the patients to sense the movement of their prostheses without having to monitor the movements visually. Such systems may play a role in the development of sophisticated brain–machine interfaces.

Signals of Change related to the topic:

SoC1009 — Implantables: Progress and Concerns
SoC872 — Brain Implants
SoC827 — Human Resources and Neuroscience

Patterns related to the topic:

P1210 — Reading Minds
P1111 — Tackling Dementia…
P1056 — Implants Overcome Paralysis

STRATEGIC BUSINESS INSIGHTS

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June 2018

SoC1019

Enabling Remote Health Care

By Lucy Young (Send us feedback.)

Changes are occurring in how, where, and from whom people receive health care. Developments in technology are bringing once-expensive equipment to schools, workplaces, and homes. Similarly, novel innovations in medical technology are creating smart tools that can find use outside hospital environments. In combination, these factors are enabling remote health care.

Redesigning existing medical technology is helping to reduce the cost of some types of equipment. On the basis of research by a professor from Stanford University (Stanford, California), Butterfly Network (Guilford, Connecticut) developed the Butterfly iQ—a handheld ultrasound scanner that works with an Apple (Cupertino, California) iPhone and is much cheaper and more versatile than are existing ultrasound systems. The scanner uses techniques from the semiconductor industry: Instead of using piezoelectric crystals that vibrate in response to a changing electric field as existing ultrasound systems do, the iQ uses a micromachine in which an applied voltage causes a membrane to move and generate the ultrasound. Because production of the iQ largely uses silicon as the core material and relies on the photolithographic techniques in use in microprocessor manufacturing, the production costs of the iQ are lower than are the production costs of existing piezoelectric ultrasound scanners. Butterfly Network envisions a future in which every household has access to one of its scanners. Although the company hopes to continue lowering the price of the iQ, it is currently marketing the device at about $2,000—a price likely out of reach of most households. However, schools and offices may find the scanner a worthwhile investment. For example, a school staff member could use the device to check a child's injured arm. Schools—and other organizations such as sports clubs—may find the PupilScreen smartphone app very useful as well. Developed by researchers from the University of Washington (Seattle, Washington), the app leverages the technology present in smartphones to assess whether someone is concussed or suffering from another traumatic brain injury. The app uses artificial intelligence and the smartphone's camera to look for changes in a person's pupil response to light. Assessing the pupillary light reflex is a standard method of determining whether a person has a serious brain injury, but recent research has revealed that it is also helpful in diagnosing concussions. The app not only makes the detection of brain injuries simpler but also enables people without medical training—for example, coaches and parents—to perform assessments.

Medical organizations and regulators will need to make efforts to ensure that the quality of care does not suffer as health care and support spreads to homes, schools, workplaces, and other locations away from medical facilities.

Making medical apparatuses more patient friendly can also benefit health care. Design Academy Eindhoven (Eindhoven, Netherlands) graduate Alissa Rees redesigned the intravenous (IV) system, which typically consists of a bag of fluid that hangs from a pole and connects to a patient's veins. Rees's system comprises a soft-fabric container that a patient wears over his or her shoulders and chest. Pouches in the fabric container hold fluids that pump into a vein in the patient's arm. The wearable system allows greater patient mobility than does the existing IV system, and it includes a connected system

that sends an alert if a problem with the pump occurs. Such a portable IV system could find home use to enable patients to convalesce in their own environments, which would also free up hospital facilities for patients who require hospitalization. The redesign of existing medical devices is not the only factor that is contributing to health care's becoming more portable; new technological innovations are also making health care away from hospitals feasible. Scientists from the Massachusetts Institute of Technology (Cambridge, Massachusetts) and Brigham and Women's Hospital (Boston, Massachusetts) used piezoelectric materials to create an ingestible flexible sensor. When a patient swallows the sensor, it sticks to either the wall of the stomach or the intestinal lining and measures the rhythmic contractions of the digestive tract. The sensor, which remains active for as long as two days, could find use in diagnosing gastrointestinal disorders and in monitoring a patient's intake of food and liquid. The scientists plan to continue developing the sensor, and future versions may include wireless transmitters. Wireless connectivity could enable patients to use the sensor at home while medics remotely gather data that are representative of the patient's normal day-to-day life.

The ability to monitor patients for a long period can enable more rapid diagnosis and treatment—both within and away from hospitals. PMD Solutions (Cork, Ireland) has created a wearable sensor that monitors breathing and can help detect blood poisoning, of which rapid respiratory rate is a significant indicator. The device uses piezoelectric material to measure a patient's breathing rate and algorithms to account for signal noise that activities such as walking can cause. The sensor also alerts medical staff if a patient's breathing rate goes above or below certain thresholds, which could indicate a medical problem. The device interfaces with smartphones and tablets, which means that it could find use in all clinical settings and in patients' homes.

The redesign of existing medical equipment and the creation of novel technologies are enabling remote health care. As the examples above demonstrate, remote health care can enable patients to receive diverse types of medical care at almost any location. Significantly, nonexperts are able to administer some of this medical care. Remote health care could alleviate pressure on centralized medical facilities—particularly in countries with aging populations. However, the emergence of remote health care could present challenges and require careful management. For example, medical infrastructure will likely need to adapt to support remote health care, and medical organizations and regulators will need to make efforts to ensure that the quality of care does not suffer as health care and support spread to homes, schools, workplaces, and other locations away from medical facilities.

SoC1019

Signals of Change related to the topic:
SoC767 — Ubiquitous…Health-Care Tools
SoC762 — Health-Care Devices…
SoC760 — Diagnosed Self

Patterns related to the topic:
P1198 — …Detection of Health Issues
P1197 — Distributed Monitoring
P1173 — Patching Patients

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SoC1022

Layers of Sensor Infrastructures

By Martin Schwirn (Send us feedback.)

Sensors are application enablers—a fact to which every smartphone user can attest. Often entire networks of sensors develop organically as more and more sensor-containing devices see deployment. But new research efforts aim at establishing expansive sensor infrastructures and implementing them to achieve multiple goals—each of which is worth pursuing in its own right. As advanced sensor infrastructures emerge, each infrastructure will form a layer of a comprehensive sensor-infrastructure network that will enable the placing of various types of data in context. Although each of these layers initially saw implementation to achieve a specific goal, the totality of such sensor-infrastructure networks will enable a wide range of applications that researchers and developers will discover as they imagine new uses and fortuitously notice relationships among phenomena.

Sensors' need for energy is a limiting factor for many proposed applications.

Many urban environments around the world already make use of a broad range of sensor networks; however, the oceans—expansive bodies of water that cover a large percentage of Earth's surface—so far have remained out of reach of comprehensive sensor solutions. The US National Oceanic and Atmospheric Administration (NOAA; Silver Spring, Maryland) recently concluded an experiment during which two semiautonomous sensor-equipped sailboat drones spent eight months collecting data in the Pacific Ocean. Saildrone (Alameda, California) collaborated with NOAA to develop the drones, which carry 15 scientific instruments capable of collecting ocean, weather, and climate data. The purpose of the experiment was to determine whether a fleet of such drones could replace the aging network of research buoys that scientists have used to gather data about specific climate and weather patterns in the Pacific Ocean since the 1980s. In a separate effort, the US Department of Defense's (Arlington County, Virginia) Defense Advanced Research Projects Agency (DARPA; Arlington, Virginia) is working on the Oceans of Things program. The program employs smart floats to collect a wide range of environmental and activity data, including information about ocean temperature and the movement of commercial boats. The program aims at creating "persistent maritime situational awareness over large ocean areas by deploying thousands of small, low-cost floats that could form a distributed sensor network" ("Ocean of Things Aims to Expand Maritime Awareness across Open Seas," DARPA, 6 December 2017; online). DARPA is also looking at speculative approaches to gain a better understanding of ocean areas that are of strategic interest. The Persistent Aquatic Living Sensors (PALS) program will identify organisms that could find use in sensor systems to detect the movements of underwater vehicles. The program will research "marine organisms' responses to the presence of such vehicles, and characterize the resulting signals or behaviors so they can be captured, interpreted, and relayed by a network of hardware devices" ("PALS Turns to Marine Organisms to Help Monitor Strategic Waters," DARPA, 2 February 2018; online). Employing organisms as sensors has several practical advantages: Organisms do not require a power source, they are highly attuned to their natural environment, they are cheap, and they can cover a large area. The methods and technology under development in the PALS program are speculative; however, if they see success in military applications, they could find use in commercial applications.

Another effort focuses on using river and lake systems as sensors to gather useful data.

Researchers at Michigan State University (East Lansing, Michigan) are looking at monitoring waterways to gain a better understanding of a region's ecosystem. Through the use of streams as sensors, farmers, land-use managers, and scientists can identify watersheds ideal for sustainable development to enable their use in food production. According to researcher Jay Zarnetske, "Our methods show that we can learn much from a relatively small number of samples if they are collected more strategically than current watershed management practices dictate" ("Streams Can Be Sensors," *MSUToday*, 29 December 2017; online). A better understanding of waterways will aid in the development of better farming methods.

Sensor solutions for use on land are also under development. For example, the Fraunhofer Society for the Advancement of Applied Research (Munich, Germany) and the government of Portugal hope to advance digital tools to support agriculture and forestry. Their plans include not only using drones and satellites to gather data that can see use in increasing crop yields, decreasing the use of pesticides, and monitoring the growth of produce but also deploying sensor-equipped "small electrically driven vehicles that work cultivation areas autonomously and in swarms" ("Fraunhofer drives intelligent agriculture forward," Fraunhofer, 8 December 2017; online). DARPA is also working on a land-based monitoring approach that, similar to the approach in its PALS program, relies on organisms. The Advanced Plant Technologies (APT) program "envisions plants as discreet, self-sustaining sensors capable of reporting via remotely monitored, programmed responses to environmental stimuli" ("Nature's Silent Sentinels Could Help Detect Security Threats," DARPA, 17 November 2017; online). The plants' intrinsic sensing mechanisms will find use to detect chemicals, electromagnetic signals, pathogens, and radiation, and the plants' biological systems eliminate the need for an energy source to power the sensing mechanism.

Such sensor infrastructures will enable a plethora of applications, but many of the sensors that researchers envision require enabling technologies. In particular, sensors' need for energy is a limiting factor for many proposed applications. Some of the applications that this Signal of Change has already mentioned are experimenting with conceivable solutions to the energy problem. One very straightforward approach is to put such sensor arrays on platforms that provide the necessary energy. A second approach is to use organisms that provide the energy necessary for their sensing capabilities. A third approach is to develop sensors that can use ambient sources of energy. Researchers at Northeastern University (Boston, Massachusetts) developed an infrared (IR) sensor that, unlike other IR sensors, consumes no standby power until the wavelengths it detects are present. In the presence of IR light, the energy from the light itself heats sensing elements, resulting in the movement of crucial components of the sensor. The sensor's ability to operate without a dedicated power supply or even a battery dramatically increases the number of potential applications for the sensor. And US research consortium Bridging the Innovation Development Gap (Kissimmee, Florida) is partnering with Face International Corporation (Face Companies; Norfolk, Virginia) to commercialize an energy-harvesting power-cell device for wireless Internet of Things sensors and transmitters. The device uses a thermoelectric material to harvest thermal energy from the environment and convert it into electricity.

SoC1022

Signals of Change related to the topic:
SoC1013 — Quantifying…Urban Environments
SoC997 — Sensors…in Health Care
SoC983 — Smart Infrastructures…

Patterns related to the topic:
P1197 — Distributed Monitoring
P1168 — …Constant Monitoring
P1138 — Energy from Everywhere