TOUCH & INTERACTIVITY AND PORTABLE TECHNOLOGY

Information DISPLAY

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Electronic Sensors Narrow the Gap Between Man and Machine

THE STATE OF THE TOUCH-PANEL MARKET

SEAMLESSLY INTEGRATING WEARABLE ELECTRONICS

THE BIRTH OF TELEMEDICINE NETWORKING

Plus

Highlights from Display Week 2015

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JULY/AUGUST 2015
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For Industry News, New Products, Current and Forthcoming Articles, see www.informationdisplay.org

ON THE COVER: The iCub robot image is courtesy of Giorgio Metta, IIT, Genoa, Italy. Photo by Lorenzo Natale. See article beginning on page 18.

Cover Design: Acapella Studios, Inc.

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editorial

Take a Break – You Deserve It

by Stephen P. Atwood

It's July. It's hot outside, and there's a lot of good stuff going on out there! It's the middle of the summer and like many of you I'm worried about managing my vacation time so as to minimize the impact to my organization while at the same time not missing out on all the things calling to me beyond my office windows. Summertime and good weather can really be an inconvenience when you have relentless work deadlines and constant pressures to manage. The pull of the outdoors and the desire to run away and see some place new is highest for me at this time of year. We live in a time when professionals take fewer vacations than ever before and businesses are generally leaner, tending toward high productivity at the expense of flexibility. It's hard to find a "convenient" time to get away, and when you do the stress of re-entry and catching up can wear you back down in almost no time. Never in recent years have I been on vacation and not worried about those hundreds, maybe thousands, of emails waiting for me when I get back. If you laugh at this, I'll bet you are in the minority these days.

Americans seem to be among the worst of professional workers around the world for leaving hard-earned vacation time on the table. Depending on which one of many surveys you can read on this subject, something like 50% of American workers use less than their allotted vacation time, many opting for long weekends or short breaks rather than real vacations of a week or more. When most Americans, including me, do take vacation, they still check email, dial in on conference calls, and generally try to stay ahead of the wave of events going back at their offices and labs. Most of those same surveys also cite higher stress levels for people who do not take time off, and worse, some indicate that long-term career prospects are worse for people who cannot pull themselves away from the office or lab. We could speculate about the underlying reasons for this, but I think it's safe to say that getting away and gaining some fresh perspectives on life can foster more creativity and ingenuity. In our industry, creativity is crucial to success!

Personally, I believe in a good work–life balance and I struggle to take my own advice sometimes, but as I am finishing up this editorial, I am looking forward to several nice breaks away from the office with my family over the next couple of months, and as inconvenient as they might seem to be, I will not sacrifice them for the demands of work – even if I have to ask the IT department to delete my email box before I come back. Now it's your turn to do so as well. You have undoubtedly earned it and your health and career will be better for it. And do not forget the people you manage in your organization. Give them the support and encouragement to feel empowered to use that vacation time well and congratulate them when they return for never checking email or answering the phone while they were away. You need them refreshed and re-energized with creativity in the long term to help your organization succeed.

Our lineup this month looks at a variety of topics related to flexible electronic networks, sensors, and interactive systems, thanks in part to the great work of our Guest Editor Russel Martin. Asked to find some interesting stories around the category of flexible and wearable electronics, Russel developed a trio of stories that he introduces in his guest editorial titled "Building on Valuable (Human) Real Estate." And, as you might have guessed from the cover, this is not a typical "displays" issue.

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industry news

Prysm Installs New Video Wall

Prysm, a video-wall manufacturer based in Silicon Valley, recently installed a 13-ft.-wide by 4-ft.-high video wall at the University of California at the San Francisco Medical Center (Fig. 1). The wall, in the passageway between UCSF Benioff Children's Hospital and the main hospital lobby, incorporates a wide range of content and interactivity designed to deliver engagement with visitors. For example, a gesture-controlled "attract mode" captures the attention of people walking past the installation by sensing their presence and immediately displaying a greeting or other content designed to stimulate curiosity. Touch-screen capabilities accommodate multiple simultaneous users who are able to open, zoom, and otherwise access information about UCSF Medical Center's hospitals, faculty, staff, and programs, including donors. (The new video wall was dedicated to the medical center's donors, who have contributed over $600 million to the research campus.)

UCSF worked with Sensory Interactive, the consultant and integrator on the project, to select the Prysm system, which is built on Prysm's laser phosphor display (LPD) technology. LPD uses a phosphor panel and laser engine to generate high-quality imagery with low-power solid-state lasers. The panel, made up of individual video tiles, uses a pattern of phosphors layered in a rigid glass or polymer structure. When excited by the laser engine, the panel emits red, green, or blue light to form image pixels. Since the phosphor is printed extremely close to its surface, the display is able to achieve a 178° viewing angle. The laser engine consists of solid-state laser diodes that generate modulated beams to energize the phosphor panel. Since the lasers are off for black pixels, very high contrast images are achieved at ultra-low power. Mirrors direct the beams from the laser engine across the phosphor panel at a refresh rate of 360 Hz. This produces flicker-free images with no motion blur, even for fast-moving video. Touch capability is realized through infra-red technology. The infra-red sensors are located in the frames around the video tiles. According to Prysm, the LPD video walls offer bright images, wide viewing angles, and high efficiency that compare favorably to other digital-signage technologies in terms of features and total cost of ownership.

***Fig. 1:** The video wall at UCSF is designed to attract and engage multiple users with interactive content based on the medical center's services and staff.*

Christie Wins Six Industry Awards at InfoComm 2015

Visual and audio company Christie won six awards at InfoComm 2015 in June, including a *Readers Choice* award for its Christie Velvet LED from *rAVe* magazine for "Favorite Video Wall Product." The Christie Velvet LED Apex Series captured a Best of Show award for "New and outstanding products exhibited at InfoComm" from *Digital Signage* magazine.

Christie laser phosphor technology won two honors; the Christie GS Series, a "Most Innovative Emerging Technologies" award from NewBay Media and the new Christie Captiva DUW350S Ultra Short Throw lens projector, a Best of Show award from *Government Video* magazine. The Christie Boxer projector was named "Best Video Projection Product – High Lumen" by NewBay Media, and the Christie FHQ981-L 98-in. LCD flat panel won a Sound & Video Contractor award.

DisplayMate Predicts Advances in Lower Display Reflectance

DisplayMate's Ray Soneira recently posted a piece on the importance of display reflectance, using as a basis for comparison the Sapphire and glass displays available for different models of the Apple Watch. The point of the article, notes Soneira, is that "low reflectance is king" and that new technologies are becoming available that will significantly reduce reflectance for both Sapphire and glass, creating dramatic improvements in display performance under real-world ambient lighting.

This applies to all displays that are used in ambient lighting, including smartphones, smart watches, tablets, laptops, PC and video monitors, TVs (if you watch during the day or with room lights on at night), and especially for displays that are mostly used in outdoor environments like digital signage and automobile displays.

Notes Soneira: "The standard way that has generally been used to improve display performance in ambient light is to fight fire with fire and just continue increasing the display's maximum brightness. But there is a practical limit to that, plus a brighter display needs more power and a bigger battery. With some new advanced technologies that will be introduced soon, the reflectance of both Sapphire and glass will be reduced significantly." (For more on how smart-watch makers need to remain aware of battery life, see the blog post "Android Wear Offers Timely Advice to Display Makers" in this month's Display Week 2015 Highlights article.)

Lowering display reflectance and improving display performance in ambient light results in better screen visibility and readability, which is something that all consumers will automatically appreciate and understand, and the easy to see visual differences and benefits will make this an important marketing advantage for displays in the very near future.

Soneira's comparison can be read at www.displaymate.com/Apple_Watch_ShootOut_2.htm

LG Display Produces LCD Panels with AIT Technology for Notebooks

LG Display recently announced that it will start mass production of Advanced In-Cell Touch (AIT) panels for full-HD notebook PCs in the

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guest editorial

Building on Valuable (Human) Real Estate

by Russel Martin

The popularity of wearable devices has grown rapidly in recent years. This category of portable devices includes activity trackers, smart glasses, wearable cameras, and smart watches, just to name a few. These devices count our steps, estimate the calories we have burned, capture the scenes around us, display incoming phone calls, and tell us our heart rate. The range of diverse features they offer us increases month by month. Wearable devices will soon identify our mood, tell us whether we are drinking enough water, and gently remind us if we have been sitting too long.

We tend to carry our portable computing and communication devices (phones) wherever seems easiest to us. Some wear cell phones in holsters like modern-day gun slingers. Some drop them into back pockets, where the devices have a habit of inconveniently popping out — or calling random individuals by mistake. Many people place them on the table as soon as they sit down. Women's phones spend most of their time in purses.

While there is much information that can be picked up about the user from their cell phone, the fact that the device's position is uncertain presents problems for many tasks. Furthermore, a phone is only in skin contact with users when they are holding it. Many physiological measurements require physical contact; for example, measuring heart rate or blood oxygen saturation. On these two counts, wearable devices such as watches and exercise monitors have a distinct advantage over phones for sensing the user. Fixed location and skin contact are advantages. By far the most common location for a watch is on the non-dominant wrist. Some devices, such as clip-on pedometers or cameras, can be placed in several locations, but they remain in one location during use. An unchanging and well-defined location allows more accurate activity classification. That, in turn, lets the device make better predictions of the user's situation, communicating it to their phones as necessary.

More significant are the opportunities afforded by skin contact. This valuable real estate allows access to far more information about users than just how they are moving. Optical measurements already can provide heart rate and blood oxygen content. Expanded methods should provide us with valuable information about the dynamic biochemistry of our bodies. This should allow us to track changes throughout the day and eventually may provide a window into our health.

In this issue, we have three articles describing methods of taking advantage of the valuable real estate that wearable devices build upon. Professor Wagner and his collaborators at Princeton University describe technology that can build electronics directly into fabrics, literally weaving it into our clothes. Professor Dahiya and co-authors from the University of Glasgow describe technology to build conforming plastic films that provide touch input and display output across a wearable device – even providing touch-sensitive skin to robots. These two articles teach us how to build upon our new property. Giorgio De Pasquale and Angela Lentini at the Polytechnic University of Turin in Italy describe how wearable sensors are a key to expanding telemedicine and connecting distant patients to doctors, thus building a hospital on this real estate.

I hope the articles in this issue of *Information Display* provide an opportunity for you to reflect upon how the location of the devices we wear determines what we can

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Developing Electronic Skin with the Sense of Touch

Although the concept may seem futuristic, research on electronic skin has wide-ranging practical impact.

by Ravinder Dahiya, William Taube Navaraj, Saleem Khan, and Emre O. Polat

MICROELECTRONICS technology and its subsequent miniaturization, which began almost immediately after the transistor was invented, have revolutionized computing and communication. However, miniaturization by itself is not the only way that electronics can evolve to add more value to our lives. Recent significant additions to the field include fabricating or printing electronics over large areas and on unconventional substrates such as plastics that flex, bend, and conform to 3D surfaces.[1] Fuelled by a large number of applications, the pace at which flexible or bendable electronics is evolving is faster than ever before. This category includes an increasing list of applications ranging from foldable or conformable displays to smartwatches and wristbands to wearable electronics and even robotic skin.

Technological advances have inspired numerous multidisciplinary groups worldwide to develop artificial organs such as electronic skin and bionic eyes. These inventions could potentially bestow lost sensory feelings to disabled individuals, or provide useful sensory capabilities to machines to enable them to improve the quality of human lives, or enable innovative non-invasive means for early detection and monitoring of chronic diseases. Recent advances in electronic-skin technology have attracted increasing attention for their potential to detect subtle pressure changes, which may open up applications including health monitoring, minimally invasive surgery, and prosthetics.

Electronic sensory or "tactile" skin should help enable robots and similar machines (when these technologies are realized) to interact physically and safely with real-world objects. For example, a robot designed for healthcare could manipulate objects more effectively or help the elderly with greater safety, if its actions were based on feedback such as pressure or temperature coming from its body parts while it was physically in contact with the object or person in question.[2] The recent incident at a Volkswagen plant in Germany, in which a worker was crushed by a robot,[3] is similar to one reported in the early 1980s in Japan[4] and reminds us of the importance of safety where robots are concerned.

Tactile sensing plays a fundamental role in providing action-related information such as sticking and slipping; vital control parameters for manipulation/control tasks such as grasping; and estimation of contact parameters such as contact force, soft contact, hardness, texture, temperature, *etc*. Tactile skin could also be indispensable for numerous medical diagnoses and surgical applications through haptic interfaces. For example, to feel the presence of tumors in underlying body tissue, the visual feedback of laparoscopic instruments is often insufficient; inserting a tool with tactile as well as visual feedback might prove more useful.[2,5] In addition, although once a topic for science fiction, the notion of restoring sensory feelings to amputees can approach reality through solutions such as electronic or tactile skin enabled by sensitive electronics over flexible substrates (Fig. 1).[2,5]

Challenges Go Beyond Skin Deep

Realizing tactile skin is challenging, as this technology requires multiple types of sensors and electronics (*e.g.*, to measure contact pressure, temperature, gas, chemical composition, etc.) on the flexible or conformable substrates and also over large areas.[1,2] Many different sensors distributed over a wide area such as the entire body of a robot would require a complex signal-processing system capable of dealing with very large amounts of raw data.

One way to deal with big data is to create tactile skin with distributed computing, allowing information to be partially processed close to the sensing elements, then sending the smaller amounts of summary data results to higher-computational units. This would mean that in addition to distributed sensors, the tactile skin would require distributed electronics, and this is another challenge for developers of tactile skin. The miniaturization of electronics, which has followed Moore's law since the 1960s, with more and more electronic components fitting into small die-sized areas, makes

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distributed electronics over large areas such as a robot's body all the more difficult.

The recent trend of printed electronics may help meet this challenge.[6] This includes printing transducer material directly on flexible substrates, as shown later in Fig. 3, or directly printing active electronic materials on the substrates.[6] Large-area printed pressure sensors, radio-frequency identification tags (RFIDs), solar cells, light-emitting diodes (LEDs), transistors, *etc*. have been reported recently.

In the case of printed pressure or touch sensors, emerging trends include screen-printing or ink-jet printing of conducting or transducer materials including piezoelectric polymers such as P(VDF-TrFE) or composites of carbon nanotubes (CNTs) and PDMS (soft silicone) *etc*. While tools such as screen printers help bring sensor-related research closer to manufacturing, the printing of active electronics over large areas with performance at par with today's silicon remains a challenge.

Factors that significantly contribute to the effectiveness of tactile skin in many applications including robotics are (a) sensor type and performance (*e.g.*, sensitivity, ability to measure various contact parameters); (b) physical aspects (*e.g.*, sensor placement, conformability, wiring); (c) data processing and hardware issues (data acquisition, signal conditioning, communication, power, compatibility with existing electronic and sensing hardware); (d) algorithms and software (processing data from tactile sensors distributed in 3D space, sensor representation, deciphering tactile information); and (e) engineering issues (integration of sensing structures with robots, maintenance, and reliability).

Fig. 1: *This conceptual image of a prosthetic device shaped like a human hand incorporates lightweight, ultra-flexible, high-performance, and cost-effective electronic skin.*[2]

Touch Requirements

A rudimentary illustration of electronic skin can be seen in touch screens in wide use today. Touch screens detect contact location in the manner of a simple switch, *i.e.*, 'contact' or 'no contact.' The physical act of touch is detected by measuring the change in resistance, capacitance, optical, mechanical, or magnetic properties of the material being touched. The various types of touch-screen technology include resistive, capacitive (self and mutual), acoustic, and optical.[2]

In terms of electronic skin, one of the more significant advantages of resistive-touch-screen technology – such as that used in the Nintendo DS game console – is that it can detect the touch or pressure of any object irrespective of the electrical property of the material and also offer protection against surface contaminants (both solids and liquids). In addition, resistive touch screens are cost-effective to fabricate and use very simple sensing circuitry. They require very low power. However, resistive touch screens need complex designs/architectures for implementing multi-touch – at a significantly high cost.

Resistive touch screens also have poor transparency and hence poor image clarity compared to that of capacitive touch screens. Capacitive touch screens allow multi-touch operations, albeit at the expense of increased per-cycle readout time and/or an additional processing block. Other touch-screen technologies such as acoustic touch screens and infrared touch screens also offer excellent transparency and durablity. However, they suffer from ambient light interference and are sensitive to liquids and contaminants.

Bendability Requirements

Touch screens based on resistive, capacitive, or acoustic technologies work for the most part on rigid and planar substrates, but these are giving way to bendable and foldable portable displays in the near future. One possibility for the future are ultra-thin bendable chips for drive electronics in displays and the bendable version of various touch-screen technologies.[7] Replicating touch-sensing mechanisms in bendable displays will create research challenges. For example, the air gap that has to be maintained in resistive touch screens could lead to false inputs in flexible layers. Similarly, the ITO used to make conductive transparent films in capacitive touch screens does not lend itself to being flexed. It is a brittle ceramic-like material.

Graphene, which has the potential to revolutionize the technology, could offer another alternative for bendable touch screens. While graphene could power semiconductors and advance circuitry in the future, as technology improves, the most immediate implementation would be touch screens. Graphene is an excellent conductor of electricity and is especially strong for its light weight – it is estimated at 100 times more durable than steel. In addition to being strong and conductive, it is also flexible, transparent, and can be grown on large areas.[8]

Distributed Computing Requirements

Creating tactile skin involves more than just integrating or realizing sensors on flexible substrates. Unlike vision sensing, it is distributed and involves measurements of a multitude of touch parameters such as pressure, temperature, slip, *etc*. Given these requirements, it is unlikely to have a unique solution such as CMOS imagers, which revolutionized vision sensing and cameras. A number of different types of sensors would be needed to detect and measure the touch parameters. This also means that the data processing and computing requirements will be complex. In robots such as humanoids, the tactile data would come from different parts of the robot's body, and schemes similar to the somatotopic maps in humans could be useful to effectively handle and utilize the tactile data. Such representations can also help in locating the tactile sensors' three-dimensional space – which might otherwise be labor intensive and error prone because the positions of the tactile sensors change with the robot's position. In terms of computing, a neuromorphic approach (circuitry that mimics the human neurological system) could be an interesting future development.

Prototype Efforts

A variety of approaches and designs are being pursued to develop an effective prototype of tactile skin. Early attempts to obtain bendable electronic skin followed the flexible printed circuit board (PCB) route, with off-the-shelf sensing and electronic components soldered to bendable PCBs that were made out of Kapton or thick polyimide. These approaches largely focused on measuring contact force or pressure. One such example was successfully used in a recently concluded European project dubbed ROBOSKIN, conducted by Professors Metta, Sandini, and colleagues (including the lead author of this article), which developed tactile skin for various robots including the iCub "humanoid" or human-style robot at the Istituto Italiano di Technologia in Genoa, Italy (Fig. 2).[10,11] [a]

Fig. 2: The iCub robot (shown above) incorporates tactile skin on most of its body parts. Its e-skin was created with off-the-shelf electronic/sensing components integrated on a flexible printed circuit board. The images at the bottom show different sections of iCub's body covered with flexible PCB-based skin. Images courtesy Giorgio Metta, IIT, Genoa, Italy.

This semi-rigid skin is one of the most functional implementations of large-area touch sensors to date and was used to cover body parts with large curvatures, such as the arms of iCub. It was made of triangular modules, each having 12 capacitive touch sensors – obtained by placing a 5-mm-thick layer of soft and rubbery dielectric material on the electrodes (shown in Fig. 2), which were realized on the flexible PCBs. A conductive cloth covering the top of the soft dielectric material acted as the second electrode. When pressed by an object, the soft dielectric deformed, and the electrodes on its two sides came closer to each other, which led to increase in the capacitance. The change in capacitance was proportional to the contact force or pressure. Besides acting as the dielectric, the soft layer also provided the extra cushion, which led to improved safety. This capacitive skin on major body parts of i-Cub changed the research paradigm, whereby robotics research focus shifted from hands-based manipulation or exploration of objects to that involving exploiting multiple contacts with large parts of a robot's body. This is similar to the manipulation of sandbags or big cardboard boxes by humans.

Other examples of PCB-based semi-rigid robotic tactile skin include Hex-o-Skin, developed at TU Munich by Professor Cheng's group[12] and at the University of Tokyo by Professor Kuniyoshi's group.[13] These solutions also use off-the-shelf sensors and electronic components. The Hex-o-Skin has multiple sensors such as proximity, vibration, and temperature. The basic sensing module in Hex-o-Skin is implemented by an hexagonal PCB, which hosts a microcontroller for data preprocessing (*e.g.*, clustering, feature extraction, *etc.*) and a transmission interface.

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[a] iCub is a "humanoid" robot developed at the Istituto Italiano di Technologia in Genova, Italy, as part of the EU open-source project RobotCub and subsequently adopted by more than 20 laboratories worldwide. It has 53 motors that move the head, arms and hands, waist, and legs; can see and hear; has the sense of proprioception (body configuration); and is capable of movement (using accelerometers and gyroscopes). According to the iCub Website, researchers are currently working to give the iCub a sense of touch and to be "aware" of how much force it exerts on objects and its environment. www.icub.org

The printing of touch sensors on flexible substrates using screen printers or ink-jet printers is another route for obtaining tactile skin (Fig. 3).[14] These printing tools have been employed to print conductive and transducer materials to develop various types of touch sensors, including resistive, piezoresistive, piezoelectric, and capacitive sensors.[9]

With technology enabling ever more advanced robots, the electronic skin of the future needs to be far superior to what is possible today with off-the-shelf components. Interesting developments in this direction include electronic skin using organic semiconductors with thin-film transistors based on active-matrix backplanes developed by Professor Someya's group at the University of Tokyo,[15] Professor Sekitani's group at Osaka University, and Professor Bao's group at Stanford University.[16] Another group that has contributed to the field includes Dr. Stadlober from Joanneum Research. These organic semiconductors have favorable features such as low-temperature solution processing and inherent bendability. The pressure sensors based on organic semiconductors often integrate transducer material such as pressure conductive rubber with the transistors. The resistance of pressure conductive rubber when it is pressed results in a change in current through the transistors, which is then detected with associated electronics. However, transistors and sensors based on these materials are slow, due to low charge carrier mobility and the large channel lengths that are possible with current solution-processed technologies. They are also less stable. Effective utilization of electronic skin in applications such as robotics requires sensory data to be acquired and transmitted quickly (less than a msec), thus enabling a robot to react quickly.

In this context, electronic skin based on high-mobility semiconducting materials such as single-crystal silicon offers significant advantages. That is why our focus at the Bendable Electronics and Sensing Technologies (BEST) group at the University of Glasgow is on developing electronic skin using silicon and other high-mobility materials that can also be processed using existing micro/nanofabrication tools.

The major challenge in using silicon for conformable electronics is posed by its brittle nature – silicon cracks on bending. Furthermore, some of the fabrication steps for silicon-based devices require temperatures much higher than for flexible substrates such as plastics. We have overcome these challenges by using transfer-printing and contact-printing approaches. In the transfer-printing method, the silicon nanowires are carved out of bulk wafers using a top-down strategy and transfer printed to flexible plastic substrates. The high-temperature processing steps are carried out before transferring the wires to flexible substrates. The skin looks like a rubbery polymer that has tiny silicon nanowires on it; these lead to thin-film transistors and sensors. The transfer printing of silicon nanowires was motivated by research conducted at Professor Rogers' group at the University of Illinois Urbana-Champaign.[17] For the first time, at Glasgow, we have demonstrated the use of this technique to develop the wafer-scale transfer of ultra-thin chips onto flexible substrates. The ultra-thin chips are attractive for compact and integrated flexible electronics as well as future touch-enabled flexible displays.

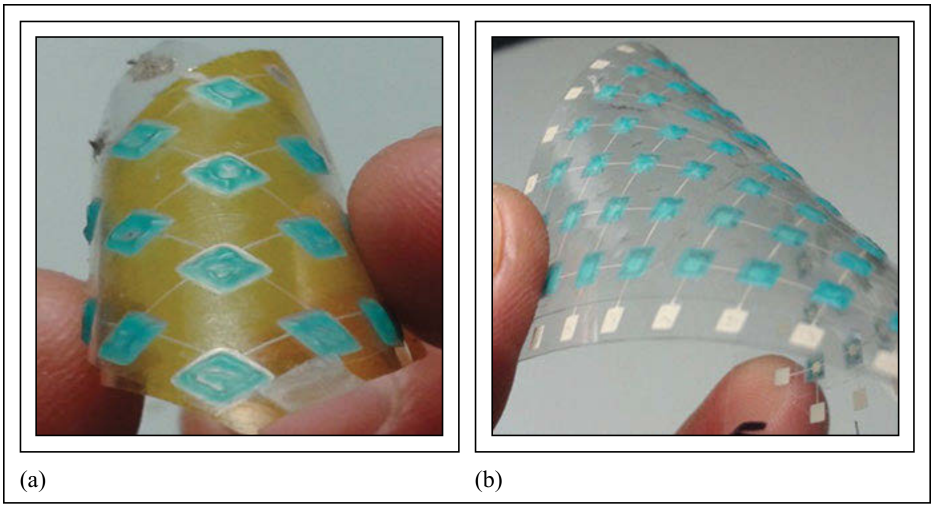

Fig. 3: *Examples of screen-printed touch sensor cells include (a) P(VDF-TrFE) on polyimide and (b) MWCNT/PDMS sensors on PET.*

Another alternative strategy is to grow silicon nanowires using a bottom-up approach and then carry out contact printing to realize electronic and sensing components on the flexible substrates. Professor Javey's group at the University of California Berkeley has used this methodology to develop sensitive electronic skin.[18] However, the actual use of these advanced tactile skin technologies in robotics has not yet been demonstrated. Perhaps this is because truly macroscale integration of electronic skin using the above advanced approaches is still a research challenge because uniformity over large areas is challenging.

The on-going EPSRC (Engineering and Physical Sciences Research Council) fellowship for the growth project "printable tactile skin" conducted by the BEST group at the University of Glasgow is currently working towards overcoming these challenges through a combination of novel approaches that involve the printing of electronics and sensors over large areas. Other alternatives for developing electronic skin include using low-temperature polysilicon technology, which has been explored for thin-film transistors for displays.

Although it may seem futuristic, research on electronic skin has wide-ranging practical impact. For example, today's artificial hands have come a long way from the fictional (but based on real-world) example of Captain Hook. Using what's called myoelectric linking, a prosthetic limb can pick up electrical impulses from any remaining muscle fibers on an arm, transmitting those impulses to articulating fingers and thumb. These prosthetic devices are continually being upgraded and remodeled to look and function as much like a real limb as possible.

As realistic as they may look, currently available prosthetic hands have physical properties that are still far from the characteristics of human skin – they are much stiffer, for example. Eventually, these advanced prosthetic devices must be up to the task of touching and being touched by other people, with as much realistic "feeling" as possible.

This goal is closer than ever with the sensitive synthetic skin being developed by the BEST group at the University of Glasgow as part of the EPSRC growth fellowship dedicated to printable tactile skin. The synthetic skin could lead to next-generation prosthetic arms with which users can feel a light touch, shake hands, and type naturally because the arm will send signals to the brain and in turn respond to brain signals. Further improving the experience will be smaller and more efficient batteries and lifelike materials that will more closely resemble real skin and be capable of more accurate communication between hand and brain. We are fortunate to be living in this exciting era and feeling the positive impacts of technology.

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Investigating the Architecture of Flexible Large-Area Hybrid Systems

Combining thin-film sensor electronics with CMOS creates a new technology that marries the advantages of flexible large-area electronics with the speed and processing power of nanoscale ICs. Several features of this new architecture could benefit the development of comfortable, wearable electronics.

by Sigurd Wagner, Josue Sanz-Robinson, Warren Rieutort-Louis, Liechao Huang, Tiffany Moy, Yingzhe Hu, Yasmin Afsar, James C. Sturm, and Naveen Verma

TODAY'S WEARABLES are designed to connect the consumer with the Internet, observe bodily functions during physical exercise, watch the health of medical patients, or monitor the stress signals of emergency professionals. Wearables may be worn on the wrist, as armbands, or in pouches. Today, most wearable devices are discrete and usually visible.

Experiments and demonstrations of electronic textiles have revealed that customers like the idea of electronic clothing – clothing that incorporates wearable devices – but want it to be as comfortable and lightweight as everyday clothing. Most people are highly sensitive to the property of a fabric that is called "hand;" is it soft, flexible, and smooth or hard, stiff, and rough? Furthermore, wearers want the electronic machinery to invisibly merge with common articles of everyday use.

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In meeting these challenges – developing wearable electronics that seamlessly integrate into everyday clothing – much can be learned by considering recent materials innovation in the area of synthetic fabrics. With industrial scaling and corresponding price reductions, novel synthetic fabrics are being incorporated into a wide range of products. In particular, fierce competition in the clothing industry has led companies to rapidly license and adopt new synthetic fabrics, thus adding value to their product offerings and achieving higher margins. For example, Lululemon, a maker of athletic wear, has licensed a proprietary antimicrobial material from Noble Biomaterials for anti-odor clothing, Nike has Dri-Fit fabrics with moisture-wicking properties, and the Swiss Barefoot Company offers Kevlar socks as an alternative to traditional shoes.

We believe that for the first generation of wearable electronics, these types of fabrics will act as the scaffolding, which will provide a physical structure for clothing with embedded discrete sensors and output devices. Driven by the need for reliability, low cost, and rapid entry to market, the makers of these initial wearables will not focus on developing new electronic components with a flexible form factor. Rather, they will exploit the vast library of existing components typically found in consumer embedded electronics. In order to mitigate the undesirable rigidity of electronic components, they will attempt to minimize their density and conceal them through strategic placement (Fig. 1).

Electronic Fibers

The question remains whether the first generation of wearables will use electronic components with wireless connections or whether hardwired interconnects should be favored due to their reduced cost, complexity, and lower power consumption. Developers have already accumulated a great deal of experience integrating conductor wires into conventional yarn during spinning. In fact, many interconnects and resistors have been spun into yarn. However, together with their packaging, these materials are considerably more rigid than textile fiber. Such textiles become even more rigid when yarns are prevented from sliding against each other because they are attached permanently by electrical contacts. Specialized textiles, with a high density of electronic components and yarn-to-yarn interconnects, may be acceptable for

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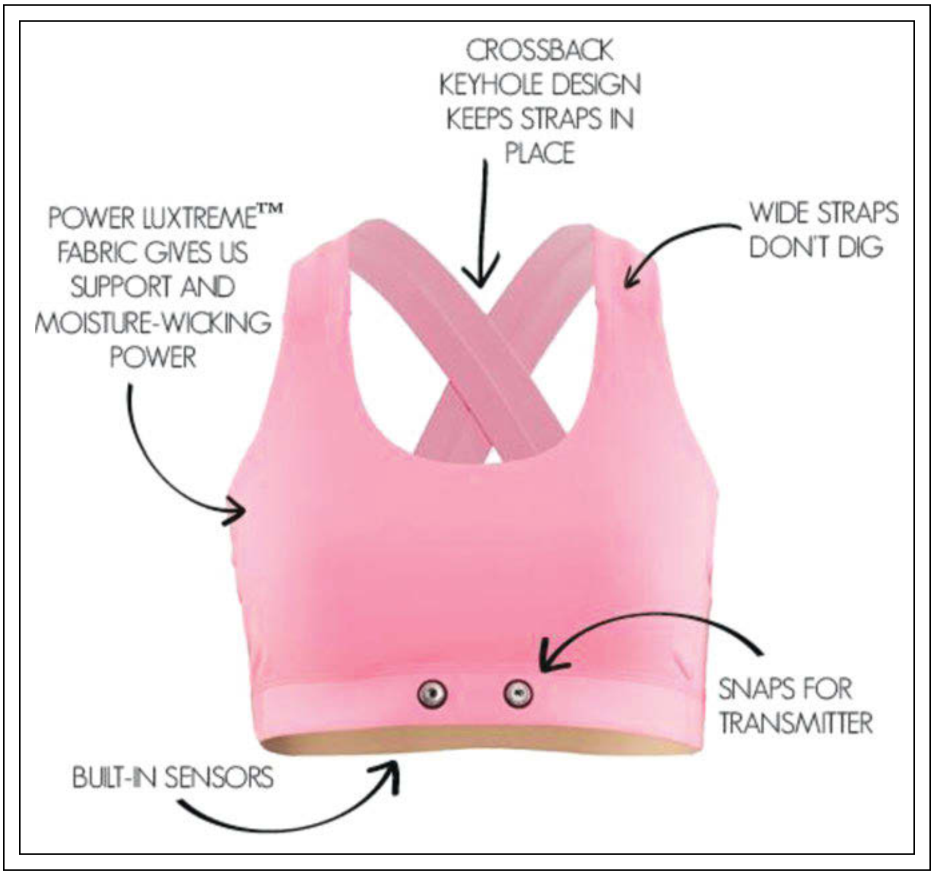

Fig. 1: *The Lululemon All Sport Bra comes with built-in sensors for heart-rate monitoring and snaps for a transmitter. Image courtesy Lululemon.*

professional users. However, to appeal to the consumer market, conventional electronic components and wiring must be introduced as sparsely as possible to ensure a comfortable hand.

In the future, fabric will no longer exclusively play the role of scaffolding for discrete and primarily rigid electronic components but will itself have inherent electronic properties. Then wearables will be particularly well placed to benefit from the experience and manufacturing infrastructure of flexible electronics. Active devices based on weaving together conductors, insulators, and semiconductor fibers will form the basis of these second-generation wearable systems. There already have been numerous demonstrations of this concept, including transistors formed by depositing pentacene on top of a woven network of metallic fibers,[1] transistors made from two crossed fibers coated with PEDOT-PSS with an electrolyte placed at their intersection,[2] and a circuit made from transistor and conductor fibers.[3] Similarly, a wide range of sensors with a fiber form factor have been demonstrated, including light sensors based on optoelectronic fibers[4] and acoustic sensors made from piezoelectric fibers.[5] Compared to first-generation wearables based on embedding rigid discrete electronic components in a fabric, wearables incorporating electronic fibers have great potential for enabling electronics that seamlessly integrate into everyday clothing. Nevertheless, much research is required both at a materials and systems level in order to make these novel devices meet the scalability and reliability requirements of a commercial product.

A Hybrid Architecture of Thin-Film Electronics and CMOS

At the systems level, wearables can leverage architectural solutions from the field of flexible large-area electronics. In particular, hybrid technologies that combine the best of CMOS and flexible electronics are especially well adapted to wearable systems. Table 1 shows the functionality division on an architectural level that our research team developed for this technology. In such architectures, CMOS is primarily responsible for computation, leveraging far faster and more-energy-efficient transistors than its thin-film counterparts. Flexible electronics provides a wide array of sensors and output devices for human–computer interaction so as to enable interfacing with the macroscopic world. Also, it has the capacity to cover large areas with energy-harvesting devices, such as solar cells, for self-powered systems. We have been able to demonstrate the viability of such architectures by building a hybrid system for structural health monitoring.[6] In this implementation, the large-area side features amorphous-silicon TFT-based sensors and access control circuitry, as well a flexible solar cell and associated thin-film power electronics for self-powering. The CMOS IC is responsible for sensor readout and sensor-data processing, as well as for controlling the system's subcomponents.

In terms of form factor, these hybrid systems are highly versatile because the thin-film sensors and output devices can be spread over the large surfaces of many materials and topographies, such as plastic foil or even paper. The display industry has led the way to batch processing, with substrates approaching 10 square meters. Current efforts to introduce additive printing and roll-to-roll processing of electronics will eventually raise throughput and reduce cost to levels that enable mass-

Table 1: Functionality divisions between flexible electronics and CMOS for hybrid systems are compared with regard to sensing, self-powering, and computation.

Flexible Electronics	CMOS
+ Diverse/conformal sensors	+ Precision instrumentation
+ Large devices harvest substantial power	+ Power management
- Low performance	+ Large-scale integration, energy-efficient transistors

market production. CMOS integrated circuits having a rigid form factor can be sparsely distributed to carry out computational and control functions.

Non-Contact Connections and Low-Wire-Count Interfaces

One of the key challenges of wearable electronics systems is connecting the different electronic components that are embedded in clothing. When designing hybrid large-area systems, we approached this problem by developing two complementary approaches for interconnects. These allow us to robustly connect different planes of the system, along with connecting CMOS ICs and flexible electronic circuits. First, we rely to a large degree on capacitive and inductive electrical connections instead of hardwired connections. Second, we reduce the number of CMOS–to–sensor-array wire interconnects, so that typically there are only 3–5 interconnects when controlling between 10 and 100 separate sensors (Fig. 3).

Figure 2 shows a schematic of the physical architecture of our large-area sensor systems. In these systems, discrete subsystem sheets are laminated together to form a single multilayer sheet. The functional thin-film subsystems are fabricated on sheets, and the CMOS IC is mounted on its own sheet. The sheets are laminated and are up-and-down interconnected inductively, as most are in Fig. 2, or capacitively, as denoted with the top electrode plate in Fig. 2. Not shown is a large passive sheet that provides in-plane interconnection for all functional sheets above and beneath.

Important to note is that the number of wires connected to the IC is small. This is made possible by specialized thin-film circuits on the functional planes. These consist of sensor arrays, scanning circuits, oscillators, rectifiers, battery-charge controllers, and circuits for sensor calibration and data compression. The sensor arrays aside, these circuits have few components and are small enough to be made on yarn without stiffening it excessively.

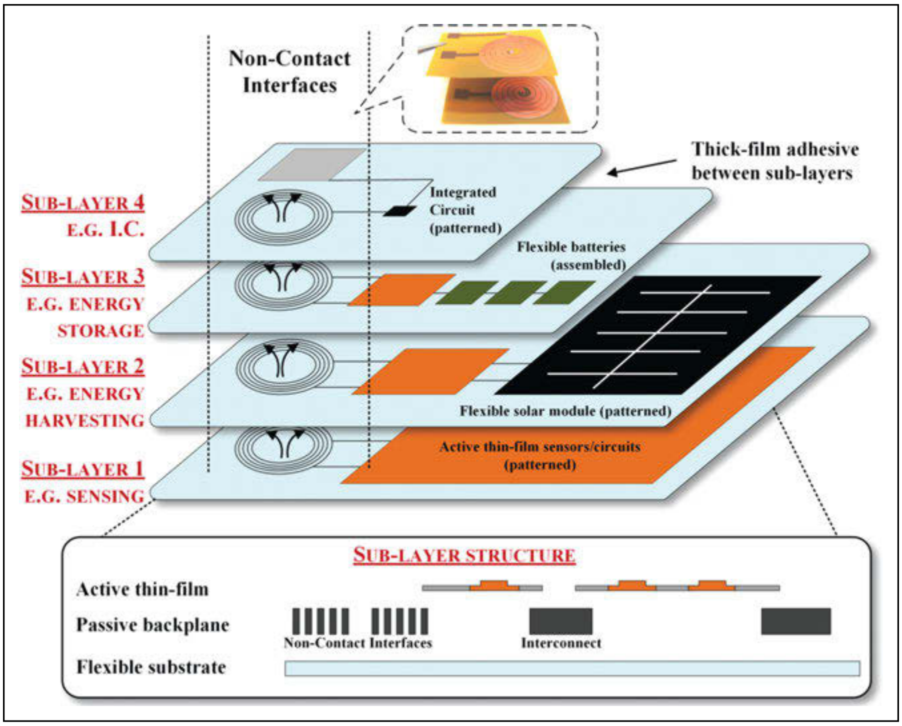

Fig. 2: A schematic of the physical architecture of an autonomous flexible large-area strain-sensor-array sheet system shows four sub-layers.[7]

The architecture of the TFT-based strain-sensing sheet is shown in Fig. 4. In our architecture, sensors are sequentially polled using a custom scanning circuit, fabricated on the

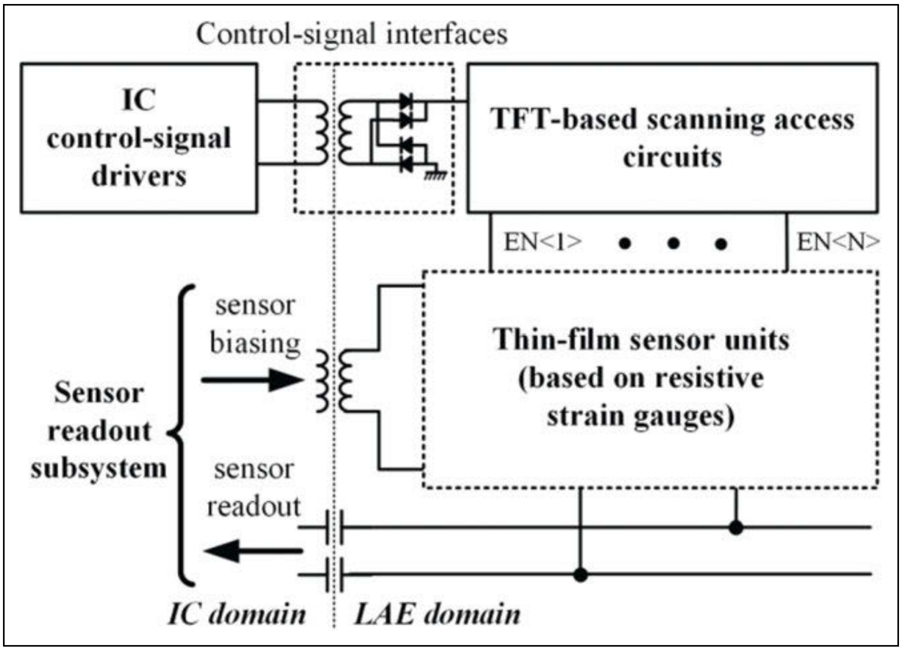

Fig. 3: A strain-sensing system incorporates inductive and capacitive signal transfer from a CMOS chip (IC domain) to a large-area flexible sheet (LAE domain). This system uses only two inductive and two capacitive interfaces.[8]

same substrate with the same technology as our TFT-based sensor elements. By reading out sensors in a multiplexed manner, we can transmit data from the large area to the CMOS domain over a single connection. Due to the modular nature of the scanning circuit, a single circuit can support *N* number of sensors. However, in practice, the number of sensors that can be polled is limited by the maximum sampling rate of the scanning circuit, which in the case of an amorphous-silicon implementation is in the kHz range (~1 kHz for a fully passive scanning circuit[6] and ~10 kHz for a powered scanning circuit). In addition to the signal connection, a small number of control connections are also required.

As shown in Fig. 4, the connections between the large-area electronics (LAE) and the CMOS domain physically consist of capacitive and inductive links, which can be used to transmit both signals and power. Because no mechanical and ohmic connections are involved, in a wearable application, yarns containing insulated electrical conductors would be left free to move against each other. In order to transmit signals from the LAE to the CMOS domain via inductive or capacitive links, the signals need to be converted from DC to AC. This step is carried out by a TFT-based Gilbert modulator, which amplifies the signal from the TFT strain sensor and also modulates it from DC to AC.

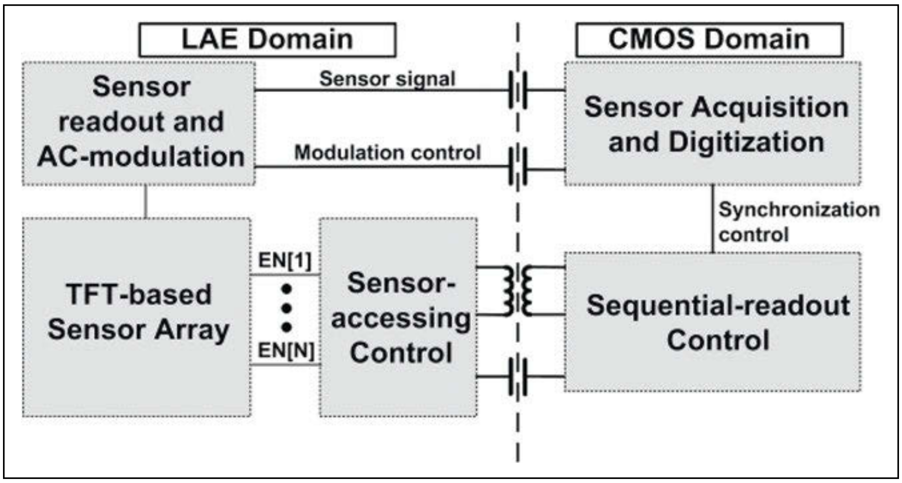

Fig. 4: *In this architectural block diagram of the strain-sensing subsystem, TFT circuits in the large-area electronics (LAE) domain enable interconnecting with the CMOS domain over as few as four points. The library of thin-film circuits includes oscillators/power converters, scan chains, and instrumentation amplifiers.*[6]

Form Factors of Components Are Adaptable for Wearables

Many of the devices employed in the system illustrated in Fig. 4 are small; examples are diodes and transistors. Others, such as capacitors, inductors, solar cells, and thin-film batteries, are large. Whether small or large, their footprint must be changed from 2-D to 1-D to naturally conform with the yarn of wearables. In many cases, one can go from large-area 2-D components to textile-compatible 1-D components by simply resizing the component. Metalized fibers cut from metal-coated polymer film and then edge-sealed are available commercially in thicknesses down to 20 µm, which is in the range of fine fibers spun to yarn for clothing and textiles (fibers are spun to yarn; yarns may be plied to thread; yarns or threads are woven or knitted to textiles). Two-sided metallization will convert such fibers into capacitors. The dimensions of the thin-film active devices used for sensors, amplifiers, and rectifiers also are commensurate with fine textile-grade fibers. A fine fiber with a circumference of ~ 50 µm will easily accommodate a TFT, as illustrated in Fig. 6. Note that textile yarns, which are spun from fibers, have diameters in the low 100-µm range. Sparsely woven yarns containing one electronic fiber will have a minimal effect on the hand of the textile. An example of a knit fabric that incorporates wire is shown in Fig. 5.

While some of the physical implementations of large-area system components are easily adapted to wearables, others pose challenges. The challenges derive in part from physical principles and in part from physical implementation. Capacitors and inductors illustrate the challenge. By their physics, both are inherently 2-D devices. But both can be made in physical implementations that are close to 1-D. Synthetic fiber cut from film with two-sided metallization can be configured as 1-D capacitors, and close to 1-D micro-inductors can be made from commercial copper on flex. While these will transmit low-power signals, in 1-D fiber format they will be too small for contact-free transmission of power, even in the mW range. While solar cells on fiber have been demonstrated, DC interconnecting such PV fibers would make the fabric too rigid, and wire-free AC interconnection would require the integration of oscillators on each PV fiber. Batteries rely on volume and are therefore inherently 3-D devices. Most likely, solar cells and batteries will have to be integrated into autonomous wearables as patches or in pockets.

Power Savings of Body-Length Wiring

When spun as part of a yarn, fine insulated metal wires can enable considerable power savings over wireless intra-wearable links. This may become an important advantage for

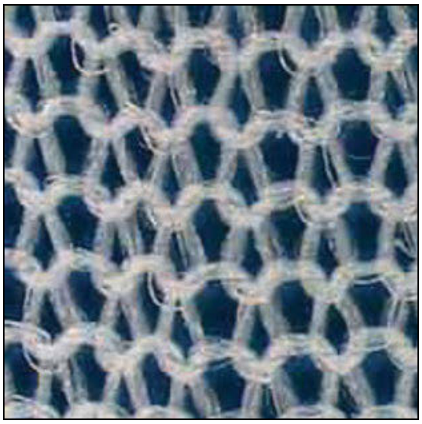

Fig. 5: *This jersey fabric is woven from a yarn of polyethersulfone fiber, blended with 25-µm-diameter silver-plated copper wire. Image source: http://www.swicofil.com/elektro_feindraht_applications.html*

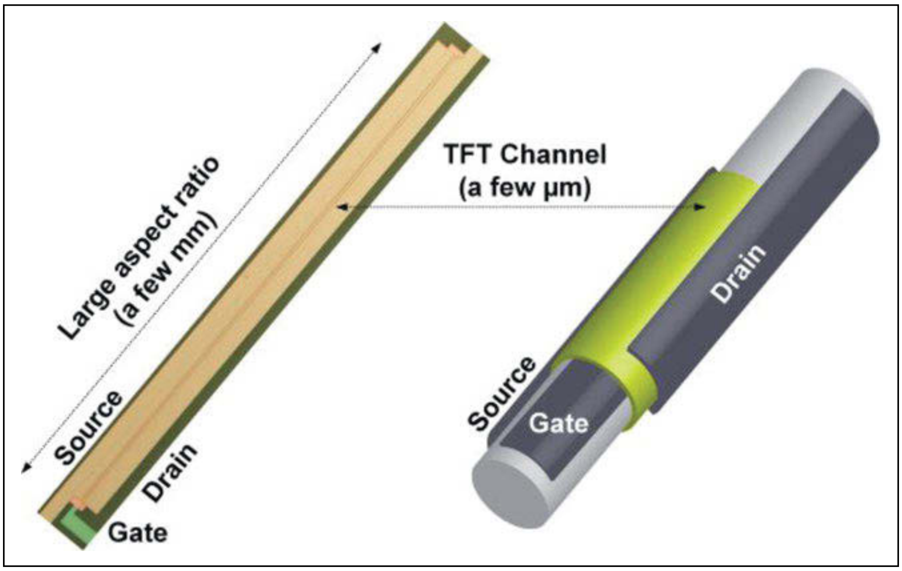

***Fig. 6:** Left: Today's typical TFT used in large-area circuits may be millimeters wide but is only tens of micrometers long (in TFTs, "length" is measured in the direction of current, from source to drain). Right: The TFT's footprint fits the circumference of a fine textile fiber, which is ~ 50 µm.*

autonomous wearables. For our work on large-area electronics, we determined the energy per transmitted bit over body-length wire interconnects. The top portion of Fig. 7 shows the experiment, where transceivers (Tx/Rx) are interconnected via inductive couplers and copper-on-plastic wires. The bottom portion of Fig. 7 shows that communication over wires needs considerably less energy per bit than wireless communication. This approach to wired communication leverages the modulation of digital data, ensuring strong coupling over the inductive interfaces and, with modulation performed to the resonant point of the interconnect and coupler network, minimizing transmit energy, thanks to maximized effective impedance. Because the wire impedance may vary during the use of wearables, the Tx/Rx ICs must be capable of self-adjusting the modulation frequency to match the resonant point of the wireline impedance.

Wearables as Part of an Ecosystem of Electronically Enhanced Spaces

Flexible displays and other large-area interfaces are in a unique position to complement the limited I/O capabilities of current wearable products and augment their ability to interact with the external macroscopic world. Large-area I/O interfaces, distributed throughout public spaces, could add much value to wearable products by seamlessly connecting with them. The small form factor of many current wearables, such as smartwatches or bracelets, means that the most common I/O devices they can adopt are small displays and

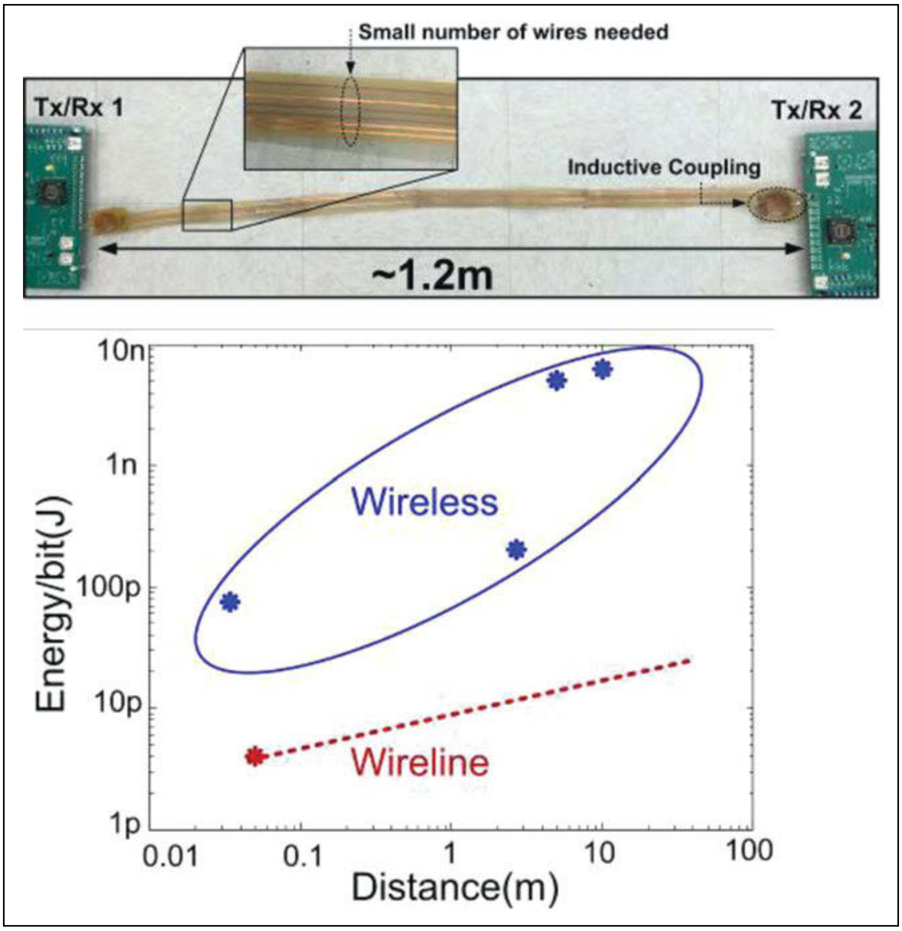

***Fig. 7:** At top is shown a test of power requirements for low-voltage AC transmission over wires configured for large-area electronics. At both ends of the interconnects, the signal is coupled inductively to transceivers. Bottom: The red line traces the energy needed for transmission over a wire, while the blue data points show published data for wireless transmission.[9]*

microphones/speakers for audio interaction. The small size of the displays forces developers to design simplified graphical user interfaces (GUIs), which restricts the complexity of software for these devices and can lead to an awkward workflow for users. Similarly, audio interfaces are hampered by the lack of accuracy of voice-recognition technology, even though significant advances have been made over the last 20 years. Even if wearable products were to be scaled to cover an entire body, accessing certain I/O devices, such as a display, could still be inconvenient.

In the future, we believe one of the greatest opportunities for wearable electronics comes not from viewing them in isolation, but rather treating them as one of the building blocks for an electronic ecosystem. With the development of large-area electronics and low-cost manufacturing techniques, electronics are becoming ever more ubiquitous. It will eventually be viable for public spaces to have ambient large-area displays and other I/O devices readily available for users. These large-area interfaces could seamlessly connect with wearable devices to provide increased functionality for the user. For example, a person could use a wearable smartwatch to monitor heart rate when exercising at the gym. Instead of incurring the inconvenience of a person looking at a watch while exercising, the information could be wirelessly transmitted to a wallpaper-format display, located on the nearest wall. Furthermore, instead of trying to control the smartwatch through its own small touch screen, the watch could interface with a large-area gesture-recognition system.

To harness the full potential of wearables, technology developers should focus on applications that treat wearables as part of an ecosystem with ever more ubiquitous electronics. In doing so, they can benefit from the rich knowledge base and manufacturing infrastructure offered by flexible electronics.

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Diagnostic Systems for Pregnancy Healthcare through Telemedicine Networking

Portable sensors and wireless networks are creating new applications in the field of pregnancy healthcare and fetal-wellness monitoring. Portable devices and smartphones can be used as network coordinators and user interfaces for remote diagnoses from home.

by Giorgio De Pasquale and Angela Lentini

TELEMEDICINE – the remote diagnosis and treatment of patients via telecommunications technology – has been undergoing rapid development, thanks to the spread of small and low-power devices, distributed wireless networks, and portable communication systems. By using telemedicine procedures, it will soon be possible to share medical data through secured protocols between patients and medical providers. The main benefits of telemedicine include cost savings, in terms of fewer hours worked by doctors and nurses and lower occupancy of hospital beds, and lifestyle enhancement because patients will be able to make fewer trips to healthcare facilities for routine exams.

The healthcare processes supported by telemedicine can be described accordingly:

- ***Prevention:*** This service is very important for people affected by high-risk disorders; for example, diabetes and cardiac diseases.
- ***Diagnosis:*** It is possible to obtain a diagnosis without leaving home.
- ***Therapy:*** This process is probably more far off in the future than the other three listed here; the goal is to automatically adapt the appropriate medical therapy to the patient's health conditions.
- ***Rehabilitation:*** This patient service is applied after hospitalization and can be used in nursing homes, rehabilitation centers, or the patient's home. An example might be for the monitoring of mobility recovery after orthopaedic operations.

The most important available tools of telemedicine are

- ***Telemonitoring:*** This service allows the monitoring of vital parameters of patients, particularly when they are affected by serious pathologies.
- ***Teleconsulting:*** This service occurs between patients and health workers, with video support for communication.
- ***Telereporting:*** This service refers to data transmission between two different health workers who need to compare their ideas about a patient's condition.
- ***Teleconferencing:*** This service occurs among a group of health workers who use video conferencing to discuss a patient's pathology.

Of the above telemedicine services, telemonitoring is the most important and has three main phases: (1) acquisition of clinical data from the patient about his or her condition, (2) sending of patient's data to medical centers or to data storage for further processing and evaluation, and (3) sending of feedback message to the patient about the received/stored clinical data.

This service is used for monitoring the vital parameters of patients, in particular when they are affected by serious pathologies. Specific data can be measured continuously or at fixed intervals. Once data has been delivered, medical personnel can perform data analysis. A typical structure for such a service, consisting of sensors mounted on patients, a mobile device to capture the information from the sensors, and a healthcare service to receive the data from the device, appears in Fig. 1. This structure is generally known as a wireless biomedical sensors network (WBSN), and it is basically an architecture of sensors (the nodes) that communicate with a gateway central node (the coordinator or mobile device) that receives the information and then sends it to a healthcare service.[1,2] A WBSN, which can be used for different applications, allows patients to move freely, thanks to the small size and light weight of the nodes and the wireless connections among them. Such a system is capable of providing not only greater comfort for patients, but economic advantages for healthcare systems.

Some portable WBSNs for pregnancy diagnosis have been proposed, but the complexity of the measurements requires additional efforts in improving existing systems reliability and accuracy. The device described in this article is at the prototype stage. It demonstrates high portability, ease of use, natural interfacing with portable electronics, and reliable data management.

Many digital devices can be used to receive measured data from the distributed sensors

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network on the patient's body, by means of short-range wireless communication. For instance, portable devices such as smartphones and tablets, which are now common in hospital settings as well as homes, can work as network coordinators through simple software applications and Bluetooth/WiFi ports. When the measured values reach a given threshold level, a first-warning message is sent to the hospital (Fig. 1); the number of warnings and their timing intervals will suggest the next move – a doctor might be advised to call the patient at home, for example, and/or have her come to the hospital.

The most important telemonitoring services are in the area of cardiac pathologies, dialysis, and diabetes. The fundamental physiological parameters detected generally include heart rate, blood pressure, blood-oxygen saturation, movements, and breathing. These services already use biomedical wearable sensors, which have very small dimensions and low power consumption, in clinical settings. They are generally user-friendly, efficient, reliable, and safe. They also allow the monitoring of physiological parameters for long periods using rechargeable batteries. In addition, researchers have recently proposed power generation that would occur directly on the human body by means of electro-mechanical transducers (energy harvesters) based, for instance, on piezoelectric materials.

The small dimensions of sensors suggest the possibility of developing smart clothes with embedded electronic components for the monitoring of vital parameters. Smart clothes would also presumably allow a more transparent and continuous (rather than sporadic, through attached sensors) monitoring of physiological parameters, and thus provide more alerts to emergency services when those parameters exceeded given thresholds. This would not only save lives but bring about a reduction in damage caused by acute events such as heart attacks.

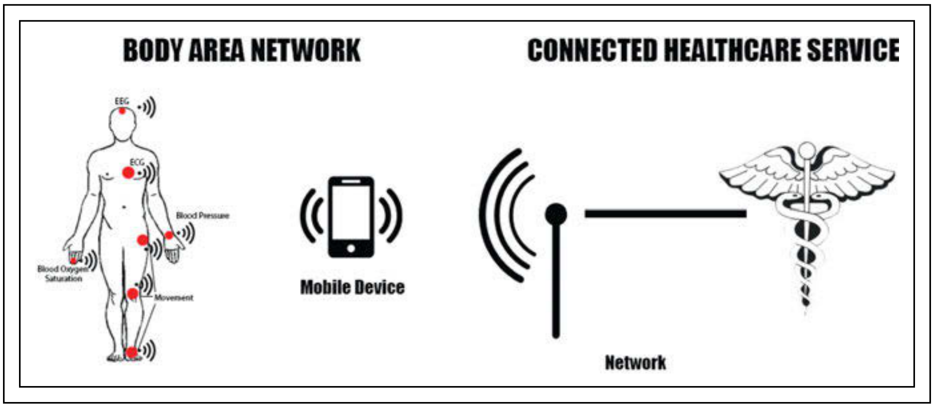


***Fig. 1:** In this potential structure for telemedicine services, the distributed sensors network sends the measured data to the local network coordinator (represented, for instance, by a smartphone), which is connected to the Internet for sharing data through secured protocols with medical centers.*

Fetal-Wellness Project

We believe that the remote diagnostic of fetal heart wellness during pregnancy is an ideal and innovative application of WBSN. In fact, solutions based on wearable sensors and data networking could provide significant benefits for the remote diagnostic of pregnant patients through self-examination at home. At this time, several commercial wearable biomedical sensors for pregnancy monitoring are available.[3–8] Portable communication devices (such as mobile phones) have several software applications supporting connections with external sensors as well as the possibility of storing the measured data. However, these simple networks are limited to the sphere of personal use and have no measured medical value. In order to validate this potentially useful application, our research group is working on new types of smart sensor

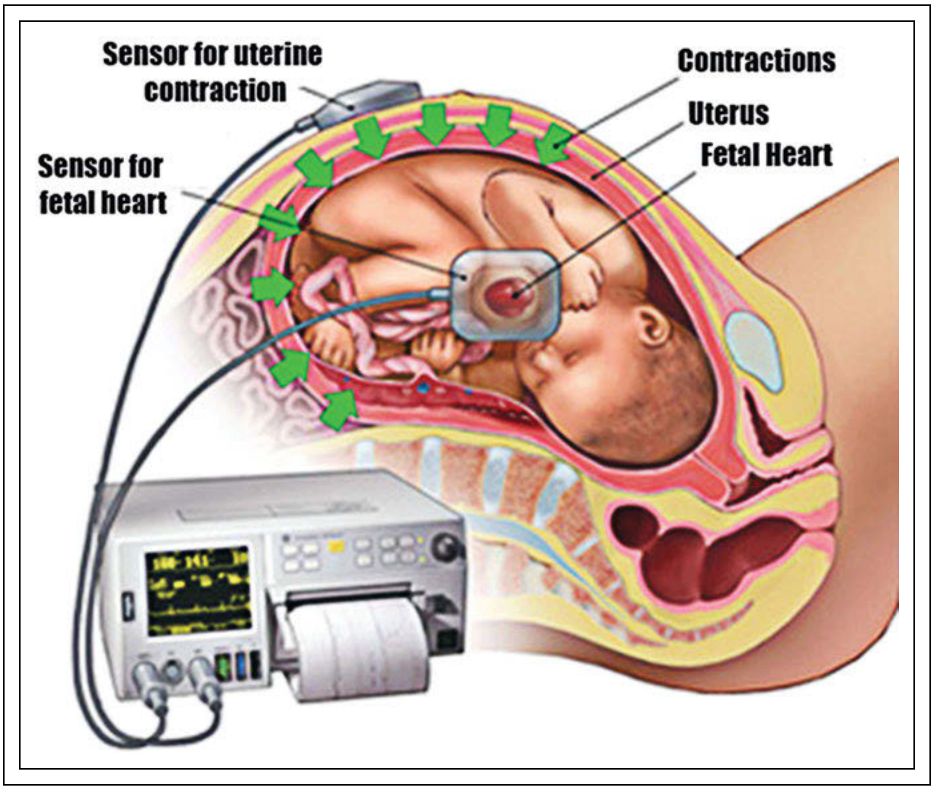


***Fig. 2:** A traditional system for cardiotocography presently used in hospitals' obstetric units incorporates a sensor for contractions and a sensor for the fetal heartbeat.*

networks for fetal heart-rate detection that are able to provide the sensitivity and sampling frequency typical of professional instruments.[9,10]

Our research group has worked for several years on self-powered and wearable sensors.[11–14] Our current goal is to apply telemedicine to a specific medical field of obstetrics: the fetal heart telemonitoring project briefly described in this article is aimed at developing prototypes for wearable sensors with wireless Internet connection for cardiotocography (CTG) examinations during pregnancy.

The methodology and facilities for pregnancy examinations have changed little over many years, while innovations introduced by telemedicine have the potential to significantly improve the efficiency of hospital practices and to reduce the associated cost and effort on the part of healthcare workers. Some examples of portable sensors for telemedicine have been introduced in the literature. For instance, the cardiotocograph by Korostelev *et al*.[15] connects a pressure sensor and an ultrasonic sensor to portable devices using the Android operating system. A system developed by Boeing *et al*.[16] for pregnancy monitoring detects the fetal heart sound with the principle of the stethoscope, in which the sound waves coming from the patient's body are captured by a microphone and used to interpret the heartbeat of the fetus. And a paper from C. Tufo from the University of Naples[17] presents some algorithms for the post-processing of cardiotocography data.

Our project started with the statistical investigation of a population of 62 patients in a hospital obstetrics unit, where it had been observed that 78% of patients had to travel more than 10 km for pregnancy examinations; and 39% of those traveled more than 30 km. Starting from the 36th week of pregnancy, the exam is repeated once per week for all patients; in the last two weeks of the pregnancy, these exams are required one to three times per week for all patients, and in the case of high-risk pregnancies, a frequency of one or more times a day is also possible depending on the specific pathology of the patient. A total of 96% of the patients interviewed expressed a very positive opinion about a home device that would be able to replace the hospital examination; 2% reported a moderately positive impression; and another 2% did not recognize any immediate benefit from this technology. Clearly, these pregnant patients were extremely positive about the idea of fetal hearth telemonitoring. This survey was conducted by referring to an ideal telemonitoring system that was not in use at the time of the interviews, but these results provide additional motivation regarding the development of the system.

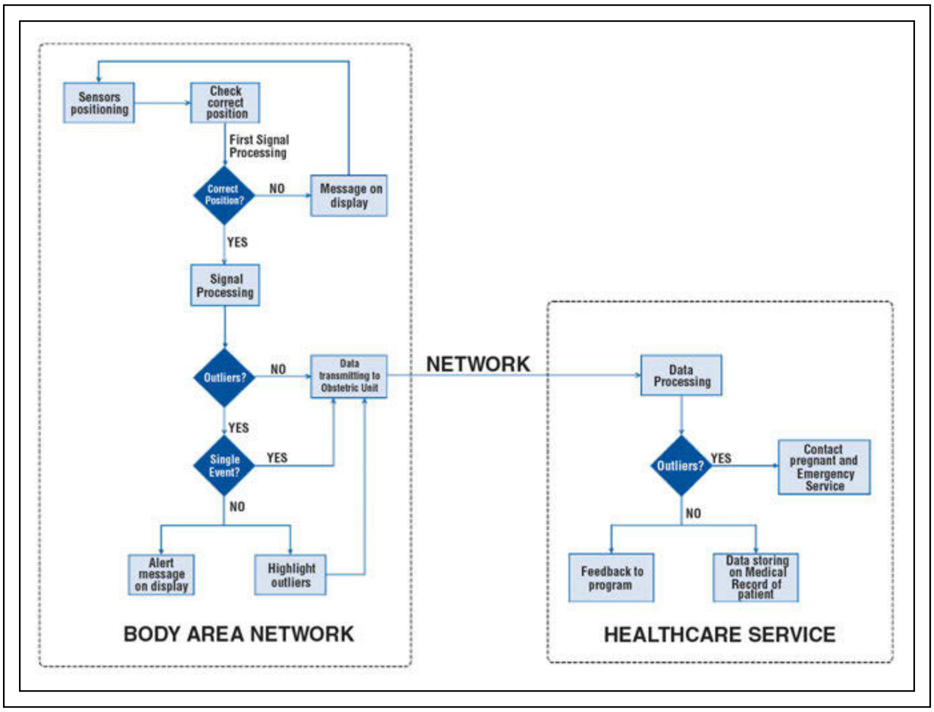


***Fig. 3:** The proposed system for the monitoring of fetal heart rates incorporates different protocols for abnormalities vs. "normal" results.*

The examination is called "cardiotocography" and is based on the measurement of the fetal heartbeat regularity. It requires two modes of detection: one for the contractions of the patient and another for the heartbeat of the fetus (Fig. 2). The exam takes from 45 to 100 minutes and requires the patient to stay perfectly still. Detection made with the hospital instrumentation is almost completely automatic; however, large and heavy devices must be used and the assistance of specialists (nurses and technicians) is mandatory. One of the main challenges associated with remote cardiotocography is miniaturizing the instrumentation without losing important information. The sensing strategy of portable instruments is different and less accurate than that of instruments operated in hospitals – we are striving to preserve the integrity of the most important data, which can identify the necessity of further and more accurate analysis. The detection modes are similar to those at home in that the patient cannot move around but the difference is they are completely automatic, do not require specialist's assistance, and do not require a trip to the hospital.

The portable monitoring device being developed by our team also uses two types of sensors: one for fetal heartbeat monitoring and one for uterine-contraction monitoring. The sensors are wireless and can communicate with traditional portable communication devices (smartphones, tablets, smart watches, *etc*.). The cardiotocography data are reported on the portable device display as they are measured before being sent via the Internet to the obstetric unit of the hospital for detailed analysis. Finally, the cardiotocography data are stored in the patient database. Remote fetal health monitoring is designed to use secure protocols to share measurements between the patient and the medical provider. If issues are indicated during the routine examination, the patient must then move to the hospital for full analysis.

The block diagram shown in Fig. 3 shows the workflow of the remote system for the diagnosis of the fetal heart rate. When the sensors are activated, they send data to the portable device, which processes the received information and also verifies the proper positioning of sensors on the body (through the evaluation of signal noise). In case of incorrect positioning, an error message sent to the mobile devices display informs the user. Otherwise, the data are measured, temporarily stored, and processed. The implemented algorithm is able to detect the occurence of unexpected measurements and to recognize isolated or repeated anomalies. In the first case, the smart device sends the processed data to the hospital obstetric unit. In the second case, a warning message (indicating the possibility of wrong/missed measurement or over-threshold value) is displayed on the portable device before sending the data to the hospital. Then, if alterations in cardiotocography are detected, the emergency medical service is activated for direct assistance at the patient's home.

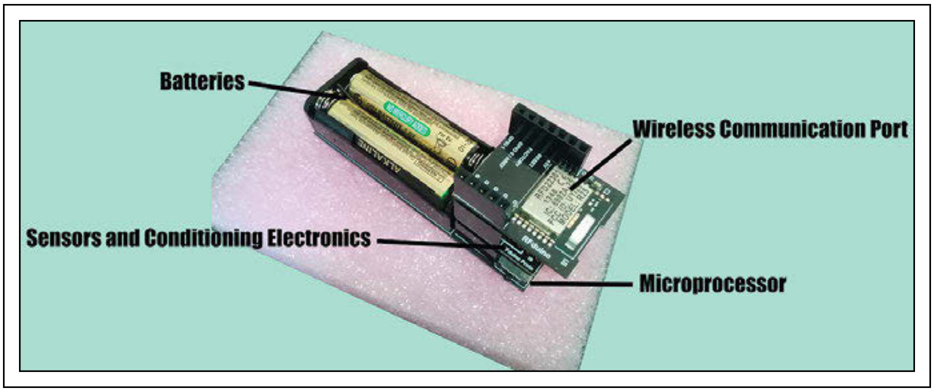


Fig. 4: One node of the distributed sensors network includes the wireless transmission unit (top level), the sensors circuit (middle level), and the microprocessor (low level); two rechargeable batteries provide the power supply.

The portable telemonitoring system is composed of three main parts: the sensor, the electronics, and the mobile device. The electronic circuit (Fig. 4) includes a microprocessor, a wireless transmission port, and two batteries for the power supply. The overall dimensions of the circuit are 100 × 60 × 30 mm. Figure 5 shows the architecture of the telemonitoring system and Fig. 6, the application interface for smartphone displays.

Challenges and Possibilities

The rapid evolution of telemedicine and wearable sensors technology is opening up the quality and convenience of care for patients, including and especially pregnant women. Among the main benefits of this progressive development is a reduction in healthcare systems costs. The positive impacts on the lifestyles of patients who would not have to travel long distances to healthcare centers are also of major benefit.

The system described in this article is in the prototype stage; the firmware and circuits have been optimized for operating in controlled conditions. The next phase will address the improvement of system reliability, the cost reduction of components, reduced packaging size, and certification. The system has been tested on the human body by volunteer researchers who measured heart rates and blood pressure. In future applications, particular effort will be given to the user interface and subsequent reduction of false positive warnings – this depends to a great degree on the way the sensors are set up on the body. The non-specialist use of the device must include very easy learning procedures and clear responses from the system.

There are no particular limitations with regard to the diffusion of the system, except for technical issues associated with the GSM network coverage of geographical areas in question. The telemonitoring strategy exploited by the system developed in this work has many potential applications in medical examinations beyond fetal healthcare. For instance, the remote diagnosis of pathologies related to glycemia, postural recovery after traumas, skin, eyes, throat, *etc.*, can be supported by the same electronic hardware and dedicated sensors and firmware.

The development of displays specifically designed for these applications — which might include those of very high resolution and low power — can improve the global performances of the system. We believe the telemedicine market is very promising for the development of the display sector. And, of course, we believe that using currently available remote fetal heart-monitoring technology, telemedicine is a likely alternative for hospital obstetric units worldwide.

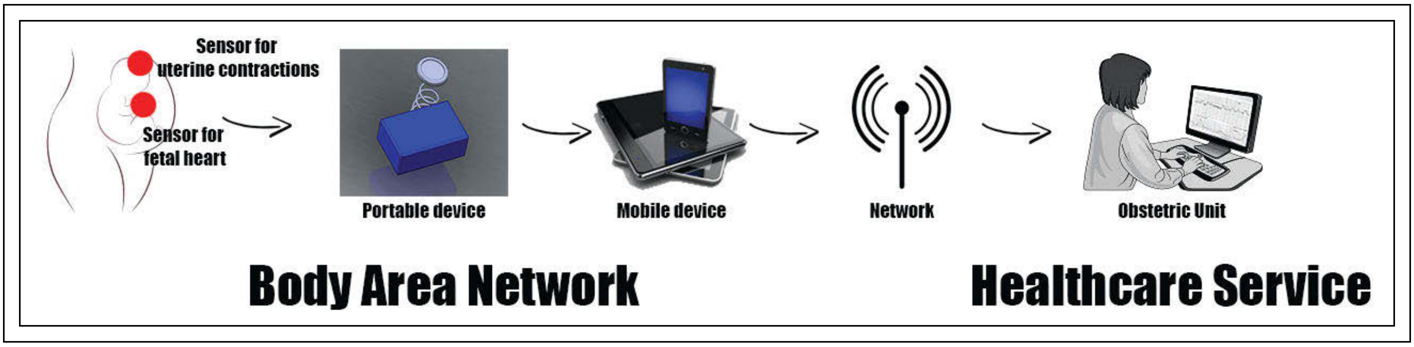
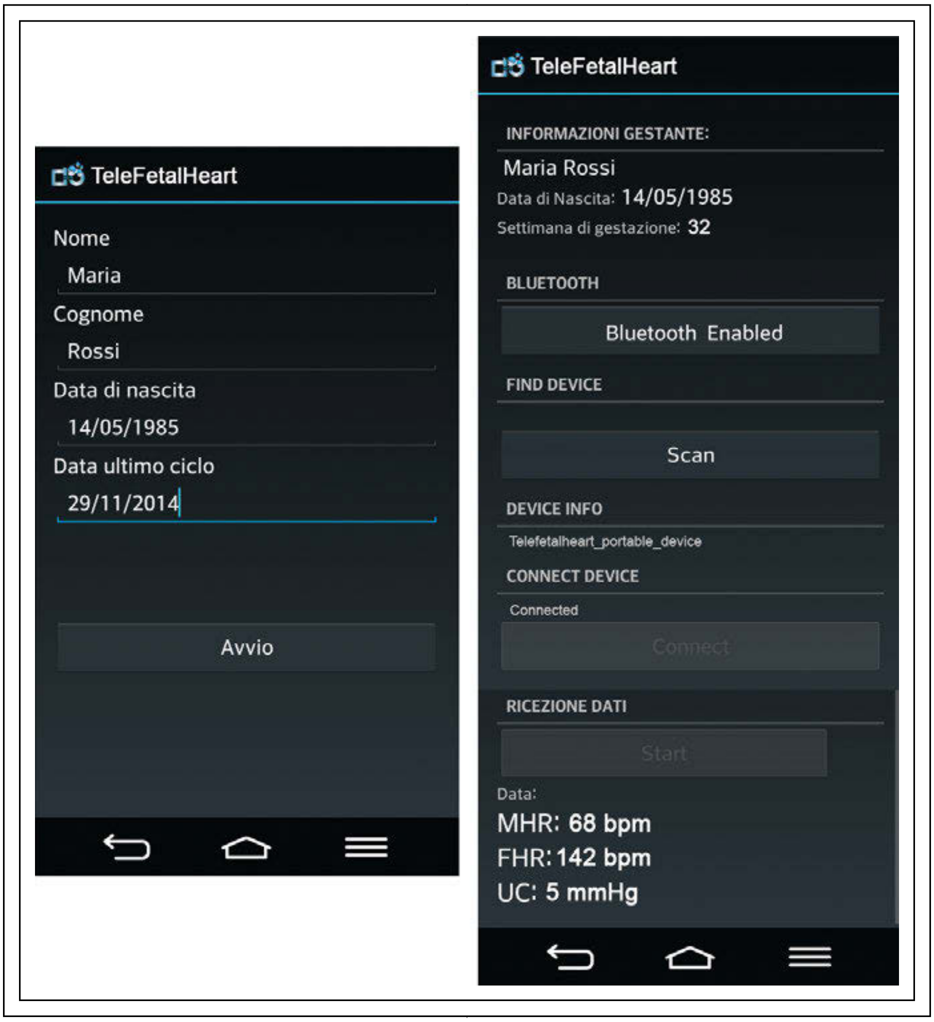


Fig. 5: The structure for the proposed fetal heart-rate monitoring system also incorporates a portable hardware node that would receive the data before sending it on to the mobile device.



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Maria Rossi
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FIND DEVICE
DEVICE INFO
Telefetalheart_portable_device
CONNECT DEVICE
Connected
RICEZIONE DATI
Data:
MHR: 68 bpm
FHR:142 bpm
UC: 5 mmHg

Fig. 6: *This graphical interface for the application developed to support the telemonitoring system would appear on smartphone/tablet displays.*

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Touch-Panel Market Dynamics and Trends

Despite market maturity in consumer applications, the touch industry is experiencing new, dynamic competition that will lead to enhanced user experiences in 2015.

by Calvin Hsieh

BENEFITING FROM new tablet PC applications and a technology shift from resistive to projected-capacitive (PCAP) with higher average selling prices (ASPs), the entire touch-panel market enjoyed remarkable shipment and revenue growth from 2010 to 2013. Revenue growth was particularly notable, increasing by almost 60% Y/Y in both 2010 and 2011. However, after 2013, fierce competition began driving a revenue decline. In 2014, shipments were up 13% Y/Y, but revenues declined 10% Y/Y due to intense pricing pressure (Table 1).

The competition is not finished yet. The industry will see further supply-chain consolidation. And the technology evolution continues. We expect to see emerging trends such as embedded touch from panel makers, enhancement of user touch-screen experiences, and new applications.

Touch-Panel Market Review

From 2010 to 2013, there were two critical factors that helped to increase touch-panel demand; one was the iPad, which created a new, larger-sized application in 2010 and the other was the Android 4.0 operating system, which enabled non-Apple brands of smartphones and tablet PCs to become more popular. In the meantime, smartphone penetration in emerging markets was deepening, especially in China and the Asia-Pacific (APAC) region. Mobile phones have been responsible for more than 76% of shares for all touch-module shipments.

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Tablet PCs represent a more than 14% share of the market by unit volume. Compared to mobile phones, the larger size of tablets gives them the potential to generate higher revenues. However, tablet PCs encountered a shipment decline in 2014 (239 million with a 4% Y/Y decline) because of product maturity and weak replacement demand. Many experts expected Windows 8 to create a new growth dynamic for touch in 2013, bringing it to a wider range of devices including laptops, but it failed. Penetration of notebook applications reached only 11%, for example. Consequently, mobile phones have been the major application driving shipment growth in recent months.

As for revenues, 2014 was a turning point. After touch makers experienced high growth for years, revenues declined 10% Y/Y in 2014. Add-on-type PCAP panels accounted for 65% (embedded PCAP panels are not included in this figure) of mobile-phone applications; resistive panels had a 15.5% share in 2012, this dropped to 0.8% in 2014. The positive influence of larger-sized applications and technology shifts disappeared in 2014. Most gross profits of makers were lower by 7–8% in 2014. The average was >10% in 2013. Taiwan-based TPK, one of the top touch-solution providers, showed a 14–18% decline during 2012.

In the near future, we might not see increased revenues for large-sized touch-enabled applications with remarkable volumes. Some new applications, such as automotive displays and smartwatches, may be helpful, although the demand for these will not be as huge as for smartphones. With the slight possible exception of the Apple Watch (selling briskly at this writing), touch-enabled smartwatch applications are still uncertain because the long-range behavior of end users regarding them is uncertain. Automotive applications, however, look more promising.

During the first half of 2014, Apple and Google officially announced their automotive plans – CarPlay and Android Auto, respectively. Each is designed to bring smartphone OS platforms, apps, and services into automobiles. Instead of replacing the existing embedded automotive telematics systems, the designers have just had automobiles leverage smartphone eco-systems that allow users access to whatever services they already have with their smartphones. A Lightning or micro USB port is used for connecting. When the smartphone is docked, it can use the interior control panel for display output as well.

The availability of this functionality should encourage auto makers to better design the displays in cars. The control panel in the central position could be an ideal position (dashboard cluster displays are usually directly in front of the wheel). Without the smartphone docked, the control-panel display is still used for information about interior vehicle settings such as air conditioning, entertainment, and navigation. After docking, the same display can display services from the smartphone for use. Users can easily switch the sources of the display back and forth.

There are more than 28 auto makers now supporting CarPlay and Android Auto. This means auto makers understand that the smartphone industry can be a supporter instead of a competitor. New user interfaces such as touch screens will continue to be introduced and

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Table 1: The overall touch-module market shipments and revenues forecast shows a slowing of growth through 2018 and declines or modest increases in revenues. Source: *IHS Quarterly Touch Panel Market Analysis Report Q1'15.*

Shipments (000s)	2012	2013	2014	2015	2016	2017	2018
Grand Total	1,290,641	1,511,751	1,701,456	1,922,022	2,114,063	2,279,280	2,401,443
Y/Y Growth	17%	17%	13%	13%	10%	8%	5%
Revenues (US$000s)	2012	2013	2014	2015	2016	2017	2018
Grand Total	$23,224,147	$28,557,077	$25,605,443	$24,555,622	$24,279,585	$24,489,829	$24,817,533
Y/Y Growth	41%	23%	-10%	-4%	-1%	1%	1%

generally adopted, replacing substantial buttons. Compared with other user interfaces such as speech recognition and gesture, touch-screen technology is currently more mature and efficient to use.

Embedded Technologies from Panel Makers

Mobile phones are still the most critical application for touch, but the component supply chain suffers from fierce competition and serious ASP challenges. Besides touch modules, mobile-phone-display ASPs also have dramatically declined in recent years. Panel makers are more interested in embedded varieties that will increase their ASPs. Since Apple's in-cell touch was successfully adopted for the iPhone 5 in 2012, panel makers have been encouraged. In 2014, embedded technology (including in-cell TFT-LCD, on-cell TFT-LCD, and on-cell AMOLED) grabbed a more than 35% shipment share of mobile-phone applications (Table 2).

Embedded touch technology has been around for years, but the only major adopting brands before 2013 were Apple and Samsung. Apple has its own in-cell patent (segmented Vcom; USPTO 8,243,027) and Samsung Display Co. has adopted on-cell AMOLED. Although panel makers have proposed some in-cell technologies and structures beginning at around 2007, all of them have failed in terms of mass production. Almost all available and produced in-cell sensor structures now are related to Apple's patent and core concept – segmented Vcom.

On-cell AMOLED (by RGB stripe) has recently benefited from technology that incorporates encapsulation glass without a color filter. Consequently, the sensor-patterning process has a lower impact on panel fabrication. Due to Samsung's resource occupation and product positioning, on-cell AMOLED is generally used for the company's premium models. In 2015, Samsung plans to adopt more on-cell AMOLED displays for the mid-range, due to declining handset market share and sufficient Gen 5.5 capacity. On-cell AMOLED can probably be the differentiation point for entry- and middle-level products. On the other hand, on-cell LCD grabbed its initial success during the 2013–2014 time frame, as the middle- and entry-level smartphone markets boomed in China.

On-cell-touch TFT-LCD sensor patterning places the touch sensors (Tx, Rx electrodes, and traces) on the top side of the color-filter glass, but beneath the polarizer. Earlier, in 2009, panel makers adopted single-side ITO (SITO; both X and Y electrodes are located on the same substrate side but with the bridge or jumper for insulation) patterning for the smartphone market but without success. Since 2013, single-layer patterning for on-cell TFT-LCD has brought new opportunities to panel makers. The market share reached 5.2% of all touch-module shipments for mobile-phone applications in 2014; it was even less than 0.5% in 2013. During 2014, more panel makers in Taiwan and China developed on-cell TFT-LCD for entry- and

Table 2: Touch-module shipment shares for mobile-phone applications show dramatic increases in PCAP shipments through at least 2019. Source: *IHS Quarterly Touch Panel Market Analysis Report Q1'15.*

Units (000s) Technology	Year 2012	2013	2014	2015	2016	2017	2018	2019
In-cell TFT-LCD	7.5%	12.5%	15.9%	16.3%	16.8%	17.4%	18.0%	18.7%
On-cell AMOLED	12.0%	16.2%	14.8%	15.2%	15.3%	15.3%	15.4%	15.4%
On-cell TFT-LCD	0.0%	0.4%	5.2%	6.9%	8.4%	9.4%	10.0%	10.4%
Projected Capacitive (add-on types)	65.0%	67.2%	63.4%	61.0%	59.2%	57.8%	56.6%	55.5%
Resistive	15.5%	3.6%	0.8%	0.5%	0.3%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

mid-level smartphones. Additionally, 7–8-in. tablet PCs and >10-in. notebook-PC applications have become the focus of these panel makers. It is still too early to make a judgment on the outcome of this war of touch-sensor integration (embedded technology). However, panel makers have some advantages such as business scale and capital so as to pose a real threat to the touch-module makers.

However, not all panel makers prefer on-cell LCD. JDI is famous for its hybrid in-cell (Pixel Eyes) and LG Display for its "advanced in-cell touch" (AIT) based on self-sensing principles. We can expect there will be new competition in the embedded sector during 2015. On-cell development and adoption was earlier and is faster than in-cell (Apple not included), but it is still not possible to say that on-cell is the final winner among panel makers.

The definitions and differences of in-cell and on-cell have no clear criteria. Conventionally, the sensor patterned on the upper glass (encapsulation or color-filter glass) was called "on-cell" and the TFT backplane glass "in-cell." But some makers used sensors embedded with a black matrix (color-filter glass) and called it "in-cell." Or, the X-Y electrodes were respectively placed on the upper and backplane glass to create "hybrid in-cell." Now, in 2015, the new definition for "on-cell" seems to mean that the sensor is patterned on the top side (facing users) of the encapsulation or color-filter glass. At least one electrode (usually Tx) at the position inside the open cell or display component (that is, between the bottom and upper glass) is categorized as "in-cell." This new definition fits what most makers are now developing.

Synaptics proposes "hybrid in-cell (HIC)" and "full in-cell (FIC)" for its in-cell structure variations. The former (HIC) has X-Y electrodes (Tx and Rx) on the backplane and a color filter, respectively, such as is used for JDI's Pixel Eyes. In FIC technology, the X-Y electrodes are only on the TFT backplane, such as for LG Display's AIT. Besides JDI and LG, Apple's patent is the most popular in-cell technology and structure.

Vcom

Apple's in-cell patent and technology use a key principle: segmented Vcom. Before the patent, panel makers designed specific sensor parts into the displays and took advantage of capacitive (charge sensing), resistive (voltage sensing), or optical (photo-sensing) principles. Almost none of these were ever produced (except in a notebook from Sharp in 2009). Segmented Vcom makes use of the existing Vcom layer in the display instead of an additional sensor part. Depending on the mode (IPS, FFS, VA, or TN), Vcom is not specifically patterned or segmented for display purposes but can be segmented for the touch-sensor electrode layout.

Due to its serving both touch sensing and display driving, Vcom requires time sharing. While it is used for display driving, it cannot support touch sensing concurrently. Consequently, display and touch have to compete with each other for precious time resources. Usually, one 60-Hz display has a frame period of 16.7 msec; display driving consumes 10 msec, leaving the rest for touch sensing. The situation will become even more serious as the display resolution gets higher. Higher resolution requires more time to deliver display signals, but this makes the time available for touch sensing less so that the sensitivity is worse. A potential solution is to use oxide to replace LTPS as the TFT technology, a change that can shorten the time needed for display addressing because of the better electron mobility and lower leakage current.

Pixel Eyes and AIT follow the same segmented principle as Apple's Vcom. The Vcom layer of IPS and FFS modes is on the TFT backplane glass, but the Vcom layer for the VA mode is on the color-filter glass (bottom side).

For Pixel Eyes' hybrid in-cell, Rx is on the top side of the color-filter glass. While Pixel Eyes is applied on IPS and FFS modes, it uses the Vcom on the TFT backplane so that the entire structure is quite similar to the GG (two pieces of glass) type. For the VA mode, the structure of Pixel Eyes looks like the DITO type (double-sided ITO; both X and Y electrodes are located on the top and bottom sides of the substrate). Regarding the sensor patterning of Pixel Eyes, it requires that Rx be on the top side of the color-filter glass (similar to on-cell touch) and Tx by segmented Vcom.

Consequently, the display production cost of Pixel Eyes should be higher than that of LG's AIT, which has only a single-layer sensor on the TFT backplane. However, Apple's in-cell production cost could be higher still. Although Apple's Tx and Rx are on the same substrate (Vcom on the TFT backplane of the FFS mode), SITO-like patterning and extremely high segmentation make its yield rate lower.

During 2015, we will see in-cell with different structures (Apple's, Pixel Eyes, and AIT) and on-cell (AMOLED and TFT-LCD) competing with add-on types. However, due to the issues and limitations described above, in-cell is limited to smartphone sizes. Bigger displays usually have higher resolution and more channels, so that time sharing and routing become more challenging. Although on-cell can be easier, a single layer is not sensitive enough for 8 in. and above. On-cell based on SITO with at least four photomasks can be applied for notebook-PC sizes. But considering the cost-down trend of the add-on type and sufficient supply chain, larger sizes should be the threshold for embedded types. Consequently, we can expect that embedded-technology makers will focus on the smartphone market for the next 1–2 years. Also, depending on in-cell-touch maturity, panel makers will probably take on-cell as a transitional technology and then adopt in-cell in the future.

Tap-Sensing and Other Pressure Technologies Enhance Touch User Experience

Despite the competition between panel makers and touch-module makers in a time of slowing market demand, the mature user interface of touch screens is not likely to bring many new surprises to end users compared with what has already occurred over the past several years. There is, however, evolution. In April, Apple released the Apple Watch and a new MacBook that use its Force Touch and Taptic Engine technology.

Apple's new trackpad on the MacBook has a glass-based capacitive-touch sensor to detect the positions touched. Force sensors (strain gauge, likely) are located at the four corners beneath to detect tapping, and the Taptic Engine (an electromagnetic mechanism) delivers haptic feedback. The Apple Watch incorporates haptic feedback by using a linear resonant actuator; its Force Touch is a slim sensor around the display. At press time, there were reports that Apple was developing new iPhones that use Force Touch technology.

Tap sensing is designed to enhance the existing user experience of touch and is not an additional input tool. An extra firm or "deep" touch can issue a different type of command than a regular one, for example. Haptic feed-

Table 3: A comparison of Force Touch and active stylus features includes sensing level, purpose, and cost. Source: *IHS Quarterly Touch Panel Market Analysis Report Q1'15*.

Comparison	Apple's Force Touch	Active Stylus (non-projected-capacitive based)
Sensing Level	A few with limited precision	Able to reach 256-2,048 levels
Technology	Strain gauge likely (MacBook)	Active stylus or EMR
Sensing Principle	Mechanical to electronic	Optical shutter or EMR
Input Device	Finger or any object	Specific stylus
Touch Screen	Separate part	Separate (EMR) or combined (N-trig)
Purpose	Enhancement of touch UX	Handwriting and drawing
Uses for Apps	Able to be defined for apps	Limited for writing, drawing or notes
Cost Concern	< $5 (force sensor only), affordable	~$10-15 (sensor or FPC board not included)

back simulates a "click" effect when users press the touch surface. The technology also measures pressure sensitivity (for drawing and similar applications). The idea behind this is that when an end user is touching the device screen, combining specific tap gestures can make the interaction handier and more useful without the need for other tools. For example, while watching a movie, a user can speed up the playback by simply tapping the user interface (such as a MacBook trackpad) without scrolling the controller bar of the GUI.

Previously, Apple had pursued patents related to stylus use. However, Apple seems to have had a different goal than pressure-sensing – Steve Jobs always despised stylus use. And despite pursuing patents, Apple will not necessarily adopt styluses for its products. Tap sensing has replaced pressure sensing as the new attraction. Compared with pressure sensing, tap sensing does not emphasize sophisticated sensing levels and has limited precision for pressure detection. But Apple never simply introduces a hardware feature; it usually considers how to deliver a better user experience. And apparently it considers Force Touch, a milestone that will enhance the existing user experience of touch screens.

Conventionally, pressure sensing is used to describe a user interface that is able to detect the pressure applied. PCAP touch sensors are fluent and capable of detecting the positions of touch but less adept at detecting pressure. The passive stylus used for resistive and PCAP has no pressure sensing.

An active stylus with a specific mechanism can fulfill the requirement of pressure sensing. For example, Wacom EMR (electromagnetic resonance) makes use of the embedded tiny capacitor unit in the stylus to deliver the pressure level along with the touch position. N-trig's solution is to convert the optical hindrance (optical shutter inside the stylus) to pressure level. Both technologies are able to reach higher sensing levels. Wacom's solution, which is used for the Galaxy Note 4, can reach 2,048 levels. N-trig's solution, used for tablet or notebook PCs, can detect from 256 to 1,024 levels.

Apple seems to have no interest in making its iPhone or iPad like the Samsung Galaxy Note series. Table 3 shows a comparison of Force Touch and Active Stylus features.

The combination of touch screen, tap sensing, and haptic feedback is a new milestone for the existing touch-based user interface. Capacitive touch is still critical to detect position, but other technology such as FTIR can improve the tap-sensing experience. Furthermore, the haptic module is adopted to make tap sensing more intuitive, with interactive feedback. Force Touch with haptic feedback makes use of existing mature technologies and does not intend to offer users the ability of handwriting and drawing. Instead, integration of the hardware and software is designed to help end users extend the user experience of touch. It will be interesting to see how end users and the market react to these features in the face of ongoing competition and consolidation. ■

Display Week 2015 Show Daily Highlights

Engineers, developers, investment bankers, analysts, and more all headed to the heart of Silicon Valley last June to visit Display Week 2015. According to show organizers, this year's attendance was up more than 10% over last year's. If you were lucky enough to be one of those attendees, one thing was for sure – there was a lot going on.

by Jenny Donelan

WITH a technical symposium, seminars, short courses, business and marketing conferences, and a three-day exhibition that included the always-popular Innovation Zone, Display Week offered more than one person could possibly see. Fortunately, you did not have to. *Information Display* magazine's crack reporters – Tom Fiske, Steve Sechrist, Geoff Walker, and Ken Werner – were on the job, homing in on specific areas of technology and sharing their discoveries via blogs throughout the show. (They are also writing longer articles that will appear in our September/October post-show issue.)

We think the blogs are one of the best things *Information Display* offers all year, so we decided to share several of them in print – one from a technical seminar, one from a keynote address, one from the exhibition, and one from a market focus conference. If you want to read more, visit www.informationdisplay.org, click on "Blogs and Newsletters," and select 2015 Display Week.

Seminar: How Do You Know How Far Away Something Is?

by Geoff Walker

The question of how you know how far away something is may not grab your attention in everyday life, but it is very important to engineers trying to create perceptually correct 3D displays. Dr. Kurt Akeley from Lytro, Inc., spent the first third of his Monday Seminar, "Stereo 3D, Light Fields, and Perception," on this question.

The answer that is commonly assumed is "binocular depth cues," including vergence (rotation of the eyes toward a fixation point), accommodation (adjustment of the focal length of the lens in the eye to match the fixation distance), retinal disparity (the out-of-focus retinal images of objects closer or further away from the fixation point), and binocular parallax (the difference in the images sensed by each eye).

Everybody automatically uses retinal disparity (also known as stereopsis) as a depth cue without thinking about it. When you look at an object some distance away, the relative blurriness of objects closer and further away gives your vision system a "context" that helps it judge where the object is in space.

Image blur also affects perceived scale. In the left-hand photo in Fig. 1, the city looks normal. However, in the right-hand photo, the background and foreground have been blurred. Since we tend to assume that blurred objects are close to us, the city suddenly looks like a miniature model.

While binocular depth cues are important, and depth-sensing can be achieved using binocular parallax even if all other depth cues are eliminated, there are many other depth cues. Some of these others include retinal image size, texture gradient, lighting, linear perspective, aerial perspective, motion parallax, monocular-movement parallax, and occlusion. You can read about those in the full blog entry, available at http://idmagazinedisplayweek2015.blogspot.com/2015/06/bygeoff-walker-how-do-you-know-how-far.html.

Keynote: Intel Shows Its Vision of the Interactive Future

by Tom Fiske

Intel Corp.'s CEO Brian Krzanich gave a compelling keynote address on the opening day of the exhibition. His thesis: the relentless pace of Moore's law will lead to richer and more engaging interactivity with our devices. RealSense, a collection of sensors and software developed by Intel, enables 3D scanning and sensing of the environment. Krzanich and his colleagues demonstrated face recognition and hand-gesture control, face-to-face interaction for online video gamers and remote meetings, and technology for more efficient warehouse management. He also demonstrated 3D scanning to 3D printing, real-time collaborative remote working with virtual 3D objects, a floating "piano" interface, and augmented-reality interactive gaming on top of a real-world space. All of these can be made possible by enhanced and rich sensing of the ambient environment and the user.

Krzanich delivered the message that we are on the cusp of something new, and I do not doubt it. New and compelling applications will certainly be found that take advantage of these and other emerging capabilities.

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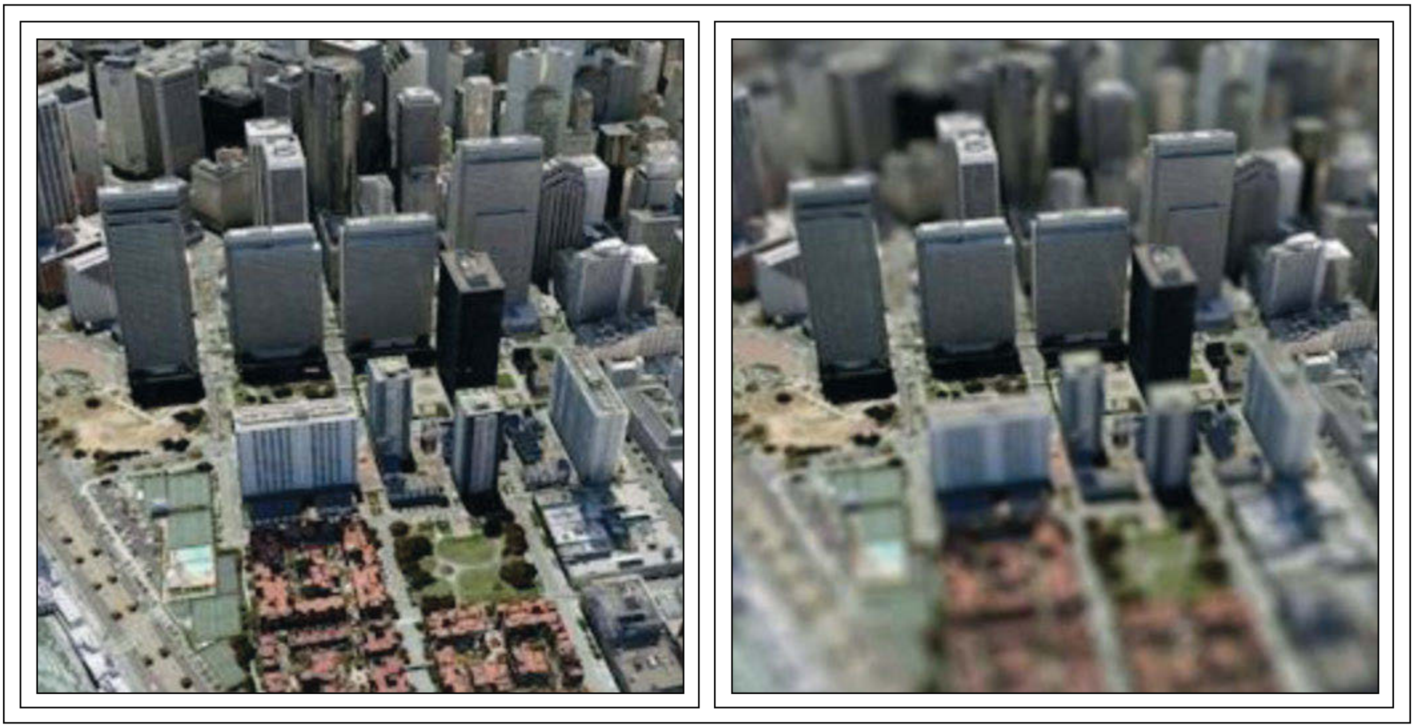

Fig. 1: Image blur affects perceived scale. The left-hand photo shows a regular aerial shot of a city. In the right-hand photo, the background and foreground have been blurred, making the city look like a miniature model. Images from http://graphics.berkeley.edu/papers/Held-MBT-2008-05/VES2008slides_HeldEtal.pdf (Martin Banks et al.*, UC Berkeley).*

Technical developments make these things possible, but we may also need to reveal more of ourselves to gain convenience or capability – such as when we let an application know our physical location in order to use mapping software. Like any technology enhancement, we have to make our own determination as to when the technology adds sufficient value to induce us to part with our dollars – and to give up a bit more of our privacy.

Exhibition: 10K from BOE Debuts at Display Week

by Steve Sechrist

Something special you might have seen at Display Week last June was an impressive 10K display from BOE at the Display Week exhibition (Fig. 2). The 10240 × 4320 pixel display (in 21:9 format) is a "technical development" model that came in a 82-in.-diagonal display. Development engineer Xinxin Mu of BOE told us the panel is a one-off that demonstrates the cutting edge of the high-resolution capabilities of BOE as the company begins looking downstream at the future of both display size and resolution. The panel

Fig. 2: Xinxin Mu (left) and Aly Langfeifei stand next to the 10K display at Display Week.

uses a direct-LED-backlit scheme that is the major reason this behemoth set consumes a whopping 1100 W of power. She also said pixel addressing is done from both top and bottom and uses a standard a-Si backplane.

Even at close-in distance, individual pixels were beyond human visual acuity (at least this human's pair of eyes) and close inspection of the amazing video images (provided by an upscaled NHK source) revealed such minute detail like a single bird discernable in a wide city-view shot, sitting atop the Brandenburg Gate in Berlin or details of the rotating restaurant from a distance shot of the Berlin TV Tower. The images were simply stunning. (This display won a Best in Show award at Display Week.)

BOE PR rep Aly Langfeifei told us the display is meant to underscore just how far China-based fabs (and BOE in particular) have progressed in their technology development. We were also told work is on-going to modify the technology and prepare it for commercial release in the (not too distant) future.

Market Focus Conference: Android Wear Offers Timely Advice to Display Makers

by Ken Werner

On Thursday morning at Display Week, the "Special Wearables Address" in the Market Focus Conference was given by Sidney Chang, Head of Business Development for Android Wear, whose topic was "Android Wear Overview and Google's Wish List." (Chang replaced Fossil CTO Philip Thompson, whose scheduled talk was "Why Wearables with a Display Will Not Succeed with Today's Display Companies." I have been assured that the switch was due to a scheduling conflict and not because Thompson was planning on telling us, quite accurately, that display and computer companies cannot be trusted to design watches!)

Chang's approach was not confrontational, but he had interesting things to say, some of them aimed directly at display makers. The first was that display makers should think very hard about "improving" traditional display parameters if they impact battery life. Although outdoor visibility is essential, it should be done in ways other than cranking up the luminance. The display must always be on, but it does not always have to be on in the same way. Chang described two modes. The "interactive mode" has full animation and full refresh rate. "Ambient mode" has reduced color depth, reduced brightness, and reduced refresh rate for showing basic information, like the time, whenever the user looks. (Pixtronix and Sharp, are you listening?)

Chang specifically discouraged display makers from going to 300 ppi for watch displays. The extra pixel density is not needed for most watch apps, he said, and most watches cannot tolerate the hit on battery life.

Chang showed the results of user studies done by Android Wear. Not surprisingly, users want the thinnest watch they can get. Many women feel that current watches, although arguably appropriate for men's generally larger wrists, are too large for theirs. Average wrist diameters are 17.5 cm for men and 15.0 cm for women. Average wrist breadths are 5.8 cm for men and 5.2 cm for women. When a group of users (presumably both male and female) were asked whether they preferred a watch diameter of 1.0, 1.1, 1.2, or 1.3 in., there was a strong bi-modal preference of 1.0 and 1.2 in. Of these, participants over 40 years old preferred the smaller size, while participants under 40 preferred the larger. (Display makers, do not try to sell 1.5-in. displays to watchmakers!)

A general issue is trying to meld the very different approaches of watchmakers and people from the display and mobile systems communities. Chang noted that watchmakers and watch users prefer choice and variety. In 2014, Fossil had 8000 watch SKUs under 15 different brands. Typical sales for each SKU were thousands to tens of thousands of units. Since Google Wear released its API, the most popular apps have been different watch faces, with one app allowing the user to take a selfie of his or her clothing and then match the color of the watch face to the color of the clothes.

Forging compatibility between the watchmakers' need for variety and the display- and system-makers need for volume will be an ongoing topic of conversation. ■

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SID 2016 honors and awards nominations

On behalf of the SID Honors and Awards Committee (H&AC), I am appealing for your active participation in the nomination of deserving individuals for the various SID honors and awards. The SID Board of Directors, based on recommendations made by the H&AC, grants all the awards. These awards include five major prizes awarded to individuals, not necessarily members of SID, based upon their outstanding achievements. The **Karl Ferdinand Braun prize** is awarded for ***"Outstanding Technical Achievement in, or Contribution to, Display Technology."*** The prize is named in honor of the German physicist and Nobel Laureate Karl Ferdinand Braun who, in 1897, invented the cathode-ray tube (CRT). Scientific and technical achievements that cover either a wide range of display technologies or the fundamental principles of a specific technology are the prime reasons for awarding this prize to a nominee. The **Jan Rajchman prize** is awarded for ***"Outstanding Scientific and Technical Achievement or Research in the Field of Flat-Panel Displays."*** This prize is specifically dedicated to those individuals who have made major contributions to one of the flat-panel-display technologies or, through their research activities, have advanced the state of understanding of one of those technologies. The **Otto Schade prize** is awarded for ***"Outstanding Scientific or Technical Achievement in the Advancement of Functional Performance and/or Image Quality of Information Displays."*** This prize is named in honor of the pioneering RCA engineer Otto Schade, who invented the concept of the Modulation Transfer Function (MTF) and who used it to characterize the entire display system, including the human observer. The advancement for this prize may be achieved in any display technology or display system or may be of a more general or theoretical nature. The scope of eligible advancement is broadly envisioned to encompass the areas of display systems, display electronics, applied vision and display human factors, image processing, and display metrology. The nature of eligible advancements may be in the form of theoretical or mathematical models, algorithms, software, hardware, or innovative methods of display-performance measurement and image-quality characterization. Each of these above-mentioned prizes carries a $2000

SID honors and awards nominations

Nominations are now being solicited from SID members for candidates who qualify for SID Honors and Awards.

- KARL FERDINAND BRAUN PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, display technology.
- JAN RAJCHMAN PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, research on flat-panel displays.
- OTTO SCHADE PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, the advancement of functional performance and/or image quality of information displays.
- SLOTTOW–OWAKI PRIZE. Awarded for outstanding contributions to the education and training of students and professionals in the field of information display.
- LEWIS & BEATRICE WINNER AWARD. Awarded for exceptional and sustained service to SID.
- FELLOW. The membership grade of Fellow is one of unusual professional distinction and is conferred annually upon a SID member of outstanding qualifications and experience as a scientist or engineer in the field of information display who has made widely recognized and significant contribution to the advancement of the display field.
- SPECIAL RECOGNITION AWARDS. Presented to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field. These awards may be made for contributions in one or more of the following categories: (a) outstanding technical accomplishments; (b) outstanding contributions to the literature; (c) outstanding service to the Society; (d) outstanding entrepreneurial accomplishments; and (e) outstanding achievements in education.

Nominations for SID Honors and Awards must include the following information, preferably in the order given below. Nomination Templates and Samples are provided at *www.sid.org/awards/nomination.html.*

1. Name, Present Occupation, Business and Home Address, Phone and Fax Numbers, and SID Grade (Member or Fellow) of Nominee.

2. Award being recommended:
    Jan Rajchman Prize
    Karl Ferdinand Braun Prize
    Otto Schade Prize
    Slottow–Owaki Prize
    Lewis & Beatrice Winner Award
    Fellow*
    Special Recognition Award

*Nominations for election to the Grade of Fellow must be supported in writing by at least five SID members.

3. Proposed Citation. This should not exceed 30 words.

4. Name, Address, Telephone Number, and SID Membership Grade of Nominator.

5. Education and Professional History of Candidate. Include college and/or university degrees, positions and responsibilities of each professional employment.

6. Professional Awards and Other Professional Society Affiliations and Grades of Membership.

7. Specific statement by the nominator concerning the most significant achievement or achievements or outstanding technical leadership that qualifies the candidate for the award. This is the most important consideration for the Honors and Awards committee, and it should be specific (citing references when necessary) and concise.

8. Supportive material. Cite evidence of technical achievements and creativity, such as patents and publications, or other evidence of success and peer recognition. Cite material that specifically supports the citation and statement in (7) above. (Note: the nominee may be asked by the nominator to supply information for his candidacy where this may be useful to establish or complete the list of qualifications).

9. Endorsements. Fellow nominations must be supported by the endorsements indicated in (2) above. Supportive letters of endorser will strengthen the nominations for any award.

E-mail the complete nomination – including all the above material by **October 9, 2015** – to swu@ucf.edu with cc to office@sid.org or by regular mail to:
Shin-Tson Wu, Honors and Awards Chair, Society for Information Display,
1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008, U.S.A.

stipend sponsored by AU Optronics Corp., Sharp Corporation, and Samsung Display, respectively.

The **Slottow–Owaki prize** is awarded for ***"Outstanding Contributions to the Education and Training of Students and Professionals in the Field of Information Display."*** This prize is named in honor of Professor H. Gene Slottow, University of Illinois, an inventor of the plasma display and Professor Kenichi Owaki from the Hiroshima Institute of Technology and an early leader of the pioneering Fujitsu Plasma Display program. The oustanding education and training contributions recognized by this prize is not limited to those of a professor in a formal university, but may also include training given by researchers, engineers, and managers in industry who have done an outstanding job developing information-display professionals. The Slottow–Owaki prize carries a $2000 stipend made possible by a generous gift from Fujitsu, Ltd., and Professor Tsutae Shinoda.

The fifth major SID award, the **Lewis and Beatrice Winner Award,** is awarded for ***"Exceptional and Sustained Service to the Society."*** This award is granted exclusively to those who have worked hard over many years to further the goals of the Society.

The membership grade of **SID Fellow** is one of unusual professional distinction. Each year the SID Board of Directors elects a limited number (up to 0.1% of the membership in that year) of **SID members** in good standing to the grade of **Fellow.** To be eligible, candidates must have been members at the time of nomination for at least 5 years, with the last 3 years consecutive. A candidate for election to Fellow is a member with ***"Outstanding Qualifications and Experience as a Scientist or Engineer in the Field of Information Display who has made Widely Recognized and Significant Contributions to the Advancement of the Display Field"*** over a sustained period of time. SID members practicing in the field recognize the nominee's work as providing significant technical contributions to knowledge in their area(s) of expertise. For this reason, five endorsements from SID members are required to accompany each Fellow nomination. Each Fellow nomination is evaluated by the H&AC, based on a weighted set of five criteria. These criteria and their assigned weights are creativity and patents, 30%; technical accomplishments and publications, 30%; technical leadership, 20%; service to SID, 15%; and other accomplishments, 5%. When submitting a Fellow award nomination, please keep these criteria with their weights in mind.

The **Special Recognition Award** is given annually to a number of individuals (membership in the SID is not required) of the scientific and business community for distinguished and valued contribution in the information-display field. These awards are given for contributions in one or more of the following categories: (a) ***Outstanding Technical Accomplishments,*** (b) ***Outstanding Contributions to the Literature,*** (c) ***Outstanding Service to the Society,*** (d) ***Outstanding Entrepreneurial Accomplishments,*** and (e) ***Outstanding Achievements in Education.*** When evaluating the Special Recognition Award nominations, the H&AC uses a five-level rating scale in each of the above-listed five categories, and these categories have equal weight. Nominators should indicate the category in which a Special Recognition Award nomination is to be considered by the H&AC. More than one category may be indicated. The nomination should, of course, stress accomplishments in the category or categories selected by the nominator.

While an individual nominated for an award or election to Fellow may not submit his/her own nomination, nominators may, if necessary, ask a nominee for information that will be useful in preparing the nomination. The nomination process is relatively simple, but requires that the nominator and perhaps some colleagues devote a little time to preparation of the supporting material that the H&AC needs in order to evaluate each nomination for its merit. It is not necessary to submit a complete publication record with a nomination. Just list the titles of the most significant half a dozen or less papers and patents authored by the nominee, and list the total number of papers and patents he/she has authored.

Determination of the winners for SID honors and awards is a highly selective process. On average, less than 30% of the nominations are selected to receive awards. Some of the major prizes are not awarded every year due to the lack of sufficiently qualified nominees. On the other hand, once a nomination is submitted, it will stay active for three consecutive years and will be considered three times by the H&AC. The nominator of such a nomination may improve the chances of the nomination by submitting additional material for the second or third year that it is considered, but such changes are not required.

Descriptions of each award and the lists of previous award winners can be found at *www.sid.org/Awards/IndividualHonorsandAwards.aspx*. Nomination forms can be downloaded by clicking on "click here" at the bottom of the text box on the above site where you will find Nomination Templates in both MS Word (preferred) and Text formats. Please use the links to find the Sample Nominations, which are useful for composing your nomination since these are the actual successful nominations for some previous SID awards. Nominations should preferably be submitted by e-mail. However, you can also submit nominations by ordinary mail if necessary.

Please note that with each Fellow nomination, only five written endorsements by five SID members are required. These brief endorsements – *a minimum of 2–3 sentences* to a maximum of one-half page in length – *must state why clearly and succinctly, in the opinion of the endorser, the nominee deserves to be elected to a Fellow of the Society. Identical endorsements by two or more endorsers will be automatically rejected* (no form letters, please). Please send these endorsements to me either by e-mail (preferred) or by hardcopy to the address stated in the accompanying text box. Only the Fellow nominations are required to have these endorsements. However, I encourage you to submit at least a few endorsements for all nominations since they will frequently add further support to your nomination.

All 2016 award nominations are to be submitted by October 9, 2015. E-mail your nominations directly to swu@ucf.edu with cc to office@sid.org. If that is not possible, then please send your hardcopy nomination by regular mail.

As I state each year: "In our professional lives, there are few greater rewards than recognition by our peers. For an individual in the field of displays, an award or prize from the SID, which represents his or her peers worldwide, is a most significant, happy, and satisfying experience. In addition, the overall reputation of the society depends on the individuals who are in its 'Hall of Fame.'

When you nominate someone for an award or prize, you are bringing happiness to an individual and his or her family and friends, and you are also benefiting the society as a whole."

Thank you for your nomination in advance.

— Shin-Tson Wu
Chair, SID Honors & Awards Committee

EuroDisplay 2015 Posts Advance Program for Ghent Event

The Advance Program for EuroDisplay 2015, which takes place September 21–23 in Ghent, Belgium, is now available on the EuroDisplay website (www.sideurodisplay.org). EuroDisplay 2015 is run by the Society for Information Display in conjunction with Ghent University and its Centre for Microsystems Technology and Liquid Crystal & Photonics Group.

Featured sessions include Emerging Liquid-Crystal Technologies, Human Interaction, and Quantum Dots, just to name a few. And among many intriguing papers listed in the program are "Eco-Friendly Quantum-Dot Light-Emitting Diode with Inorganic Charge-Transport Layer" from Korea Electronics Technology Institute, Korea University, and the Fraunhofer Institute for Applied Polymer Research; and "Quantifying the Ability of Individuals with Macular Disease to See and Read Content on Virtual and Augmented-Reality Devices," with authors from Heriot-Watt University, Princess Alexandra Eye Pavilion, and the University of Edinburgh.

Keynote speakers at EuroDisplay will include Ian Underwood of the University of Edinburgh, who will speak about the commercial track record and potential of European display research in the global market; Kayvan Mirza from Optinvent, who will discuss wearable displays as the next mobile paradigm; and Nelson Tabiryan of Beam Company, whose topic will be "The Fourth Generation of Optics."

Conference organizers note that EuroDisplay 2015 takes place during the well-known annual musical event, the Festival of Flanders, which is being held in Ghent this year. For this reason, anyone still needing to make room reservations should do so as soon as possible. EuroDisplay also urges attendees to take in some of the many concerts going on during the week. For more information, visit the Festival of Flanders website at http:// www.gentfestival.be/en.

EuroDisplay belongs to the IDRC (International Display Research Conference) series of SID conferences and is slightly more focused on academic research than on product development, as compared to Display Week, for example. For more information about Eurodisplay 2015 visit www.sideurodisplay.org. General Chair Herbert De Smet can be reached at Herbert.DeSmet@elis.UGent.be.

Mark Your Calendar: Vehicle Symposium Is October 22 and23

The 22nd Annual Vehicle Displays and Interfaces Symposium and Exhibition takes place October 22 and 23, 2015, in Dearborn, Michigan. Automotive displays are a hot topic these days and most display designers, engineers, manufacturers, researchers, sales and marketing professionals, and system integrators should consider attending.

The symposium will feature technical presentations by scientists and engineers from the display technology, photonics, vehicle systems, and applications communities. Areas of focus will include the automotive marketplace, display and lighting technologies for vehicular applications, the human–machine interface, application issues, and advanced vehicle-display technologies such as sunlight readability, nanotechnology, and metal oxides. New this year is a $1,000 award to the student with the best oral or poster presentation. A concurrent table-top exhibition will include more than 35 companies from both the automotive and display worlds. For more information, visit www.vehicledisplay.org. ■

editorial

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Our cover story from the University of Glasgow, titled "Electronic Skin with Touch," explores the very real possibility of creating a flexible network of distributed computing and sensing nodes suitable for either augmenting human skin in a wearable topology or creating tactile skin-like pressure and temperature-sensing surfaces for robotics. The iCub robot (shown on the cover) incorporates tactile skin on most of its body parts. Its e-skin was created with off-the shelf electronic/sensing components integrated on flexible printed circuit boards. We can see iCub relaxing in San Francisco, maybe after a day of sight-seeing in and around the Golden Gate Bridge. Clearly, he is using his vacation time well.

From robotics and electronic skin, we move to wearable fabrics, in which the electronics could someday literally be in the fibers of what you wear. In their Frontline Technology article, "Investigating the Architecture of Flexible Large-Area Hybrid Systems," Professor Sigurd Wagner and his colleagues from Princeton University discuss their work to embed transistors in textile fibers and distribute sensors and processing elements throughout fabrics. These then become "wearable" materials that can be utilized for countless new applications.

One of those new applications may be health monitoring, and from the Polytechnic University of Turin we have an Enabling Technology article by Giorgio De Pasquale and Angela Lentini titled "Diagnostic Systems for Pregnancy Healthcare through Telemedicine Networking." Consider this the macro-level view that explores many new methods and paradigms for remote diagnostics and patient health data collection that can be enabled in part by the distributed wearable systems discussed above. We are looking at the dawn of a new era of capabilities in wearable technology that will be realized in some cases within this current decade.

Meanwhile, we also wanted to check up on the touch and interactivity marketplace and so we asked author Calvin Hsieh to give us a Display Marketplace submission titled "Touch Panel Market Dynamics and Trends." Calvin's balanced view combines both a technologist's "wow" with a business analyst's "hmm" and explains how the stiff competition that exists today is not dampening the innovation and creativity that is flourishing in this field. That's good to see today, as I think the marketplace is primed for ever-improving user-interface experiences.

It seems like just a couple weeks ago we were all in San Jose for Display Week 2015. Our extensive coverage of that event is coming up next month in the September/October issue of *ID*, but in the meantime we wanted to highlight some of the most interesting topics featured in our on-line blogs written by the team that covered the show for *ID*. These various short subjects came from the technical seminars, keynotes, and the market focus conferences as well as the exhibits. Don't forget to look for all of our exciting Display Week 2015 coverage coming in the next issue. Meanwhile, I wish you and your families a wonderful summer season and hope that you will take full advantage of the season to relax and rejuvenate. ■

guest editorial

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learn from them. As these devices become smaller and more integrated into our clothing and accessories, we gain convenience but, more importantly, deeper insights into our health. These advances provide opportunities to distinctly alter how rapidly health conditions are diagnosed and how health care is delivered.

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industry news

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second half of this year. AIT is LG's proprietary in-cell touch technology that employs a touch sensor embedded within the LCD panel, replacing the type that uses the touch panel on top of the LCD.

Panels with AIT technology have been introduced for smartphones such as the LG G4, but this is the first time the technology is being applied to larger devices such as notebook PCs. AIT eliminates the space needed for a touch-function cover glass and as a result reduces the panel's thickness by 1 mm (approximately 25%) and its weight by 200 grams (approximately 35%) compared to a conventional 15.6-in. touch-embedded panel with full-HD resolution. It also offers a brighter and clearer screen picture since there is no light loss or light reflection caused by the cover glass. In addition, it features responsive touch and precise calibration of the touch point, even with water drops on the screen.

Goworld/Orient Display Introduces Automotive 8-in. One-Glass P-CAP

Goworld/Orient Display recently announced an 8-in. projected-capacitance touch panel featuring OGS (one-glass solution) construction for improved optical performance and a thinner profile (Fig. 2). It incorporates a highly durable multi-touch and gesture P-CAP design for rugged wide-temperature automotive applications. Features include antiglare and gloved operation. Low reflection is achieved with the addition of a special polarizer plate.

Fig. 2: *Goworld/Orient Display's new P-CAP display for automotive applications features one-glass construction.*

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