making sense of sensors

Sensors and sensor networks are not new. They already play a role in our health and well-being, present in everything from digital thermometers to car braking systems. But over the next ten years, sensors will become smaller and more pervasive, allowing for more continuous monitoring of our bodies and the world we live in. Sensors will provide, in far more detail than is currently possible, new understandings of factors affecting our well-being and the choices we make. They will even offer a view of our health at a cellular level. The impact of emerging sensor technology will be significant, making the invisible visible and creating opportunities to improve our health earlier than has ever been possible before.

The ability of sensor and sensor networks to monitor and collect data at the scales of bodies, networks, and environments will offer a more complete picture of our health at any given moment. The addition of analytical tools that can process this new wealth of data will reveal patterns and allow us to take actions to increase our capacities for well-being at the appropriate scale.

bodies:
sensors on and inside of us

Medical care in the next decade will see the emergence of body area networks, collections of small wireless skin-patch sensors that can monitor multiple vital signs. The ability to transmit and access this data via local terminals and mobile phones will change how in-hospital and remote medicine are practiced. Technologies like BioMEMS, tiny devices the size of transistors on computer chips, and nanosensors will be embedded in organs or travel through blood vessels to monitor biomarker levels. By transmitting data to external devices, these tiny sensors will enable earlier diagnosis and treatment of disease in addition to closely tracking daily health measures.

networks:
how healthy is yours?

Research shows that behaviors and characteristics such as happiness and obesity spread through social networks. Sensors will play an integral role in determining the health of a network by providing a steady stream of data about the health of the individuals within it. The aggregation and analysis of this data will paint a picture of a network's overall health, and advances in visualization tools will make this data easy to understand and act on. Already, sensor-based fitness tracking devices and smart phone applications, encourage users to tap into their social networks for motivation and support. Someday, your network will be able to communicate with your environment to promote healthy choices, or will text you with an alert to avoid individuals who have been exposed to a disease.

environments:
measuring impact

The ability to measure air pollution with lightweight, hand-held devices and cell phones, and to share this data through distributed sensor networks, is already leading to a rise in crowdsourced environmental research. Over the next decade, these mobile devices will allow us to collect real-time data about a variety of pollutants and help us address environmental concerns, as we go about our daily lives. The pooling of this location-tagged data will provide invaluable information about our physical environment.

Fixed sensors will also play a role: sensors installed in "smart" homes will track patterns of behavior, detecting falls and generating reminders to take our medication, while sensors embedded in packaging will allow the tracking of food across the globe. These collective efforts will generate insights that can help us live healthier lives

—Alexandra Carmichael and Vivian Distler

an interview with **professor alex "sandy" pentland, phd**

Professor Sandy Pentland is a pioneer in computational social science, organizational engineering, and mobile information systems. He directs the MIT Media Lab's Human Dynamics Group and authored the 2008 book, *Honest Signals: How They Shape Our World*. He also directs the Media Lab Entrepreneurship Program, and is among the most-cited computer scientists in the world.

by **vivian distler**

Research Manager, Health Horizons Program
Vivian has explored how social networking platforms have contributed to the emergence of collective action groups around shared health concerns.

Vivian: We wanted to talk to you about the work that you're doing on sensors in health and how we might think about what a healthy or a sick network looks like at different scales.

Sandy: Well, there's a shocking projection that 400 million wearable sensors will be on people by 2014. Most of those sensors will be aimed at very specific medical problems. But humans evolved as a social species. We have an amazing ability to assess other people and their health. Before you make any explicitly medical measurement, you can tell a great deal about people's state of health.

I talked about this in my book, *Honest Signals*. When you listen to people's voices, for example, people can usually tell when other people are depressed. We've built sensors that screen effectively for depression by changes in voice tone and pitch. Some of my students started a company to build some of these tools that look at behavior and signaling, called Cogito Health.

Vivian: What are the things on a larger scale that you could use for diagnosis or screening of disease?

Sandy: People are inherently social, and we display our stress, our distress, through our behavior. We did a study with MIT students where, using cell phones, we could accurately detect when people were coming down with the flu, when they were stressed or depressed, just by how their pattern of activity and communication changed. It's common sense, but we've never made it something that's really a system. Now we can.

Another spin-off company, Sense Networks, has used this kind of knowledge to screen for diabetes risk. If your behavior is similar to people who have diabetes, then your odds of diabetes are much higher. Understanding how people adopt these patterns of behavior and how we can change them is really core to our whole health system. People are not rational decision makers. We're much more creatures of habit, and the habits are copied from the people around us. So behavior change has to do with social reinforcement far more than it has to do with information or argument.

If we recognize that, we can set up networks so that they reinforce healthy behaviors and not unhealthy behaviors. If you map out the networks of who listens to who, you can find small sets of people that are key to setting new ideas loose within the community. And if you reach them, they're the ones that are the biggest change agents.

Vivian: How do we get from the 400 million wearable sensors to reaching those influencers and affecting behavior change within the network?

Sandy: The Quantified Self movement is a wonderful example of people spontaneously beginning to collect this information about themselves, and I think you're going to see a lot more about that. There's an enormous new transparency that's beginning to happen. You can now know about your patterns of behavior in ways that were very hard to do before. You can also know where you stand in comparison to your peers because they're doing it, too.

It's not just about information, per se, it's about social influence and social comparison. If you can see stories about people like you that are doing really well, people will tend to copy that.

Vivian: Who is going to be doing this? Will it be a bottom-up expansion of the Quantified Self movement?

Sandy: What I see happening is as these devices get out there, there'll be startups that emerge that help you see what are people like me doing. What are the ideas or the behaviors that I could use to live better?

For instance, I don't know how much the people I work with sleep. We're going to give a small group of them Zeo sleep-tracking devices and look for patterns. Do sleep disorders correlate with events in the outside world? If you sleep less, does that mean you become less social? Less active? More stressed? We'll combine the mobile phone monitoring, the Zeo data, and lifestyle questionnaires—it's the combination of all these different sources of information that's powerful.

Vivian: How do you see this evolving in terms of ubiquity in people's lives over the next 10 years?

Sandy: I see two branches. One branch is the medical branch, where your pacemaker reports back to your doctor. That will happen and it'll have important effects. But one I think is going to be a lot more interesting is the Quantified Self side, where people get to know more about their lives, their patterns, how they compare to other people, and how those relate to outcomes.

One concern is we need ways to look at people's information and combine it that are safe and benefit the people that are contributing the information. With the World Economic Forum, we're working to establish data ownership rights. It's your data, it's from your body, you own it. You can choose to share it and you can set up safe ways to do that, but you should share it when you get something out of it.

Vivian: What are some of the concerns around tracking people's data?

Sandy: Well, people usually say they don't like to be spied on. They want control over what is done with their data. Control and transparency.

Say you don't want to share your exact data, but you might be willing to share, anonymously, the number of miles traveled a day. Not where, just how many miles. That would allow you to compare your magnitude of travel with other people's magnitude. It's an information exchange where you're contributing the minimum information you feel comfortable with in order to get some answers back that you find valuable.

Vivian: What are some unintended consequences you might foresee?

Sandy: If we don't put the right policies and structures in place, then the bad guys become more powerful. Would you really want to live in Zimbabwe if the government knew everything about you? Maybe not. It's a new power, with pluses and minuses. We have to figure out how to use it wisely.

Vivian: Might we use sensors and sensor networks to compare ourselves to our neighborhood? What does this mean for creating healthy living environments or healthy neighborhoods?

Sandy: Researchers have looked at patterns of communication and mobility within neighborhoods, and drawn amazingly strong correlations with sociometric outcomes. There do seem to be information ghettos where people don't communicate with the outside world very much.

The bottom line is we're moving into a domain where we have enough data and enough people living different ways that we can begin to figure out, for the first time, what leads to good neighborhoods and bad neighborhoods, good personal lives, good families, and good health.

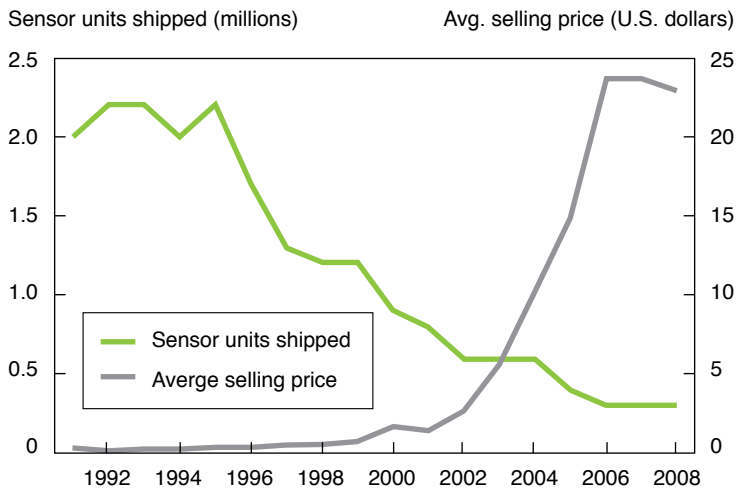
ubiquitous sensing

The market for many different types of health-related sensors will continue to grow significantly over the next ten years. As the technology improves, we can expect the cost of sensors to continue to decline and demand to increase globally. The graphics below illustrate these expected trends.

As the price of image sensors for digital cameras dropped more than 75%, from an average of more than $20 in the early 1990s to $5 in the year 2001, the number of image sensors sold rose slowly. Once hitting that price point, sales increased sharply. This drop will continue over the next decade and sensor use will proliferate globally in order to measure an increasingly wide variety of the factors that shape health and well-being.

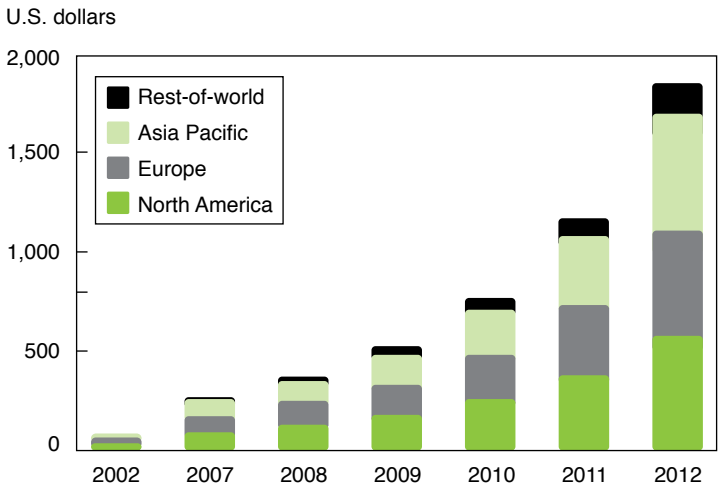
We can expect the total global revenue for wireless sensors and transmitters, broken down by region of the world, to increase significantly through 2012, with sensors coming into widespread use in North America, Europe, and Asia.

As Sensor prices drop, demand increases



Source: http://image-sensors-world.blogspot.com/2010/04/historical-view-on-image-sensor-market.html>

Global increase in wireless sensor revenue



Source: www.dolcera.com

WHERE DO WE SEE THIS TODAY?

emerging sensor technologies

Sensor technologies that will have a major impact on health over the next ten years are already in development. Some are at the scale of body embedded under our skin or circulating in our bloodstream; others are in the external environment. Also on the horizon are platforms and tools that can help us better understand and make connections based on the data collected by the next-generation sensors we will use to monitor our health, our networks, and our environments.

Collecting data about our BODIES

Blood-clot detectors. Nanoparticle sensors, about 120 nanometers in diameter and sheathed with strands of nucleic acids that bind to specific molecules, are injected into the bloodstream to continuously monitor for thrombin, a biomarker associated with blood clots.

Cancer-sniffing e-nose. An array of gold nanoparticles and a gas chromatograph are component parts of a sensor that can "smell" the emission of certain organic compounds in the breath of individuals with lung, breast, colorectal, and prostrate cancers. Researchers hope to be able to use this technology to develop an inexpensive, non-invasive, and portable tool for cancer detection.

Implantable blood pressure monitor. Currently in clinical trials, this tiny sensor, inserted in the femoral artery near the groin, measures a patient's blood pressure 30 times per second. Also implanted under the skin, a micro-cable connects the sensor to a transponder unit that wirelessly transmits the data to a small external device for storage and use in medical analysis.

Making sense of data at the NETWORKS scale

Connecting the dots. Harvard's Nicholas Christakis, co-author of *Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives*, is a leading authority on health and social networks. His research team has created visualizations that reveal how happiness, smoking, and obesity spread through social networks.

Building networks based on sensor data. Pachube is a data platform that makes it easy for people to collect, manage, and share sensor and environmental data and build global communities based on this information.

Pulse of the nation. Mood-related words on Twitter have been used to create a visualization of Americans' mood throughout the day.

Increasing understanding of data about our ENVIRONMENTS

Smart carpets. Working to create a safer home environment for seniors, researchers have developed a type of sensor that can be printed on thin, flexible sheets using "organic ink." Sensor sheets imprinted with thousands of these low-cost sensors and sandwiched between a room's carpet and carpet pad can detect falls and even changes in gait.

What's it like outside today? CitiSense, an NIH-funded project at UC San Diego's California Institute for Telecommunications and Information Technology (CalIt2), plans to create a network of wireless environmental sensors encased in small portable devices carried by San Diego residents as they go about their daily business. The sensors will collect air quality (and possibly noise pollution) data for transmission via cell phone to a central server where software will analyze the data and provide up-to-the-minute environmental information.

Asthma triggers. Asthmapolis is a GPS-based sensor device that fits on most commonly used asthma inhalers. It records instances of inhaler usage and transmits collected data to a server that creates maps showing where and when asthma attacks occur.

SENSING **BODIES**

medical device innovation

Sensor technology has played a dramatic role in the evolution of diabetes management. The ability to monitor a patient's blood glucose levels has moved from the laboratory or doctor's office to the home to any time, any place. The introduction of small, handheld glucometers was revolutionary, and as sensors continue to shrink in size, monitoring will become even less intrusive. This evolution provides a benchmark for how developments in sensor technology will improve the quality of life for patients with other health conditions that require continual monitoring, such as heart arrhythmias and high blood pressure.

Ancient times

Sushrata, a physician in ancient India, describes ants' attraction to urine as a test for "sweet urine disease."

Late 19th/mid-20th century

Benedict's test, Fehling's test, and dip and read diagnostic strips are used to test for presence of sugar in urine.

1960

1962

Leland Clark and Ann Lyons develop the first biosensor, the glucose enzyme electrode.

1970

1972

Patent issued to Anton Clemens for Ames Reflectance Meter, the first blood glucose meter.

First Blood Glucose Meter

Source: http://www.diabetesmonitor.com/supplies-and-how-to/ames-reflectance-meter-arm.htm

1980

1980s

Home glucose monitoring devices, such as Bayer's Glucometer and Roche's Accuchek, are marketed to consumers in response to research showing that home monitoring improves glycemic control.

1990

Home Glucose Monitor

Source: http://www.roche.com/media/media_backgrounder/media_diabetes.htm

2000

2006

Real-time continuous glucose monitoring devices becomes available with FDA approval of Medtronic's Mini-Med system, which uses a disposable transcutaneous glucose sensor connected to a transmitter and a receiver.

2010

TODAY

- University of Florida researchers are developing a sensor that can detect glucose levels in exhaled breath, replacing need for blood testing.
- University of Connecticut scientists are prototyping a tiny wireless device embedded with sensors and transmitters that can be injected under a patient's skin for long-term monitoring of blood sugar levels.
- Multiple research projects are developing contact lenses that can be used to monitor glucose levels non-invasively.

Breath sensor

Source: www.tokokesehatan.com/

2020

2020

Glucose monitoring and insulin delivery will be integrated, continuous, and will no longer require the frequent finger pricks patients currently endure.

urban noise pollution

Advancements in sensor technology are leading to the development of new tools of measurement that make the invisible visible. Empowered with information, people can make more informed decisions about their health and demand change at each of the scales discussed in these Perspectives. This example highlights the role of sensors in tracking a particular environmental concern.

The availability of lightweight, inexpensive sensors and sensor networks will make easier and more commonplace the continual measurement of pollutant levels in the air, ground, and water. The monitoring of noise pollution will also become more prevalent. Research confirms that, in addition to causing hearing loss, noise pollution disrupts sleep, raises stress, and triggers hypertension leading to heart attacks and strokes. Taking the lead in addressing the problem, the European Union (EU) requires all member states to map noise levels near major roads, railroads, and airports, and in urban areas, once every five years.

Currently, EU officials collect the data from sound level meters installed at selected sites for short periods of time, then use computer modeling to generate noise "maps" by extrapolating the local measurements to wider geographic areas. In addition to being costly and time-consuming, this approach fails to provide a level of granularity sufficient to accurately assess the noise levels residents are tolerating.[1]

But other solutions for accurately monitoring and mapping urban noise pollution are emerging. One approach leverages the ubiquity of mobile phones; another relies on fixed sensor networks.

The Sony Computer Science Laboratory in Paris and its partners are expanding on the concept of participatory sensing and citizen science with NoiseTube, a mobile software application that turns a GPS-equipped mobile phone into a noise sensor. Users can measure their exposure to noise wherever they are, annotate these location-specific measurements with additional information, such as the source of the noise, and upload the data to the NoiseTube server. The aggregated data is used to generate collective, detailed maps of a city's noise pollution that can be accessed in real-time by concerned citizens, public health officials, and other interested parties

Skeptical about using mobile phones as noise measurement devices, researchers in Italy and Switzerland, are instead deploying networks of cheap wireless sensor nodes in specific areas over long periods of time.[2] Fixed on light poles and buildings, the nodes are equipped with multiple sensors that can monitor noise levels and other types of environmental factors, including wind speed and direction. Careful spacing of the nodes can correct for inaccurate estimates of noise pollution generated by existing computational models. This project is based on a number of ongoing efforts, including CitySense, jointly developed by Harvard University and Raytheon's BBN Technologies, to collect and map air pollution levels and other environmental data with fixed sensor nodes.

While these examples are of Europe-based efforts to monitor noise levels, we can expect that as cities in China, India, and other developing countries continue to grow and become more industrialized, their populations will also demand that more attention be paid to identifying sources of noise pollution. Sensor technology will play an expanding role in our ability as citizens to understand this and other forms of environmental contamination, to make decisions about exposing ourselves to these health risks, and to demand change.

NoiseTube's mobile phone application

Source: www.noisetube.net

1 Nicolas Maisonneuve, et al., "Citizen noise pollution monitoring," in dg.o *'09: Proceedings of the 10th Annual International Conference on Digital Government Research*, (Digital Government Society of North America, 2009), 96-103, www.csl.sony.fr/downloads/papers/2009/maisonneuve-09a.pdf.

2 Silvia Santini, Benedikt Ostermaier, and RobertAdelmann, "On the use of sensor nodes and mobile phones for the assessment of noise pollution levels in urban environments," in Proceedings of the 6th international Conference on Networked Sensing Systems (2009), 31-38, www.vs.inf.ethz.ch/publ/papers/santinis_inss2009_ontheuse.pdf.

responses

Although sensors and sensor networks are becoming smaller and more pervasive, it is not enough to say that having the technology will make us healthier. We still have to integrate sensors into our everyday lives, and develop tools to understand and use the information we're getting from sensors in order to build our capacities for well-being, and mitigate risks of illness. The following are response strategies to the forecasts in this perspective. They can be mapped onto the "Well-being Response Landscape" described in the Overview: they are immediate, intermediate or long-term, and are aimed at either treating or managing illness or building new health capacities.

Manage chronic disease better with closer monitoring

The management of chronic disease will evolve as sensor technology proliferates, making it possible for health care providers and even patients to continuosly monitor critical health information such as blood glucose levels or blood pressure. Access to these data streams may require rethinking what it means to manage illness on a daily basis, whether in the hospital, at home, or on the go. Data visualization tools and easy-to-use feedback loops will make responses to changes in health indicators more immediate and effective. (Immediate illness response)

Create built environments that inform daily choices.

To maximize the potential of embedded sensors, they will need to be incorporated into the physical locations where people make daily decisions about their health—where they live, work, and play. The resulting abundance of data will create demand for trusted sources that can provide products and services to help interpret the information and make it actionable. The design of health-smart homes and communities will give rise to new opportunities for making just-in-time feedback available to help build capacity for routine health practices. (Immediate capacity building response)

Engage in environmental monitoring as a public health initiative

Armed with low-cost devices, citizens will be able to monitor their environments and demand that others—including industry leaders, government officials, and fellow citizens—take action. The ability to aggregate, analyze, and visualize information about healthy and unhealthy spaces will fuel the actions people must take to minimize health risks. As our understanding of epigenetics (the study of the effect of the environment on our genes) begins to grow, we can expect environmental monitoring to become even more critical to those of us concerned about the health and well-being of our descendents. (Long-term capacity building response)

Promote health and well-being by harnessing the power of personal networks

The current trend of using the size of one's social or professional network as a status symbol is likely to shift to an emphasis on the health of one's networks. Tapping into these networks to promote healthy behaviors can have a far-reaching impact. Regular monitoring of the overall health of a patient's networks may become an important part of a health provider's checklist. (Long-term illness response)

key tensions

Meaningful data vs. too much information

The massive amounts of data collected by sensors will require visualization and interpretation software that can transform raw data into real information that consumers and organizations can act on.

Health benefits vs. privacy concerns

While increased access to data about our bodies, networks, and environments will help us live healthier lives, some people will be uncomfortable sharing their personal information and others will have concerns about data security.

The "cool kids" vs. the outcasts

Rather than bringing people closer, there is the potential for using information to define new, polarized groups. Information "elites" may arise, intent on excluding individuals or networks displaying "unacceptable" patterns of data.

For more information about IFTF's Health Horizons Program contact Dawn Alva at (650) 233-9585 or **dalva@iftf.org**.