Interactive Displays: The Next Omnipresent Technology

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Visual display of information is an obvious requirement in today's highly digital world, and constitutes a powerful means of conveying complex information. This stems from the ability of the human eye and brain to perceive and process vast quantities of data in parallel. The history of visualizing information can be traced to the ancient era, when our ancestors carved images on cave walls and monuments (around 30 000 BC [1]). Mosaic art form emerged in the 3rd millennium BC [2], using small pieces of glass, stone, or other materials in combination to display information. These pieces are similar to pixels in the modern electronic display. The electronic display has become the primary human–machine interface (HMI) in most applications, ranging from mobile phones, tablets, laptops, and desktops to TVs, signage, and domestic electrical appliances, not to mention industrial and analytical equipment.

In the meantime, user interaction with the display has progressed significantly. Through sophisticated hand gestures [3]–[13], the display has evolved to become a highly efficient information exchange device. While interactive displays are currently very popular in mobile electronic devices such as smartphones and tablets, the development of large-area, flexible electronics, offers great opportunities for interactive technologies on an even larger scale. Indeed technologies that were once considered science fiction are now becoming a reality; the transparent display and associated smart surface being a case in point. These technologically significant developments beg the question, "Will interactive displays be the next omnipresent technology?" This article will review current mainstream interactivity techniques and predict what we believe will be future interactive technologies.

I. INTERACTIVE DISPLAY TECHNOLOGIES

Human–machine interactivity can be categorized based on touch or touch-free gestures. The former is primarily employed in the small- and medium-scale screens used in smartphones and tablets, while the latter is more popular in larger displays. Various techniques for interactivity have been developed (see Fig. 1). Currently, these are mainly based on resistive, capacitive, surface acoustic wave, acoustic pulse recognition and infrared schemes [3]. Recently, touch-free (e.g., gesture recognition by optical imaging) and force-touch techniques have emerged and are now in commercial devices. These advanced features bring human–machine interactivity to a new level of user experience.

A. Touch Interactivity Architectures

The first generation of touch screens employed resistive-based architectures [4], in which two transparent electrically resistive layers are separated by spacer dots and connected to conductive bars in the

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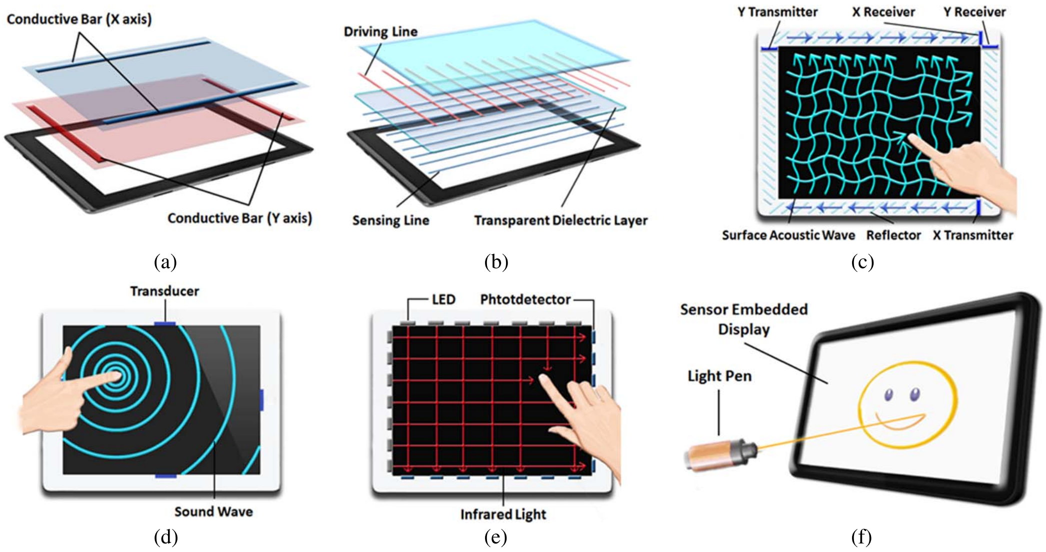

Fig. 1. ***Interactivity based on (a) resistive, (b) capacitive, (c) surface acoustic wave, (d) acoustic pulse recognition, and (e) infrared touch architectures; and (f) touch-free interactive display based on image sensor.***

horizontal (X-axis) and vertical (Y-axis) sides, respectively. A voltage applied on one layer can be sensed by the other layer, and *vice versa*. When the user touches the screen, the two layers are connected at the touch point and work as voltage dividers, and the touch location is then calculated. These first generation devices were limited to locating a single point, restricting their use for complex gestures.

In capacitive-based touch panels, electrodes are arranged as rows and columns and are separated by an insulating material such as glass or thin film dielectric. When a conductive object comes in contact with the screen surface, the electrostatic field is perturbed hence changing the capacitance between electrodes [5], [6]. Capacitive touch panels are most commonly used in smartphones because they support multitouch without altering the visibility and transparency of the display.

In surface acoustic wave and acoustic pulse recognition interactivity schemes, the touch position is detected by acoustic waves [7], [8]. In the former, ultrasonic waves are transmitted and reflected in the X- and Y-directions. By measuring the touch-induced absorption of the waves, the location can be determined. In acoustic pulse recognition, transducers are fitted at the edges of the touch panel. A touch action on the screen surface generates a sound wave that is then detected by the transducers, digitalized and subsequently processed to determine the touch position.

In the infrared-based architecture, two adjacent sides of a touch screen are equipped with light emitting diodes, which face photodetectors on the opposite sides, forming an infrared grid pattern [9], [10]. The touch object (e.g., finger or stylus) disrupts the grid pattern, from which the touch location is determined.

The techniques described above detect 2-D single touch or multiple touch, i.e., touch locations on an X-Y plane. Recently, commercial products released by Apple support force sensing, expanding touch interactivity to 3-D [11]. Here, screen deflection, and hence the corresponding change in capacitance, serves as a measure of the extent of applied force, which is then augmented with a haptic response. An alternate arrangement for 3-D interactivity has been recently developed using a force sensitive (piezoelectric) layer and augmenting it with the standard capacitance touch [12]. The advantage of using a piezoelectric layer is that it generates its own power and thus can be operated in power savings mode. In addition, it is sensitive to touch at the edges of the display; a feature, which is intrinsically limited with deflection.

B. Touch-Free Interactivity Architecture

While a variety of touch technologies are currently in use in products, touch-free gesture recognition has emerged recently. One current technique relies on locating discrete infrared sources and detectors at different positions on the display edges to construct the touch event. However, imaging is not possible because of the discrete nature of the sensors. The pixelated approach reported recently employs an image sensor integrated at every display pixel. This way the display is actually able to view the underlying gestures of the user. Alternately the event can be remotely triggered by a light pen [14]–[17]. The interactive display can be transparent using, e.g., oxide semiconductor technology, and be able to carry out invisible image capture. This development has the potential for high technological impact in human interfaces.

Voice recognition is another technique for remote interactivity [18]. Tremendous progress has been made in this area with very impressive results. Existing commercial products include Siri and Echo from Apple and Amazon, respectively. Despite that, challenges remain in voice signal processing and machine limitations of speech perception. This is particularly true with differently spelled but similar sounding words, and signal recognition in a noisy acoustic background. These problems can be eventually overcome with use of much faster processors and more memory to bring into consideration contextual information.

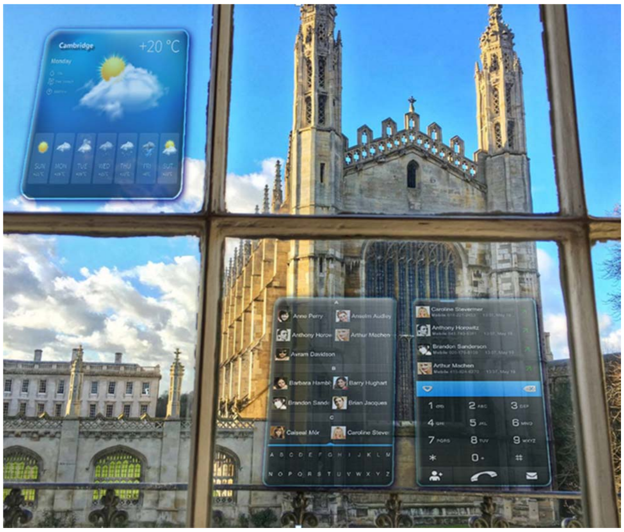

Fig. 2. *Conceptual figure of future windows-based interactive display.*

II. THE FUTURE IN HUMAN–MACHINE INTERACTION

The future interactive medium will not be a dedicated display but will be in the form of smart surfaces integrated with everyday objects. These interactive surfaces can be made of glass, textile, or cellulose fibers that suitably embed one or more of the previously described architectures for touch or touch-free interactivity. This could be a game changer as it means that we can constantly interact with an intelligent ambient and not feel disconnected. We will see a rapid proliferation of smart surfaces, and one technology that is fueling smart surface development is glass, which by all accounts is silicon dioxide. By layering other oxide materials comprising semiconductors, conductors, and insulators, active electronics can be integrated on these surfaces without compromising the original transparency, thanks to the large bandgap of oxides in general [19]–[21].

Thus, any glass surface can be turned into an interactive media, as conceptually depicted in Fig. 2. Thanks to the growing advancements in large area [22]–[24] and flexible [25]–[27] electronics technologies, such surfaces can be extended to the windshield of cars, table tops, and walls, and eventually to curtains and clothing. These could revolutionize the way we perceive personal lifestyles and work environments.

While display interactivity has become an indispensable component of many people's lives, especially for mobile device users, there is growing expectation for even more advanced form of interaction requiring the need to sense and provide feedback, particularly in the area of healthcare monitoring. For example, a user's biological state, such as heart rate, body temperature, and glycemia levels could be sensed and the corresponding health information can be analyzed and results imaged to users. From a feedback standpoint, the

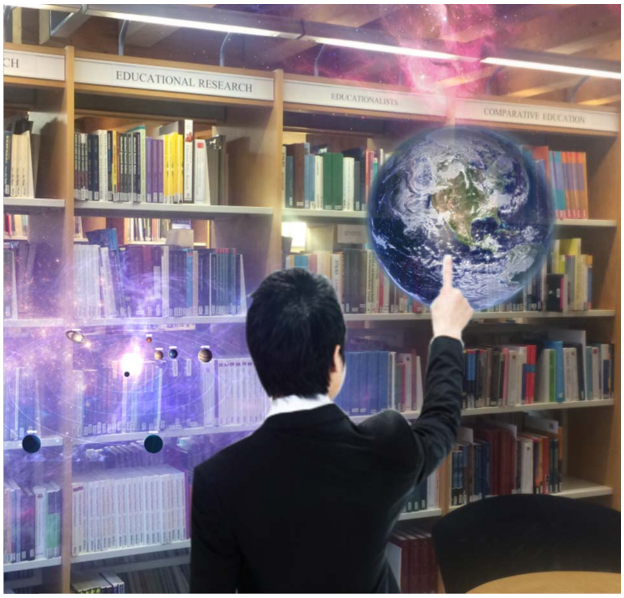

Fig. 3. *Conceptual depiction of immersive interaction.*

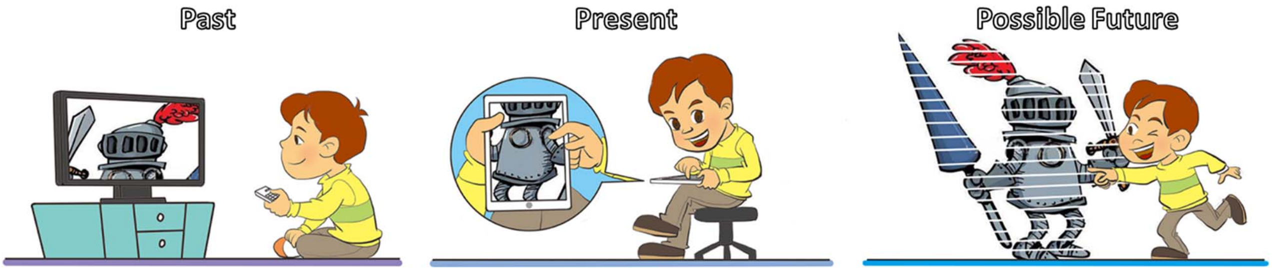

Fig. 4. *The past, present, and future in interactive displays.*

current feedback medium is light, sound, or vibration, which does not completely satisfy user needs. Haptic feedback with an awareness of the underlying context will bring in a new dimension, in which, for example, temperature and shape can be experienced by the user following contextual information on screen. For example, when the weather is illustrated on screen, the temperature and related conditions could be felt by haptic feedback. This could be extremely useful for the visually impaired.

Equally significant is interactivity with the immersive ambient as widely described in science fiction and in movies (e.g., *Minority Report* in 2002). For example, projected keyboards can replace traditional physical keyboards. This will allow users to immerse themselves in visual information and manipulate that information remotely using both hands. For instance, a user can zoom around a virtual planet earth in the solar system (as conceptually depicted in Fig. 3). This will no doubt trigger a child's passion for science and the environment. Immersive interactions not only provide a new experience to users but also to much improved services resulting in higher work productivity.

So, how far away are we from all this becoming a reality? Some prototypes of future interactive displays have already been demonstrated. An 18-in, large-sized, flexible OLED display [28] with a bending radius of 30 mm was reported in [28] and a transparent double-sided touch display in [29], in which users could maintain face-to-face interaction. In [30], a dynamically shaped display was presented, providing a deformable interface free of form factor to enrich the physical interaction of users with general purpose computing interfaces. Microsoft announced the release of Hololens in 2016, which provides the user with immersive interactions with virtual objects [31]. Indeed these future interactive display technologies beyond what has been described above will become reality in the not so distant future.

III. CONCLUSION

The history and current status of interactive displays have proven that HMI is a must-have component in the livelihood of people by providing a convenient and highly efficient information exchange platform. The evolution of HMI of the past, current, and possibly in the future is conceptually depicted in Fig. 4, in which HMI will be extensively employed, with a strong potential to become ubiquitous not only for the mobile device but in the way we will interact with our environment. This will go beyond the current signal domains of mechanical (i.e., touch/haptics) and light (i.e., display), to thermal and possibly odor transmission and perception.

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