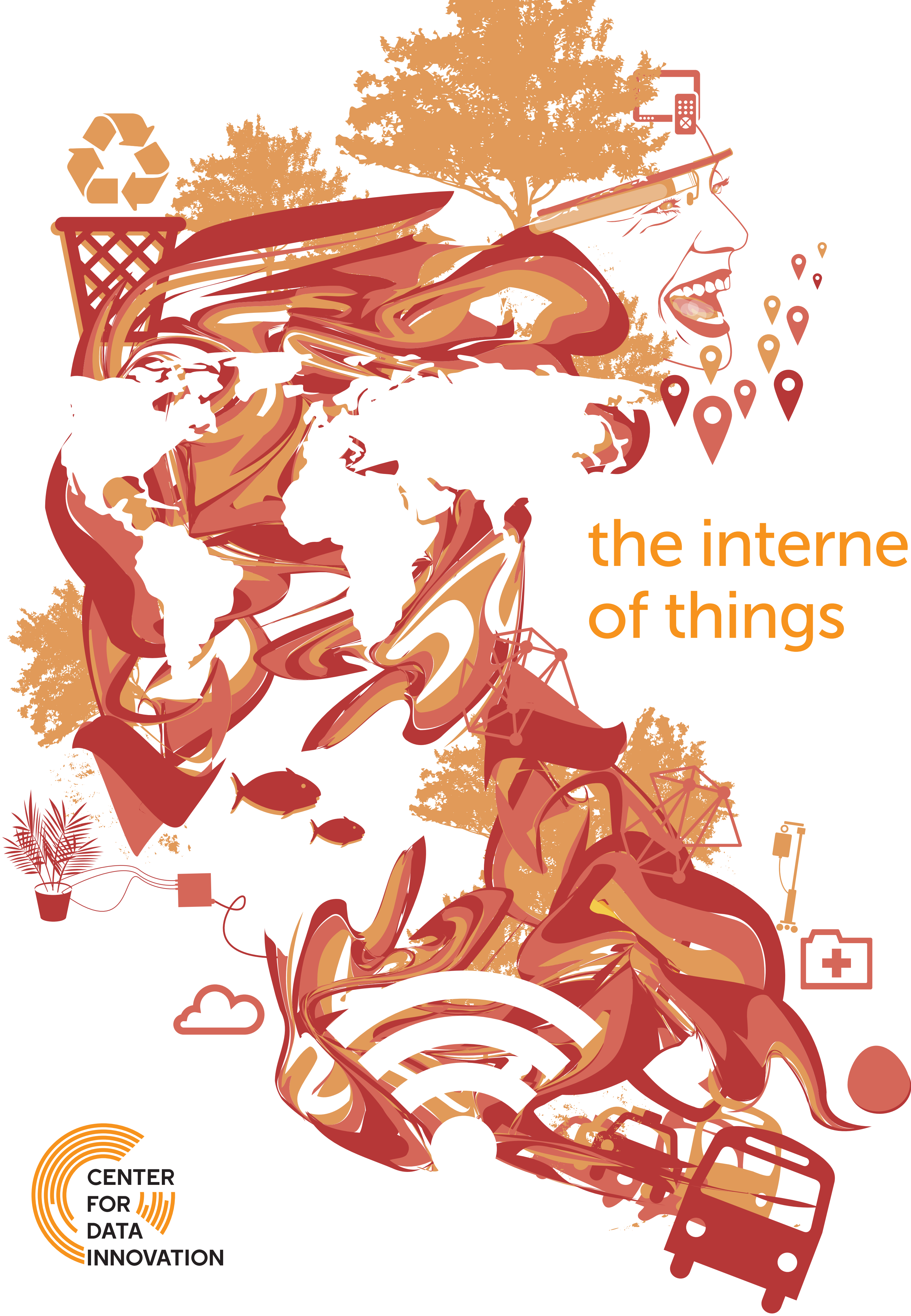

the internet of things

CENTER FOR DATA INNOVATION

the internet of things

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The "Internet of Things" refers to the concept that the Internet is no longer just a global network for people to communicate with one another using computers, but it is also a platform for devices to communicate electronically with the world around them. The result is a world that is alive with information as data flows from one device to another and is shared and reused for a multitude of purposes. Harnessing the potential of all of this data for economic and social good will be one of the primary challenges and opportunities of the coming decades.

A combination of technologies, including low-cost sensors, low-power processors, scalable cloud computing, and ubiquitous wireless connectivity, has enabled this revolution. Increasingly companies are using these technologies to embed intelligence and sensing capabilities in their products, thereby allowing everyday objects to sense, learn from, and interact with, their environment. Some of these devices engage in machine-to-machine communication. For example, sensors on the roadway electronically alert cars to potential hazards, and the smart grid sends dynamic electricity pricing data to home appliances in order to optimize power consumption. Other devices communicate information to their users, either directly through the product itself or indirectly through a web browser on a PC or mobile device. For example, decision support systems on farms may combine data on soil conditions from environmental sensors with historic and future pricing and weather data to produce recommendations to farmers on how to plant and fertilize particular plots of land.

This transformation, while significant, will in many ways be inconspicuous to the average person because the changes to the physical environment will be invisible or subtle. A "smart" home or a "smart" bridge looks much the same as a "dumb" one—all of the intelligence is built into the infrastructure. Consumer products that have embedded intelligence (e.g., clothes dryers or thermostats) will not look significantly different from those in use today. Yet, despite outward appearances, the impact of the Internet of Things will be profound and will offer opportunities to address many of today's major societal challenges. Its possibilities include new products and services that will help protect the environment, conserve energy, increase agricultural productivity, make transportation safer and faster, enhance public safety, and lead to better and more affordable health care. In addition, some products will simply assist busy consumers by providing timely information: thus, a smart refrigerator could remind its owner to buy milk when it is running low.

Big changes are made up of little changes, and the Internet of Things could bring millions of incremental changes in the coming years. This report showcases the diversity of devices that make up the Internet of Things today, the potential application these devices may have for addressing different real-world problems, big and small, and the policy principles that will help government leaders maximize the benefits enabled by these new technologies.

ENVIRONMENT

With over seven billion people on the planet, managing the Earth's natural resources is an increasingly daunting challenge, but one that the countries of the world must surmount to achieve sustainable economic development. Protecting the environment will require multifaceted solutions, but the Internet of Things offers unique opportunities to address issues such as clean water, air pollution, landfill waste, and deforestation. Sensor-enabled devices now closely monitor the environmental impact of our cities, collecting details about sewers, air quality, and trash. Outside of the city is no different, as sensor-enabled devices monitor our forests, rivers, lakes, and oceans. Many environmental trends are so complex, that they are difficult to conceptualize, but collecting data is the first step towards understanding, and ultimately reducing, the environmental impact of human activity.

atmosphere

The **Air Quality Egg** is a device that uses sensors to collect and share data about the air quality outside a person's home or office. While government agencies, such as the U.S. Environmental Protection Agency, monitor pollutants daily from centralized locations in metropolitan areas, the Egg collects data in real time from its user's immediate environment. The base station relays the air quality data over the Internet where a website aggregates and displays data from every Egg in operation. This real-time data can be used to design and measure the impact of urban pollution policies and changes. It also encourages residents to learn more about their city and understand how their actions impact their community. Air Quality Eggs can be found across North America, Western Europe and East Asia and may eventually play a role in developing countries with the most rapid urban population growth and highest rates of pollution.[1]

trash cans

BigBelly is a solar-powered trash receptacle and trash compactor that alerts sanitation crews when it is full. Waste management facilities use historical data collected from each BigBelly bin to plan their collection activities and make adjustments, such as adjusting the size of a receptacle. BigBelly systems are found throughout cities, corporate campuses, college campuses, parks, and beaches. Boston University has reduced its pickup from an average of 14 to 1.6 times a week.[2] The university not only saves time, but also energy since its trash collectors are using fewer garbage bags and producing less CO^2 during trash pickup. Given that household waste is expected to rise to 2.2 billion tons by 2025 from the current 1.3 tons produced now, additional tools will be needed to handle higher volumes of trash.[3]

forests

Invisible Tracck is a small device covertly placed in trees in protected forest areas to help prevent illegal logging. The devices, which are smaller than a deck of cards, alert authorities when illegally harvested trees pass within range of a mobile network. Law enforcement officials can then locate the production sites and stop these activities. Invisible Tracck is currently deployed in the Amazonian forests in Brazil, which lost an average of 3.46 million hectares of primary forest each year between 2000 and 2005.[4] Many illegal deforestation activities have gone undetected because satellite range and radio frequencies are often weak in remote areas. Invisible Tracck now ensures that even the most vulnerable, remote areas of Brazil can be policed and protected.[5]

waterways

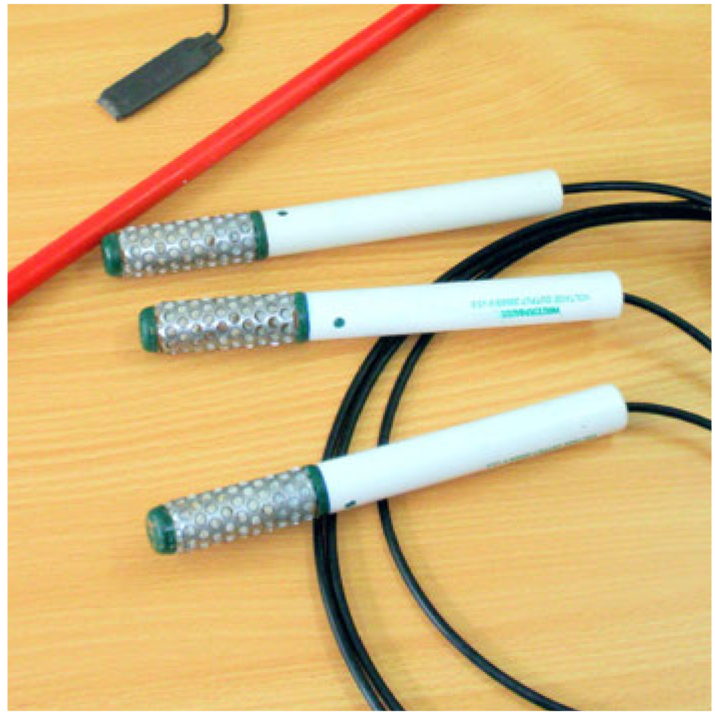
Australia's **Integrated Marine Observing System** is a network of sensors along the Great Barrier Reef to collect data for researchers exploring the impact of oceanic conditions on marine ecosystems and climate change. Buoys equipped with sensors collect biological, physical, and chemical data. Data is sent to a base station on shore using a variety of wireless technologies, including microwave, satellite, and 3G mobile networks, depending on the distance to shore.[6] The system has been deployed since 2010 in seven different sites along the Great Barrier Reef and has collected data integral to research on fish movement, biodiversity, and damage to coral reefs.[7]

AGRICULTURE

Sustainable agricultural practices help meet immediate societal needs while protecting land and other natural resources for future generations. The Internet of Things is helping to create smart farms where every process can be monitored to reduce waste and improve agricultural productivity. Also known as precision farming, this method of farming uses data analysis to customize operations so as to maximize agricultural output based on variable inputs.[8] These practices may enable significant opportunities for savings, given that as much as 60 percent of water diverted or pumped for irrigation is wasted.[9] In addition, to ensure food safety, data-driven solutions enabled by the Internet of Things will allow consumers to track and monitor produce from farm to fork.

irrigation systems

WaterBee is a smart irrigation system that collects data on soil content and other environmental factors from a network of wireless sensors to reduce water waste. The system analyzes the data it collects to selectively water different plots of land based on need.[10] Waterbee can be used for a variety of commercial applications, including on farms, vineyards, and golf courses. Smart irrigation systems save energy, water, and money. Using a prototype, fourteen sites in Europe were able to reduce their water usage on average by 40 percent.[11]



grain bins

SmartBob is a device that electronically measures and reports on the level of contents in the bins, tanks, and silos used to store grain and other foodstuffs on farms. Farmers use the device to remotely manage their inventory of bulk goods, such as corn or seed. CheckItNow allows farmers to monitor online the temperature of grain bins and receive an alert if the temperature rises outside of an acceptable range. Yellow Box is a device that allows farmers to use their mobile devices to remotely operate their grain bins, including the chutes, conveyer belts, and auger motors involved in loading the grain. The farmer can monitor the process using a video feed, and the system will automatically shut down operations if it detects a problem. By eliminating the need for farmers to go into grain bins, these devices mitigate safety risks, such as exposure to grain dust and becoming entrapped in grain.[12]

insect traps

Z-Trap is an electronic insect trap that helps farmers remotely monitor an insect population and protect their crops from insect damage. In 2010, insects cost U.S. farmers around $20 billion in damaged crops and an additional $4.5 billion for insecticide.[13] Z-Trap helps prevent crop damage by using pheromones to trap insects and then compile data on the number of different types of insects in the trap. Z-Trap wirelessly transmits the data, including its GPS coordinates, allowing farmers to view a map of the types of insects that have been detected.[14] By remotely monitoring pests, farmers can place traps at a density dictated by specific needs, thereby saving time and money and minimizing the use of insecticides.

tractors

Tractors increasingly rely on data to help farmers optimize their operations. For example, since the optimal density of a hay bale depends on the moisture content of the hay, **John Deere** introduced a baler that senses the moisture and then automatically signals to the tractor to move faster or slower as the hay is baled.[15] GPS systems on these tractors can be fully integrated into field operations. Seeding equipment tied to GPS control, can prevent wasteful overlap or planting through waterways. The GPS system can also manage crop-protection and fertilizer-distribution tools, leading to precise application and less waste. The savings of time and fuel these tools allow can have a substantial environmental and economic impact.

ENERGY

As a result of growing populations and increasing demand, global energy consumption will rise by over 50 percent over the next thirty years.[16] Addressing global climate change and providing access to clean and affordable energy are major international priorities. The Internet of Things will help provide solutions to the global energy challenge by enabling clean energy technologies, creating better energy market dynamics, and optimizing the efficiency of existing products. For example, to improve use of energy in the home, the Internet of Things will automate and encourage energy-efficient practices such as running appliances at off-peak times.

electricity meters

Smart meters provide real-time, two-way communication between customers and the utility and enable a number of benefits. Smart meters allow customers to receive granular detail about their electricity usage and to modify their energy consumption according to price signals. Dynamic pricing facilitates the use of renewable energy sources like wind and solar, which are highly variable. For example, cheaper rates incentivize customers to use these sources when the additional capacity is available. Smart meters also allow utilities to collect electricity usage information automatically, rather than manually sending someone to manually read the meter. Automatic detection of outages can also lead to faster repairs.

wind turbines

New **GE wind turbines** use sensor and grid data to operate more efficiently, both bringing down the cost of clean energy production and increasing electricity production. By equipping its turbines with sensors and algorithms to analyze the sensor data, GE is able to optimize energy production and keep the turbines running even in variable wind conditions. Wind energy has become increasingly important to the U.S. energy market, and sensor-equipped turbines have helped cut the cost of wind energy from 15 cents per kilowatt hour to 6.5 cents per hour, facilitating the expansion of renewable energy options.[17]

clothes dryers

Increasingly, home appliances will be capable of communicating with the smart grid to optimize the energy they use based on dynamic price signals. The **Whirlpool Smart Electric Dryer** uses real-time electricity rates to automatically schedule energy-intensive tasks during off-peak hours when electricity is cheaper and more plentiful. Not only can users save twenty to forty dollars per year by time-shifting their energy use, they can also help reduce overall peak demand on the grid; this means fewer power plants have to be built.[18] The dryer also uses sensors to detect and alert users of possible problems, such as a blocked vent, or when a load of laundry is dry. Similar features are available on other home appliances, such as a refrigerator that monitors and alerts users about the duration of power outages so they do not eat spoiled food.[19]

thermostats

Nest is a thermostat that can help homeowners consume up to 20 percent less energy, saving an estimated $173 per year and paying back their initial investment cost in under two years.[20] Nest has four different types of sensors: activity sensors that detect whether someone is home, humidity sensors, weather sensors, and temperature sensors that detect how quickly the temperature changes. Nest collects data to learn the daily routine of users and their temperature preferences, and then combines this with outdoor weather data to tailor the home's heating and cooling settings based on the time of day and whether anyone is home. Users can control Nest remotely from their smart phone or computer. Finally, Nest sends users a monthly energy report, as well as other alerts, such as when it is time to change air filters, which can reduce heating and cooling bills by 5 percent. [21]

PUBLIC SAFETY

Keeping the public safe is one of the most important responsibilities of the government, and the Internet of Things is helping provide the information needed to improve public safety. The availability of real-time data is crucial in an emergency situation since a faster response time can mean the difference between life and death. For example, every minute of delay in responding to someone having sudden cardiac arrest decreases the expected survival rate by 5.5 percent.[22] Whether it is an earthquake, a car theft, or a medical emergency, connected devices that can send and receive information quickly in an emergency can help make the world safer.

bridges

In 2012, the Federal Highway Administration rated 1 out of 9, or approximately 67,000 bridges, as structurally deficient.[23] Preventing future disasters such as the collapse of the I-35 Mississippi River Bridge in Minneapolis remains a top public safety priority. **Wireless bridge sensors** can help reduce this risk by monitoring all aspects of a bridge's health, such as vibration, pressure, humidity, and temperature. Researchers at the University of Maryland, College Park have tested bridge sensors on the I-495 Bridge in Maryland and were able to use data analysis to detect structural changes that had developed after repairs. The system can also send automated alerts by email or text messaging to bridge engineers if an immediate threat is detected.[24] Jindo Bridge (pictured) in South Korea was one of the world's first fully-automated smart bridges with over 600 wireless sensors continuously monitoring the bridge's structural health.

buildings

Each year seventy to seventy-five earthquakes occur throughout the world in a populated area with sufficient magnitude to cause damage.[25] The U.S. Geological Survey **Advanced National Seismic System** uses accelerometers and real-time data analysis to monitor the structural health of buildings in earthquake prone regions. Sensors detect the degree of the building's movement, the speed that seismic waves travel through the building, and how the frame of the building changes.[26] Software then analyzes the data to determine the building's structural health immediately.[27] Some Department of Veterans Affairs hospitals have deployed this system so that in the event of an earthquake, hospital administrators will know if it is necessary to evacuate patients and staff.

vehicles

OnStar provides a variety of in-vehicle technologies for communications, navigation, remote diagnostics, and safety. **OnStar's Automatic Crash Response** system uses sensors to detect a crash and then automatically alert emergency responders. The system transmits a variety of critical information to responders, including the precise location of the vehicle, the direction the vehicle was traveling, the number and speed of impacts, and whether the vehicle has rolled over. The Toyota Collaborative Safety Research Center is taking this a step further to use crash data to predict the type and severity of injuries that occupants in a crash likely sustained.[28] Automatically collecting and sending this information means that appropriate help can arrive sooner, potentially saving lives.[29]

maps & schematics

Google Glass is a hands-free, head-mounted computer worn as eyewear that gives users the ability to access the Internet, communicate with others, and record their surroundings with voice commands.[30] Mutualink, a company that makes communications technology for first responders, has demonstrated the potential to use Google Glass to share critical information with first responders in emergencies. For example, firemen may review the schematics of a burning building, police officers may watch real-time surveillance video when responding to a shooting, and EMTs may review the electronic medical records of patients.[31]

TRANSPORTATION

Transportation officials work to improve the safety, reliability, and cost of transportation, and they can do their jobs better with better information. Sensors will increasingly be deployed to create intelligent transportation systems that count vehicles on the roadway, calculate travel times, detect potholes, or determine the occupancy rate in car parks. Data from these systems will be integrated into traffic management solutions that help optimize traffic signals, determine where maintenance is most needed, and allow transportation officials to better plan for future capacity.

roads

HiKoB road sensors are compact, low-power, wireless sensors that can be embedded into the roadway to measure variables such as temperature, humidity, and traffic volume. The sensor data is sent over a wireless network to a server for processing and analysis. The system then provides real-time information on road conditions. This information allows road crews to prioritize road maintenance during harsh weather conditions, which are responsible for almost a quarter of vehicular accidents.[32] The system can also alert drivers of potential hazards, through roadway signage or traffic signals.

parking

A significant amount of congestion on the road is caused by drivers in search of parking.[33] **ParkSight** is a network of self-powered, wireless parking sensors that collect and report real-time information on the occupancy of individual parking spaces. The parking sensors are either embedded in the pavement or mounted on the top of the pavement, and sensors data is collected and made available to drivers and parking facility operators. For example, a parking garage can use a digital sign to display how many spaces are open and on which level. Drivers can also use a mobile app to locate available parking spaces, a feature that eventually will be integrated into in-car navigation systems. By simply tapping on a map, drivers can see how much it will cost to park, how long they can park there, and pay for parking once they make their decision. City officials can also use parking sensors to enforce parking violations as well as plan for future parking needs.[34]

vehicles

Delphi Connect is a small device that allows drivers to monitor and control their vehicle remotely via the Verizon LTE network. The device connects to the on-board diagnostics port found in all vehicles made after 1996, and monitors information about the vehicle's overall health, such as battery voltage, fuel level, and engine status. The device sends drivers alerts for maintenance issues, so that they know what is wrong before they take their car in to be serviced. The device includes GPS, so vehicle owners can see both historical maps of when, where, and how far they have driven, as well as real-time information about their vehicle's location. Drivers can use their smart phone to control their car, such as remotely locking or unlocking the doors. Parents can enable additional controls to monitor their teenage drivers, so that they receive an alert if their children leave a pre-established geographic region or go over a set speed limit.[35]

transit

MetroBus, the public bus service in St. Louis, Missouri, uses electronic sensors on its buses to collect data on variables such as speed, engine temperature, and oil pressure. Computers analyze the data and offer recommendations to service technicians, helping improve the reliability of the city's transit system and lower overall operating costs. The result has been fewer bus breakdowns and longer vehicle life times. By using predictive analytics to identify potential maintenance failures before they happen, the local government has saved five million dollars per year in maintenance costs and the same amount in personnel-related costs.[36]

HEALTH

PREVENTION, SCREENING & DIAGNOSIS

The Internet of Things offers new solutions for preventing, screening, and diagnosing a variety of health conditions. Devices allow individuals to monitor every aspect of their health, including weight, body mass, sleep cycles, and daily activity levels. Preventable health conditions constitute 80 percent of overall disease burden and 90 percent of health care costs.[37] By collecting and tracking data about their health, patients are able to identify health problems sooner and get treatment faster. Not only does this cut down on health care costs, it also provides new opportunities for improved quality of life. For example, technology can help monitor the health of older adults, allowing them to stay in their homes longer and retain their independence. The demand for these types of health-related technologies is growing quickly.

Already, 69 percent of American adults track at least one health indicator, and the U.S. market for wireless health monitoring devices is projected to reach $22 billion by 2015.[38]

baby monitors

The **Mimo baby monitor** is a body suit that monitors a baby's body temperature, motion, and breathing patterns.[39] Sensors use Bluetooth wireless communication to relay this data to a base station, which then transmits it to the Internet to be analyzed by the company's sleep analysis software. Parents can use a mobile app on their smart phone to see their baby's data in real-time, monitor their sleeping habits over time, and keep track of eating schedules and diaper changes. Parents can also setup the device to receive alerts on their phone if anything changes.[40] The company hopes this technology will help prevent some of the 4,000 infant deaths that occur each year in the United States without any obvious cause.[41]

elderly monitors

Lively is a system composed of activity sensors placed on objects around the home that monitors the daily behavior of an individual living alone. For example, sensors may be placed on a refrigerator door, a pill box, and car keys to collect data on an individual's eating, medication, and sleep habits. The system unobtrusively learns a person's routine over time and then can alert family, friends, or caregivers of changes that may indicate a problem. Since many older adults lack Internet access, Lively transmits the data using mobile networks.[42]

hand-washing stations

According the U.S. Centers for Disease Control and Prevention, an average of one in twenty patients will contract an infection while receiving healthcare treatment.[43] **HyGreen** is a hand washing reminder and recording system designed to prevent diseases from spreading within hospitals by holding hospital staff accountable to hygienic standards. The system uses two devices—one at the hand-washing station and one at the patient's bedside. The first device detects when someone is washing their hands, and logs the worker's ID number, time, and location in a central database. The second device recognizes the worker and flashes green if they have washed their hands or reminds them to wash if they have not.[44] Workers are recognized by small electronic badges. This system helps prevent infections from occurring and spreading in a hospital. If an infection does occur, the system provides hospital managers with better data to understand how and when it may have occurred.

helmets

Shockbox is a small, flexible sensor that fits inside of a sports helmet and monitors the history of head impacts athletes sustain. Shockbox sensors communicate using Bluetooth to immediately alert parents, coaches, and trainers in the event of a concussion-level impact. The mobile app will show the direction and severity of the hit along with the player's name and date and time.[45] The phone application has the capacity to link with up to 100 helmet sensors and connect to sensors within a hundred yard range. In that athletic head injuries cause 21 percent of traumatic brain injuries among U.S. children and adolescents, it is critical to understand when someone has been hit too hard.[46]

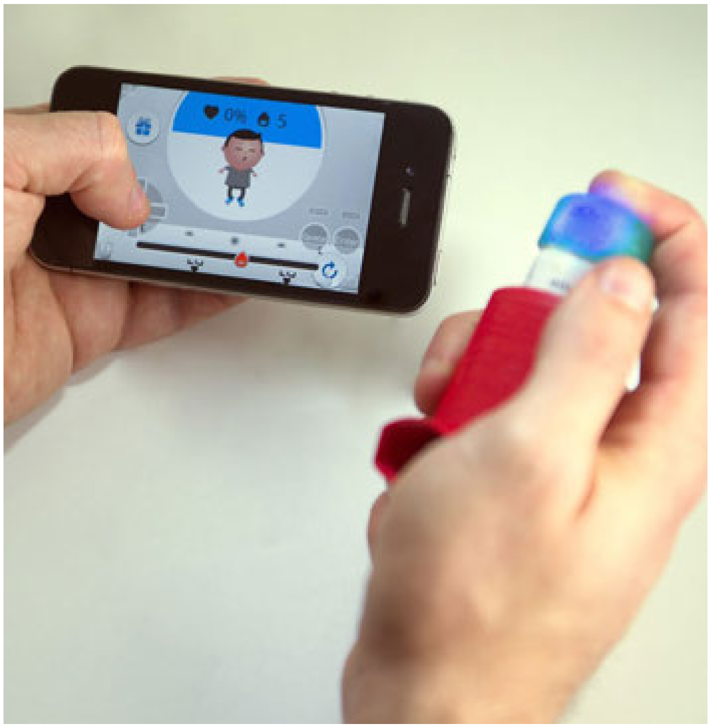
HEALTH

TREATMENT, MONITORING, & DISEASE MANAGEMENT

The Internet of Things is providing new tools to monitor and manage health conditions. These devices collect data about existing health conditions, thereby giving individuals and their health care providers more information to make health care decisions. Individuals will also be able to use technology to monitor and treat specific conditions. Continuous remote monitoring allows doctors to offer better care to patients when they need it and to make adjustments as necessary, rather than making patients wait until the next appointment. Individuals with diabetes, for example, can use continuous glucose monitoring to learn when their glucose levels get too low or high and to track insulin delivery.

inhalers

Asthma has enormous negative impacts on children, resulting in 100 million missed school days and 10 million emergency room visits per year in the United States.[47] **GeckoCap** is a "smart" button that can be attached to any inhaler to remind children to use their inhaler and automatically record each time it is used. The data is automatically stored in the cloud, allowing parents and health care providers to view the usage history through an online interface as well as discover if the inhaler is running low. Parents can also use the online interface to set goals to encourage their children to develop healthy habits and provide them rewards for adhering to a medication regimen over time.[48]



pill bottles

A significant number of patients do not take their medications as prescribed, resulting in increased costs and worse health outcomes. For example, the United States spends $100 billion on health care expenses due to poor medication adherence.[49] And diabetes patients with low levels of adherence have health care costs almost twice that of those with high levels of adherence. **Vitality GlowCaps** are smart pill bottles that remind patients to take their medication with escalating reminders that include flashing lights, audio reminders, SMS messages, and phone calls. The pill bottle detects when a patient opens and closes the bottle and records that the patient has taken a dose. This information is transmitted over the AT&T mobile network. Patients can allow their doctors, family members, or other care givers access to their medication adherence reports. GlowCaps have helped increase the medication compliance of their users from just over 70 percent to over 95 percent, making a sizeable dent in the $290 billion annual cost of drug non-adherence in the United States.[50]

shirts

The **Nuubo Smart Shirt** is a sensor-equipped shirt that monitors a patient's vital signs and movement.[51] The sensors in the shirt can take regular measures on items such as heart rate, blood pressure, and body temperature. In addition, it can conduct an electrocardiogram (ECG). The shirt sends data wirelessly to a server for data analysis where, for example, software can detect anomalies in the ECG. Since the shirt allows people to move around, it has potential applications for patients in hospitals, low-risk patients at home, and athletes in training. The shirt also includes a GPS so health care providers can locate patients in the event of an emergency.[52]

heart monitors

The **CardioMEMS Heart Sensor** is an implantable medical device for monitoring heart failure. Heart failure affects 5.7 million people in the United States and costs the country $34.4 billion annually in health care services, medication, and lost productivity.[53] The device, which is about the size of a paper clip, is implanted into a patient's pulmonary artery using a minimally-invasive technique and measures pulmonary arterial pressure. Data from the device is collected wirelessly and transmitted to a central database for the patient's health care providers to review. A rise in pulmonary arterial pressure is the clearest sign of a potential problem. Until now, doctors had to use a change in weight to predict potential problems, a less accurate technique. When health care providers are alerted to a problem, they can advise a change in medication to treat the condition. In a randomized clinical trial, the CardioMEMS Heart Sensor resulted in a 30 percent reduction in hospitalization rates in heart failure patients after six months.[54]

CONSUMER CONVENIENCE

While many products that make up the Internet of Things will have an impact on major societal challenges, others will be used, at least initially, simply to improve quality of life by addressing matters of consumer convenience. These products collect and use data to give consumers information when they need it, such as when to water a plant, whether to pick up eggs at the grocery store, and how much to exercise their dog.

gardens

Bitponics is a smart gardening system that allows consumers to monitor and maintain their personal garden electronically. A combination of sensors, base station, and Wi-Fi network allow the system to monitor the pH, water temperature, air temperature, light, and humidity in the garden. Other smart devices, such as sprinkler systems, can be connected and automatically turned on and off remotely over the Internet. Garden data is stored and merged with that of others users in the cloud to help develop an optimal strategy for caring for the plants. The system will alert users when they need to take a certain action or suggest how to fix a problem.[55]

egg cartons

The Egg Minder, produced by the companies GE and Quirky, is a sensor-enabled egg carton that detects how many eggs are in the container and how long they have been there. Sensors are implanted at the bottom of each of the fourteen egg cups which determine whether there is an egg in the slot or not. The purpose of the Egg Minder is to help reduce food waste. LED lights in the tray show which eggs are oldest and should be used first, and the tray sends an alert to the consumer's smart phone when it is running low on eggs.

water monitors

Belkin Echo Water precisely monitors water usage in a household using a single sensor placed under the sink. The device collects data on vibrations that occur in the plumbing when water is used, such as taking a shower, flushing a toilet, or washing dishes. The device transmits the data to the Internet for analysis where its algorithms can uniquely identify each fixture in the home, how long it is used, and how much water is consumed.[56] Users can then access this information on their smart phone. Echo Electricity is a similar product for monitoring home electricity usage by individual appliance using the unique electric signature generated by devices when they are turned on and off. Echo Electric can track 90 percent of usage reflected in a typical electric bill.[57] In addition to monitoring usage patterns, these devices can help detect when repairs are needed.[58]

dog collars

The **Whistle Activity Monitor** is a dog collar designed to help owners monitor their pet's behavior and create effective preventative healthcare plans for their pets.[59] A sensor in the collar detects the dog's sleeping and eating habits, time spent alone, and other activities. This data is synched with a mobile app that owners can use to get a better picture of what their dog is doing while they are away.[60] The app benchmarks the dog's activity with their normal behavior patterns, as well as the typical, healthy patterns of other dogs in its breed and age group.

RECOMMENDATIONS

The Internet of Things presents an enormous opportunity for achieving economic and social benefits; however, maximizing those benefits will require smart policy decisions. In particular, there is a need for policymakers to break away from old ways of thinking about data as something to be tightly controlled, and instead view it as a valuable resource to harness for social good. With that in mind, policymakers should work diligently to clear away outdated policies designed for a "small data" world to ensure that the opportunities ahead for a "big data" world can be realized.

In particular, policymakers should do the following:

LEAD BY EXAMPLE

Given the many opportunities available for the Internet of Things to make a significant impact on existing societal challenges, policymakers should be some of the most prominent champions of this technology. At the national level, transportation agencies should ensure that funding for highways and bridges includes money for sensor technology; agencies responsible for government buildings should deploy smart building technologies; and regulatory agencies should ensure that they have sufficiently fast-paced processes available to review innovative technologies like remote health monitoring. At the state and local level, public utility commissions should encourage the deployment of smart meters; cities should invest in intelligent transportation systems; and local police departments should pilot test augmented reality and wearable computing technologies, as well as sensor-based networks such as gunshot detection systems.

REDUCE BARRIERS TO DATA SHARING

The Internet of Things solves many problems by getting the right information to the right place at the right time, whether it is delivering smart grid pricing data to home appliances or illegal-logging alerts to police in Brazil. Data flows can be impeded for physical reasons (e.g., lack of network connectivity), technical reasons (e.g., lack of technical standards), or legal reasons (e.g., lack of intellectual property rights to share data). Policymakers should help identify and reduce all types of barriers to data sharing, such as by ensuring the appropriate technology infrastructure is available, convening industry groups to promote interoperability, and ensuring that legal frameworks facilitate data sharing between different entities, including between government and the private sector.

GIVE CONSUMERS ACCESS TO THEIR DATA

Businesses that make Internet of Things devices should provide their customers secure access to their own data in a non-proprietary, machine-readable format. When businesses do not voluntarily provide this, policymakers may need to intervene. Providing access to customer data does not mean that businesses must give up ownership of the data, only that they should strive to provide customers with copies of their own data to enable additional innovation. In addition, the data should be provided to their customers at least at the same level of granularity as it is shared with third parties.

AVOID INUNDATING CONSUMERS WITH NOTICES

As more and more devices collect and use data, mandatory disclosure about how data is being used could end up inundating consumers with undesired notifications. In many cases, the use of data will be ordinary and insignificant. While organizations should be transparent about their use of data and disclose this information, it may not make sense to present this information proactively and directly to the consumer. Imagine how much progress would have been slowed if at the turn of the twentieth century consumers had to sign a consent agreement before entering any building that used electric lighting. When it comes to active disclosures, the default should be to allow consumers to opt in to receiving them, not require them to opt out.

REGULATE THE USE OF DATA, NOT THE COLLECTION

Whereas in the past, most innovation occurred before any data was ever collected, in the future data collection will be just the beginning of the innovation process. Many of the potential benefits from the Internet of Things will arise from the ability to analyze, utilize, share, and combine data after it is collected. For example, imagine a wireless device that collects data on a home's plumbing system. One service might use data from a pressure sensor installed in a home's plumbing system to detect leaks whereas another service might use that same data to monitor the health of an older adult living alone by checking for anomalous behavior. Or it might turn out that this data is only useful if it is combined with other data, such as from an activity sensor or a smart pill bottle.

Adhering to outdated data principles, such as requiring that the purpose of data collection be defined at the outset, that data only be used for the purpose it was collected, and that data collection be limited to the least amount of data necessary to fulfill a specific purpose, will only impair progress. A more constructive approach would be to allow more permissive data collection and to closely monitor and restrict uses that could result in consumer harm. Focusing on use would allow more opportunities for innovations in both the devices that will make up the Internet of Things and the solutions proposed to address big societal problems.

ENDNOTES

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