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 because of 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 30000 BC [29]). Mosaic art form emerged at the 3rd millennium BC [30], 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 emerged to become the primary human-machine interface 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 [1]-[10], 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 smart phones 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 point of view article will address this by reviewing current mainstream interactivity techniques and try to predict what we believe will be the future interactive technologies and how they might be used

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 smart phones and tablets, while the latter is more popular in larger displays. Various techniques for interactivity have been developed. Currently these are mainly based on resistive, capacitive, surface acoustic wave, acoustic pulse recognition and infrared schemes [1]. Recently, touch-free (e.g. gesture recognition by optical imaging) and force-touch have emerged and are now in commercial devices. These advanced features bring human-machine interactivity to a new level of user experience.

Touch Interactivity Architectures

The first generation of touch screens employed resistive based architectures [2], in which two transparent electrically resistive layers are separated by spacer dots and connected to conductive bars in the horizontal (X-axis) and the vertical (Y-axis) sides, respectively. A voltage applied on one layer can

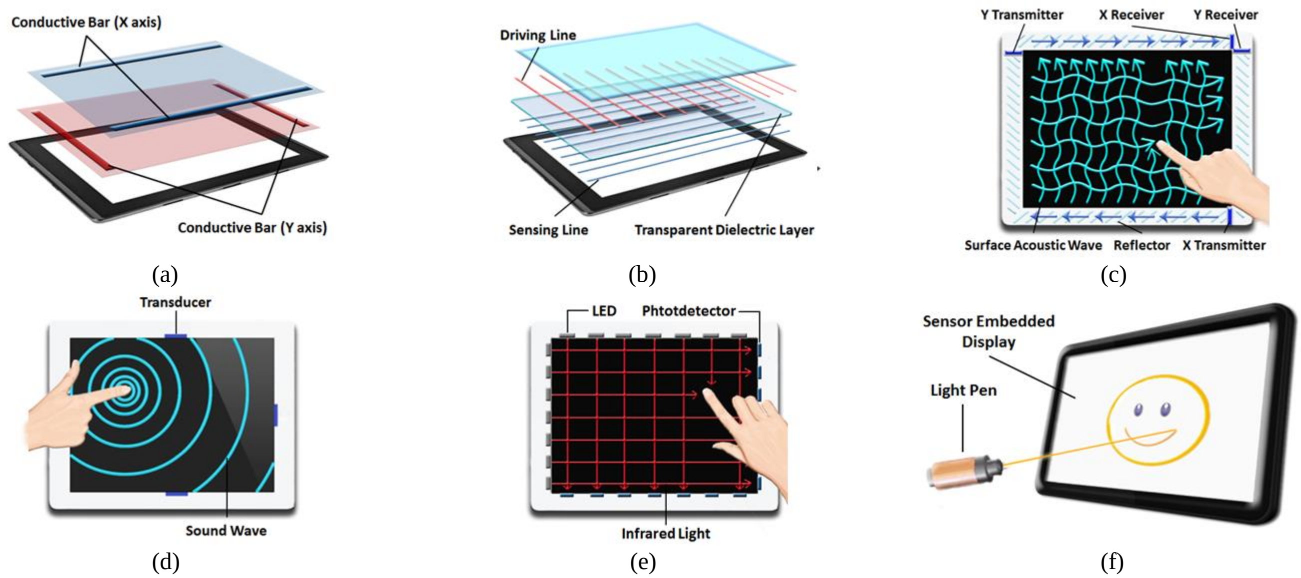


Fig. 1. Interactivity based on (a) – (e): resistive, capacitive, surface acoustic wave, acoustic pulse recognition and infrared touch architectures, and (f): touch-free interactive display based on image sensor.

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 [3,4]. Capacitive touch panels are most commonly used in smart phones because they support multi-touch 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 [5][6]. 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 [7][8]. The touch object (e.g. finger or stylus) disrupts the grid pattern, from which the touch location is determined.

The techniques described above detect two-dimensional single- or multi-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 [9]. 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 [31]. The advantage of using a piezoelectric layer is that it generates its own power and thus can be operated in power saving mode. In addition, it is sensitive to touch at the edges of the display; a feature, which is intrinsically limited with deflection.

Touch-Free Interactivity Architecture

Whilst 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 [11-14]. 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 interface applications.

Voice recognition is another technique for remote interactivity [15]. Existing commercial products include Siri and Echo from Apple and Amazon respectively (we will not discuss them in details as it will be out of scope of the current point of view). Nevertheless, challenges remain in voice signal processing and machine limitations of speech perception. This is particularly true with differently spelled but similar sounding words, and speech recognition in a noisy background. These problems can be eventually overcome with use of much faster processers and more memory to bring into consideration contextual information.

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 such as windows. These interactive surfaces can be made of glass, textile or cellulose fibres 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 when the mobile phone is misplaced or lost. 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 [16]-[18].

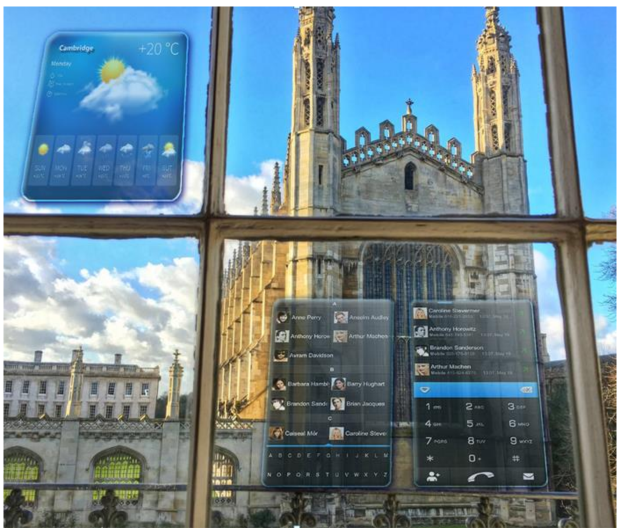


Fig. 2. Conceptual figure of future windows based interactive display.

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 [19]-[21] and flexible [22]-[24] 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 working 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 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 based on the contextual information on screen. For example, when the weather is

Fig. 3. Conceptual depiction of immersive interaction.

illustrated on screen, the temperature and related conditions can be felt by haptic feedback. This could be extremely useful for the blind.

Equally significant is the capture of interactions 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 with touch-free interaction using both hands. For instance, a user can zoom around a virtual planet earth rotating in the solar system (as conceptually depicted in Fig. 3), no doubt triggering a child's passion for science and the environment. Immersive interactions not only provide a new experience to users but also much improved services resulting in higher work productivity.

So, how far away are we from all this becoming a reality? Some prototypes of the future interactive displays described above have already been demonstrated. An 18-inch, large-sized, flexible OLED display [25] with a bending radius of 30 mm was reported in [25] and a transparent double-sided touch display in [26], in which users could maintain face-to-face interaction. In [27], a dynamically-shaped display was presented, providing a changing-form-factor, deformable interface to enrich the physical interaction of users with general purpose computing interfaces. Furthermore, with holography-related techniques, Microsoft announced the release of Hololens in 2016, which provides the user with immersive interactions with virtual objects [28]. Indeed these future interactive displays are becoming closer .

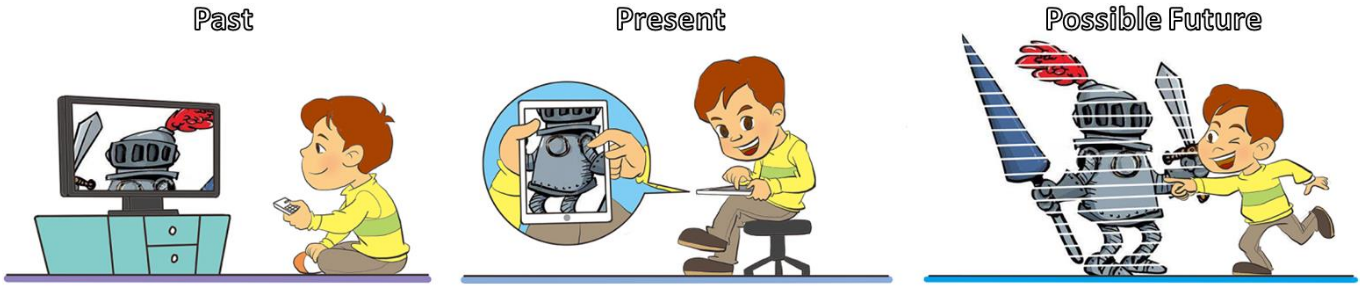


Fig. 4. The past, present and future in interactive displays.

CONCLUSION

The aim of developing technology is to bring convenience to the lives of humans. The history and current status of interactive displays have proven that HMI is 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 the foreseeable future, HMI will be more 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 odour transmission and perception.

REFERENCES

[1] G. Walker, “A review of technologies for sensing contact location on the surface of a display”, in *J. Society of the Inform. Display*, vol. 20, issue 8, pp. 413-440, 2012.

[2] C. Jr. William, H. S. George, “Discriminating contact sensor”, U.S. Patent 3 911 215 A, Oct. 1975.

[3] G. Barrett and R. Omote, “Projected-capacitive touch technology”, in *Inform. Display Mag.*, vol. 26-3, pp. 16-21, 2010.

[4] E. A. Johnson, “Touch display – a novel input/output device for computers”, in *Electron. Lett.*, vol. 1, issue 8, pp. 219-220, 1965.

[5] R. Adler and P. J. Desmares, “An economical touch panel using SAW absorption”, in *IEEE Trans. Ultrasonics, Ferroelectrics and Frequency Control*, vol. UFFC-34, no. 2, pp. 195 – 201, 1987.

[6] K. North and H. D’Souza, “Acoustic pulse recognition enters touch-screen market,” in *Information Display* 22-25, Dec. 2006.

[7] N. Cohen, “Timeline: a history of touch-screen technology”, National Public Radio, Dec. 2011.

[8] A. Butler, S. Izadi and S. Hodges, “Side Sight: multi-“touch” interaction around small devices”, in *Proceedings of the 21st annual ACM symposium on User interface software and technology*. ACM, 2008.

[9] O. Raymudo, “Iphone 6S display teardown reveals how 3D touch sensors actually work,” message posted to Macworld, 13th Oct. 2015.

[10] S. Jeon et al., ‘‘Gated three-terminal device architecture to eliminate persistent photoconductivity in oxide semiconductor photosensor arrays,’’ in *Nature Mater*., vol. 11, no. 4, pp. 301–305, Feb. 2012.

[11] S.-E. Ahn et al., “Metal oxide thin film phototransistor for remote touch interactive displays,” in *Adv. Mater*., vol. 24, no. 19, pp. 2631–2636, May 2012.

[12] S. Jeon et al., “Dual gate photo-thin film transistor with high photoconductive gain for high reliability, low noise flat panel transparent imager,” in *IEEE Int. Electron Devices Meet*., 2011, pp. 14.3.1–14.3.4.

[13] S. Jeon et al., “Nanometer-scale oxide thin film transistor with potential for high density image sensor applications,” in *ACS Appl. Mater. Interfaces*, vol. 3, pp. 1–6, 2011.

[14] S. Lee, S. Jeon, R. Chaji, A. Nathan, “Transparent semiconducting oxide technology for touch free interactive flexible displays," Proc. IEEE, vol. 103, No. 4, April 2015.

[15] H. Zhang and W. L. Ng, “Speech recognition interface design for in-vehicle system.”in *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 29-33. ACM, 2010.

[16] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano and H. Hosono, “Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors,” in *Nature*, 432, no. 7016: 488-492, Nov. 2004.

[17] K. Nomura, H. Ohta, K. Ueda, T. Kamiya, M. Hirano and H. Hosono, “Thin-film transistor fabricated in single-crystalline transparent oxide semiconductor”. *Science*, *300*(5623), pp. 1269-1272, 2003.

[18] H. Hosono, "Recent progress in transparent oxide semiconductors: Materials and device application." *Thin Solid Films*, vol. 515, no. 15, pp. 6000-6014, May 2007.

[19] G. Eda, G. Fanchini and M. Chhowalla, “Large-area ultrathin films of reduced graphene oxide as a transparent and flexible electronic material”, in *Nature Nanotechnology*, 3, pp. 270-274, Apr. 2008.

[20] M. L. Chabinyc et al, “Printing methods and materials for large-area electronic devices”, in *Proceedings of IEEE*, vol. 93, issue 8, pp. 1491-1499, Aug. 2005.

[21] T. Someya et al. "A large-area, flexible pressure sensor matrix with organic field-effect transistors for artificial skin applications." in *Proceedings of the National Academy of Sciences of the United States of America* 101.27: 9966-9970, 2004.

[22] Y. Chen, J. Au, P. Kazlas, A. Ritenour, H. Gates and M. McCreary, “Electronic paper: Flexible active-matrix electronic ink display”, in *Nature* 423.6936, pp. 136-135, May 2003.

[23] R. J. Hamers, “Flexible electronic futures”, in *Nature*, 412, pp. 489-490, Aug 2001.

[24] X. Lu and Y. Xia, “Electronic materials: Buckling down for flexible electronics”, in *Nature Nanotechnology*, 1, pp. 163-164, 2006.

[25] J. Yoon et al, “World 1st large size 18-inch flexible OLED display and the key technologies”, in *SID Symposium Digest of Technical Papers*, vol. 46, issue 1, pp. 962-965, June 2015.

[26] H. Heo, H. K. Park, S. Kim, J. Chung, G. Lee, and W. Lee, "Transwall: a transparent double-sided touch display facilitating co-located face-to-face interactions." in *CHI'14 Extended Abstracts on Human Factors in Computing Systems*, pp. 435-438. ACM, 2014.

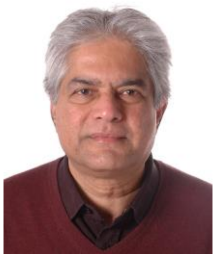
[27] D. Leithinger, S. Follmer, A. Olwal, and H. Ishii, "Shape displays: spatial interaction with dynamic physical form," in *IEEE Computer Graphics and Applications,* vol. 35, no. 5, pp. 5-11, Sep. 2015.

[28] H. Chen, A. S. Lee, M. Swift, and J. C. Tang, “3D collaboration method over HoloLens™ and Skype™ end points," in *Proceedings of the 3rd International Workshop on Immersive Media Experiences*, pp. 27-30. ACM, 2015.

[29] J. M. Chauvet, E. Brunel Deschamps and C. Hillaire, “*Dawn of art: the Chauvet Cave: the oldest known paintings in the world*”, HN Abrams, 1996.

[30] A. Joan, and R. Wallenfels, “*Art of the First Cities: the Third Millennium BC from the Mediterranean to the Indus*”, Metropolitan Museum of Art, 2003.

[31] A. Nathan, J. Lai, S. Cha, C. Church, “Pressure sensing display device”, US 20140008203 A1, 9th Jan 2014.



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