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DEFTECH Update

June 2018

Dear Reader,

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

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: Festo

Soft Robotics Revolution: Researchers are exploring novel capabilities of soft robotics. Festo in Germany has developed a robotic tentacle that can wrap around objects. Stanford University and UC Santa Barbara have developed a soft robotics arm that can extend from less than 30 centimeters to more than 70 meters. Harvard University and other institutions have created an experimental soft robot that has no electrical components; instead, a chemical reaction generates gas that powers a pneumatic system.

Implication for Defense and Security*: New soft robot designs could enable far more capable military robots than those that are common today. For example, an extensible soft arm could enter otherwise hard-to-reach spaces while causing minimal disturbance to its surroundings. Specific applications include equipment repair, search-and-rescue efforts, and surveillance. Robots without electrical components could perform tasks in explosive atmospheres or within areas that experience large amounts of electrical interference.*

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

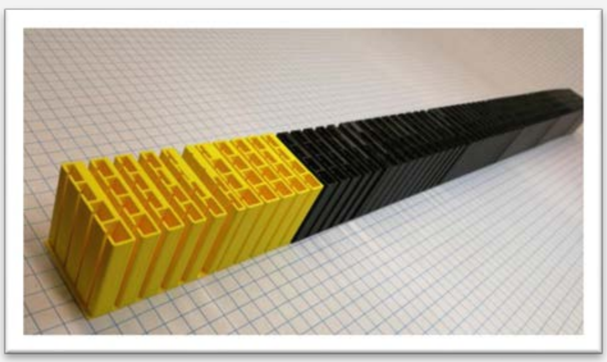

Image source: Duke University website

Metamaterials for Underwater Cloaking: Researchers at institutions including Rutgers University and Duke University are making progress in the development of metallic metamaterials capable of manipulating underwater sound waves in unusual ways. The research could potentially lead to cloaking applications of metamaterials in the future.

Implication for Defense and Security*: Metamaterial cloaking devices, if technologically feasible, could have a major impact on defense and security. For example, the technology could be invaluable in helping defense organizations gain strategic advantage by concealing sea-based assets such as submarines or missiles. Although the technology is only in its infancy, some potential nearer-term applications exist including enhanced oceanographic imaging.*

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

Image source: IBM Research

Investing in High-Performance Computing: Chip manufacturers, tech firms, and governments are investing in cutting-edge computers. Google, IBM, and Intel Corporation are all developing advanced quantum-computing hardware that has a greater number of qubits than previous hardware has. The European Commission recently announced plans to invest roughly €1 billion ($1.24 billion) in the development of new supercomputers.

Implication for Defense and Security*: High-performance computers are important strategic assets for military organizations—for example, to enable complex simulations that aid new weapons development. Countries with large military forces, including China and the United States are making substantial investments in next-generation supercomputing. New computing designs—including quantum computing—could prove disruptive by solving previously intractable problems including those used to implement cryptography.*

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

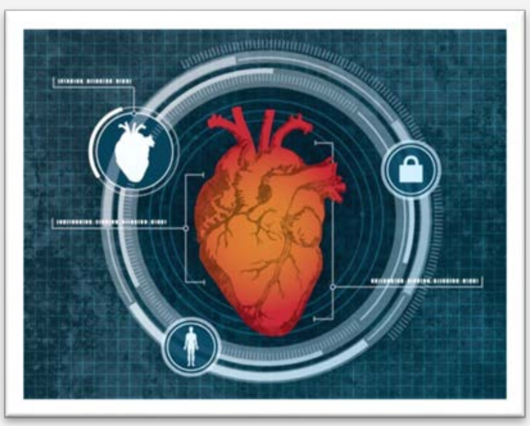

Image source: Bob Wilder/University at Buffalo

Biometric Sensor Improvements: High-quality fingerprint replicas fool some fingerprint readers. Although some readers use AI to identify whether a fingerprint is fake, alternative biometrics may be more foolproof. Researchers from the State University of New York at Buffalo and Texas Tech University have developed Cardiac Scan—a computer-security system that uses low-power Doppler radar to take the dimensions of a person's heart as a personal identifier.

Implication for Defense and Security: *New biometrics could improve access control for secure locations and systems. Because hearts are unique and generally do not change shape unless afflicted by disease, biometric systems that use the heart could be more secure and less prone to fooling than are fingerprint- and iris-scanning systems. Moreover, the system could see use for remote identification, monitoring individuals from as far as 30 meters away.*

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

Image source: Panasonic

Quantifying and Analyzing Urban Environments: As a result of sensor infrastructures proliferating and individuals in urban areas increasingly interacting with their environments digitally, information is increasingly accessible and new applications are emerging. Examples include measuring pollution exposure by correlating smartphone data with stationary air-quality sensors, and a Panasonic-led project in Denver to use communications networks, energy infrastructures, sensors, and security cameras to improve urban dynamics.

Implication for Defense and Security*: Cities are already deploying smart city applications to aid crime prevention and response, and as a defense against terrorist acts. As well as complete systems that combine sensors, networks, and software, vendors have an opportunity to design urban security applications that leverage existing sensor data, for example from smartphones, connected vehicles, or smart infrastructure.*

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

Image source: Neurable

Reading Minds: An increasing number of devices for analyzing brain activity noninvasively are under development. Functional near-infrared spectroscopy (fNIRS)—which essentially uses light that shines through the skull to measure brain activity—has promise. Facebook and Openwater are among fNIRS developers. Other vendors creating brain-measuring devices include Neurable and CTRL-Labs. Applications include typing and control of computer games.

Implication for Defense and Security*: Devices that allow seriously injured soldiers to use computers for communication and other purposes could aid rehabilitation. Noninvasive devices such as fNIRS also have potential as human machine interfaces for healthy personnel. For example, a soldier needing a handsfree (or perhaps a covert) control mechanism could operate a robot using a helmet-based brain analysis device.*

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

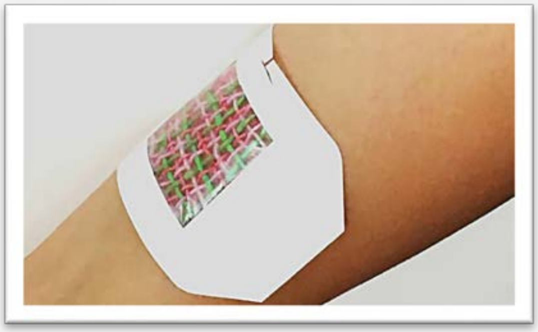

Image source: TechCrunch website

Smart Hydrogel-Based Bandages: Recently, a team of US engineers developed a proprietary hydrogel-based smart bandage that enables the controlled, heat-activated release of therapeutics. This smart bandage shows great potential in enabling physicians to prescribe the optimum doses of therapeutics. Conceivably, the research team could incorporate additional functionalities into the bandage such as smart sensors that provide it with autonomous drug-delivery capabilities.

Implication for Defense and Security*: Smart bandages capable of delivering therapeutics could shorten recovery times and improve outcomes for wounded military personnel. Plausibly, future versions of such bandages could provide convenient in-field treatments by providing wound cleaning and pain management in bandage form.*

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

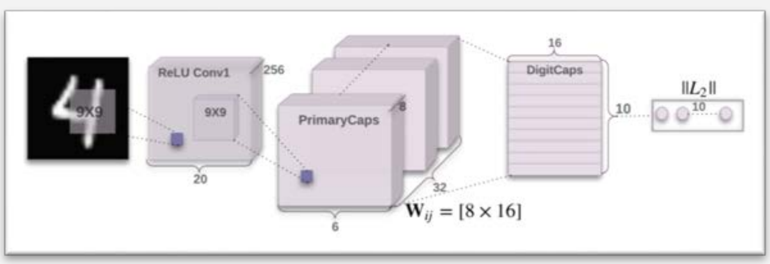

Image source: Medium website

Capsule Networks: Neural network pioneer Geoffrey Hinton recently released a research paper outlining a new type of artificial neural network known as a capsule network. Using a new training method—dynamic routing—a capsule network excelled at recognizing objects from unfamiliar camera angles and when images were distorted.

Implication for Defense and Security*: Defense and security organizations have significant needs for reliable image-analysis technologies. Although capsule networks research is still at the early stage, this new neural network has potential to become the standard approach for image recognition and similar applications in the long-term due to improved accuracy and reduced training data requirements. Because no organization is yet an expert in the area, the competitive playing field is fairly open.*

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

Image source: Edgy Labs website

Implantables Progress: Technological advances in areas as diverse as materials science and power generation are progressing and enabling the development of an expanding range of implantable devices. Examples include a spinable polymer suitable for dissolvable implantable medical devices and a piezoelectric system that uses the vibrational energy the heart produces to generate power for a pacemaker.

Implication for Defense and Security*: Improving implantable devices offer an obvious benefit for wounded military personnel, but also paves the way for new implantable technologies that enhance the capabilities of soldiers and other personnel. For example, perhaps future implantable devices could enhance human strength or enable covert communications and surveillance.*

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

Image source: YouTube / DroNet

Autonomous Drones: Various research projects explore distinct methods of operating drones at least partially autonomously. MIT Lincoln Laboratory has developed military swarm drones that are able to self-organize. Researchers from the University of Zurich and other institutions are developing the DroNet neural network, which will use data street vehicles have collected to help drones learn how to navigate safely through city street.

Implication for Defense and Security*: Drones are already common in defense applications, though most require human pilots. Autonomous and semi-autonomous drones would allow the flexibility to deploy drones in greater numbers and to use them in areas without reliable communications (such as inside buildings). Leveraging technologies and data developed for autonomous cars could accelerate progress in autonomous drones.*

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

Image source: EEJournal website

Working with Living Materials: Researchers are leveraging the capabilities of living materials in the development of new technologies, especially for sensing applications. Examples include DARPA's Advanced Plant Technologies program that aims to leverage plants' intrinsic sensing mechanisms to detect chemicals, pathogens, or radiation, and MIT's development of a 3D-printed patch with genetically programmed bacteria cells that is suitable for pathogen and pollutant detection.

Implication for Defense and Security*: Living materials have clear potential to aid defense and security organizations by improving detection of chemicals, pathogens, and radiation. In plant form, living sensors might be suitable for deployment over wide areas at fairly low-cost. In other cases, living materials might combine with electronics to enhance traditional sensors.*

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

Image source: Printed Electronics Now website

3D-Shape Touch Controls: Conductive organic films can enable manufacturers to form touch-based interfaces of an almost unlimited variety of shapes. In one example, Canatu, Cypress Semiconductor, and NISSHA have collaborated to develop a 3D automotive panel with raised and sunken sections and a hemisphere—all of which are touch interfaces.

Implication for Defense and Security*: Conductive organic films are creating new user interface options for designers of military vehicles, equipment, and supplies. Varied shapes for control systems may improve usability for pilots, drivers, and operators, and the potentially low-cost of conductive films could open up new touch-based applications in areas where conventional touch screens would be too expensive—for example, smart packaging for food or medical supplies.*

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

P1199

Working with Living Materials

By Ivona Petrache (Send us feedback.)

Researchers are leveraging the capabilities of living materials in the development of new technologies and applications.

Abstracts in this Pattern:

- SC-2018-03-07-017 on sensors
- SC-2018-03-07-071 on lighting
- SC-2018-03-07-011 on compound detection
- SC-2018-03-07-068 on functional living ink
- SC-2018-03-07-091 on bacterial conversion

The US Department of Defense's (Arlington County, Virginia) Defense Advanced Research Projects Agency (DARPA; Arlington, Virginia) recently launched the Advanced Plant Technologies program, which focuses on using plants as intelligence-gathering sensors that researchers can monitor remotely. The plants' intrinsic sensing mechanisms will find use to detect chemicals, pathogens, or radiation. And researchers at the Massachusetts Institute of Technology (MIT; Cambridge, Massachusetts) are looking into using nanobionic plants for lighting applications. The researchers embedded nanoparticles into the leaves of watercress plants, which caused the plants to emit a dim glow for several hours. This work could eventually enable plants to reduce energy consumption by serving as an alternative to electrical light sources.

Other MIT researchers developed a 3D-printing technique that prints with ink that contains live genetically programmed bacteria cells. The researchers printed a thin transparent patch on which bacteria-cell-containing ink forms the shape of a tree. The bacteria cells in each branch of the tree are sensitive to a specific compound and light up on exposure to those compounds on a patch wearer's skin. The patch likely has applications in pathogen and pollutant detection. And researchers from the Swiss Federal Institute of Technology in Zurich (Zurich, Switzerland) created a 3D printer that can use functional living ink, which comprises a sugar-containing hydrogel base, live bacteria, and a culture medium. The researchers can customize printouts to meet specific needs by using the appropriate bacterium in the ink. For example, one bacterium gives off a stable and moisture-retaining material that can see use in treating burns.

Researchers from the University of Dundee (Dundee, Scotland) and other institutions have used pressure to force *Escherichia coli* bacteria to convert carbon dioxide and hydrogen into formic acid, which has several industrial uses. Although the research is at an early stage, it could eventually enable companies to develop more environmentally friendly production processes.

Signals of Change related to the topic:

- SoC944 — Exploring Biobased Materials
- SoC641 — Harnessing Nature
- SoC446 — Harnessing Living Materials

Patterns related to the topic:

- P1018 — Biological Processing in Cleantech
- P0996 — Biological Material in Architecture
- P0092 — Interactive Materials

May 2018

P1206

Investing in Novel Computing

By Sean R. Barulich (Send us feedback.)

Chip manufacturers, tech firms, and governments are investing in the research and development of cutting-edge computing technologies.

Abstracts in this Pattern:
SC-2018-04-04-096 on computing power
SC-2018-04-04-043 on quantum chips
SC-2018-04-04-025 on supercomputers
SC-2018-04-04-004 on AI park

Companies are expressing the need for more computing power to enable technological advancements in nearly every industry, which will enable an increasing number of applications. For example, while speaking at the annual World Economic Forum (Cologny, Switzerland) meeting in Davos, Switzerland, in January 2018, Microsoft (Redmond, Washington) CEO Satya Nadella claimed that improvements in computing power and new computing technologies are necessary to solve some of the world's most difficult problems. In addition, Nadella mentioned that quantum computing will be an enabler of artificial intelligence (AI). Some tech firms have already taken steps to develop such new computing technologies. For example, Google (Alphabet; Mountain View, California), IBM (Armonk, New York), and Intel Corporation (Santa Clara, California) are all developing advanced quantum-computing hardware that has a greater number of qubits than previous hardware has. *Qubits* are the quantum analogue of traditional computing's bits, but creating large numbers of qubits is difficult. IBM and Google both developed their own 50-qubit quantum chips, and Intel recently confirmed that it has produced a 49-qubit quantum chip.

Government and intergovernmental organizations are also investing in new computing technologies. For example, the European Commission recently announced the EuroHPC initiative, through which it and several EU member states will invest roughly €1 billion ($1.24 billion) in the development of high-performance computers. The European Commission plans to use the EuroHPC initiative to produce two new supercomputers in Europe that will be among the world's ten fastest. China is also investing in the development of advanced computing technologies. For example, the government of China is planning to build a $2 billion AI research park capable of accommodating 400 companies. Zhongguancun Development Group Co. (Beijing, China)—the state-owned developer of the park—"is hoping to partner with foreign universities and build a 'national-level' AI lab in the area" and aims for the park to attract companies that focus on big data, biometric technologies, cloud computing, and deep learning.

Investments in cutting-edge computing technology may give stakeholders a competitive edge in next-generation computers and related technologies.

Signals of Change related to the topic:
SoC1005 — …Value from Digital Change
SoC997 — Sensors…and AI in Health Care
SoC987 — …Smart Worlds

Patterns related to the topic:
P1193 — Expanding Digitalization
P1187 — …Humans and AI
P1158 — Simulation and Testing

P1210

Reading Minds

By Lucy Young (Send us feedback.)

Improvements in technologies that analyze and interpret brain activity could enable applications across industries.

Abstracts in this Pattern:
SC-2018-04-04-023 on devices
SC-2018-04-04-006 on software
SC-2018-04-04-003 on behavior

An increasing number of devices for analyzing brain activity noninvasively are under development. Neurable (Cambridge, Massachusetts) has developed a headband that contains electroencephalogram (EEG) sensors and enables people to use their thoughts to play a virtual-reality game. In the game, players need only concentrate on an object to summon that object to them. CTRL-Labs (New York, New York) is developing a forearm band that measures signals that travel between the brain and the hand. The band interprets these signals to act as an interface between the wearer and a computer, enabling the wearer to control the computer with little or no movement of his or her hand. Functional near-infrared spectroscopy (fNIRS)—which essentially uses light that shines through the skull to measure brain activity—has great promise as a consumer-friendly brain-scanning technique. Facebook (Menlo Park, California) is attempting to use the technique to enable mind-controlled typing. And Openwater (San Francisco, California) is developing fNIRS technology that it claims can sample data in milliseconds and has a resolution that is a billion times that of functional-magnetic-resonance-imaging (fMRI) machines.

Although advances in hardware that measures brain activity are vital to reading minds, developments in software that interprets these measurements are also important. Researchers from Kyoto University and the Advanced Telecommunications Research Institute International (both Kyoto, Japan) are using artificial intelligence (AI) to decode magnetic-resonance-imaging (MRI) brain scans and generate visualizations of images that test subjects are thinking about. The researchers demonstrated that their AI can decode hierarchical images that have several layers of structure and color. Developments in technologies that analyze and interpret brain activity lay the foundation for increasing the understanding of the brain. These developments could benefit research such as the recent investigation of the link between brain lesions and criminal behavior that scientists from the Beth Israel Deaconess Medical Center (Harvard University; Cambridge, Massachusetts) and other institutions conducted. Such research could have implications for a range of industries, including health care and law enforcement.

Signals of Change related to the topic:
SoC537 — Mind and Machine Merge
SoC349 — Neuroscience on Trial
SoC275 — Brainware

Patterns related to the topic:
P1077 — Understanding Neurology…
P0271 — Refreshing the Mind
P0143 — Accessing Human Thought

Strategic Business Insights

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April 2018

SoC1007

Operating Drones

By Peter Batty (Send us feedback.)

The term *drone*—or *unmanned aerial vehicle* (*UAV*)—describes a variety of vehicles, from remotely operated aircraft to autonomous quadcopters guided by GPS and sensor information. Partial or complete autonomy of operations is crucial to expanding the usability and functionality of drones and thereby enabling a wider range of applications for them. Various research projects explore distinct methods of operating drones at least partially autonomously.

Success stories about drone deployment often refer to remote-control craft such as those in use by the military in conflict zones. In these cases, computers take care of the nuances of flying (as they do for other modern military aircraft), but a human operator guides the drone's weapons to a target and ultimately deploys them. Giving certain types of drones that gather intelligence or jam communications full autonomy is high on the agenda of many armed forces around the world. For example, the US Department of Defense's (Arlington County, Virginia) Project Perdix aims to coordinate swarms of miniature (a wingspan of about half a meter) drones that can launch from a human-piloted fighter aircraft. The Perdix microdrones—originally developed during a student project at the Massachusetts Institute of Technology (MIT; Cambridge, Massachusetts)—have been modified for military use by researchers at the MIT Lincoln Laboratory. Demonstrations have shown that more than 100 microdrones can launch simultaneously at high speed (Mach 0.6, or 735 kilometers per hour) from special pods on the host aircraft. The drones' software enables collective decision making that leads to adaptive formation flying and swarm self-healing in which other drones fill the gaps in formation resulting from a drone's malfunctioning or taking damage from enemy fire.

Cost advantages and technological affordances of autonomous and remote-control drones enable their use in a wide range of applications.

Progress toward fully autonomous drones has been rapid. GPS technology enables drones to find their location anywhere around the world, and inexpensive cameras and various sensors enable more sophisticated drones to understand and navigate their environment. Researchers from the University of Zurich (Zurich, Switzerland) and other institutions are developing the DroNet (short for *Drone Network*) convolutional neural network, which will make sense of the data street vehicles have collected to help drones learn how to navigate safely through city streets. The researchers aim "to train a UAV from data collected by cars and bicycles, which, already integrated into urban environments, would expose other cars and pedestrians to no danger" (http://rpg.ifi.uzh.ch/dronet.html). Drones have already learned to avoid pedestrians and urban obstacles and not to fly across oncoming traffic. Because DroNet does not require significant computing power and the hardware necessary to provide it, the artificial-intelligence software can see use with even very small drones.

The term *full autonomy* can also refer to drones that use software to fly preprogrammed routes or carry out preplanned activities. Airobotics (Petah Tikva, Israel) has developed a drone solution that integrates a quadcopter drone, intuitive user control software (to design drone routes, for example), and a landing station that enables automatic payload swapping and battery charging. The firm envisages its drone solution's seeing use to augment or fully perform routine activities such as monitoring for security and safety issues (checking for leaks at oil-and-gas facilities or dams, for example), inspecting plant equipment, and surveying and mapping. The drone solution requires no trained human operators, and the drones eliminate the need for humans to inspect potentially hazardous equipment. In contrast to DroNet, which enables drones to make navigation decisions in real time, the drone solution Airobotics developed focuses on sending drones on predetermined paths to participate in routine tasks.

An expanding range of navigation and operational software will increase the uses for drones. Cost advantages and technological affordances of autonomous and remote-control drones enable their use in a wide range of applications that were once conceivable only with manned vehicles in exceptional circumstances. For example, search-and-rescue missions can benefit tremendously from advances in navigation and control systems for drones. In November 2017, commercial-drone-service provider Terra Drone Corporation (Tokyo, Japan) and telecommunications company LG Uplus Corp. (LG Corporation; Seoul, South Korea) demonstrated a new control system that uses a cellular network to enable confirmation of the position of a drone that is beyond visual line of sight. During the demonstration, an autonomous drone flew over a South Korean park roughly 20 times the size of a football stadium and located a 6-year-old wearing a red jacket in about three minutes, sending safety personnel information about the child's location before returning to the control center. The system provides operators with information about the drone's latitude and longitude, weather conditions in the drone's location, and operational information such as the drone's flight speed and remaining battery power. In addition, the system prevents a drone from colliding with other aircraft or birds and enables it to land in a safe location via parachute in case of emergency. Drones' rapid deployment and airspeed also enable first responders to reach people in need of immediate aid. In early January 2018, a new drone system undergoing testing in New South Wales, Australia, came to the aid of two swimmers who were struggling in difficult conditions. The Little Ripper Lifesaver UAV, the development of which Westpac Banking Corporation (Sydney, Australia) has sponsored since early 2016, is part of an initiative by Westpac Life Saver Helicopter (Surf Life Saving Australia; Sydney, Australia) to augment lifesaving and shark-spotting services. The drone carries a flotation pod to help distressed swimmers, and, in this case, the drone pilot was able to launch the drone, fly it to the swimmers, and deploy the floatation pod in about 70 seconds. The swimmers then made their way safely back to the beach.

As costs of drone technology come down and drones' operational requirements decrease, drones will find ready diffusion in numerous markets. Drones are already finding use in educational and research settings. For example, BonaDrone (Vallbona d'Anoia, Spain) develops kits that enable students to design and 3D print drone parts that they can assemble into working drones. The kits come with teaching materials specific to the class, and the company aims to expose students to—and generate their interest in—various aspects of science and technology subjects. Ocean Alliance (Gloucester, Massachusetts) also employs drones for educational and scientific purposes. The organization—with the help of the Olin College of Engineering (Needham, Massachusetts)—developed SnotBot drones for use in collecting information about whales nonintrusively. For example, the SnotBots "hover in the air above a surfacing whale and collect the blow (or snot) exhaled from its lungs" (https://shop.whale.org/pages/snotbot).

SoC1007

Signals of Change related to the topic:
SoC942 — …Emergency Response
SoC866 — A Flock…of Drones
SoC796 — Drone Update

Patterns related to the topic:
P1074 — Drones' 1,001 Uses
P0998 — Drones…Hype Cycle
P0981 — Automating Transportation

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April 2018

SoC1009

Implantables: Progress and Concerns

By Lucy Young (Send us feedback.)

Technological advances in areas as diverse as materials science and power generation are progressing and enabling the development of an expanding range of implantable devices. Developments in materials technology could give implants new benefits. For instance, researchers at Vanderbilt University (Nashville, Tennessee) are using a spinable polymer to create electrical circuitry that self-destructs at room temperature. The material could enable the creation of dissolvable implantable medical devices; once the implant is no longer necessary, medics could hold ice to the skin where the implant is, causing the implant to break apart. Although the technology is in the early stages of development—and any such implant would need to break down and leave the body safely—its main benefit is that removing the implant from the body would no longer require painful and risky surgery.

Surgeries for implants such as pacemakers, which stimulate the heart with electrical pulses to keep the organ's rhythm consistent, present a number of risks. In general, the batteries in pacemakers work for about 12 years, and surgery is necessary to replace the batteries in conventional pacemakers when they run out of power. Leadless pacemakers sit inside the heart itself, during which time tissue grows around them, making their removal difficult once their battery has expired. To avoid risky retrieval of the pacemaker, surgeons may leave the expired pacemaker where it is and place a new pacemaker nearby. Researchers at the State University of New York at Buffalo (Buffalo, New York) are developing a piezoelectric system that uses the vibrational energy the heart produces to generate power for a pacemaker. Theoretically, this system would never require replacement, and it would eliminate the need for additional surgeries to ensure the patient has a functional pacemaker. The researchers are working on scaling down their initial 1-centimeter-cubed device into a half-centimeter-long strip and developing a method for attaching a backup power source to the device.

Research that focuses on methods of implantation is important as well, because the simpler and safer the implantation method, the greater the number of patients who are able to receive implants and the wider the variety of implants that are implantable. For example, a robot autonomously inserted dental implants into a patient with minimal human involvement in China in 2017. Developed by researchers from Beihang University (Beijing, China) and an affiliate hospital of the Fourth Military Medical University (Xi'an, China), the robot implanted artificial teeth within a margin of error of 0.2 to 0.3 millimeter, which is the necessary standard for the operation. The researchers developed the robot in part to reduce the risk of human error during surgical procedures. The robot was able to work in small hard-to-see areas of the mouth that often make procedures difficult for human surgeons to complete. Similar uses of robotic systems could enable the implantation of devices in other areas of the body that are tricky for surgeons to access.

Another ethical question is arising as implant technology advances: Should the use of implants that treat medical conditions be mandatory or optional?

As implant technology is progressing and gaining novel capabilities, new issues are arising. Even though no large-scale hacking of medical implants has yet occurred, concerns about such hacking have grown in recent years as medical-device manufacturers have added wireless connectivity to their products. In late 2017, Abbott Laboratories (Lake Bluff, Illinois) announced a voluntary recall of about 465,000 pacemakers in response to an advisory order the US Food and Drug Administration (FDA; Silver Spring, Maryland) issued. Abbott's radio-frequency-telemetry pacemakers wirelessly transmit data about the patient and the device for use by medical staff, and the FDA became concerned about the potential for criminals to hack the implants using commercially available equipment. Abbott released a software update to prevent such hacking. In addition to having fears about unauthorized access to smart implantable devices, some people have concerns about the extent of data that medical professionals and caregivers will have access to via smart implants and other smart devices that see use within the human body. In November 2017, the FDA approved Abilify MyCite—a digital pill from Otsuka Pharmaceutical Co. (Tokyo, Japan) that treats schizophrenia and related conditions. The pill contains an ingestible sensor that relays data to a wearable patch when the pill has reached the patient's stomach. The patch then relays these data to a companion smartphone app, which records when the patient took the pill and notifies (with the patient's permission) caregivers and physicians of any missed doses. Proteus Digital Health (Redwood City, California) developed the sensor technology in use in this pill, and the FDA cleared the company to market the technology back in 2012. Although the system helps to ensure that patients take their medication, some people are concerned that the monitoring of medical compliance will make patients feel coerced into following medication regimens that do not suit them—especially if insurance companies demand use of trackable pills and can monitor compliance of use.

Another ethical question is arising as implant technology advances: Should the use of implants that treat medical conditions be mandatory or optional? For example, a doctor in Germany contacted a child-welfare agency after parents refused a cochlear-implant surgery for their 18-month-old deaf child. The parents, who are also hearing impaired, believe that even the implant would not enable them to teach the child to speak, and they have concerns about surgery-associated risks; however, the doctor believes the surgery is necessary. A judge will have the final say, which could have implications for all children who are born deaf in Germany. As the functionality and capabilities of implants improve and the methods of implantation advance, ethical questions about mandatory implants will arise and need answering.

SoC1009

Signals of Change related to the topic:
SoC938 — …Human Augmentation
SoC872 — Brain Implants
SoC871 — Augment and Advance

Patterns related to the topic:
P1063 — (Em)Powering Implants
P1056 — Implants Overcome Paralysis
P1007 — Medical Implants

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May 2018

SoC1011

Proliferating Sensor Applications

By Peter Batty (Send us feedback.)

SoC997 — Sensors, Data, and AI in Health Care discusses new sensor technologies that will gather data previously difficult or impossible to access. These data will in turn feed sophisticated artificial-intelligence (AI) systems. Miniaturized, energy-efficient sensors could enable ubiquitous and discreet monitoring of the environment and individuals.

Sensor systems already find use in many security, safety, and health-care applications. For instance, biometric sensors that read fingerprints are now a standard feature of many smartphones. A fingerprint reader, which provides convenience by enabling a person to unlock his or her device by scanning a finger instead of by entering a code or password, is a worthwhile feature for many people. However, fingerprint readers have notable and well-documented flaws. High-quality fingerprint replicas (consisting of wax or another malleable material) can fool some fingerprint readers. Synaptics (San Jose, California) and other developers of sophisticated sensors claim their sensors use AI to identify whether a fingerprint is fake. But faking a person's heart is more difficult than faking a person's fingerprint. Researchers from the State University of New York at Buffalo (Buffalo, New York) and Texas Tech University (Lubbock, Texas) have developed Cardiac Scan—a computer-security system that uses the dimensions of a person's heart as a personal identifier. The system employs low-power Doppler radar to take an initial measurement of a person's heart, which takes about 8 seconds, and then continuously monitors and recognizes that person's heart. The system monitors the person's heart constantly, so it can quickly determine if another person attempts to use the computer. Because hearts are unique and generally do not change shape unless afflicted by disease, biometric systems that use the heart could be more secure and less prone to fooling than are fingerprint- and iris-scanning systems. The current iteration of Cardiac Scan is insufficiently portable for commercial use in mobile devices and many environments, but its developers envisage the system's eventual integration into computer keyboards and cell phones. Moreover, the system could see use at airport screening barricades, where it could monitor individuals from as far as 30 meters away.

Improved sensor technology is naturally of interest to defense organizations.

Sophisticated sensor systems could benefit safety applications. For example, athletes such as football players and boxers run the risk of experiencing head injuries while playing their sport. In football, concussions are common among players despite their use of protective headgear. Repeated head injuries can result in depression, dementia, and various neurological conditions. Prevent Biometrics (Edina, Minnesota) has developed a head-impact-monitoring mouth guard that collects data that could aid in efforts to improve athlete safety. The mouth guard contains accelerometers, a proximity sensor, and a Bluetooth module that relays impact data to an iPad (Apple; Cupertino, California) app. This mouth guard is noteworthy because its lightweight, compact electronics are durable enough to undergo the boiling process necessary to mold the mouth guard to fit the wearer's mouth. The Prevent Biometrics mouth guard may also find use in applications that do not focus solely on athlete safety. For example, because the mouth guard measures the force of impact, it could see use to deliver fairer rulings in boxing matches by enabling referees to call knockouts on the basis of an analysis of objective head-impact data rather than on the basis of an analysis of subjective evidence.

Designers of new sensor systems are looking for very interesting, currently experimental solutions that could find use in health-care-related applications. For example, researchers at the Massachusetts Institute of Technology (Cambridge, Massachusetts) developed a 3D-printing technique that prints with ink that contains live genetically programmed bacteria cells that emit light on exposure to various chemical or molecular compounds and certain stimuli such as changes in pH and temperature. According to the researchers, this technique enables the creation of interactive 3D devices and structures and could see use in the fabrication of wearable sensors. To demonstrate the technique, the researchers printed a thin transparent patch on which bacteria-cell-containing ink forms the shape of a tree. The bacteria cells in each branch of the tree are sensitive to a specific compound and light up on exposure to those compounds on a patch wearer's skin. New manufacturing technologies are enabling the creation of novel sensor types. For example, scientists at Duke University (Durham, North Carolina) programmed bacteria with a synthetic gene circuit, enabling them to self-assemble for the fabrication of a pressure sensor. The bacterial colony grows in the shape of a dome before the gene circuit triggers the bacteria to produce a protein that can latch onto inorganic particles—gold nanoparticles in this experiment. As a result, a gold shell forms around the bacterial colony, producing a device that can function as a pressure sensor. Modifying various factors of the bacterial-growth environment—for example, altering the size of the pores in the growth membrane—enables the researchers to change the size and shape of the bacterial colony. The use of self-organizing material in fabrication is not new (researchers usually employ such materials to grow quantum dots), but the natural variability of end products may limit the ultimate utility of the technique.

Improved sensor technology is naturally of interest to defense organizations such as the US Department of Defense's (Arlington County, Virginia) Defense Advanced Research Projects Agency (DARPA; Arlington, Virginia). DARPA, along with other military organizations, could move sensor technologies in completely new directions. The requirements of military applications could lead to sensor systems that enable continuous monitoring of expansive environments. For example, DARPA's Near Zero Power RF and Sensor Operation (N-ZERO) program tasked researchers with developing a sensor that requires virtually zero power. To meet this challenge, researchers from 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 researchers claim that their sensor could passively monitor the environment for signs of fires, explosions, or other phenomena that give off IR energy. The mechanically robust sensor's ability to operate without a dedicated power supply or even a battery could enable it to operate for many years without human intervention. Another way to circumvent the power limitations that many sensors have is to use living organisms with their own energy system as sensors. For example, researchers working on DARPA's Advanced Plant Technologies (APT) program aim to use plants as intelligence-gathering sensors that they can monitor remotely. The intrinsic sensing mechanisms of the plants will find use to detect chemicals, pathogens, or radiation, and the biological systems of the plants eliminate the need for an energy source to power the sensing mechanism. The APT program is at an embryonic stage of research in comparison with the N-ZERO program, but it reveals the breadth of thinking among researchers participating in DARPA projects.

SoC1011

Signals of Change related to the topic:
SoC997 — Sensors…in Health Care
SoC974 — Toolboxes for Materials Innovation
SoC944 — Exploring Biobased Materials

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

May 2018

SoC1013

Quantifying and Analyzing Urban Environments

By Martin Schwirn (Send us feedback.)

Data analytics has been a growing business field for decades. In the online world, the capture, collection, and analysis of data are relatively straightforward; in the real world, many types of information are difficult to capture and translate into machine-usable data. But urban environments—because of their growing size, their increasing complexity, and their multitude of dynamics—present opportunities for data analytics to play an increasingly potent role in increasing productivity, establishing efficiencies, reducing problematic issues, and improving quality of life for inhabitants.

Because individuals are increasingly interacting with their environments digitally and sensor infrastructures are proliferating, information is more readily accessible now than it has ever been. For instance, the ubiquitous use of cell phones has transformed the devices into a massive sensing infrastructure. Researchers from the Massachusetts Institute of Technology (MIT; Cambridge, Massachusetts) Senseable City Lab (http://senseable.mit.edu) and other institutions used tracking data from cell phones to conduct a study about the level of pollution exposure that people experience in New York, New York. The researchers compared cell-phone data that track people's movement with data from stationary air-quality-monitoring stations. In this work, the researchers used cell phones as sensors to identify the position of individuals and to track their movement during the course of a day to gain a better understanding of their exposure to pollutants.

Urban environments have multiple networks that increasingly rely on and generate digital data.

Researchers can use measurements and sensor data to develop a better understanding of dynamics in energy consumption, traffic management, crime occurrences, and so on. Hudson Yards—an extensive real-estate development in New York, New York—is emerging as a quantified community. For years, New York University's (New York, New York) Center for Urban Science and Progress (CUSP) has been measuring and modeling a number of factors, including air quality, energy use, inhabitant health, pedestrian movements, recycling, traffic flow, and waste disposal. CUSP director Steven E. Koonin believes the project will help data scientists gain a better understanding of and develop new ways to model communities. In fact the CUSP website outlines the field of studies the researchers are engaging in: "Urban informatics uses data to better understand how cities work. This understanding can remedy a wide range of issues affecting the everyday lives of citizens and the long-term health and efficiency of cities" (http://cusp.nyu.edu/urban-informatics). Similarly, Andorra—a small country of 77,000 people between France and Spain—is serving as a "living lab" for researchers from the MIT Media Lab's City Science Initiative to test urban models in a real-world context. The initiative focuses on developing prototypes of innovations for urban environments and then deploying and testing them. For example, the initiative's CityScope Andorra is a three-dimensional platform that uses augmented reality to visualize urban data and dynamics on a small model of Andorra. This living-lab approach enables researchers to develop hypotheses and work with the country's authorities to implement novel technologies and approaches and then collect data to see how concepts play out in the real world.

Cities see advantages in making their urban environments smart by installing sensor infrastructures, analyzing a wide range of urban dynamics, and proactively managing urban networks and processes. SoC913 — Making Urban Environments Smart from 2016 mentions how smart-city initiatives are becoming a priority for urban planners, administrations, and infrastructure developers and discusses efforts in Columbus, Ohio, and other US cities; Amsterdam, Netherlands; Singapore; and Australia. More recently, Denver, Colorado, partnered with Panasonic Corporation (Kadoma, Japan) to work on a smart-city project, which is the second such project Panasonic has participated in as part of its CityNOW initiative (its first project was in Fujisawa, Japan). Panasonic's CityNOW initiative focuses on "driving transformational change for municipalities, their residents and private developers through public-private partnerships designed to optimize the management and deployment of city services, enhance peoples' lives and reduce energy consumption" (https://na.panasonic.com/us/smart-city-solutions-0). The Denver project does not encompass the entire city of Denver but a 1.6-square-mile area near the city's airport. The project aims to use communications networks, energy infrastructures, sensors, and security cameras to improve urban dynamics in this area of the city.

Urban environments have multiple networks that increasingly rely on and generate digital data. Traffic networks have seen intense analysis in efforts to increase vehicle throughput on city streets, and car manufacturers' efforts to include an increasingly broad range of sensors in their vehicles to analyze passenger behavior and perhaps even enable autonomous applications will provide a wave of new data for use in traffic management. Interest in improving the capabilities of electrical grids is growing as the ratio of renewable energy increases on the supply side and the use of electric and hybrid vehicles increases on the demand side. Policy makers' and law-enforcement agencies' safety and security efforts—and the resulting use of sensor technologies and digital cameras—provide another layer of data-collection and data-analysis capabilities. Similarly, environmental concerns are driving the collection of health-related information within cities and communities.

Urban environments consist of many individual buildings, and buildings have been resistant to effective data collection for many years. But the costs of sensors and data-analysis solutions are decreasing, enabling buildings to become data providers. In 2015, OVG Real Estate (Rotterdam, Netherlands) completed a new office building for Deloitte Touche Tohmatsu (New York, New York) in Amsterdam, Netherlands. Deloitte required the new building to achieve a very high sustainability rating (according to requirements set forth by a UK rating system). To accomplish this goal, OVG incorporated some 40,000 sensors into the building. The sensors can, for instance, determine the occupancy of rooms and adjust lighting and heating appropriately to avoid wasting energy, but they can also track individual employees. The information the sensors collect can find use in many additional applications. A system that OVG built on top of this sensor network enables the building to guide visitors to parking spots, assign employees desks when necessary, and even notify cleaning personnel which areas require attention. Since then, the idea of proactively managing office buildings—particularly health-related factors of office buildings—has gained acceptance. For instance, *Wall Street Journal* technology columnist Christopher Mims argues that "as a profusion of environmental sensors becomes increasingly available, indoor air quality is something building managers can track and manage" ("Why Office Buildings Should Run Like Spaceships," *Wall Street Journal*, 8 October 2017; online).

SoC1013

Signals of Change related to the topic:
SoC983 — Smart Infrastructures…
SoC918 — The Road to Industry 4.0
SoC913 — Making…Environments Smart

Patterns related to the topic:
P1133 — Connected Policing
P1051 — Advancing Traffic Management
P0658 — Quantified Communities

SoC1016

Soft-Robotics Revolution

By Guy Garrud (Send us feedback.)

During the past half century, robots have had a transformative effect on several industries and on industrial-scale manufacturing in particular. For example, the automotive industry makes extensive use of industrial robots for assembling, welding, and painting cars and other vehicles; however, several of the advantages of these industrial robots—in particular, their speed, strength, and ability to conduct complex tasks repeatedly with precision—also limit their potential applications. Industrial robots often require cages to separate them from human workers to prevent their injuring the human workers. Industrial robots are also ill suited to tasks that involve soft materials such as textiles or fresh foods. But the field of soft robotics offers the potential for commercializing robots that can safely interact with humans and fragile products. Soft robotics is an area of intense activity in terms of research and, increasingly, commercialization. Soft robotics has the potential to broaden the range of robotics applications tremendously. More important, soft-robotics technologies could be key to automating certain tasks and could enable applications to interact with a range of environments in novel ways.

Nascent markets for soft robotics include agriculture and health care.

Researchers are exploring novel capabilities of soft robotics. For example, Festo (Esslingen am Neckar, Germany) has developed a robotic tentacle that can wrap around objects. The inner face of the tentacle features suction cups, some of which are pneumatic, enabling the tentacle to grasp and release objects. Researchers from Stanford University (Stanford, California) and the University of California, Santa Barbara (Santa Barbara, California), have taken a more innovative approach to soft robotics—specifically to the locomotion of soft robots. Instead of creating a robot that moves, the researchers demonstrated a robot whose main means of locomotion is a growing pneumatic arm. This growing arm—which can extend from less than 30 centimeters to more than 70 meters in length—acts as a probe, entering otherwise hard-to-reach spaces while causing minimal disturbance to its surroundings. This unique soft robot could see use in a wide range of applications, including installing wiring, participating in search-and-rescue efforts, and even firefighting. Soft robots typically use hydraulic or pneumatic systems to power their movements, which offers the potential for developing robots that require no electrical power or at least can operate at a distance from electrical motors and control circuitry. For example, engineers from Harvard University (Cambridge, Massachusetts) and other institutions have created an experimental octopus-shape silicon soft robot that has no electrical components; instead, a chemical reaction generates gas that powers a pneumatic system. The pneumatic system enables the robot to raise and lower sets of limbs in turn. Robots that have no electrical components could be extremely useful in some applications—for example, performing tasks within explosive atmospheres in industrial settings or within areas that experience large amounts of electrical interference.

Soft robots are already seeing commercialization in some sectors. For example, online supermarket Ocado Group (Hatfield, England) has invested heavily in soft robotics for use in its warehousing operations. The supermarket stocks a wide variety of foodstuffs, many of which require gentle handling to prevent damage. The company worked with multiple partners to develop a pneumatic robot hand that can grip a variety of the 48,000 items the retailer keeps in stock without damaging them.

More nascent markets for soft robotics include agriculture and health care. Some parts of the agriculture industry can be extremely labor intensive. For example, fruit harvests rely on large numbers of seasonal human workers. In the United Kingdom, a shortage of seasonal workers in 2017 led to some crops' going unharvested. Handling fresh fruit, including removing fruit from trees and bushes, requires a combination of strength, dexterity, and precision that is more readily achievable with soft robots than with their more rigid counterparts. Soft robotics could also play an important role in geriatric care. Several countries—most notably Japan—are experiencing population aging. As the older generation moves into retirement and eventually old age, demographic pressures place increasing expectations on existing care infrastructure. In particular, some analysts anticipate a growing shortage of trained care workers. Although robots present a potential solution to this problem, robots for use in geriatric care require both the strength necessary to aid in physical tasks such as lifting patients and the delicacy to avoid accidentally bruising or otherwise injuring patients.

Advances in soft robotics can enable the development of nontraditional applications. For example, researchers from the Massachusetts Institute of Technology (MIT; Cambridge, Massachusetts) and Harvard University have developed a form of soft robotics that combines hydraulic or pneumatic envelopes with rigid origami-style skeletons to create artificial muscles that can lift 1,000 times their own weight. Research that focuses on combinations of soft pneumatics and rigid skeletons has also enabled researchers at Harvard University's Harvard Biodesign Lab to develop a soft exosuit that reduces the energy the wearer expends while walking. Likewise, researchers at SRI International (Menlo Park, California) spin-out Seismic (Menlo Park, California) are developing a suit that incorporates electromechanical muscles to augment the muscles of the wearer.

Soft robotics has the potential to expand the range of robotics applications substantially, to serve as a key enabler of automation, and to enable robots to interact with their environments in new ways. Indeed, advances in soft robotics are providing developers with a variety of approaches they can tailor to individual applications—for example, prioritizing a soft robot's dexterity, speed, and grip strength to suit a user's needs.

SoC1016

Signals of Change related to the topic:
SoC996 — Industrial Robots…
SoC971 — …Efficiency versus Innovation
SoC865 — Wearable Robotics

Patterns related to the topic:
P1184 — Robots' Newest Moves
P1098 — Technology for the Disabled
P1042 — Robots Diffuse…