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Next-Generation User Interface Technologies for Mobile and Consumer Devices

March 2014

Topics Include:

- Gesture Recognition
- Eye Tracking
- Touch Screens and Haptics
- Speech Recognition
- Vision/Image Processing
- Augmented Reality
- Security Biometrics
- Sensor Fusion & Middleware
- Relevant M&A Transactions
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Next-Generation User Interface Technologies For Mobile/Consumer Devices

Report Overview

Increasingly, the most differentiating features of consumer electronics devices are the user interfaces. Touch screen displays have had a substantial impact on the smartphone market and gesture recognition has played a major role in the gaming industry. New emerging user interface technologies have the potential to significantly affect market share in smartphones, tablets, computers, televisions, and a variety of other electronic devices.

As a result, there has been a significant amount of user interface technology M&A activity, including acquisitions by many of the largest technology companies (e.g., Apple, Google, Intel, Microsoft, Qualcomm, Amazon, etc.). Given the growing importance of these technologies, there may be a robust M&A market in this sector over the next several years.

This report provides a brief overview of a variety of mobile device user interface technologies. In addition to discussing the technologies themselves, the report also summarizes some of the historical M&A transactions in this sector and provides highlights of a variety of relevant private technology companies.

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About the Author

"*Good bankers, like good tea, can only be appreciated when they are in hot water.*"
- Jaffar Hussein (Governor, Malaysian Central Bank)

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Mark Grossman is a managing director at Pagemill Partners. At Pagemill, he has successfully completed more than 35 transactions around the world including M&A deals, divestitures, and strategic capital raises. Previously, Mark worked as an investment banker at SVB Alliant where he was involved in a variety of technology M&A transactions. Prior to becoming an investment banker, Mark was a Managing Director and senior technology research analyst at several Wall Street firms. As an analyst, he wrote research on technology industry trends and covered dozens of public technology companies, and he received a number of accolades including the Wall Street Journal "Best on the Street" award. Mark began his financial career as an Associate at Goldman Sachs. Prior to graduate school, Mark was a Project Engineer at General Electric, where he managed the development of a variety of complex electronics systems. Mark has a bachelor's degree in electrical engineering from Polytechnic University (NYU-Poly), and both a masters' degree (Electrical Engineering) and an MBA from the Massachusetts Institute of Technology, where he completed a two-year dual-degree program. Mark may be reached at mgrossman@pmib.com or +1 650 354 4086.

About Pagemill Partners, a Division of Duff & Phelps Securities, LLC

Pagemill Partners is a premier investment bank focused on successful transactions for middle market technology companies. Pagemill Partners specializes in merger and acquisition advisory services and has successfully completed more than 200 transactions since the beginning of 2005. This includes advising companies in transactions with IBM, Microsoft, Intel, Oracle, Computer Associates, Qualcomm, General Electric, Salesforce, SAP, and many other industry leaders. Pagemill Partners works in close partnership with its clients to help achieve extraordinary outcomes and is able to repeatedly do so through the team's combination of transaction experience, domain expertise, and personal commitment to the success and objectives of its clients and their shareholders. Pagemill's team has collectively completed hundreds of transactions across a wide range of industries, geographies, and strategic circumstances. Pagemill was acquired by Duff & Phelps at the end of 2011 and is now a Division of Duff & Phelps Securities LLC.

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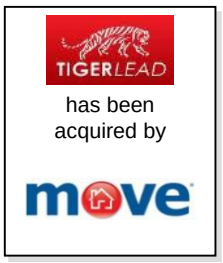
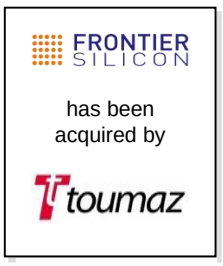
Select Pagemill Partners Tombstones

Select Pagemill Partners Tombstones (cont.)





Chapter 1 – Introduction

"*The last thing one knows – is what to put first*."
- Blaise Pascal

Introduction

In 2007, Apple revolutionized the technology industry with the introduction of the iPhone. While the iPhone had many impressive characteristics, the most differentiating feature was its touch screen user interface which helped catapult Apple into a leadership position within the smartphone market. Apple had previously transformed the computer industry when it introduced the Macintosh in 1984. The most significant feature of the Macintosh was its innovative computer mouse interface, which enabled intuitive "point and click" use rather than having to type in long obscure DOS commands. Nintendo dominated the gaming market in 2007 and 2008 as a result of the Nintendo Wii. The key feature of the Wii was its Wii Remote controller which could detect 3D motions by the user and made games much more interactive. Microsoft subsequently gained significant share in gaming due in large part to its Kinect gesture recognition technology.

As all of these examples indicate, the features that most differentiate electronics products are commonly human-machine interface (HMI) technologies. As form factors continue to shrink (e.g., wearable devices) and become more pervasive (e.g., automobile electronics, smart home), HMI technologies will become increasingly critical. Not surprisingly, there has been growing interest from a variety of major technology companies. For example, Intel Capital created a $100 million fund last year to invest in "perceptual computing" technologies such as 3D image sensors, touch apps, imaging, gesture, voice, emotion sensing, and biometrics. Many of the largest technology companies have already made one or more acquisitions in the HMI space (e.g., Microsoft, Intel, Qualcomm, Amazon, Apple, Google, etc.). While there have already been a number of important acquisitions in this sector, there may be a robust M&A market in this sector over the next several years.

This report provides a brief overview of next-generation user interface technologies that are either currently used in mobile electronics or may be used in the future. This includes gesture recognition, eye tracking, speech recognition, touch screen haptics, vision/image processing, augmented reality, and other biometric sensor technologies. The report also includes a brief overview of interface technologies used for security (e.g., fingerprint sensing, voice authentication, etc.) and sensor fusion.

In addition to providing overviews of each technology, the report also discusses some of the historical M&A activity in each sector and provides descriptions of a variety of innovative private companies addressing next-generation user interface technologies.

A Note on Highlighted Companies

The highlighted companies in this report (most of which are private companies or small non-U.S. based public companies) are not meant to be an all-inclusive list as there are hundreds of start-ups addressing next-generation HMI technology. However, we believe it provides a good sampling of what is out there. Importantly, while we may have had calls or meetings with some of the highlighted companies, we have included only publically-available information. That is, in many cases, these companies may have extremely interesting next-generation solutions or unannounced design wins, but we included only information that is either on their Web site or in published articles.

Report Overview

The chapters in this document include:

- Chapter 2 provides an overview of gesture technologies, in which users can control applications through the movement of their hands, fingers, head, or body.
- Chapter 3 discusses eye tracking, in which a person's gaze can be used to control what is displayed on the screen.
- Chapter 4 describes touch screens as well as touch screen haptic technologies (which help provide tactile feedback when a screen is touched).
- Chapter 5 covers speech recognition and voice assistant technologies.
- Chapter 6 describes security biometric technologies such as fingerprint sensors, voice authentication, facial recognition, and eye recognition.
- Chapter 7 contains an overview of sensor fusion and middleware solutions that utilize the data from a variety of sensors to enhance the user experience.
- Chapter 8 provides an overview of other biometric sensor technologies such as ECG sensors (which monitor the heart), EEG sensors (which monitor brainwaves), and other technologies related to biometric sensors for health/wellness.
- Chapter 9 discusses a variety of other technologies such as augmented reality, vision/image processing, pico-projectors, MEMS auto-focus chips, 3D imaging, and affective computing/emotion analytics.
- Chapter 10 provides some final thoughts.
- The Appendix includes a summary of M&A transactions that are mentioned throughout the rest of the document.

Chapter 2 – Gesture Recognition

"*I have a big problem with conductors who gesture a lot.*"
- James Levine

Introduction

Gesture recognition refers to technologies in which the movement of a person's hands, fingers, head or body can be used to control electronics. In one common implementation, one or more optical sensors capture images of the user and advanced software interprets the images to determine what action (if any) the user is requesting. For example, a TV user might be able to bring a finger to his lips to mute sound or a PC user could scroll by moving her hands up or down. This is generally much more intuitive to users relative to typing on a keyboard, and can significant enhance usability.

The highest profile implementations of gesture recognition have been in gaming. As noted in the Introduction chapter, Nintendo's Wii changed the gaming market with its Wii Remote controllers. Microsoft subsequently rolled out its Kinect technology which enables users to play games and make selections using only hand and body gestures, without holding any type of controller. Gesture recognition has also been implemented in a number of high-end televisions (e.g., LG and Samsung remote controls) and computers (e.g., it is a key highlight of Intel's Ultrabooks). There is also significant interest in implementing gesture recognition in cars, to enable drivers to control certain car features (make selections from the entertainment system, answer a call, etc.) with just a wave of the hand, as that is viewed as much safer than having the driver look down to press buttons on the dashboard.

There are a number of methods to implement gesture recognition. The Wii Remote, for example, included a MEMS accelerometer which could detect user movements – the Wii MotionPlus further improved motion detection by adding a MEMS gyro. However, there is growing interest in implementing gesture recognition vision systems in which optical sensors repeatedly capture images of the user and complex software algorithms are then used to determine what the user's gestures are, without the user having to hold any device.

As with most of the technologies described in this report, it is relatively easy to develop a simple gesture recognition system that works in ideal conditions, but the challenge is to make it robust under a broad range of different circumstances. For example, with vision-based gesture systems, users can be at a variety of distances and angles from the image sensors and have a broad range of different physical characteristics and movements. Additionally, there can be many different types of lighting conditions. Consumers can quickly become frustrated with new technologies when they work only intermittently or when there are latencies, so making these solutions robust is critical but can take many years of development and optimization.

As many devices now incorporate conventional CMOS image sensors (sold by companies such as OmniVision, Aptina, Sony, Samsung, and others), optical gesture recognition can potentially be implemented with no additional hardware costs. However, to improve the performance of optical gesture recognition systems, some solutions utilize more specialized optical imaging sensors. Specifically, optical gesture recognition can generally be made more robust when images are represented in 3D (with a "z" dimension), rather than with conventional 2D representations. For example, with a 2D representation, it may be difficult to determine if a person's hand is moving towards or away from the camera. As a result, a number of solutions have been developed that can capture "3D" images (stereoscopic, time of flight, etc.).

With stereoscopic solutions, two separate image sensors are used to capture the same image but from slightly different locations (a "right" and "left" image). By comparing the two images, software can estimate the distance of objects in the image.

Another approach is referred to as "Time-of-Flight (ToF)." ToF is a type of light detection and ranging (LIDAR) technology. Light (typically invisible infrared light) is emitted and the reflected light from each object in the image is captured by an array of sensors. By calculating the amount of time it takes for the infrared light to complete a round trip, the distance of each object in the image can be determined, enabling a 3D representation of the image. This greatly enhances the ability for accurate gesture recognition, but also adds some additional cost (e.g., LEDs, image sensors that capture infrared light, etc.) relative to 2D solutions. ToF was part of the gesture recognition technology developed by Canesta (acquired by Microsoft).

While vision-based gesture recognition is most common, a number of other gesture recognition technologies have been developed, based on technologies such as ultra-sound and electrical impulses from muscles.

Gesture recognition has been implemented by a variety of major technology companies in a broad range of devices, although the market is still viewed as being in its infancy. Some examples include:

- Microsoft accelerated the market for gesture recognition with the original Kinect accessory product and Kinect is a key part of its newer Xbox One gaming systems. Kinect is sold as part of the base Xbox One system rather than as a separate optional add-on.

- Intel has announced its RealSense 3D cameras which will add depth-sensing to help improve the accuracy of gesture recognition and facial movements.

- At CES 2014, a variety of companies introduced gesture-related remote controls. For example, Samsung announced its new TV Smart Control, which incorporates improved gesture recognition technology (as well as voice interaction).

Select Gesture Recognition M&A Transactions

Some notable acquisitions in the gesture recognition space have included the following. In addition, EETimes just reported that Fairchild Semiconductor acquired Xsens (which developed MEMS-based 3D body tracking products) although neither company has confirmed the acquisition yet.

- **Apple/PrimeSense** – In November 2013, Apple acquired Israeli-based PrimeSense for reportedly about $345 million (per the 451 Group). PrimeSense initially developed 3D sensing software and camera systems utilizing off-the-shelf components, and later developed its own 3D imaging SoC chip as well. The Company was best known for licensing the hardware design and chip used in the original Xbox 360 Kinect motion sensing system. The Company's "light coding" technology uses near-IR light and off-the-shelf image sensors. When reflected off images, the light is distorted based on the distance and this information is used to determine distance.

- **Google/Flutter** – In October 2013, it was reported that Google acquired Flutter, a private start-up which developed a gesture recognition app that worked with conventional Web cameras (requires only downloading the software). Flutter continues to offer its software online. The transaction size was not announced but the 451 Group estimated the valuation at approximately $40 million.

- **Intel/Omek Interactive** – In July 2013, Intel acquired Omek Interactive. Omek was an Israeli company – in Hebrew, Omek means "depth" – focused on the gesture recognition sector. The company developed software for creating a gesture recognition interface based on information provided by a 3-D camera. Intel Capital had been an investor. The transaction valuation was estimated to be approximately $50 million (per the 451 Group).

- **Qualcomm/GestureTek and EPOS** – In July 2011, Qualcomm announced that it acquired certain assets from GestureTek. Qualcomm noted that the technology would be integrated into future versions of its SnapDragon solutions. Qualcomm also acquired ultrasound technologies for stylus and gesture recognition from Israeli-based EPOS Development in September 2012.

- **Microsoft/Canesta and 3DV** – Canesta was a private company that developed CMOS 3D image sensors. Unlike conventional image sensors, Canesta's "time of flight" technology also measured the arrival time of collected photons, enabling the distance of each pixel of the image to be calculated which could then be used to determine the distance of objects from the sensor (essentially LIDAR on a chip). Honda had been an investor in Canesta, as Canesta had been working on using its technology to determine the distance of nearby cars (per a New York Times article) but later focused on video game applications. In October 2010, it was announced that Microsoft was acquiring Canesta. Separately, in 2009, Microsoft reportedly acquired 3DV Systems for about $35 million (per the 451 Group). 3DV had developed 3D motion detection cameras.

Select Private Gesture Recognition Company Overviews

There are numerous private companies focused on gesture recognition. This section highlights a few of them. Some software companies provide a broad range of software for motion sensing/sensor fusion including gesture recognition middleware, but are included in the Sensor Fusion chapter (e.g., Movea provides a broad range of motion-related middleware and has announced a number of gesture recognition partnerships, but we included Movea in the Sensor Fusion chapter). Similarly, there are some vision processing companies that also offer some gesture-related software which are included the Vision Processing section in Chapter 9.

SoftKinetic

SoftKinetic sells a suite of gesture recognition solutions (its DepthSense family) including 3D time-of-flight CMOS image sensor chips, module level cameras that can be embedded into systems, and complete stand-alone cameras. In addition, the company has developed a substantial amount of middleware to enable easy implementation of gesture recognition. Although its IISU ("Interface IS U") middleware is well suited for its own 3D imaging chips and hardware, it is designed to also work with other types of gesture recognition hardware solutions. The SoftKinetic solution can be used for hand, finger, or full body gesture recognition. SoftKinetic's image sensors use ToF technology and measure how long it takes for infrared light to travel from the camera and back, which can then be used to determine the distance to objects captured by the camera.

At CES 2014, SoftKinetic had demonstrations addressing several different end markets including mobile devices, PCs, TVs, and automotive. It announced an in-vehicle gesture-based infotainment solution in partnership with Freescale, using the Freescale i.MX 6 ARM-based processor and SoftKinetic's middleware. SoftKinetic also announced in a 2013 press release that its ToF camera and middleware have been integrated into Nvidia's Tegra NOTE 7 tablet platform. At the 2013 Consumer Electronics Show (CES), TI demonstrated a 3D time-of-flight (ToF) image sensor chipset that integrated SoftKinetic's DepthSense technology and incorporated SoftKinetic's middleware for finger, hand and full-body tracking.

SoftKinetic was founded in 2007 and in 2010 it merged with Optrima (which had been focused on 3D image sensors). The company is based in Brussels, Belgium.

Leap Motion

Leap Motion has developed a peripheral device (Leap Motion Controller) that connects to a PC or Mac computer or notebook via a USB cable and enables hand gesture recognition. The device is relatively small (only about 3" long) and sits on the table in front of a computer. According to the company, its Leap Motion Controller tracks all 10 fingers up to 1/100th of a millimeter, which is much more accurate than traditional motion control technologies. The Leap Motion Controller can track in all three dimensions and at over 200 frames per second. It enables a broad range of gesture related control (flipping through pages by lifting a finger, drawing with a fingertip in the air, shooting with your finger, steering cars with your hands, playing air guitar or drums, sculpting, etc.). The Leap Motion Controller sells for $79.99 on the company's Web site.

Leap Motion also provides an SDK and APIs for developers and its Web site includes a variety of apps specifically for its Leap Controller technology. One of its major investors, Highland Capital, has established a $25 million fund for companies developing technologies based on the Leap Controller. Investors in Leap Motion include Highland Capital, Andreessen Horowitz, Founders Fund, and SoSventures International.

Extremely Reality

Extreme Reality (EXT3D) has developed 3D motion analysis software solutions that work with conventional CMOS image sensors. The company's Extreme Motion technology captures images of people and then creates skeletal models of the people, which are then used to analyze motion. The company believes this core "skeleton positioning technology" enables much more accurate body motion analysis than other conventional body motion tracking solutions. Extreme Reality offers a platform agnostic SDK and has 14 patents granted.

In 2013 Sega Networks released a new video game named Go Dance based on Extreme Reality's technology for the iPhone, iPad and iPod touch that allows players to dance to hit songs and score points based on their moves (while avatars imitating the players dance on screen). Several other games using Extreme Reality's technology have been announced (e.g., Top Smash Tennis, Beat Booster and Pro Riders Snowboard). In addition to gaming, the company indicates that its technologies can be used for security/identification applications. In November, 2013 it announced the completion of a $10 million Series D round. Extreme Reality was founded in 2005 and is based in Herzelia, Israel.

PointGrab

PointGrab provides hand gesture recognition software that utilizes standard 2D cameras, rather than specialized 3D sensors. Its solutions can track hand movements up to about 5 meters, while consuming only a relatively small amount of CPU power. It targets applications such as TVs, PCs, smartphones and tablets, and more recently has also begun targeting home appliances, lighting, and industrial applications.

PointGrab's algorithms can accurately identify the coordinates of a hand (X, Y positioning) which can be used for cursor control. It can identify closing of the hand, which can be used to implement functions such as mouse clicking. It can also track two hands, enabling functions such as zoom and rotate. A variety of other hand gestures can be used (thumbs up, drag and drop, etc.). It currently supports Windows 7 and 8, Linux, and Android.

At CES 2014, PointGrab announced that it partnered with Sunplus to bring gesture control to the home appliances market. Gestures can be used to turn lights on or off or to dim them. Similarly, gestures can be used to turn appliances (e.g., air conditioners, etc.) on or off. PointGrab was founded in 2008. The company is headquartered in Israel with representatives in the U.S., Japan, Taiwan and Korea.

Thalmic Labs

The bulk of gesture recognition technologies are based on optical systems, but we wanted to include at least one non-optical technology company. Thalmic Labs has developed a nine-axis motion sensor armband that can read the electrical signals from muscle movements in the forearm. The armband incorporates a gyroscope, an accelerometer and a magnetometer. As a result, the armband can identify a broad range of bodily gestures as well as the movement parameters of the arm (direction, speed, and angle). The output of these sensors is converted to digital and processed and the resulting commands are sent via Bluetooth to a smartphone or computer. Thalmic is based in Canada and its investors include Salesforce.com CEO Marc Benioff and ATI co-founder Lee Lau.

Chapter 3 – Eye Tracking

"*Beauty is in the eye of the beer holder.*"
- Kinky Friedman

Introduction

Eye tracking involves determining where a person is looking at or the motion of the eye. This can then be used to control what is displayed on the screen or to help make selections. Eye tracking is not a new concept. For example, in the early 1900s a non-intrusive eye tracker was developed that reflected light off of the subject's eyes and recorded the results on film. During the 1950s and 1960s, Alfred Yarbus performed a variety of eye tracking experiments and published the first major book on the subject. Most of the early eye tracking solutions were developed for psychological testing, but during the 1980s and 1990s eye tracking had some limited commercial use for marketing studies and to assist handicapped people with computers. More recently, however, there has been growing interest in utilizing eye tracking technology as an interface for electronic devices, including smart phones, computers, and automotive applications.

Although there are a variety of different eye tracking technologies, most of the solutions addressing consumer applications utilize the optical method in which light (in many cases infrared light) is reflected by the eye and then captured by an image sensor. The images are then analyzed to determine where the user is looking. Because different parts of the eye (cornea, pupil, sclera, etc.) reflect and absorb light differently, the direction of a person's gaze can be determined from the images.

This can then be used to control the location of the cursor/pointer on a display or to control the display in other ways. For example, a user looking at a map on a display could potentially adjust the map in any direction just by looking at the edge of the map, or zoom in just by staring at a certain spot, making it easier to navigate.

While many eye tracking solutions have been developed, the challenge in commercializing the technology is making it work consistently across a broad range of users (e.g., different eye types, some with contacts lens, some with glasses, etc.) in many different environments (e.g., dark rooms, light rooms, etc.) under a variety of circumstances (users in different positions, viewing angles and distances from the screen). In addition, penetrating the consumer market requires a low cost, small form factor with low power consumption. Historically, many of the eye tracking solutions worked well in ideal conditions but had problems in real world situations.

While eye tracking solutions vary, they often include: a light source (it is possible to rely on conventional lighting, but many solutions use one or more LED lights, and often infrared LED sources are used as infrared light is not visible to the human eye); an image sensor (in some cases a traditional CMOS image sensor and in other cases an infrared image sensor to improve performance); a processor (in some cases the main processor is relied on to handle the analytical processing, but some solutions have a dedicated chip for this); and software (which analyzes the captured images to determine where the user is looking and provides an interface to various applications).

There are certain apps for which simply gazing at a particular point can cause the application to take action. For example, a mapping program could scroll up, down, left or right if the user stares at certain spots on the edges of the map for a period of time. However, a general limitation of eye tracking is that in many cases it still requires using some other method to "click"/select the item that the user is gazing at (i.e., using gaze, a user can move the screen pointer to a specific menu item on the screen, but then must hold his gaze while he presses a key on the keypad or uses his voice to select it). Making selections based solely on gaze is challenging since it can lead to inadvertent selections as the user examines his choices. Blinking has been explored as a way to make selections (stare at a point and then blink for a period of time to select) but that is also challenging to implement since people naturally blink every few seconds.

Eye tracking is still early stage with respect to commercial adoption in high volume consumer devices, but there appears to be interest in it. At CES 2014, there were several different eye tracking companies.

Eye Tracking M&A

In 2011, TandemLaunch (an accelerator/incubator for tech companies) acquired Mirametrix, a private company that developed eye tracking technologies and solutions. However, there has not yet been much M&A activity in the consumer eye tracking sector.

Select Eye Tracking Companies

The following are brief overviews of some privately-held eye tracking companies:

Tobii
Tobii has developed a number of eye tracking solutions. Its products incorporate near-IR microprojectors, optical sensors, and image processing software to determine the location a person is looking at. The company's solutions have been used for research and to help people with disabilities, but Tobii is now focused on high volume consumer applications.

Tobii sells a complete add-on solution that incorporates all of the required hardware and analytical software. The technology takes care of the user interface and enables users to scroll and zoom, and navigate through menus using eye tracking. Tobii EyeX Engine is available for Windows and is optimized for Windows 8, with porting to other operating systems expected in the future. In January 2014, Tobii announced it was teaming up with SteelSeries to launch the first mass-market consumer eye tracking devices for gamers. Tobii is based in Norway with offices in the U.S., Germany, Japan, and China. Its investors include Intel Capital, Northzone, Investor Growth Capital, and Amadeus.

The Eye Tribe
The Eye Tribe is an eye tracking firm focused on mobile devices. The Eye Tribe software enables eye control on mobile devices, allowing hands-free navigation of websites and apps, including eye activated login, enhanced gaming experiences, and cloud-based user engagement analytics. At CES 2014, the company introduced a $99 eye tracking peripheral that can easily attach to a computer, notebook, or tablet via a USB cable. The company was founded by four PhDs from the University of Copenhagen. The Eye Tribe is based in Denmark.

SensoMotoric Instruments (SMI)
SensoMotoric Instruments (SMI) was founded in 1991 and has developed a variety of computer vision products including eye tracking peripherals and glasses. The company was historically focused on applications such as medical, psychology and market research and indicates that 6,000 of its eye tracking systems are in operation. However, more recently it has introduced solutions for the consumer markets and announced its "SMI RED-n" consumer eye control technology for gaming and computing at CES 2014. The company also announced that Sony Labs is using its technology to test eye tracking for the PS4. SMI is based in Germany.

Chapter 4 – Touch Screens / Haptics

"*Touch is the mother of the senses.*"
- Helen Fisher

Introduction

Apple revolutionized the smartphone industry when it introduced the iPhone. Although the iPhone had many innovations, the touch screen was one of the most differentiating features. While basic touch screens had been used for decades, Apple was first to optimize the touch screen interface to make it easy to use and cost effective. As a result, virtually all smart phones and tablets now incorporate a touch screen, and an increasing number of notebook PCs and other devices have touch displays.

There are a variety of different types of touch screen technologies. A brief overview of the general mainstream touch displays include:

- **Capacitive** – Capacitive touchscreens take advantage of the fact that the human body is an electrical conductor. A capacitive touchscreen typically includes an insulator (e.g., glass) and a transparent conductive layer such as indium tin oxide (ITO). When a finger touches the screen it distorts the screen's electrostatic field and causes a change in capacitance which can be measured to determine the finger's location.

  There are actually a variety of different types of capacitive touch technologies. The most common general type for high-end portable devices (smart phones, tablets, etc.) is mutual projective capacitance in which there is a matrix of rows and columns with a capacitor at each intersection. A voltage is applied to the rows and columns and when a finger touches the screen, the local electrostatic field changes, reducing the mutual capacitance, which can be measured to determine the location at which the screen was touched. A major advantage of this approach is that it enables multi-touch (it can recognize multiple fingers) which is critical for many features that consumers are now used to (zooming in and out using two fingers, etc.). Many other capacitive technologies and a variety of non-capacitive touch technologies can recognize only one touch at a time, which is a limitation.

  One disadvantage of capacitive is that it doesn't work if a person is wearing gloves or with an ordinary stylus/pen (although special pens have been developed that can be used). Most of the major high-profile touch devices (iPhone, iPad, Samsung Galaxy, etc.) utilize capacitive touch technology.

- **Resistive** – The general principle behind resistive touch screens is that there are two thin transparent layers coated with transparent conductive material (the outer layer covered on the back, the inner layer coated on the front) separated by a small gap. When the outer screen is pressed, the two layers touch, completing an electrical circuit and creating a voltage divider. Based on the resistance of the materials and measured voltages, the location of a touch can be determined. Resistive touchscreens are relatively low cost and work well with a stylus (especially good for handwriting recognition) or when a user is wearing gloves. However, it generally doesn't support multi-touch well and isn't as sensitive as capacitive touch since the user has to press down on the screen. As a result, while there have been a number of phones with resistive touchscreens, most high-end mobile devices generally utilize capacitive touch, although resistive is common in other markets (such as ATM machines).

- **Other (Infrared, Ultrasound, etc.)** – Over the years, many different types of touch screen technologies have been developed. Some examples include infrared (IR LEDs and photodetectors are placed around the edge of the display and can detect if a finger or object touches the screen), ultrasound/surface acoustic wave (ultrasonic waves pass over the surface of the display, and when the display is touched some of the wave is absorbed), infrared projection (a transparent sheet is illuminated with infrared light and "leaks" light when the user touches the screen), optical imaging (image sensors around the edge of the screen capture shadows to pinpoint the location of each touch), dispersive (detects the piezoelectricity in the glass due to touch, which can be used to pinpoint the touch location), and acoustic pulse (a touch generates a sound wave and sound transducers are used to determine the position of the touch).

Although a variety of new touch technologies have been developed as potential alternatives to capacitive touch, capacitive works very well, is robust, can implement multi-touch, and costs have been driven down with volume. As a result, displacing this technology in devices such as smart phones and tablets is challenging. However, as touch technology becomes increasingly pervasive in a variety of products, there are a growing number of different applications for touch screens, providing a number of opportunities for other touch technologies (e.g., the capacitive technology used in smart phones and tablets generally doesn't scale well to large size screens, many applications don't require multi-touch, etc.).

Some of the major suppliers of capacitive touch screen controller chips include Atmel, Cypress, and Synaptics. There are a number of other controller chip companies in the market including several Korean companies (e.g., Melfas, Zinitix, Imagis Technology) and several Taiwanese players (YoungFast, etc.). Some of the major suppliers of complete touch screen modules include TPK, Nissha, Wintek, Panjit, and 3M.

Touch Screen Technology M&A

The following are a few touch screen related M&A transactions. There have also been a variety of display related acquisitions (e.g., Amazon acquired Liquavista from Samsung, which had previously acquired Liquavista), but we include only touch-related deals.

- **Microsoft/Perceptive Pixel** – In July 2012, Microsoft acquired Perceptive Pixel. Perceptive had developed very large screen multi-touch displays. Apparently, Steve Ballmer had been using a Perceptive Pixel display in his office. Microsoft indicated that they are looking for ways to drive the cost of the technology down.

- **TPK/MasTouch and Cando** – TPK has been the largest touch screen module supplier and has made a number of acquisitions. It acquired a majority of the shares of MasTouch Optoelectronics (a controller chip company). In 2011, it acquired a just-under 20% stake in Cando for about $193 million (per Capital IQ). Cando is one of TPK's major touch sensor suppliers and is a subsidiary of AU Optronics.

- **Gores/TE Connectivity EloTouch Products** – In 2012, private equity firm Gores Group acquired the touch screen solutions business from TE Connectivity for $380 million, or slightly less than 1X revenue (per Capital IQ). The business provided a range of different types of touch screen technologies.

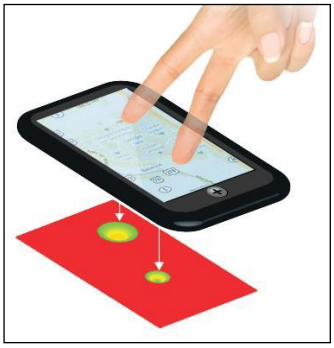
Select Touch Screen Technology Companies

A small public company that has been focused primarily on alternative touch screen technologies is Neonode. Neonode's zForce is based on infrared technology in which infrared light is projected over the surface of the screen, and photodetectors measure the light patterns. When a finger or stylus touches the screen, it interferes with the infrared light and based on the measurement of the light and advanced algorithms, the location of the object or finger can be determined. The technology doesn't require additional screen layers, works with a stylus or gloved fingers, and doesn't require force on the display. The company has leveraged its core technology to also implement proximity sensing, such that the device can detect finger or object movements that are around the outside of the device rather than just on the screen. Neonode had an IPO in September 2013.

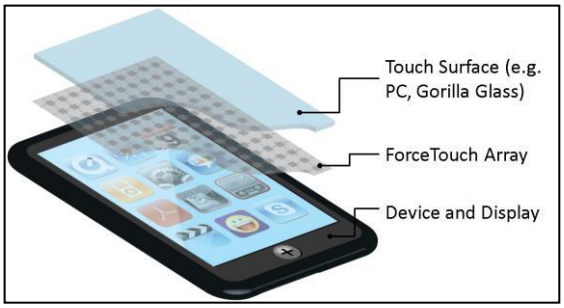
There are a number of start-up companies that have developed alternative technologies to the capacitive touch sensing technologies commonly used in current smartphones. In some cases, their focus is either large screen markets such as television or large PC displays (as capacitive doesn't scale to larger sizes well) or on smaller screens such as wearables (in which multi-touch isn't critical). In other cases, the technology provides certain features or advantages that conventional capacitive screens do not provide. Some examples are below.

NextInput

NextInput has developed a force sensitive touch surface technology (ForceTouch). In addition to being able to determine the location of a touch, its technology also can determine the amount of force applied by a finger or stylus. This enables a variety of new ways to control applications. That is, a light touch can be interpreted differently from a stronger touch, which can greatly expand the number of potential control gestures. Adding force makes interaction much more intuitive in many cases. It can also enhance many applications (e.g., gaming).



The ForceTouch Array is a MEMS sensor layer below the surface of the display, so it doesn't affect the optical clarity of the display. NextInput indicates that its technology is substantially less costly (in volume) and consumes about half the power of capacitive touch, and that it can work with a stylus, and in virtually any environment (high EMI location, underwater, etc.). The company's Web site indicates that it plans to begin commercializing its technology in 2014. NextInput is based in Atlanta.



FlatFrog

FlatFrog has developed a touch display technology (Planar Scatter Detection) in which infrared light is injected into a transparent screen (plastic, glass, etc.) and is detected at the other end. The light travels through the material via total internal reflection, but when a finger touches the surface, it causes a disturbance to the light which is detected. Using advanced signal processing, the location of the touch can be determined. FlatFrog indicates that its technology supports multi-touch and that it is less costly than capacitive, especially for larger displays since capacitive requires a large increase in sensors as display size increases. Its technology can also be used to detect pressure since the amount of pressure impacts how much light escapes from the medium. FlatFrog has developed a 32" touch table incorporating its technology which it sells but which also provides a demonstration of its solution.

In 2013, FlatFrog announced a partnership with Dialog Semiconductor, in which Dialog developed a Smartwave multi-touch IC which was specifically optimized for FlatFrog's technology. Subsequently, Dialog announced that its first customer for the new chip was Wistron, which had developed a 23" touch module targeting all-in-one PCs and monitors. FlatFrog is privately held with headquarters in Lund, Sweden (near Copenhagen). Its investors include Intel Capital as well as Invus, Sunstone Capital, and Fårö Capital.

New Touch Display Materials

The vast majority of touch screens (including both capacitive and resistive) utilize indium tin oxide (ITO) as a transparent conductor. Indium is actually a relatively rare and expensive material so there have been a number of companies that have tried to develop lower cost alternatives. Another reason there is interest in alternative transparent conductive materials is to improve the performance of touch displays and to help make them less fragile and more flexible. An example of a company that has developed an alternative to ITO is Cambrios Technologies, which is discussed briefly below.

Select Touch Screen Material Company

Cambrios Technologies

Cambrios Technologies has invented a new transparent coating material (ClearOhm), based on silver nanowires, that has a number of advantages relative to ITO. Because silver conducts very well, ClearOhm has very low resistance/high conductivity which helps improve electrical performance. In addition, the material is highly flexible and less prone to breaking than ITO. It can be used on glass (e.g., Gorilla glass) as well as plastic or OLED displays, and can scale to large size displays. Lastly, Cambrios indicates that in high volumes ClearOhm can be substantially less expensive to produce than ITO. As a result, Cambrios believes its solution will be an important part of next-generation touch technologies across a variety of displays. In addition to mobile device touch screens, Cambrios' technology has applications for solar and automotive heads up displays.

Cambrios has announced partnerships with a broad range of companies in the touch screen supply chain including Nissha Printing, Sumitomo, Chisso, TPK, Okura, and Shin-Etsu. In October 2013, Cambrios announced a joint venture with TPK and Nissha to help accelerate the adoption of ClearOhm into the market place.

After many years of development, Cambrios has begun commercializing the technology. In late 2012, Cambrios announced that LG would incorporate ClearOhm into 23" touch panels, and in October 2013 it announced ClearOhm would be used for a Lenovo 20" all-in-one end product (Lenovo Flex 20). At CES 2014, Cambrios demonstrated a number of handsets from other brands utilizing ClearOhm. It also announced that its manufacturing capacity tripled in 2013. Cambrios is based in Silicon Valley and its investors include several strategic parties (including Samsung) as well as a number of VCs including, ARCH Venture Partners, Alloy Ventures, and others.

Touch Screen Haptics

One limitation of traditional touch screens is the lack of any tactile sensation when touching the screen. For example, many people find it difficult to type more than short messages on a touch screen keyboard since you can't feel the buttons, which is why there is demand for tablet keyboards and why many people still use notebook PCs rather than tablets. However, there is growing interest in technologies that will change that.

Haptics technology involves providing tactile feedback to users to improve the user's experience. Haptic technologies have been used in a variety of applications. For example, there have been a number of game controllers/joysticks that include haptics, such that the controller vibrates in certain gaming situations to make the game seem more realistic. The most basic use of haptics in handsets is for "vibration mode" in which the phone vibrates when a call is received. Haptic technologies, however, are increasingly being incorporated into touch screens in order to improve the user experience and provide feedback when the display is touched.

The most common method for implementing haptics on a display is through the use of actuators. One or more small actuators are incorporated under or on the side of the screen. When the user touches the screen, the actuator can be turned on by the app or operating system, which causes the display to vibrate and provides tactile feedback.

Depending on where the actuators are placed, the types of actuators used, the frequency that they operate at, and the number of actuators used, a variety of different effects can be created. For example, when a user touches a specific spot on the screen (e.g., a letter on a QWERTY keyboard), it can be made to feel like that particular spot is providing tactile feedback. The goal with high quality haptics solutions is to give the impression to the user that he is touching actual physical keys, even though the display remains flat.

In addition to typing, haptics can greatly improve the user experience in a variety of other applications such as gaming. In general, the greater the number of actuators used and the more complex the actuators (wider frequency range, ability to implement complex waveforms, etc.), the more realistic the haptic experience can be, but that also results in higher cost and greater space requirements.

An August 2013 press release from Lux Research indicated that they are projecting that the haptics market will grow from $842 million in 2012 to $13.8 billion in 2025, and that 89% of the market in 2025 will be for consumer electronics devices. Research firm Markets and Markets announced in April 2013 that its report "Haptic Technology Market for Touchscreen" projects that the haptics market will grow at a CAGR of 41% from 2013 to 2018 and exceed $51 billion in 2018.

The largest nearly pure play haptics technology company is Immersion Corporation, which is a publically listed company. Immersion has developed a variety of haptics technologies that it licenses to other companies. According to Immersion's February Investor Presentation, 66% of its revenue in 2013 came from mobile devices, but it also addresses automotive, gaming, and medical markets. Immersion has over 1,400 patents, most of which are related to haptics. It offers a variety of different haptic solutions, including single actuator, multi-actuator, and high-fidelity actuator solutions. It also provides software and effect libraries to help developers create desired haptic effects.

In early 2013, Apple was awarded a patent for a haptic feedback system that is optimized for multi-touch surfaces ("Method and apparatus for localization of haptic feedback"). The patent involves using two actuators in which one actuator provides feedback to the user and the other creates a vibration to suppress the first to prevent it from propagating to the rest of the screen, resulting in localized haptic feedback.

Select Haptics M&A Transaction

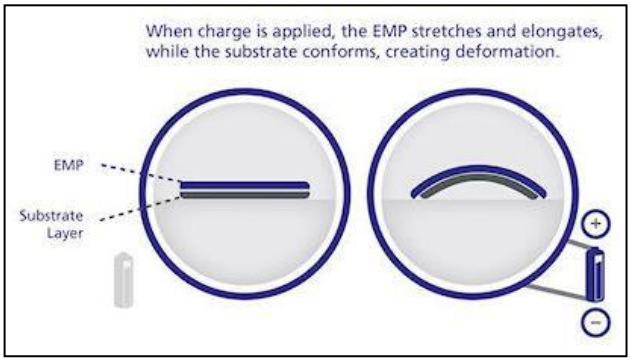
A notable haptics acquisition was the following:

- **Bayer MaterialScience/Artificial Muscle** – Artificial Muscle was spun out of SRI International in 2004 to commercialize its Electroactive Polymer Artificial Muscle technology. Artificial Muscle was focused on haptics for mobile devices. EAP technology consists of a thin layer of dielectric polymer film sandwiched between compliant electrodes. When voltage is applied across the electrodes, the electrodes attract each other. As a result, the film contracts in thickness and expands in area, which can be used to create haptic effects. In 2010, Artificial Muscle was acquired by Bayer MaterialScience.

Select Private Haptics Related Companies

A number of start-ups have addressed the haptics market. The following describes three of these companies.

Novasentis



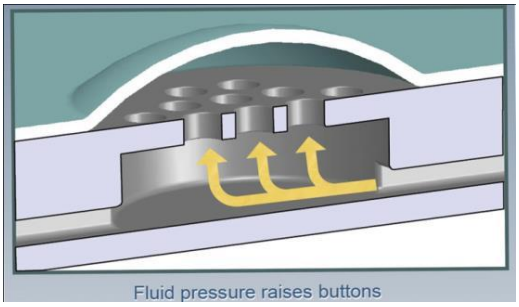
Novasentis (previously Strategic Polymer Sciences, Inc.) has developed a unique and innovative actuator/sensor based on electrical-mechanical polymers (EMP) related to a new class of ferroelectric materials. The EMP material is ultra-thin, light and flexible and elongates when an electric field is applied and produces electric charge when it is deformed due to pressure (from a finger) and can, therefore, act as both an actuator and a sensor. With digital control, the actuators can produce precise localized vibrations (the frequency of which can be varied), sounds, or deformation. It can also be used as a sensor to recognize touch/pressure.

Leveraging this core technology, Novasentis has developed its Clic family of ultrathin (<120 microns) haptic actuators. The company has also introduced as a demonstration product its Awake ultra-thin keyboard (about the thickness of a business card) that incorporates haptics (can produce a variety of vibrations and sound effects when a key is touched). It is designed to replace conventional keyboards. According to the company, Novasentis has a variety of next-generation solutions in development that it believes have the potential to have a significant impact on the haptic market.

Novasentis was founded in 2006 by former Apple executive Ralph Russo and the inventor of the EMP technology Dr. Qiming Zhang. Dr. Christophe Ramstein (previously CTO at Immersion Corporation) was hired as CEO in 2012 and Novasentis expanded its patent portfolio and focused on commercialization. In November 2013, Novasentis announced it raised an $8 million Series B round that included new investor Samsung Ventures and previous investor Chengwei Capital. The company is based in Burlingame, California and has offices in Pennsylvania, Korea, and Japan.

Tactus Technology

Tactus has developed a unique technology based on microfluidics that can create transparent physical buttons on a touch screen surface on demand. For example, when a user wants to type on a keyboard, physical keyboard buttons rise from the surface enabling users to feel the keyboard buttons as they type (eliminating one of the main complaints regarding touch screen typing). Unlike traditional haptics solutions that try to give the illusion that there are physical buttons, the Tactus solution actually creates temporary physical buttons on the screen. In addition to the advantages of "tactile feel," the Tactus solution also enables finger resting (some pressure on the buttons is required to type a key). When the user doesn't want to use the keyboard, the physical buttons recede into the screen leaving a flat smooth screen. While keyboards are the most obvious use for the technology, the technology can create buttons (of virtually any shape) anywhere on the screen which can be used for a variety of other applications (e.g., games, etc.).


Fluid pressure raises buttons

The underlying technology is based on microfluidics. Small transparent fluid channels are routed throughout the "Tactile Layer" and the fluid can expand the polymer layer above it to create physical buttons. A small controller chip is used to control the fluid channels and create or recede buttons. An API is provided to enable applications to control where and when buttons are created.

The Tactus solution is designed to integrate with capacitive touch screens, with the Tactile layer replacing the cover lens (top-most layer). Tactus has demonstrated its solution in a number of tablet form factors.

In January 2014, Tactus announced that it closed the first portion of its Series B funding, which included new investor Ryoyo Electric Corporation and previous investor Thomvest Ventures, as well as other unnamed corporate investors. Tactus noted that it has 17 granted patents and more than 45 patent applications. Tactus is based in Fremont, CA.

Redux Labs

Redux Labs has developed haptic (Surface Sensation) and speakerless audio technologies (Surface Sound) for smartphones, tablets, PCs, automotive, and other applications. Its solutions are based on its patented “bending wave” technology that controls sub-sonic and sonic waves across a flat or curved surface.

Its Surface Sensation haptic solutions deliver a customizable haptic effect to a specific coordinate on the screen and include transducers (piezoelectric transducers for small form factor devices and voice coil exciters for larger form factors), control modules or chips, and algorithms for implementing its bending wave technology. Its haptic technology can deliver feedback at very specific points anywhere on the display.

Because the transducers can manipulate waves, the glass of a smartphone, tablet or TV screen can also be transformed into a surround sound loudspeaker (its speakerless “Surface Sound” audio technology). At CES 2014, Redux demonstrated its OnScreen platform, a flat screen audio OEM technology for TVs that enables manufacturers to deliver high quality audio out of the box, without speakers in the TV bezel or a soundbar. The company has also introduced its Surface Wear audio technology for sports, gaming and augmented reality glasses.

The Redux Web site indicates that it has exclusive rights to exploit over 300 granted patents in bending wave technology with over 100 additional patent applications filed. The company is based in Cambridgeshire, England (a few miles from Cambridge).

Chapter 5 – Speech Recognition

"*She had lost the art of conversation but not, unfortunately, the power of speech.*"
- George Bernard Shaw

Introduction

Voice is a natural interface technology that has become increasingly common in electronics devices. Speech recognition has been around for many years. At the 1962 World's Fair, for example, IBM demonstrated a system that could understand 16 words, and in the 1970s a system developed by Carnegie Mellon University could recognize more than 1,000 words. However, most of the early speech recognition systems required saying each word slowly one at a time. By the 1990s, consumer speech recognition programs became available (e.g., Dragon), although they were fairly expensive and required a significant amount of set-up time as users had to repeat words multiple times to "train" the software. With significant improvements in processing power and algorithms, speech recognition has dramatically improved during the past decade and has been incorporated into a variety of devices.

For many devices, speech recognition is used for simple commands (e.g., providing an address to a navigation system, calling a cell phone number by saying the number or the name of the person, changing the station on a TV, etc.). However, with Apple's introduction of the Siri personal assistant, speech has become a full-fledged interface technology that allows users to control and interact with mobile devices. Accomplishing this requires not only translating speech into words (basic speech-to-text technology), but also advanced natural language query technologies that are capable of piecing the words together into sentences/commands and then "understanding" what the user is asking for. This is much more complex as languages and grammar rules are complicated, words can have a variety of meanings depending on the context, and users can ask questions or give commands in a variety of different ways.

As mobile products shrink in size (such as wearable devices), speech recognition is expected to become an even more common interface, as it doesn't require a keyboard or large screen. For example, speech recognition is included in both Google Glass and the Samsung Galaxy Gear watch.

A number of the major technology companies have developed speech recognition technologies (Apple Siri, Google Now, Samsung S Voice, etc.) and many mobile devices incorporate some type of speech technology to varying degrees. A public company that is primarily focused on speech recognition related solutions is Nuance Communications which sells a broad range of different types of speech recognition products for a wide range of different end markets.

One area of focus for improving speech recognition is that many of the existing speech recognition systems compress the user's speech and send it over the network to dedicated servers that do the analysis needed to translate and understand the speech, and the results are then sent back over the network to the device. This, however, causes some latency issues and doesn't work if the device does not have network access. As a result, one emerging approach is to perform the analysis in the device, but this requires utilizing significant processing power. Intel, for example, recently announced (in partnership with an unnamed voice recognition software company) a solution to power speech recognition locally in the device. Intel indicated it would implement the technology in its upcoming "Jarvis" headset.

There is also interest in combining speech recognition with noise reduction/voice enhancement technologies to further optimize performance. That is, users increasingly speak at a distance from devices and often in noisy environments. For the speech recognition to work, the device must be able to extract the voice commands from the background noise. By combining speech recognition with voice enhancement technologies, the overall performance of voice-based assistants can be improved.

Another focus area is to continue to improve the natural language query technology. While Siri, Google Now, and other speech-related solutions have become much better at understanding and responding to simple commands and questions, they are still a long way from being able to have a real conversation and understand more complex questions or commands. This is likely an area that will continue to significantly improve for decades to come, as there is still enormous room for further improvement.

Select M&A Speech Recognition Transactions

Unlike many of the other technologies discussed in this document in which there were only a handful of M&A transactions, there have been a large number of speech technology related transactions during the past couple of decades. Nuance Communications alone has acquired more than 40 companies since 2005 when it was formed by the merger of Nuance and Scan Soft (and Scan Soft had acquired many companies before that), and a large portion of those acquisitions were speech-related. (Pagemill alone has completed 9 transactions with Nuance).

Below are a small handful of the many speech/natural language related M&A transactions in recent years. We mention only those related to the consumer markets, as there have also been many acquisitions of companies focused on speech recognition for business, medical, and call center type applications.

- **Yahoo/SkyPhrase** – In December 2013, Yahoo acquired SkyPhrase (per the 451 Group), a start-up that had been focused on building solutions that better understand natural language. This core technology can improve speech recognition systems by providing a better understanding of what the user is asking for.

- **Intel/Indisys** – In September 2013, Intel acquired Indisys for reportedly more than $26 million (per the 451 Group). Indisys was a Spanish company focused on natural language recognition technologies.

- **Facebook/Mobile Technologies (Jibbigo)** – In August 2013, Facebook acquired Mobile Technologies (doing business as Jibbigo), a speech recognition and machine translation app company. The app enables users to text or record voice content in over 25 languages that is then translated on screen or read in another language (per the 451 Group).

- **Google/SR Tech Group Patents, SayNow, Phonetic Arts** – In July 2013, Google acquired a speech-related patent portfolio from SR Tech Group LLC (including a patent for "Speech interface for search engines"). In January 2011, Google acquired SayNow which had been viewed as a Google Voice competitor. In December 2010, Google acquired Phonetic Arts which had developed advanced speech synthesis (text-to-speech) technologies (per the 451 Group).

- **Amazon/Evi, Ivona, and Yap** – Amazon has made several acquisitions in the speech technology area. In April 2013, Amazon reportedly acquired Evi Technologies for $26 million (per the 451 Group). Evi's True Knowledge Answer Engine attempts to understand questions by analyzing its database of facts, and it can be used for general search as well as voice interactions. Amazon also reportedly acquired Ivona Software (multi-lingual speech synthesis system) in early 2013, and Yap (voice to text) in November 2011.

- **Apple/Siri** – In April 2010, Apple acquired Siri. Siri was initially available as an app in the App Store, but Apple later incorporated the Siri Assistant into the iPhone 4S in October 2011. The transaction price was not announced, but reportedly the valuation was about $200 million (per the 451 Group).

- **Nuance Communications/SVOX, Vlingo, Loquendo, and Many, Many Others** – As previously noted, Nuance has acquired more than 40 companies since 2005, many of which had speech recognition technologies. A few recent examples include: SVOX for about $123 million ($81 million upfront, $42 million deferred), Vlingo for $196 million (excluding the equity interest that Nuance already owned), Loquendo for $75 million, and Ditech Networks for $23 million (per 10K reports, Capital IQ and the 451 Group). Pagemill was an advisor on the SVOX transaction.

In addition to these speech-specific M&A transactions, there have been a number of artificial intelligence and natural language query acquisitions that while not specifically focused on voice/speech could potentially be utilized to enhance speech interfaces. For example, Google recently acquired DeepMind (an artificial intelligence company) for reportedly more than $400 million and had previously acquired Wavii (a natural language technology processing start-up focused on news summaries) for reportedly about $30 million (per the 451 Group). Although neither was specifically a speech technology company, it is believed that these types of technologies could be used to further enhance the ability of devices to understand user queries and commands.

Select Private Speech Recognition/Voice Enhancement Companies

During the past decade, a large number of speech recognition companies have been acquired. Many of them were acquired by Nuance, although there have been others (OnMobile acquired Telisma, etc.). However, there are still a number of interesting start-ups in the sector. Highlighted below is one company focused on speech recognition and another focused on voice enhancement technologies to help improve voice recognition.

NovoSpeech

NovoSpeech is an early stage Israeli company focused on speech recognition for mobile devices. The company indicates that it examined the bottlenecks in existing speech solutions and developed a number of unique technologies that enable a high level of accuracy even in noisy environments. The company indicates that its solutions require relatively little processing power such that it can be implemented on-device without requiring access to the cloud, resulting in less latency and the ability to work even if the device does not have network access. The company initially introduced products with limited vocabulary requirements for embedded applications (Pulsar1000) and mobile devices (Quasar1000), but its main focus has been in developing its Speech++ large vocabulary (100K+ words) solution for mobile devices. NovoSpeech announced a paid pilot program with Vocollect Healthcare in mid-2013.

Malaspina Labs

Malaspina Labs has developed advanced audio processing technologies that improve speech comprehension in noisy environments. With hands-free calls, video conferencing, speech recognition interfaces (e.g., Siri, etc.), and speech authentication becoming increasingly commonplace, users are speaking at a greater distance from electronic devices. However, this makes speech comprehension more difficult, especially in noisy environments. Malaspina has developed a proprietary technology called “Model Based Speech Discrimination” to isolate speech from background noise.

Unlike traditional methods that try to filter out background sounds based on spectral frequency (which doesn't work well if the background noise happens to include frequencies that are in the range of human voice), Malaspina's approach uses a mathematical model of human speech to detect complex patterns of sound made by human vocal chords. The company believes this significantly differentiates its VoiceBoost solutions from other voice enhancement technologies.

The VoiceBoost solution is offered as portable C-language software and is system and language independent with support for ARM, NXP, Tensilica, and Ceva DSPs. It can be used within mobile phones, tablets, headsets, hearing aids and other mobile devices. VoiceBoost is optimized for very low power consumption, low latency, and can operate with one or multiple microphones. VoiceBoost provides a dedicated ASR Assist mode which improves the performance of embedded and Internet-based ASR engines.

Malaspina has also developed a low latency speech synthesis engine (VoiceForm) that can reconstruct a completely noise-free synthesized voice signal which can replace the noisy voice input. That is, once the VoiceBoost technology determines which part of the input signal is human voice, rather than try to filter out the background noise, a completely new (noise free) signal can be synthesized based on the detected human voice signal. This is especially beneficial for voice-command assistants.

In February, the company announced a partnership with Wolfson Microelectronics in which Wolfson will make VoiceBoost available on its WM5102S Audio Hub for mobile devices. The included VoiceBoost Voice Activation solution offers either speaker-dependent or speaker-independent voice recognition options, enabling the user to 'wake' a device from a low-power state by speaking a user-defined trigger phrase, without the need for physical interaction with the phone, such as button presses or typing. Malaspina is based in Vancouver, Canada.

Chapter 6 – Security Biometrics

"*Happiness has many roots, but none more important than security.*"
- Edward Stettinius, Jr.

Introduction

The previously discussed HMI technologies were primarily for enhancing the user experience by making it easier for a user to control an application or device without using a conventional keyboard/mouse. Another aspect of HMI technologies, however, is security. Remembering and having to manually type in passwords is cumbersome and has security risks. In addition, it is impractical for many small form factor devices. As a result, there is growing interest in utilizing biometric interface technologies for security purposes. Some examples include fingerprint sensors, voice authentication technology, and facial/eye recognition systems. This chapter briefly discusses some of these technologies.

Fingerprint Recognition

Fingerprint readers enable users to log onto a device or application by swiping or placing a finger on a sensor. The user will have her fingerprint read a few times during set-up and can then subsequently gain access by placing her finger on (or swiping across) the fingerprint sensor.

Historically, the two general types of fingerprint sensors were area sensors (in which the user places a finger motionless on a large sensor array) and swipe sensors (in which the user swipes a finger across the sensor and the images of each portion of the finger are pieced together by the computer).

The sensor array in a swipe sensor is generally significantly smaller than that of a traditional area sensor, resulting in a much smaller footprint as well as lower cost for a swipe sensor, since the sensor array's cost is typically proportional to its size. The disadvantage of a swipe sensor is that it generally is not as robust as an area sensor since multiple images of the finger have to be pieced together and users swipe their fingers at a variety of different speeds, which can make it more difficult to capture fingerprints, resulting in more false negatives and false positives. For portable devices, however, it had generally been viewed that the size and cost advantages of swipe sensors outweighed other factors and most of the fingerprint sensors that had been implemented in notebook PCs and mobile phones in recent years were swipe sensors.

However, the iPhone 5S introduced Apple's Touch ID sensor which is small enough to fit within the Home button. Unlike traditional area sensors that are relatively large so the user's entire fingertip can fit, Apple's "touch sensor" solution reads only a portion of the finger. That is, during set-up the user's fingerprint is read in a number of different positions and subsequently the system can identify the user from just a small portion of the fingerprint. The Touch ID sensor is only 170 microns thin and is protected by the sapphire crystal Home button. The steel ring around the button detects a finger and activates the sensor. Apple estimates that the probability of a false positive is about 1 in 50,000 and since it allows only 5 attempts before requiring a passcode it is unlikely that a person besides the owner could gain access.

A variety of different technologies have been used to capture fingerprint images. Some examples include: thermal (the ridges of a finger contact the sensor and have a higher measured temperature than the valleys of the finger which can be used to create an image), optical imaging (the finger is illuminated and an image sensor captures fingerprint images), ultrasound (very high frequency sound waves penetrate the epidermal layer of skin and the reflected signal is captured), pressure (pressure from ridges of a finger is used to create an image), passive capacitive (the dermal layer of the finger and the sensor array act as parallel plate capacitors separated by the epidermal layer; the measured capacitance varies between the ridges and valleys of the finger), active capacitance (similar to passive capacitance but a small voltage is applied to the finger creating an electric field related to the pattern of ridges and valleys in the dermal layer), and RF (an RF signal is applied to the user's finger and the resulting signal which is changed based on the fingerprint patterns is then read by a detector).

Although each type of fingerprint sensor technology has been commercialized, many of them are not well suited for the consumer markets (e.g., not robust enough, too large, too expensive, etc.). Optical fingerprint sensors, for example, are commonplace for conventional stand-alone fingerprint readers, but have not gained traction in mobile devices. In general, one of the biggest challenges is the significant variations in types of fingers and environmental factors (e.g., finger may be dirty, clammy, dry, etc.), and with swipe sensors there is significant variation in how users swipe their fingers.

Most of the fingerprint sensors implemented in mobile consumer devices utilize some type of capacitive or RF technology, which can be implemented at relatively low cost in small form factors. In addition, both of these technologies make measurements based on the dermal layer of skin, rather than just the external epidermal layer (which is more prone to changes based on external factors such as whether the finger is dry, wet, or has lotion or other materials on it). For example, Apple's Touch ID and sensors from Fingerprints utilize capacitive technologies and sensors from Validity utilize RF technologies. AuthenTec had historically used RF but UPEK (which it acquired) utilized capacitive technologies.

In addition to the iPhone 5S, a variety of other consumer products have incorporated fingerprint sensors including notebooks from companies such as Lenovo and Fujitsu, and a number of mobile phones (e.g., HTC One Max). At Mobile World Congress 2014, Samsung provided details about its upcoming Galaxy S5 smartphone, including that it will incorporate a fingerprint sensor. As with the latest iPhone, the S5's fingerprint sensor will also be incorporated into the Home button, but it will require swiping a finger across the sensor as opposed to just holding a finger on the button. One interesting part of the announcement is that Samsung partnered with PayPal to enable PayPal payments using the fingerprint sensor. That is, a user can authorize a PayPal transaction using the fingerprint sensor rather than typing in a PayPal password. Samsung is opening the use of the sensor to 3rd party developers. Apple allows users to authenticate iTunes store purchases using the fingerprint sensor, but has not opened it up to outside parties.

There has been significant consolidation of fingerprint sensor companies in recent years (Synaptics acquiring Validity, AuthenTec acquiring UPEK, Apple acquiring AuthenTec). These acquisitions are discussed in more detail below.

Select Security Fingerprint Sensor M&A Transactions

There have been a number of fingerprint/biometric acquisitions in the general security market (e.g., DigitalPersona/Identity Stream, Assa Abloy (HID)/Lumidigm, Francisco Partners/Cross Match Technologies, etc.), but below are a few specifically related to the consumer markets:

- **Synaptics/Validity** – In October 2013, Synaptics announced that it agreed to acquire Validity for approximately $92.5 million in stock and cash plus an earn-out of $162.5 million for a total potential consideration of up to $255 million (per Capital IQ). Validity was a privately-held fingerprint sensor solutions company. Its solutions were incorporated into a number of notebooks, tablets, and phones.

- **IDEX/PicoField** – In September 2013, IDEX announced an agreement to acquire the assets and intellectual property of PicoField Technologies, which was focused on touch fingerprint sensor design and development tailored for consumer devices.

- **Apple/AuthenTec (which acquired UPEK)** – In July 2012, Apple announced that it was acquiring AuthenTec, a small cap public company focused primarily on fingerprint sensor solutions, for $356 million, which was about a 58% premium to AuthenTec's stock price at the time of the announcement (per the 451 Group). AuthenTec had about $70 million of revenue in 2011. In 2010, AuthenTec had acquired UPEK, another major fingerprint sensor company which was originally spun out of STMicroelectronics.

Facial Recognition

With facial recognition, images of a person's face are taken via an image sensor. When the user wants to log on later, the image of the person's face is compared against the set-up pictures using a variety of complex algorithms to determine if it is the same person, in which case access is granted. Typically, there are certain key parameters the system focuses on to help match images (e.g., distance between the eyes, width of the nose, shape of the cheekbone, etc.).

The incremental cost of this technology can be relatively low assuming a device already has a standard image sensor. However, accurate facial recognition is very challenging, since a person's face can change quite a bit from day or day (e.g., shaved/not shaved, before or after a haircut, bad hair day, smiling/frowning, tan/not tan, etc.). In addition, room lighting can have a significant impact on facial images so features will vary based on ambient lighting. Also, the technology has to adjust for the fact that a person's face may be at varying distances and angles from the camera. All of this makes facial recognition challenging, especially for mobile devices with limited processing power. In many mobile device implementations, facial data is transmitted over the network to servers that perform the actual face matching and the results are sent back to the device.

While facial recognition has been used extensively in law enforcement agencies, it has had only moderate traction in consumer devices. Google introduced Face Unlock in Android 4.0 (Ice Cream Sandwich) in 2011. Face Unlock can be used as an alternative to a screen lock PIN. A couple of initial criticisms of Face Unlock were that there was a high level of false positives (i.e., someone with a face that was somewhat similar to the phone's owner could get past security) and that photos of a person could be used to gain access. In subsequent Android updates, changes were made to improve the technology and to require the user to blink to gain access (so that static photos won't work). However, the percentage of users actively utilizing Face Unlock is still thought to be relatively low.

Last year, it was reported that Google filed a patent for a face recognition technology in which the user would make a "silly face" (e.g., stick tongue out, etc.) and then have to repeat that same type of expression to unlock the device.

Facial recognition in general was expected to get a boost when Google introduced Google Glass as there had been reports that it would have a feature enabling Glass wearers to identify people (and bring up information about the person) just by looking at them. However, a congressional committee wrote an open letter to Google expressing privacy concerns if Glass included facial recognition capabilities. Subsequently, Google prohibited the use of facial recognition (for Glass) for identifying anyone other than the user.

Although we included facial recognition in the chapter on security, there is also significant interest in facial recognition for other applications. For example, facial recognition can be used to identify people to provide user preferences. A smart TV could identify which person is watching and change settings based on that (e.g., bring up that person's favorite types of shows). An automobile could determine who is driving and make seat, mirror, and entertainment adjustments based on that.

Another major area of interest for facial recognition is social media, such that images or videos of a person can be identified and tagged. For example, facial recognition technologies have been used by both Facebook and Google for searching to find photos and videos of a person. As a specific example, when a Google+ user turns on the "Find my Face" feature, photos and videos that the user tags are utilized to develop a model of the user's face. When someone else looks at a photo or video with a face that appears to match the user's face, they receive a suggestion to tag the user. As a result, there have been a number of facial recognition acquisitions related to photo tagging.

Select Facial Recognition M&A Acquisitions

There have been a number of consumer-related facial recognition acquisitions, although several have been more focused on facial recognition for social media type applications rather than security. Some examples include:

- **Google/Viewdle and PittPatt** – In October 2012, Google (through Motorola Mobility) acquired Viewdle, a Ukrainian company focused on facial recognition technologies for applications such as photo tagging. In addition to facial recognition, Viewdle was also diversifying into pattern recognition (gestures, etc.). The deal was reportedly in the $40 to $45 million range (per the 451 Group). In 2011, Google acquired Pittsburgh Pattern Recognition (PittPatt). PittPatt was a start-up that was formed from a project at Carnegie Mellon University and developed facial recognition technology to match people's faces, including face detection, face tracking, and face recognition.
- **Facebook/Face.com** – In June 2012, Facebook acquired Face.com, an Israeli start-up focused on facial recognition technologies for photo-tagging and related applications. Its solutions helped developers build applications that could identify people from photos, although it stopped providing its facial recognition APIs after the Facebook acquisition. The deal value was reportedly approximately $60 million (per Capital IQ).

Eye Recognition

Another type of security technology that can be used with mobile devices is eye recognition, in which images of the user's eye are captured during set-up and subsequently compared to images of the eye of the person trying to log in. If the images match, the user is granted access.

There are two general types of eye recognition technologies – iris recognition and retina recognition. With iris recognition, images of a person's eye are captured (typically near-infrared light is used to illuminate the eye) and the unique patterns of the iris are used for matching purposes. Retina scans involve shining a bright light into the pupil and capturing images of blood vessels in the back of the eye. The term retina scan is sometimes incorrectly used to refer to all eye recognition technologies, but iris recognition is by far the most commonly used and less invasive technology.

An advantage of iris recognition compared to other security technologies is that unlike a person's facial features, for example, which can change from day to day, the patterns in a person's eye vary little over time and so matching is generally easier. A negative is that many people don't like the idea of having their eyes scanned, so making it as unobtrusive as possible is critical (i.e., having to move an eye close to the camera is generally not something consumers want to do). Too strong a flash of infrared light can damage the retina so weaker flashes are used but that typically requires the eye to be relatively close to the camera.

Iris recognition has been used for many years in a variety of general security applications (high security building access, etc.) but there has been interest in incorporating it into mobile devices. The goal is to make it effective at a distance, such that the user doesn't have to move closer to the device than during normal usage.

Voice Authentication

As many devices now include a microphone for voice communications, there is interest in utilizing voice authentication technology in which the device can recognize a person's voice for security access. With voice authentication, typically a person will pick a specific pass phrase and repeat the phrase a few times in set-up mode. Subsequently, the security system then requires the user to say the specific phrase and can recognize if it is the user's voice (another person saying the phrase would not gain access).

An advantage of voice authentication is that the incremental cost can be minimal; assuming the device already has a microphone, as it doesn't require additional hardware such as a fingerprint sensor. It is also well suited for wearable devices that are relatively small. One of the issues that some voice recognition solutions have is that it requires significant processing power which can't be supported by the device, so the voice information is sent over the network for analysis and a server on the other end performs the computations and lets the device know if access should be granted or not. This can result in latency issues and also does not work if there is no network access (zero bars). Some historical solutions also had issues if there was background noise and had too many false negatives.

Select Voice Authentication M&A Transactions

There have been a number of voice authentication technology acquisitions, although most of the targets were focused on voice authentication for institutions and phone calls, rather than for consumer devices. Some voice authentication M&A transactions have included:

- **Verint/Victrio** – In October 2013, Verint announced the acquisition of Victrio which had developed "passive" voice biometrics solution with predictive analysis that can accurately detect fraudsters and authenticate customers without caller interruption.
- **VoiceTrust/Perceive Solutions** – In February 2012, VoiceTrust acquired the Montreal based voice technology firm Perceive Solutions. Perceive had developed voice biometrics solutions that can identify and authenticate speakers in any language with free form speech.
- **Nuance/PerSay** – In 2010, Nuance acquired PerSay. PerSay was an Israeli start-up focused on the voice biometrics markets, for systems used in the banking, insurance, governments, and telecommunications industries.

Many Other Biometric Security Technologies

There are a variety of other biometric security technologies that have been developed. As an example, we have seen solutions in which the user can gain access through handwriting recognition (the user writes a word on the touch screen using a finger). There are also solutions based on a variety of other biometrics, as well as multi-factor authentication (combining multiple security factors to further enhance security).

Select Biometric Security Technology Companies

The following are a number of mostly private biometric security companies. There are a variety of companies that have developed biometric solutions for government, military, corporate, and telephony applications, but we included companies specifically focused on mobile device applications. Although we primarily highlight private companies in this document, we included Fingerprint Cards, which is a small cap public company in Sweden.

Porticus Technology

Porticus is a small privately-held company that has developed unique voice authentication and multi-factor solutions. Based on more than a decade of research in voice forensics and biometrics, Porticus has developed its VoiceKeyID voice authentication solution, which can be used for unlocking a device or for enabling access to certain applications (e.g., financial transactions, etc.). A user decides on a pass phrase and repeats it three times at set up, and then subsequently speaks the phrase to gain security access. The Porticus solution is based on voice phonemes, so it is language independent (it doesn't try to translate the spoken pass phrase but just confirms that the spoken phrase sounds the same).

The Porticus solution was specifically developed for mobile handsets and operates entirely in the device without requiring any network access (eliminating latency problems and issues related to not having network access). It was also designed to have low power consumption and requires relatively little processing power. The software can be incorporated into a chip or implemented through the operating system or an app. Although the basic solution provides two factor authentication (user's voice, pass phrase), it supports four factor authentication (including the device's ID and the device's location). Thus, security could potentially be granted only if the user has the correct mobile phone, is in certain locations, knows the pass phrase and has a voice match. This provides significantly more security than simply typing in a password.

Porticus has a licensing business model. The company has a number of patents around its voice authentication technology, as well as multi-factor security incorporating voice authentication in general. VoiceKeyID is available for iOS and Android OS platforms, with Windows support expected soon. Porticus has also implemented its technology on a commercially available DSP. The Company is headquartered in Wellesley, Massachusetts and maintains research and development facilities in Vilnius, Lithuania.

Fingerprint Cards AB

Fingerprint Cards (FPC) sells a variety of area, swipe and touch fingerprint sensors which all utilize capacitive technology. FPC's sensors contain tens of thousands of small capacitive plates, each with their own electrical circuit embedded in the chip. When a finger is placed on the sensor electrical charges are generated, creating a pattern between the finger's ridges or valleys and the sensor's plates. Using these charges, the sensor measures the capacitance pattern across the surface. The measured values are digitized and processed. FPC's high sensitive pixel amplifier (HSPA) technology allows each pixel element in the sensor to detect very weak signals, improving image quality.

FPC announced in January that its solutions are incorporated into 21 market launched mobile devices including a number of Fujitsu smartphones and tablets selling in Japan (DoCoMo, SoftBank), a variety of smartphones sold by Pantech in Korea, and mobile devices from Konka in China. FPC has a variety of patents related to its own fingerprint technologies, but also acquired more than 100 patents in 2013 related to wireless technology. The company had 76 employees as of December 2013, and is headquartered in Gothenburg, Sweden. Its stock is listed on the Stockholm exchange.

Mobbeel

Mobbeel has developed a variety of different biometric security solutions specifically targeting mobile devices. Its "MobbID" technologies include voice recognition, facial recognition, handwriting/signature recognition, and iris recognition. Its voice recognition technology is text-independent and can work in any language. Its facial recognition technology analyzes video frames and works with conventional mobile cameras. Mobbeel's signature recognition technology can identify a user's handwritten signature on a touch display as a means of identification. Its handwriting technology uses "online recognition" in which the details of how a person actually creates a signature (strokes, speed, time, etc.) is captured and analyzed, rather than "offline recognition" in which only the final signature image is analyzed. This "online" method makes it more difficult to pass through security by copying a person's signature. The Iris recognition technology uses a mobile device's existing camera and doesn't require additional hardware or infrared light. Its software can also combine these biometric technologies for multi-factor authentication. Mobbeel's technologies can be implemented on-device or over the cloud by a server.

Mobbeel has developed a variety of related applications. For example, it has solutions (MobbSign, etc.) that enable a user to sign documents using a handwritten signature and embed biometric data to make it legally valid. Its Biowallet Signature solution is a biometric authentication system for the Android platform. BioWallet2Browser is designed to secure a user's browsing experience on the Internet by storing passwords on the phone and automatically using them once the user provides biometric recognition. MobbKey is a secure remote access system to unlock doors. The company is based in Spain.

Biometry

Biometry is a biometric authentication company focused on mobile devices. The company has developed an integrated suite of software (One Software) that can support various combinations of face and voice/speech authentication. For example, in one security mode, the user has to say four randomized words. The Biometry software then not only verifies it is the user's voice, but also that it is the user's face and that the correct words were said. This provides multiple layers of security (the voice, the face, and the words all have to match) which can be adjusted based on trust/risk level. For example, for a small value online purchase one biometric authentication can be used, but for higher value purchases multiple biometrics can be required. It also eliminates the need for a user to remember passwords. The company is based in Switzerland with offices in Silicon Valley and Estonia.

Animetrics

Animetrics is a developer of 2D-to-3D face recognition and face creation solutions. The Animetrics product family delivers facial recognition identity solutions using technologies that are capable of addressing high levels of variation in pose and lighting conditions. The Animetrics technology takes a 2D image of a face and generates a 3D model for accurate verification and identification. This 3D model can also be rendered as a lifelike avatar.

Animetrics has historically targeted military and government type applications (identifying suspects or missing people) running on computer systems, and has achieved traction in these markets. However, more recently it has introduced solutions for smartphones. Specifically, the FaceR MobileID solution is designed to help recognize and match faces using a mobile phone, and the FaceR CredentialME is an advanced facial recognition security application. These solutions can run on iPhone or Android smartphones and leverage Animetrics' core FACEngine facial recognition technology that converts 2D to 3D images. Animetrics has 4 key patents and is based in New Hampshire.

AOptix

AOptix is a privately-held company with two distinct product lines: Identity Solutions and Communications. The Communication unit has developed a number of ultra-high data rate wireless technologies that are not discussed here. The Identity Solutions business includes smart mobile identification solutions. The AOptix Stratus MX Made is a rugged hardware peripheral that fits over a standard iPhone and houses high-quality iris and fingerprint capture technology. AOptix Stratus MX captures iris and fingerprint images both indoors and outdoors, even in direct sunlight. Used in conjunction with either the AOptix Stratus App for iOS or a custom application built using the AOptix Stratus Client SDK for iOS, users can collect biometric data for enrollment or identification. The company is based in Silicon Valley with an office in Dubai.

Chapter 7 – Sensor Fusion & Middleware

"I believe in a long, prolonged, derangement of the senses … in order to obtain the unknown."

- Jim Morrison

Introduction

The number of sensors in mobile devices continues to increase. Many devices now have a variety of positioning sensors (accelerometers, gyroscopes, magnetometers, etc.) as well as a number of interface sensors (CMOS image sensors, microphones, etc.). Adding sensors to a device is relatively easy, but effectively utilizing all of the data to greatly enhance the performance or functionality of the device is more complex. In addition, many sensors require a significant amount of "behind the scenes" management (e.g., calibration). Sensor fusion refers to the idea of combining the data from a variety of different sensors and sources to enhance the overall performance of the product.

Beyond basic sensor fusion, there is growing interest in making smartphones and devices "contextually aware" such that they provide users with relevant information based on all available data sources and this requires utilizing data from many sensors and a variety of other data sources, and interpreting the data to provide higher level information.

A number of companies have developed sensor fusion related technologies including both semiconductor solutions and software/middleware solutions.

Select Sensor Fusion Company Examples

Apple developed the M7 coprocessor, which is included in the iPhone 5S. The M7 (based on ARM Cortex-M3) collects and processes data from a variety of sensors (accelerometers, gyroscopes and compasses), offloading this from the main A7 processor. Examples of private software and semiconductor companies addressing sensor fusion are given below.

Movea

Movea has developed a broad range of middleware solutions addressing the sensor fusion/motion processing markets. Its technology bridges the gap between a broad range of sensors and applications, and includes technologies related to gesture-based control, activity monitoring, and indoor navigation. The company licenses its technology for products such as smart phones/mobile devices, smart TVs/set-top boxes, gesture-enabled remote controls, and sports/wellness products. Movea's customers include OEMs, ODMs, and semiconductor companies. Movea has over 480 patents covering a variety of different technologies that involve sensors and motion.

Some examples of recently announced applications include: gesture-based interaction support for set-top boxes (in partnership with STMicroelectronics), absolute in-air pointing for 6-axis motion-enabled TV remote controls, an indoor navigation design suite for the Android operating system, a sensor hub chip solution (in partnership with Microchip), a multi-sport activity tracking wristband (in partnership with Texas Instruments and Xm-Squared), a 12-axis sensor platform (in partnership with Freescale), a next-generation pedometer from Oxylane's Geonaute brand, and the Babolat Play tennis racket (which incorporates a gyro and accelerometer and can provide a variety of performance data to tennis players). Many of Movea's customers and end products have not been publically announced.

Movea's solutions include development tools (to add motion capabilities), MotionCore (motion processing and data fusion IP for context aware mobile applications), MoveaTV (motion processing platform for next generation gesture-based Interactive TV), and MoveFit (motion expertise and solutions for smarter sports equipment). A recent focus has been context awareness in which a mobile device utilizes knowledge of its location, what is around it, and other data to provide high quality useful information to the user. At Mobile World Congress 2014, Movea announced that its SmartMotion technology has been ported to the Atmel SAMG53 and that its first SASH (Smart Architecture Sensor Hub) evaluation kit for Android (built on STMicroelectronics' STM32F401 controller) is available. Movea's investors include CEA Investissement, Gimv, I-Source, Technicolor, and Intel Capital.

Sensor Platforms

Sensor Platforms is a private company that, not surprisingly, focuses on sensor platforms. Its FreeMotion Library targets sensor fusion and user context awareness for mobile applications. The Library provides the intelligence to combine and process data from sensors (e.g., accelerometers, barometers, gyroscopes, magnetometers) on mobile devices, and interpret that data into contextual information meaningful to application developers. The FreeMotion Library works with Android and Windows 8 operating systems, and can also be embedded in microcontrollers and/or smart sensors.

The software can help manage and improve the operation of sensors in devices (e.g., turn on and off sensors as needed, background calibration, reduce power consumption, and improve performance). In addition, it can provide a variety of context aware features to leverage the sensor data and provide useful information.

Some recent announcements by Sensor Platforms include a collaboration with Murata (MEMS sensors) for next generation smartphone/tablet applications, the addition of dead reckoning to its Library, a partnership with QuickLogic, a partnership with Atmel (new sensor hub platform), and an announcement that its software is now optimized for Nvidia's Tegra 4. Sensor Platforms is based in Silicon Valley. Its investors include Newbury Ventures, Carinalli Ventures, New Science Ventures, and Arrowpath.

Hillcrest Labs

Hillcrest Labs has developed a broad range of software and hardware solutions for motion-enabled products. The company's Freespace MotionEngine software products include: Smart TV (for smart TVs, set-top boxes, and other connected TV devices), Mobile (for smartphones and tablets), Lite (in-air pointing for remote controls and mice), and Universal (for head mounted displays and body trackers). These solutions provide a variety of sensor fusion and calibration algorithms, and provide application ready data. In addition, Hillcrest has developed a sensor hub software stack (SH-1 Sensor Hub) that is optimized for and can be pre-integrated into the Atmel ARM-based SAMD 20 microcontroller. This provides a complete "always on" chip level solution for implementing sensor fusion. The company also has modules and white-label products (pointer, remote).

Hillcrest has an IP portfolio that includes over 80 granted and 200 filed patents exclusively owned by Hillcrest Labs. In addition it has a one-way license of a portfolio of motion patents from Technicolor.

Some recent announcements from Hillcrest have included: Intel's reference design kit for IPTV set-top boxes and media servers will use Hillcrest's in-air pointing and motion control technology; a multi-year agreement with TCL to bring motion control to smart TVs, a strategic agreement with HiSense to incorporate Freespace into HiSense TVs and set-top boxes; a partnership with Atmel for sensor hub microcontrollers; and a partnership with SMK electronics for a new 6-axis in-air pointing remote. Hillcrest is based in Rockville, Maryland and is funded by NEA, AllianceBernstein, Columbia Capital, and Grotech Ventures.

PNI Sensor Corporation

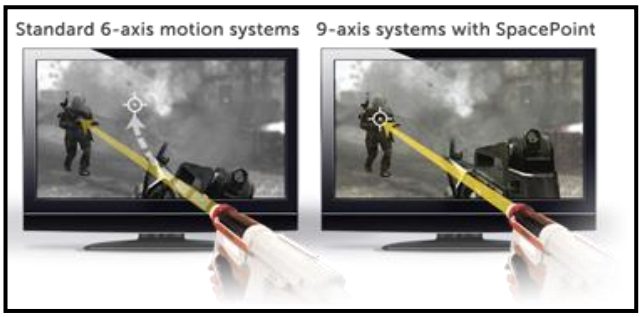
PNI has been an innovative sensor company since the 1980s. For many years, PNI was primarily known for its magneto-inductive sensors and has generally been recognized for being a technology leader in magnetometer/compass chips. The company continues to sell a variety of geomagnetic compass chips and compass modules. For example, PNI indicated that its recently announced RM3100 solution delivers more than 20x higher performance than existing MEMS or Hall Effect geomagnetic sensors. PNI's digital compass solutions have been used in a variety of products and markets. While the company was primarily known for geomagnetic products, more recently PNI introduced its Sentral Sensor Fusion chip and algorithms.

Most smart mobile devices now incorporate a variety of sensors including an accelerometer (to detect the orientation of the phone), gyroscope (to measure tilt/rotation), a digital compass (to determine absolute direction as it can identify which way is North), and sometimes a barometer (to determine altitude which can improve GPS tracking).

However, managing all of these sensors is complicated and includes a variety of “behind the scenes” activities such as calibrating the sensors and filtering the data. This often eats up a significant portion of the main processor’s cycles, resulting in substantial power consumption and reduced device performance.

The PNI Sentral Fusion Sensor chip is designed from scratch to manage other sensors including gyros, accelerometers, and magnetometers. This provides a variety of advantages. For example, PNI indicates that its Sentral chip can perform sensor fusion/management at less than 1% of the power consumption of a general microprocessor, which can help significantly extend battery life.

Using a proprietary “constant calibration” technology and filter algorithms, PNI indicates that Sentral can also significantly improve accuracy and reliability and reduce the need for complex algorithm development, enabling easy implementation for motion processing. Although Sentral is a chip-based solution, importantly PNI can also implement many of its sensor fusion algorithms in software.



PNI has also introduced Spacepoint Scout, a complete 9-axis motion tracking development module that includes PNI’s own geomagnetic sensor, as well accelerometers and gyros from partner companies. PNI’s sensor fusion software is then used to fuse the data together. This results in extremely accurate tracking and pointing performance and can greatly enhance consumer applications such as gaming.

At CES 2014, PNI announced its Motion & Measurement (M&M) modules, an integrated platform for accurate motion and heading measurement in wearable fitness devices, smartphones, video game consoles, and TV remote controls. These solutions incorporate the Sentral motion coprocessor with a variety of other sensors (gyro, accelerometer, magnetometer) to achieve high accuracy motion tracking with low power consumption.

PNI’s products are used in a variety of consumer electronics devices, including the Wii U Game Pad, as well as in a variety of robotic, navigation and automotive applications. The company is based in Santa Rosa, CA.

Chapter 8 – Brain, Heart & Other Biometric Sensors

"*The brain is a wonderful organ; it starts working the moment you get up in the morning and does not stop until you get into the office.*"

- Robert Frost

Introduction

With growing interest in wearable devices (e.g., according to TechCrunch, Intel recently acquired wearable company Basis for over $100 million) and in utilizing smartphones for body/health monitoring, dozens of companies have developed solutions that can monitor signals from the human body such as heart rate, temperature, and even brainwaves for health/wellness/medical type applications. There have even been interesting developments in using brainwaves for controlling applications. This section briefly discusses some of these biometric sensor technologies.

Heart Sensors (ECG Sensors)

Electrocardiogram (ECG) sensors measure electrical activity of the heart. Heart muscles have negative charges (membrane potential) at rest and during each heartbeat the charge shifts towards zero (depolarization) and then back again. By measuring and analyzing the resulting electrical signals over a period of time, an ECG sensor can determine a variety of information about the heart (heart rate, abnormalities, etc.). ECG sensors are commonly used by hospitals, but there is growing interest in utilizing ECG technology for consumer applications, such as tracking health/wellness from a smartphone.

Neuro-technology (EEG Sensors)

There is interest in measuring and using brain wave activity. This typically involves wearing a headset that includes an electroencephalogram (EEG) sensor. The EEG signals from the brain are converted to digital and analyzed and can be used to determine if a person is focused/concentrating or not (for research/education applications) and if there may be wellness issues (for health reasons). It can also be used to sense a person's mood.

In some cases, EEG sensors can even be used to make simple control selections. For example, by measuring a user's EEG signals when he is thinking about "jumping" and measuring it when he is thinking about "running", an application can potentially allow the user to control a game character that has to run and periodically jump just by thinking, without using any other type of control or body movement. Typically, this requires some amount of set-up time for each user, as brain wave patterns vary from person to person in different circumstances. However, this offers the potential for some "science fiction like" control by thought alone.

In a recent interview, Jai Menon (CTO of Dell's Enterprise Solutions Group) indicated that Dell was investigating the use of a device that a user could wear and by measuring alpha (brain) waves, it could determine the person's mood (happy or sad, etc.). This could then be used by the device to, for example, play certain types of music to cheer the person up.

Some Key Body Sensor Challenges

There are a broad variety of solutions addressing the health/wellness markets. Some key challenges with many of these body sensors are to make the sensors as unobtrusive as possible and to reduce power consumption. Wireless communications to transfer data between a sensor and a smartphone consumes a meaningful amount of power, so low power wireless communications is important to keep the device small.

Select Biometric Solution Companies

The following are some companies focused on biometric solutions.

NeuroSky

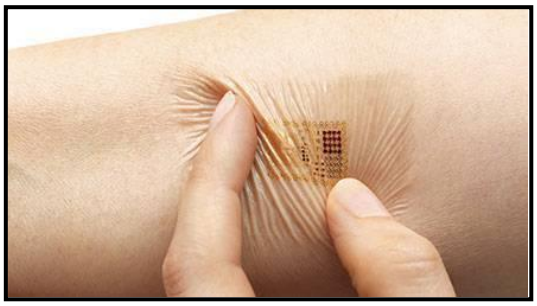
NeuroSky has introduced a number of solutions targeting both EEG sensors (brainwaves) and ECG sensors (heart rate). It has developed integrated chips, modules, and software/algorithms addressing these markets, and also offers a complete headset.

NeuroSky has developed solutions for the heart-rate/ECG monitoring market. The NeuroSky CardioChip is a system-on-a-chip (SoC) solution targeting the health and wellness market. It can be used to monitor ECG, heart rate, and heart rate variability. The chip integrates a low noise amplifier, a 16 bit ADC, sensor-off detection, hardwired DSP blocks, and a systems management unit. It targets bio-signals ranging from microvolts to millivolts. NeuroSky also provides a variety of complex algorithms to help determine heart rate, respiration rate, stress level and other parameters based on the readings.

NeuroSky has been a pioneer in developing solutions for the EEG/brainwave monitoring market. Its ThinkGear AM (TGAM) EEG sensor module senses the signals from the brain, filters out extraneous signals, and converts the results to digital for a variety of applications. The module includes NeuroSky's own semiconductor chip which is optimized for this application. The chip includes A/D conversion, amplification off head detection, noise filtering for both EMG and 50/60Hz AC powerline interference, and NeuroSky's eSense brainwave pattern technology. NeuroSky also provides advanced algorithms that can be used to determine mental activity/meditation, familiarity, and other parameters. In addition, NeuroSky offers a complete headset solution that incorporates its TGAM technology. NeuroSky indicates that its TGAM solution powers over 1 million consumer EEG devices around the globe.

In November 2013, NeuroSky announced that it received an investment from SoftBank to accelerate the development of mobile health/wellness solutions. NeuroSky was founded in 2006, and is headquartered in San Jose, California with offices in Asia and Europe.

MC10



MC10 is a pioneer in flexible electronics, with a focus on biosensor applications. One of the major issues with bio-sensing is that traditional electronics are relatively bulky. Although a semiconductor silicon die is very thin, traditional semiconductor packaging (to protect the silicon chips) and printed circuit boards (to interconnect different chips) are thick and rigid. Ideally biosensors could be applied directly onto the skin without a person even noticing it while it is on. MC10 has developed technologies that allow extremely thin, flexible, conformal, transparent devices that can stretch, bend, and twist while on a person's skin. This has the potential to greatly accelerate the penetration of biosensors into several markets.

The MC10 solutions generally incorporate sensors to measure important parameters (temperature, heart rate, hydration level, UV levels, etc.) and then wirelessly transmit the data to a smartphone or other device. Because of the thinness of the MC10 solution, it can easily be incorporated into wrist bands or other accessory products, but even more significantly can be directly stamped onto the skin itself. Some examples of initial products/applications include:

- MC10 developed a prototype called BioStamp, which can be stamped directly onto the skin and is then sealed with a spray-on bandage. The sensors can detect parameters such as body temperature, hydration levels, and UV exposure. This information can then be uploaded to a smartphone or sent to a doctor. The patch uses a thin film battery. The imprint can last for several days, withstanding stretching, flexing and even showering.

- The company created a baby temperature monitor that can be applied directly to an infant's skin, such that temperature can be continuously measured without waking the baby up or disturbing the baby in any way.

- MC10 partnered with Reebok to developed CheckLight, a head impact indicator for contact sports.

- The company is developing a new type of catheter that includes nanometer-thin sensors, providing real-time feedback for doctors.

MC10 believes there are a large number of applications for its flexible electronics, well beyond bio-sensing. MC10's investors include North Bridge Venture Partners, Braemar Energy Ventures, Windham Venture Partners, Aberdare Ventures, Osage University Partners, Terawatt Ventures, Medtronic, Mitsui Ventures, and several undisclosed strategic investors. Announced partners include Reebok, Medtronic, and Massachusetts General Hospital. MC10 is headquartered in Cambridge, MA.

Toumaz Group

Toumaz Group has two divisions. The Frontier Silicon portion of the business focuses on digital radio chips and connected audio and was formed when Toumaz acquired Frontier Silicon in August 2012 (Pagemill was the advisor on the transaction). More relevantly, the Toumaz Sensium Healthcare division has developed ultra-low power wireless solutions for monitoring vital signs. Sensium Vitals is an ultra-low power wireless system that monitors vital signs of general care patients using light weight wearable single-use patches that monitor heart-rate, respiration rate and temperature, and communicate the data wirelessly to any Web enabled device. Sensium Vitals is the first ultra-low power, wearable, wireless patient monitoring product to have received FDA (510k) clearance. Toumaz also indicates that it developed the first radio chip to enable the wireless connection of medical devices in compliance to the latest IEEE 802.15.6 Medical Body Area Network (MBAN) standard. Toumaz is a public company listed on the AIM exchange and is based in London.

Emotive

Emotive has developed solutions for the neuro-technology interface market. The Emotiv EPOC is a high resolution, multi-channel, wireless neuroheadset. The EPOC uses a set of 14 sensors plus 2 references to tune into electric signals produced by the brain. It also includes a gyroscope to generate positioning information and wireless connectivity to provide data to PCs or mobile devices. Emotiv's EEG headset solution provides the benefits of EPOC but also provides access to all of the EEG raw data. Emotiv offers a number of software suites to analyze/interpret the brainwave data including Expressiv (interprets the user's facial expressions such that if the user smiles the character in the game can smile as well), Affectiv (monitors the user's emotional state, enabling an application to adjust based on how the user is feeling), and Cognitive (provides the ability to control objects/selections using thought). A variety of potential applications exist including games, art, and music, as well as research and advertising. The headset can also be used by disabled patients to control, for example, an electric wheelchair.

Chapter 9 – Augmented Reality & Vision/Image Processing

"*Reality leaves a lot to the imagination.*"
- John Lennon

Introduction

A number of visionary HMI technologies appeared on Star Trek. In addition to the main Enterprise computer and Data (a lifelike android), one of the most interesting was the holodeck, a simulated reality facility in which people could interact with computer generated people and objects which appeared, communicated, and felt completely realistic to anyone inside the holodeck. While anything approaching the holodeck is still many decades away, there are a number of technologies under development that will move us in that direction.

One interesting research development combining a number of technologies has been "SixthSense," which was created at MIT's Media Lab. The SixthSense prototype includes a pocket projector, a mirror and a camera which are incorporated into a pendant-like wearable device. The projector and the camera are connected to the mobile computing device in the user's pocket. The projector projects visual information enabling surfaces, walls and physical objects to be used as interfaces, and the camera recognizes and tracks user's hand gestures and physical objects using computer-vision based techniques.

Some examples of applications that SixthSense can implement include: identifying objects and automatically projecting information about or related to the object (identifying a painting and projecting data about the artist, identifying a news article and projecting a video related to the article), taking a picture based on the user's gestures (the user creates a rectangular frame with his fingers and it takes a picture of the image in that frame), and navigating a map (the map is projected on any surface and the user can use hand gestures to pan or zoom). The prototype costs about $350 to build. Although not designed to be a commercial product, it provides some insight into where the industry is heading.

This chapter briefly discusses augmented reality, vision/image processing, pico-projection, MEMS auto-focus, virtual reality, affective computing/emotion analytics, and other related technologies.

Augmented Reality

Augmented reality (AR) refers to combining real world images with digitally generated data and/or images. That is, in contrast to virtual reality in which all of the imagery is computer generated, augmented reality augments actual images. A simple example of augmented reality is the yellow “first down line” that is added to the field during NFL TV broadcasts. A goal with AR is to integrate the digitally created content as seamlessly as possible such that it appears as part of the real world image.

Augmented technologies can be implemented in a variety of ways. For example, real world images can be captured via image sensors and displayed on a screen while a variety of 3D graphics are added to enhance the image. Alternatively, augmented reality can be implemented through glasses or head mounted devices in which the user sees the real world but computer generated graphics are added to enhance the image a person sees. Although Google Glass was not specifically developed as an augmented reality device, several developers have created apps to implement AR on Google Glass.

The number of potential applications for augmented reality is enormous. For example, an image of a car engine can be taken and can then be augmented to show the user how to perform certain types of car maintenance (graphics and instructions overlaid on the actual engine image). AR can capture an image of an object or place that a person is looking at and then add relevant information (what the object is, information from online resources about the object or place, etc.). AR is commonly used for advertising purposes (adding 3D images to real world objects), and can be used for engineering design, gaming, navigation, and a variety of other applications.

Several major technology companies have developed AR-related solutions. For example, Qualcomm’s Vuforia is a software platform for Android and iOS that enables apps to see images from a Vuforia target database on the device or in the cloud. When a target is recognized, the app generates augmented reality experiences. Microsoft filed a patent in 2013 for augmented reality glasses, which fueled speculation that it may have plans to create such as product for gaming. A recent article in EETimes indicated that the Korea Advanced Institute of Science and Technology (KAIST) created a processor with 36 cores that is specifically optimized for augmented reality applications.

Select Augmented Reality Private Company

An example of an AR company is Metaio which is discussed below.

Metaio

Metaio was founded in 2003 and initially offered AR to industrial and automotive customers for product design and factory planning. In 2005, it released the first end-consumer Augmented Reality application called KPS Click & Design, allowing users to place virtual furniture into an image. Metaio subsequently introduced a number of innovative AR solutions including the first browser plug-in for web-based AR applications and a fully integrated AR app for mobile devices.

Metaio currently provides a broad range of AR-related solutions including: Creator (an AR publishing tool that enables users to create a broad range of AR materials using simple drag and drop), SDK (a software development kit for AR), Cloud (lets users manage AR and content in a single place), Visual Search (creates projects in which up to 1 million patterns can be automatically managed using Continuous Visual Search), Junaio (advanced AR Browser for iPhone and Android), and Engineer (hardware IP that enables drastically reduced power consumption for “always on”). It also provides AR services to select customers.

Metaio has over 1,100 customers including many top-tier companies such as Volkswagen, Mitsubishi, Audi, McDonalds, Macy’s, Adidas, Red Bull, and Lego. In December, Metaio announced that it won the 2013 Volkswagen Augmented Reality Tracking Challenge (tracking is ability to recognize and continuously overlay digital content to a real-world object as it moves through space).

In January, it was announced that Metaio’s 3D Augmented Reality will be integrated into Intel’s RealSense Computing SDK. Metaio also collaborated with Intel to produce two apps specifically optimized for future Intel Atom Processor based Android tablets. At Mobile World Congress 2014, the company demonstrated a hands-free augmented reality maintenance solution utilizing wearable computing step-by-step instructions visualized through Epson Moverio BT-200 and Google Glass. It also presented its new AREngine AR hardware IP, which Metaio claims provides 6000% faster initialization and 80% reduction in power consumption on silicon. Metaio is based in Munich, Germany.

Embedded Vision / Image Processing

Earlier chapters discussed gesture recognition, eye tracking, and facial/eye recognition, all of which typically rely on optical image sensors. However, there is a more general category of embedded vision, which includes all of these applications, as well as a variety of others. As one example, using image sensors a device might not only capture images but also recognize what those images are and take appropriate actions. So if a person, for example, captures an image of a certain product in the store, the mobile device might be able to recognize what the product is and bring up relevant information (reviews, coupons, etc.) about that product. Applications likes these require substantial processing power as well as advanced imaging software. As a result, there is growing interest in advanced vision processor chips that are specifically optimized for vision-type applications, as well as for leading-edge software that can implement image processing and analysis.

Mobile devices are incorporating a growing number of image sensors. In addition, the complexity of image sensors is increasing (e.g., high pixel count sensors, 3D/depth sensors, light field sensors which enable users to refocus even after a picture is taken, etc.). Augmented reality technologies are becoming more commonplace and there are many applications in which there is interest in not just capturing images but in being able to analyze and post-process images and determine what the objects in the image are. Emerging technologies like simultaneous localization and mapping (SLAM), which enable devices to build internal maps of local environments without having prior knowledge of the local environment, require substantial processing power. In many cases, the processing required for these types of applications greatly exceeds the capabilities of mobile devices, which have limited processing power and cannot consume too much power.

Traditional microprocessors are not specifically designed to handle vision processing. Just as digital signal processors (DSPs) and graphic processing units (GPUs) were developed to better handle tasks that were not well suited for ordinary processors (e.g., baseband cell phone processing, PC graphics), some companies have developed vision processing chips (VPUs) that are specifically optimized for the types of parallel processing required for vision/image applications for mobile devices. This can help enable a variety of advanced features and functions while also freeing up the main/application processor to better handle other tasks and greatly improve the user experience.

In addition, a variety of companies have developed various types of image processing software to help analyze, enhance, search, and utilize captured images/video. Amazon, for example, recently updated its iOS app to incorporate its “Flow” technology, which enables users to capture images of products which are then recognized through visual search technologies. As a result, a user can simply point the iPhone camera at products the customer wants to buy (books, DVDs, grocery items, etc.) and the items register in the Amazon app and can then be purchased, if available on Amazon.

One interesting new development in vision processing is Google's Project Tango. Project Tango is focused on giving mobile devices a human-like understanding of space and objects by using computer vision and sensors. As an example, a device may be able to develop a complete internal map of the inside of a user's house and then use that for a variety of applications such as interior design or even having game characters play, for example, "hide and seek" in images of the user's house rather than in a generic house. The initial prototype development product looks somewhat like a traditional Android phone (although it is thicker) and incorporates a regular image sensor (4MP camera), a depth sensing sensor/receiver, and a lower resolution motion tracking camera, as well as dedicated vision processing chips (developed by private company Movidius which is highlighted later in the chapter). Google has a development kit for the experimental Project Tango product and anticipates many new innovative applications will be created which eventually will find its way into conventional smartphones.

Select Imaging Technology M&A Transactions

Some examples of recent image recognition M&A transactions are noted below. Although we are including only transactions from the past five years in this report, it is interesting to note that Google had acquired an image recognition technology company named Neven Vision back in 2006. Neven's technology could identify objects and people in images.

- **Qualcomm/Kooaba** – In January 2014, it was reported that Qualcomm Connected Experiences acquired Kooaba (per the 451 Group). Kooaba was a Switzerland-based company that developed a variety of image recognition technologies related to augmented reality. That is, its technology can recognize objects within captured images and then bring up relevant information about the objects.

- **Google/Industrial Perception** – In December 2013, a New York Times article reported that Google had acquired seven robotic related acquisitions, including Industrial Perception, which was focused on computer vision systems for controlling robotic arms and other applications.

- **Yahoo/IQ Engines and LookFlow** –Yahoo acquired LookFlow (image recognition technology company) in October 2013 and IQ Engines (which had an image recognition platform that could help identify objects, landmarks, or people in an image for mobile and Web applications) in August 2013 (per the 451 Group).

- **Dropbox/Anchovi Labs** – In September 2012, Dropbox acquired Anchovi Labs, which was focused on vision processing and image classification using learning and artificial intelligence technologies (per the 451 Group).

Select Embedded Vision Processor Companies

The following describes a couple of companies that have developed vision/image processor chip solutions. There are also many image processing software companies addressing different aspects of image/video analytics.

Movidius

Movidius has developed computational imaging chipsets that enable always-on smart capture and continuous vision processing applications for mobile devices. The company notes that embedded vision requires a highly programmable processor capable of sustained computational loads and memory bandwidths to keep pace with the demands of high-computation imaging applications and within the tight constraints of low power mobile platforms.

Movidius has created a high performance mobile imaging chip solution based on novel processor micro-architectures and memory systems. Unlike distributed approaches, the Movidius architecture maximizes throughput per clock cycle per milliwatt for computational imaging applications due to wide data parallelism and an optimized mix of fixed-function hardware and high performance programmable vector processors, all running at modest clock rates. Additionally, its memory architecture allows it to maintain sustained high parallelism with ultra-low latency and low power. The Company indicates it can achieve a teraflop of performance using only hundreds of milliwatts of power.

The Myriad 1 Mobile Vision Processor is optimized for advanced vision processing on mobile devices that have limited battery life. The Myriad 1 incorporates a variety of technologies that are specifically optimized for vision processing (highly parallel, customized memory fabric, ability to handle any kind of data, etc.). The Myriad 1 was designed to be very power efficient with a small footprint. The chip platform includes a vision software library and a portfolio of development tools, simplifying the development of vision-related applications. Applications include smartphones, tablets, PCs, wearable devices, and robotics. As previously noted, the Myriad 1 is incorporated into Google's Project Tango prototype.

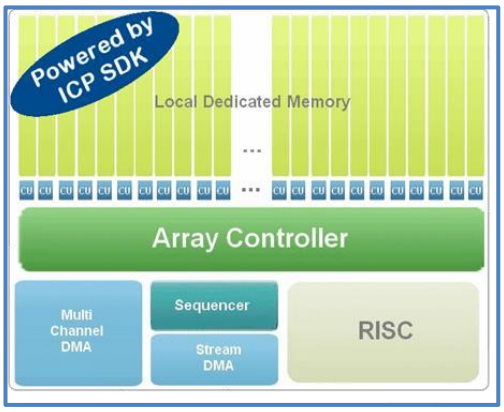
Movidius is targeting a wide range of applications such as gesture controls, eye-based interfaces, augmented reality simulations, post-capture refocusing and zooming, location based service and e-Commerce. In one augmented reality demo on its Web site, a user can try on various types of sunglasses (a tablet shows a live image of the user's face with different types of sunglass on, although the user isn't wearing sunglasses). In another demo, a user can capture an image of a room and arrange furniture in the augmented reality room without actually physically moving furniture.

In July 2013, Movidius announced a $16 million capital raise and that Remi El-Ouazzane (former VP and GM of Texas Instruments' OMAP unit) would assume the CEO position and that Dan Dobberpuhl (founder of P.A. Semiconductor, which was acquired by Apple, and SiByte, which was acquired by Broadcom) would assume the Chairman position.

Movidius, established in 2005, is headquartered in San Mateo, California and operates development centers in Dublin, Ireland and Timisoara, Romania. Movidius is a venture-backed company with investors including: AIB Seed Capital Fund, Atlantic Bridge, Capital-E, DFJ Esprit and Robert Bosch Venture Capital.

CogniVue

One issue with gesture recognition, and other computer vision applications in general, is that it can require a substantial amount of processing power to analyze video. Traditional processors, however, are not specifically optimized for vision-related applications, which can result in in sub-optimal performance, latency issues, and high power consumption. Alternatively, many mobile devices transmit data over the network to servers that perform the analysis, but that can result in latencies and won't work if the device doesn't have network access.



CogniVue has developed software, IP, and an Image Cognition Processor (ICP) that are specifically optimized for vision type applications. CogniVue's first ICP solution is the CV2201 APEX chip, which was designed specifically for vision processing and incorporates a RISC processor and local dedicated memory. CogniVue believes it can achieve a more than 100X advantage in performance per power relative to conventional approaches. The APEX can either be a stand-alone chip or its IP core can be integrated into a larger SoC (CogniVue licenses its APEX IP to other companies for integration).

CogniVue has also developed an APEX Software Development Platform and SDK for Embedded Vision. The ICP SDK framework contains APIs, libraries, and tools used to help developers create applications, capture images from sensors, render images to the display, and accelerate image cognition functions (such as gesture recognition).

CogniVue is targeting consumer, automotive, and industrial applications for its technology. It has announced a partnership with Freescale addressing vision processing in automotive. CogniVue is based in Gatineau, Quebec (just outside of Montreal) in Canada.

Pico-Projection and HUD Displays

A basic type of augmented reality technology is the pico-projector in which rather than just displaying images on its screen, the device can project images or videos on walls or other surfaces. This makes it easier for other people to see and can be used for business purposes (e.g., showing PowerPoint slides without a separate projector) or for entertaining friends (e.g., showing videos). Unlike traditional bulb-based projectors, pico-projectors generally use LEDs or laser diodes for illumination. While integrating some type of projection into a mobile device is relatively easy, the challenge is making it small (ideally so it doesn't increase the size of the overall device) and effective (powerful enough for the projected image to be clear even from a distance) with low power consumption.

Several relatively small pico-projector add-on products are available, although the goal has been to incorporate the technology directly into notebook PCs, tablets and smartphones. There have been a few smartphones that have integrated pico-projectors (e.g., the Samsung Galaxy Beam), but they typically are much thicker than conventional smartphones in order to accommodate the projection technology and generally the illumination power has been relatively weak compared to conventional projectors. Several public chip companies have developed pico-projector chipsets (e.g., Texas Instruments) and STMicroelectronics acquired an Israeli company named bTendo, which had developed pico-projection technology. A pure-play public company in the pico-projector sector is MicroVision. MicroVision's PicoP technology utilizes a MEMS scanner which is coupled with blue, red, and green laser lights to create a projected image. A number of start-ups have developed pico-projection solutions, although with the market taking longer to ramp up than had generally previously been anticipated, some have refocused on other markets.

A somewhat related market to pico-projection is heads-up displays (HUD) for applications such as automobiles. Increasingly consumers are making decisions about which car to purchase based not on the engine features, but on the car's infotainment/display systems. As the amount of electronics in cars increases, the number of things a driver may want to look at also increases. However, the more a driver looks down at the dashboard, the less focused he is on the road. With HUD technology, images can be projected right on the car's windshield, making it easier for a driver to see without looking down. For example, road images for navigation can be projected on the windshield, making it easier for drivers to follow directions. Warning signals can be displayed on the windshield so the driver can immediately see when there is an issue, rather than waiting for him to notice that a warning light on the dashboard is on. As the technologies required for pico-projectors and HUD are similar, some of the pico-projector companies are also addressing the HUD market.

Select Pico-Projection M&A Transaction

An example of a pico-projection M&A transaction was the following:

- **STMicroelectronics/bTendo** – In August 2012, STMicroelectronics acquired smartphone projection technology company bTendo. bTendo was based in Israel and had already been working closely with STMicro for a couple of years prior to the acquisition. The bTendo scanning laser projection engine produces a focus-free high-resolution output that can display images or video on surfaces. At the time of the announcement, the bTendo module was less than 1.7 cubic centimeters and was less than 5 millimeters high (per the 451 Group and company press releases).

Select Pico-Projection/HUD Private Company

An example of a private pico-projection and HUD technology company is Lemoptix.

Lemoptix

Lemoptix is a Switzerland-based company that has developed a unique MEMS scanning mirror technology. Leveraging this core technology, Lemoptix has developed a broad range of solutions addressing a variety of markets, including pico-projectors, HUD displays, and 3D gesture control and motion tracking.

The technology can be used for pico-projectors, enabling a smartphone to project presentations, images, or video on a wall or screen (or even on a glass as shown in the picture to the right). It can also be used for heads-up displays (HUD) in automobiles (allows the display of images and information right on the windshield of the car as indicated in the image to the right).

In 2013, Lemoptix announced that it received prototype purchase orders from two Fortune 10 consumer electronics companies for its solutions, and that it also received two prototype purchase orders for its HUD solutions from automotive companies.

Lemoptix, based in Lausanne, Switzerland, was incorporated in 2008 as a spin-off from the Swiss Federal Institute of Technology and the core technology had been in development for many years before that. The company recently received an investment from Swisscom Ventures.

MEMS Optical Auto-Focus Chips

Optical imaging is critical for many of the technologies previously described in this report (gesture recognition, eye tracking, facial recognition, augmented reality, vision processing, etc.). In addition, consumers are increasingly using smartphone cameras as their main camera/video recorder. An important technology related to imaging and cameras is auto-focus. For many vision-related applications having a focused image can be critical.

The most common method of implementing auto-focus in mobile phones has been voice coil motors (VCMs) which mechanically move the lens module to focus on an image. Typically the way this works is electrical current is passed through an electromagnetic coil, which creates a magnetic field causing the lens holder (which contain permanent magnets) to move away from the image sensor, if desired, while springs push the lens holder back. Based on the amount of current through the coil and the resulting magnetic field, the lens can be adjusted to any position to improve the focus.

However, VCM technology has a number of limitations and drawbacks. Specifically, VCMs are somewhat bulky and also consume a significant amount of power (especially for video or rapid photography when there is a need for many rapid-fire adjustments). Although the industry had been able to reduce the size of VCMs, it is generally acknowledged that further reductions will likely result in degraded performance. VCMs also have a number of technical issues such as hysteresis and lens tilt, and it is increasingly difficult to further drive costs down. As a result, there has been growing interest in utilizing MEMS technologies to implement auto-focus (as well as other features such as image stabilization and zoom). MEMS auto-focus solutions have the potential to be substantially thinner and consume far less power than VCMs, and can also have a variety of technical advantages.

MEMS Optical Auto-Focus Chip M&A

An example of an M&A transaction in this segment is shown below:

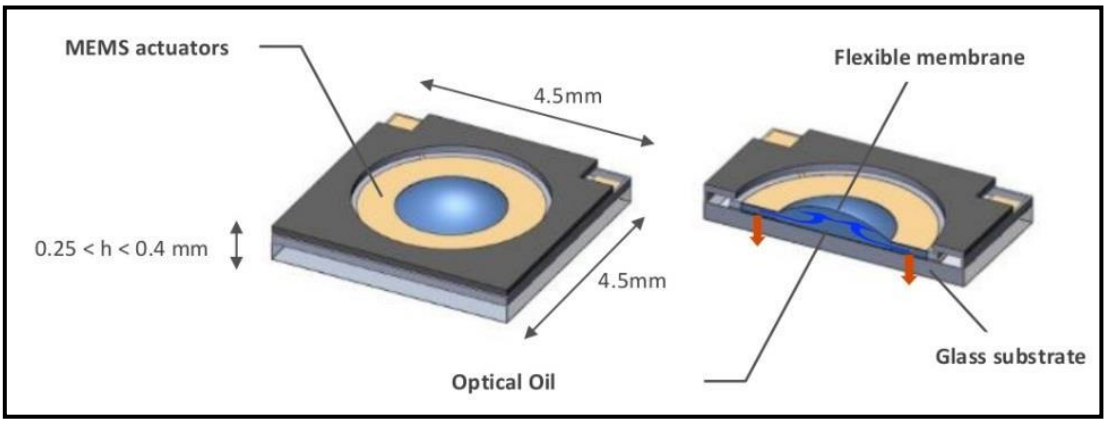
- **Tessera/Siimpel** – In May 2010, Tessera announced the acquisition of Siimpel for $15 million (per Capital IQ). Siimpel had developed a MEMS auto-focus solution addressing the smartphone camera market.

Select MEMS Optical Auto-Focus Chip Company

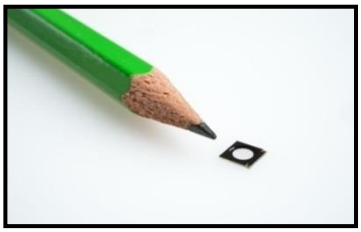
Although there are several MEMS auto-focus technology companies, each uses MEMS in a different manner to perform auto-focus. An example of a private company focused on this technology is Wavelens.

Wavelens

Wavelens has created a MEMS-based auto-focus solution for smartphones and portable electronic devices. The Wavelens solution contains an optical membrane with MEMS actuators around the periphery. When actuation occurs, optical oil flows through the membrane center. As a result, the membrane's curvature changes which also changes the focal length. This can be used to focus on an image.



Wavelens indicates that its technology has numerous advantages over VCMs including compactness (4X more compactness), power consumption (1000X better) and reliability (no moving mechanical parts). In addition, Wavelens believes the cost can be dramatically less than VCMs once its MEMS chip is produced in high volume, as its solutions benefit from traditional semiconductor scaling. Unlike some MEMS solutions which require very high voltages, the Wavelens chip needs only about 10 volts (which also reduces the cost for driver electronics). The optical MEMS has a functional thickness of less than 100µm. The Wavelens solution can also be modified to handle a variety of wavelengths including infrared light. Although Wavelens is initially focused on auto-focus, it believes that its technology can also be utilized for optical zoom and image stabilization. The core technology is patented and was initially developed within CEA-LETI. Wavelens is based in Grenoble, France.



Virtual Reality/Holographic Imaging/Telepresence

There are a variety of related technologies that involve advanced 3D imaging. Some of these include:

- **Virtual Reality** – Unlike augmented reality (which augments real images), virtual reality creates an entirely computer simulated environment. The term is somewhat ambiguous and is sometimes used for something as simple as conventional video games with realistic graphics. However, we use it to refer to immersive solutions which give the user the sense (at least to some extent) that they are in a different virtual world. Historically, this was most commonly implemented through helmet mounted displays that provide 3D video imaging.

- **Holographic/3D Imaging** – Holographic imaging enables 3D images to be recorded and displayed. A hologram records information about the light that came from a scene in all directions (rather than in just one direction like a photo). Typically two lasers are used (one is directed at the image and the reflected light hits the recording medium, the other is directed at the recording medium), and the interference pattern between the two lasers is recorded. However, there are a variety of other 3D imaging technologies that aren't necessarily holograms. There are a number of solutions that have been developed that can project 3D images in mid-air. For example, a person giving a PowerPoint presentation can project images of graphs and graphics in mid-air in front of the audience. However, these solutions are fairly expensive and large. Last year it was announced that a group of researchers from Hewlett Packard Laboratories developed glasses-free, multi-perspective, 3D display technology for mobile devices (as reported in MIT Technology Review and other media reports).

- **Telepresence** – Telepresence includes a number of technologies that simulate a person being present or allowing a person to feel as if he is present at a location besides the one he is at. This goes beyond simple video conferencing and may include, for example, creating holographic/3D images of the people on the other end of the line.

Affective Computing/Emotion Analytics

Affective computing is the concept of computing devices being able to recognize (and even simulate) human emotions. Typically, sensory input is used to determine the user's emotional state. This could include optical imaging, voice input, or even brainwave patterns. By analyzing sensory data (the user's facial expressions, body language and gestures, speech, etc.), computing devices can determine a user's mood and can use this information to better meet the user's needs. For example, if a user is getting frustrated with a game, the device can adjust the difficulty level or provide some hints. If the user appears to be in a bad mood, it can play music to cheer the person up. Longer term, this should improve the ability of computers to interact with people.

Select Emotion Analytics Company

An example of a company that has developed emotion analytics technology is nViso, which is highlighted below.

nViso

nViso has developed technology that analyzes facial expressions to determine human emotions. It has been shown that basic human emotions (happiness, surprise, fear, anger, disgust, and sadness) are generally conveyed by facial expressions. In 1978, Ekman and Friesen developed the Facial Action Coding System (FACS), which focused on categorizing human facial expressions for determining emotions. Based on this basic background scientific work, nViso has developed complex algorithms that capture 3D images of a person's face, measure the major facial muscles associated with emotions (specifically tracking 43 facial muscles), and then analyze the data to determine a person's emotional state in real time. The nViso solution is designed to work even with relatively poor lighting conditions and with motion blur. nViso provides APIs for mobile apps allowing data capture using smartphones or tablet devices.

The initial applications for nViso's technology have been marketing-related (e.g., determining consumer responses on a second by second basis as they watch a video or while they view images or displays). However, longer term, the technology can be used to improve interaction between computing devices and people. For example, if an electronic device can recognize a person is sad, it could potentially take action to try to make the person happy (play certain music, make a game less difficult, etc.). The company's Emotion Video Analytics is available using IBM SmartCloud Enterprise. nViso has announced a number of ad research partnerships and has a real-time 3D facial imaging API. At Mobile World Congress 2014, nViso demonstrated its solution running on a Ceva DSP. The company is based in Lausanne, Switzerland, and has an association with the Swiss Federal Institute of Technology (EPFL).

Many Innovative Technologies in Development

The technologies discussed in this chapter and report only scratch the surface of the types of interface technologies that are being developed. For example, although it was the subject of a Google April Fool's Day joke (on April 1, 2013, Google announced "Google Nose" which could search for smells), there are actually a number of start-ups developing olfactory interface technologies that can either determine what something smells like or produce odors (e.g., a user paying a racing game might smell burning rubber which helps make the game more realistic). It will be very interesting to see the number of new and innovative technologies that are developed over the next decade.

Chapter 10 – Some Final Thoughts

"*And in the end….the love you take is equal to the love you make*."
- Paul McCartney

The technology landscape can change very quickly. A decade ago (when the leading mobile phone OEMs included Nokia, Motorola, and Sony Ericsson), who would have predicted that the handset market would soon be dominated by companies such as Apple, Samsung, Huawei, LG and Lenovo (with a majority of the operating systems provided by Google)? Over the next decade, it is certainly possible that we will see continued market share leadership changes, and this may be based on new products incorporating innovative human interface technologies that greatly improve the user's experience.

There is growing interest in HMI technologies from a broad range of different types of companies (e.g., smartphone OEMs, consumer electronics companies, software companies, chipmakers, Web companies, social media companies, etc.). It is interesting to note that some of the companies listed in this report that have made user interface related acquisitions include Apple, Google, Yahoo, Intel, Qualcomm, Microsoft, Amazon, and Facebook.

With HMI technologies becoming increasingly important, a variety of start-ups focused on innovative user interface solutions, and strong interest from many of the largest technology companies, there may be a robust M&A market in this sector over the next several years.

We hope this document has been useful. We tried to highlight a variety of technologies and companies, but obviously had to limit the number of topics covered, the amount of space devoted to each topic, and the number of companies covered. Our hope is to periodically issue future editions with updated data and additional topics. As a result, if there are any comments or recommendations, let us know. We will attempt to address any comments we receive in future editions.

Finally, if you have, or know anyone that has, M&A interest (sell side or buy side) in this sector, or any area within technology for that matter, please give us a call. We look forward to speaking with you.

Appendix: M&A Summary

"*I am a brain, Watson. The rest of me is a mere appendix*."
- Sherlock Holmes

The following table is a summary of many of the M&A transactions noted throughout this report. In many cases, the valuation of the deal was not publically announced and we relied on third party data sources for this information when available. In some cases, the Enterprise value listed does not include earn-outs (e.g., the Synaptics/Validity deal had a substantial potential earn-out of more than $162 million).

Date	Acquirer	Target	Target Description	Enterprise Value ($M)
Jan-2014	Google	DeepMind Technologies	General-purpose, artificial learning, algorithm-based simulation software	$400.0
Jan-2014	Qualcomm	Kooaba	Mobile image recognition software application for software developers and businesses to integrate into mobile applications	
Dec-2013	Google	Industrial Perception	3D vision systems for robotics and other applications	
Dec-2013	Yahoo	SkyPhrase	Speech recognition software that enables users to more easily communicate with computers by using natural language	
Nov-2013	Apple	PrimeSense	3D gesture recognition/machine vision technologies for digital devices; provides SoC solutions and software	$345.0
Oct-2013	Verint Systems	Victrio	Biometric voice recognition and authentication SaaS that enables secure access to accounts and passive background monitoring	
Oct-2013	Yahoo	LookFlow	Image recognition and machine learning technology	
Oct-2013	Synaptics	Validity Sensors	Fingerprint biometric sensors for use in identity authentication	$92.5
Oct-2013	Google	Flutter	Gesture recognition software application that enables PC users to control a range of applications via a built-in webcam	$40.0
Sep-2013	IDEX	PicoField Technologies	Biometric consumer device fingerprint scanning and sensor systems for mobile device manufacturers	
Sep-2013	Intel	Indisys	Natural language recognition software and Web and mobile artificial intelligence interactive customer service software	$26.0
Aug-2013	Facebook	Jibbigo (Mobile Technologies)	Speech-to-speech mobile device based translation software that translates spoken words for use with iOS and Android devices	
Aug-2013	Yahoo	IQ Engines	Image recognition technology that can determine which objects are in a scene for photo tagging and other applications	
Jul-2013	Google	SR Tech Group, LLC - Patents	Portfolio of speech-related patents including "Speech interface for search engines"	

Sources: Capital IQ, 451 Group, company reports, and media reports.

Date	Acquirer	Target	Target Description	Enterprise Value ($M)
Jul-2013	Intel	Omek Interactive	Gesture recognition software and hardware for use in consumer electronics, auto, gaming and healthcare	$50.0
Apr-2013	Google	wavii	Smart phone news aggregation and reader application that delivers customized news feeds	$30.0
Apr-2013	Amazon	Evi Technologies	Mobile speech-recognition application that enables mobile device users to receive answers to spoken questions and instructions	$26.0
Jan-2013	TPK	MasTouch Optoelectronics	Projected capacitive mode touch-and-control panel boards	
Jan-2013	Amazon	Ivona	Multi-lingual speech synthesis systems	
Jan-2013	Nuance	VirtuOz	Web-based virtual assistant customer service software	
Oct-2012	Google	Viewdle	Facial recognition software for mobile devices. Also developing image recogntion solutions (smiles, gestures, etc.)	$40.0
Sep-2012	Dropbox	Anchovi Labs	Computer vision and articifial intelligence technologies for classifying objects	
Sep-2012	Nuance	Ditech Networks	Voice-to-text conversion and voice quality assurance software	$22.5
Sep-2012	Qualcomm	EPOS Development	Embedded semiconductor software that uses digital positioning technology to control user input movements	
Aug-2012	STMicro-electronics	bTendo	Embedded MEMS for use in video-projection applications for mobile device and digital camera manufacturers	
Jul-2012	Apple	AuthenTec	Biometric fingerprint authentication sensor systems and software for computer and electronic device manufacturers	$356.1
Jul-2012	Microsoft	Perceptive Pixel	Multi-touch display technologies and large screen displays	
Jun-2012	Facebook	Face.Com	Facial recogntion (primarily for recognition of faces in uploaded photos)	$60.0
Apr-2012	Gores Group	TE Connectivity	Touch screen solutions business (sensor-based touch screen displays and computers sold under EloTouch brand)	$380.0
Feb-2012	VoiceTrust	Perceive Solutions	Biometric speech-recognition software for the purpose of authenticating users	
Dec-2011	Nuance	Vlingo	Mobile speech-recognition voice command application (Nuance paid $196.3M, but already had an equity stake in Vlingo)	$225.0
Nov-2011	Amazon	Yap	White-label voice-to-speech recognition SaaS	
Aug-2011	Nuance	Loquendo	Multi-language recognition and text-to-speech conversion software	$75.3

Sources: Capital IQ, 451 Group, company reports, and media reports.

Date	Acquirer	Target	Target Description	Enterprise Value ($M)
Jul-2011	Qualcomm	GestureTek	Camera-enabled gesture recognition software	
Jul-2011	Google	PittPatt	Facial recognition software that identifies human faces in photographs and tracks the motion of human faces in video	$38.0
Jun-2011	Nuance	SVOX	Desktop and mobile voice automation and authentication, speech recognition and text-to-speech conversion software	$122.5
May-2011	TPK	Cando	Multi-touch capacitive touch panel products (TPK acquired only about 20% of the equity for about $190 million)	$954.7
Feb-2011	TandemLaunch Technologies	Mirametrix	Gaze tracking systems for use in vision research and content analytics applications	
Jan-2011	Google	SayNow	Voice/telephony related solutions including conference-call type voice meetings	
Jan-2011	Nuance	PerSay	Biometric voice authentication software	
Dec-2010	Google	Phonetic Arts	Speech synthesis (speech to text) technologies and solutions	
Oct-2010	Microsoft	Canesta	3D image sensor semiconductors and software for consumer electronics and videogames and auto	
May-2010	Tessera	Siimpel	MEMS auto-focus chips for smartphone cameras	$15.0
Apr-2010	Apple	Siri	Mobile application that enables iPhone and iPod Touch users to ask questions and receive answers and recommendations	$200.0
Mar-2010	Bayer Material Science	Artificial Muscle	User touch-based interface devices and haptic actuators for use in consumer electronics and medical devices	
Jan-2010	AuthenTec	UPEK	Biometric security and access control systems for computer and electronics manufacturers	$32.0
Mar-2009	Microsoft	3DV	Motion-detection cameras used in gaming and web-conferencing by both consumers and enterprises	$35.0

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Notes

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