International Journal of Automation and Computing 14(1), February 2017, 10-20
DOI: 10.1007/s11633-016-1039-6

Innovative Developments in HCI and Future Trends

Mohammad S. Hasan[1] Hongnian Yu[2]
[1]Faculty of Computing, Engineering and Sciences, Staffordshire University, UK
[2]Faculty of Science and Technology, Bournemouth University, UK

Abstract: The recent developments in technology have made noteworthy positive impacts on the human-computer interaction (HCI). It is now possible to interact with computers using voice commands, touchscreen, eye movement, hand gesture, etc. This paper compiles some of the innovative HCI progresses in various areas, e.g., specialised input/output devices, virtual or augmented reality, wearable technology, etc. It also identifies some future research directions.

Keywords: Human-computer interaction (HCI), virtual reality, augmented reality, haptic feedback controller, smart-home.

1 Introduction

The recent technological developments in computing have changed the human-computer interaction (HCI) quite significantly. Current desktop or laptop computers are equipped with speedy and vast processing capabilities, e.g., multi-core processors with hyper threading, larger and faster main memory, powerful graphics cards, solid state drive (SSD) based secondary memory as well as built-in input-output devices (e.g., webcam and sound card). These computers normally run operating systems such as Linux, Mac OS, Windows, etc. Similarly, mobile devices, e.g., smart-phones, smart-watch, tablet computers with 8-core processor, 3GB or higher RAM, 32GB or higher SSD storage, multi-touch screen, high resolution cameras, global positioning system (GPS), near field communication (NFC), sensors (e.g., proximity, fingerprint, acceleration, barometer, etc.) are common nowadays. Many of these advancements have enabled these devices to process information in real time, e.g., voice commands, human body pulse rate monitoring, etc. Furthermore, the cost of such devices has dropped drastically because of the competitions among the leading manufacturers, e.g., Apple, Asus, Dell, HP, Lenovo, Samsung, etc. The mobile devices generally run operating systems such as Android, Bada, iOS, Tizen, Windows, etc. The mobile computing HCI has developed in diverse directions and users can interact with modern devices in many ways, e.g., touch, voice, heart pulse, body temperature, etc.

This paper reviews some of the latest developments in hardware and software for HCI in various areas, e.g., specialised input/output devices, virtual or augmented reality, wearable technology, etc. It is an extended version of [1] and attempts to identify future trends, research directions and challenges.

Review
Special Issue on Emergent Control and Computing Techniques for Industrial Applications
Manuscript received January 20, 2016; accepted May 16, 2016; published online December 29, 2016
Recommended by Guest Editor Dongbing Gu

The rest of the paper is organised as follows. Sections 2 to 9 discuss some of the recent innovative developments. And Section 10 draws some conclusions.

2 Specialised input/output devices

2.1 Curved and ultra high definition (UHD) or 4K resolution displays

Curved displays or monitors, shown in Fig. 1, are already available as consumer products and are manufactured by Dell, LG, Samsung, etc. These offer better viewing angle, less reflection, better 3D experience, etc. However, these displays also have some drawbacks, e.g., higher cost, wall hanging problem, etc.[2]. The UHD or 4K resolution displays are able to produce 4 times more than the HD, i.e., in the order of 4 000 pixels horizontally for clearer and crispier viewing experience as shown in Fig. 1. Many manufacturers produce displays that are curved and support UHD resolution.

Fig. 1 Curved and UHD (4K) desktop displays[3]

2.2 Curved and flexible displays

Mobile device manufacturers have launched devices with curved displays, e.g., Samsung Galaxy S6 Edge[4] which can display notifications, text messages, weather information on the curved edge for the convenience of the user as shown in Fig. 2. Other areas of developments are flexible and transparent displays as shown in Figs. 2 and 3 that have been developed by Samsung, LG, etc. Many of the flexible displays use polymide film as the backplane. Polyimides are strong, flexible plastics that can achieve a high degree of curvature by allowing a much thinner backplane than the conventional plastic[5]. Transparent displays with a transmittance of 30% have already been achieved which is shown in Fig. 2. These displays could be useful in advertising, security, applications, etc.

Fig. 2 Curved smart-phone screen[4] and transparent display[5]

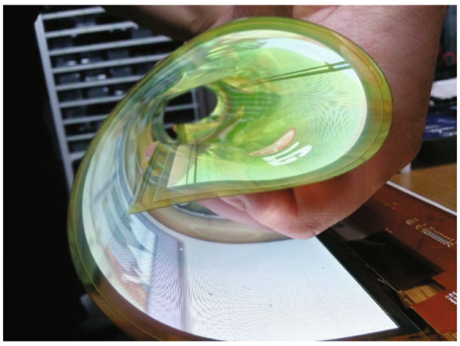

Fig. 3 Flexible display[5]

2.3 Projection or virtual keyboard

It is a small portable device that connects via a wireless technology, e.g., Bluetooth to a smart-phone, tablet, laptop, and projects a keyboard on a flat surface to interact with as shown in Fig. 4. It allows the user to use a conveniently sized keyboard without even carrying a physical keyboard. These devices even take the shape of a key fob. Celluon Epic[6] and the V200 key fob[7] are some examples.

Fig. 4 Virtual projection keyboard[7]

2.4 Hand gesture, voice recognising devices

Today, daily life devices, e.g., smart TV, gaming console, integrate HCI support to recognise hand gestures (e.g., flip to left or right, move, thumb up, grab, rotation etc.) and voice commands, etc. And based on the user′s interaction, these can perform various actions, e.g., menu scrolling, muting, image rotation, which is shown in Fig. 5. A user can also use one universal device to control multiple devices, e.g., TV, audio system, etc. Such a device is shown in Fig. 5 as well. Similarly, modern game consoles and accessories support motion detector, 3D depth sensor and players are able to interact hands-free.

Fig. 5 Hand gesture control[8]

2.5 Brain signal capturing headset

A brain signal capturing headset is able to detect the changes in voltage when the human brain neurons are working on a thought. The headset normally carries a number of electrodes or sensors that are attached to the human scalp to record the electroencephalographic (EEG) signals and then these signals can be converted into a digital form that can be processed by a computer[9]. For example, an epilepsy patient can pick a soft ball using a headset and a robotic arm which is shown in Fig. 6. Such systems have been used to drive cars where the driver′s captured brain signals are processed by a laptop to drive the vehicle[10]. As an example, the Emotiv EPOC/EPOC+ headset[11] is quite popular in the research community. It offers a convenient brain-computer interface with high resolution, 14 EEG channels and 2 references and is shown in Fig. 7. The headset has been used to drive a taxi, a wheelchair, etc.[12]

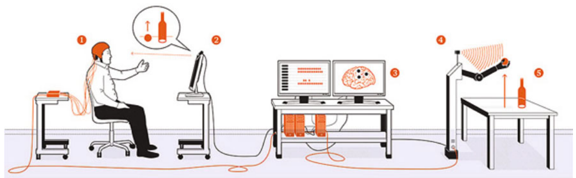

Fig. 6 Controlling a robotic arm using a brain signal capturing headset[9]

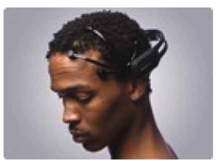

Fig. 7 Emotiv EPOC/EPOC + headset[11]

3 Augmented reality, virtual reality, haming

3.1 Augmented reality headset – Microsoft HoloLens

Microsoft Hololens is an optical head-mounted display (OHMD) that offers 3D augmented reality platform[13]. It blends holograms with reality where the user is able to design and customise holograms as shown in Fig. 8. It is compatible to Windows 10 which is the current version of the Windows operating system.

Fig. 8 Microsoft Hololens[13]

3.2 Virtual reality headset

Headsets such as HTC Vive, Oculus Rift, are very popular in the world of virtual reality, gaming, etc. HTC Vive carries 70 sensors, 360° head-tracking with a refresh rate of 90 Hz to produce lower delay[14]. Oculus Rift[15], shown in Fig. 9, offers low latency 360° head tracking capable of detecting subtle movements to produce natural experience, stereoscopic 3D view, etc.

Fig. 9 Oculus rift virtual reality headset[15]

3.3 Virtual mannequin and virtual fitting room

Many online clothing retailers are now using the virtual mannequin technology to reduce the volume of returned goods because of the wrong size or fitting[16]. The online shoppers enter some of their basic measurements and a virtual mannequin is generated[17] as shown in Fig. 10. Another area of development is in-store virtual fitting room. In this case, the customer is able to try the clothing virtually in real time and very quickly without even going into a fitting room[18] as shown in Fig. 11.

3.4 Google Cardboard

Google Cardboard[19] allows users to build a very low-cost headset to experience virtual reality using smart-phones as shown in Fig. 12. As the name suggests, the Google Cardboard comes with cardboard, lenses, straps, etc. The smart-phone needs to run a special application to create the stereoscopic view for both eyes. Various smart-phones, e.g., Apple iPhone, Google/LG Nexus, HTC Sensation, Huawei Ascend, LG G2, Optimus, Samsung Galaxy, Sony Xperia, are compatible to Google Cardboard.

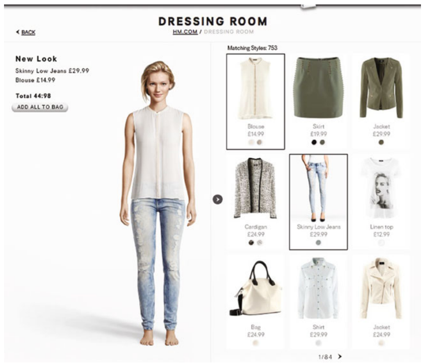

Fig. 10 Virtual mannequin technology[17]

Fig. 11 Virtual fitting room[18]

Fig. 12 Google Cardboard[19]

3.5 Haptic feedback controller

Haptic feedback controllers produce realistic feedback, e.g., force, vibration, to the user for virtual reality, gaming, tele-robotics, medical applications, e.g., computer aided surgery, etc. Many current game controllers already support this feature in various forms. For instance, the Steam Controller released by the game developer Valve, shown in Fig. 13, offers two track pads to deliver various physical sensations to the player[20]. Another example is Reactive Grip motion controller[21], shown in Fig. 13, that can deliver motion and force feedback to the user using sliding contactor plates.

Fig. 13 Steam controller by Valve[20] and Reactive Grip motion controller[21]

4 Wearable technology

4.1 Smart glass

Smart glass, e.g., Google glass is a smart-phone-like hands-free device that is able to take voice commands as shown in Fig. 14. It is a heads-up display (HUD) equipped with a camera, microphone, and GPS, and can perform various tasks, e.g., taking and viewing pictures, online searching, reading emails, satellite navigation, taking and making calls, etc.[22] However, Google has stopped commercial production of the Glass in 2015. Another example in this is Garmin′s biker′s smart glass.

Fig. 14 Smart glass, e.g., Google glass and its application[22]

4.2 Smart-watch

Mobile devices are not limited to only phones, tablet, etc. Various manufactures, e.g., Apple, LG, Motorola, Samsung, Sony, have released smart-watches as shown in Fig. 15. These devices normally communicate with a smart-phone using wireless technology, e.g., Bluetooth to make or receive phone calls, display messages, notifications, etc. Smart-watches can also play music, take photos, display stored photos, perform flight check-in, monitor human body fitness, run simple applications, without a smart-phone[23, 24]. Standalone smart-watches have the functionality of a phone on top of the features offered by a standard smart-watch. These devices allow the user to insert a SIM card into ant integrated slot and can connect directly to a 3G or 4G cellular network without the need of a phone. The SIM card slot and a typical standalone smart-watch are shown in Fig. 16. One major advantage is that these can also be used as a paired device with a smart-phone[25].

Fig. 15 iWatch by Apple[23] and the Galaxy Gear by Samsung[24]

Fig. 16 Integrated SIM and micro SD card slots in a standalone smart-watch and QOne Standalone smart-watch[25]

4.3 Smart jewellery

HCI has also entered the world of fashion and jewellery in the form of Smart devices[26]. For example, the "Cambridge Silicon Radio (CSR) and Cellini Bluetooth Pendant", shown in Fig. 17, is capable of connecting to a smart-phone and is able to change its LED colour or brightness depending on the mood or clothing of the user. Furthermore, it can also generate a notification of incoming calls, emails or text messages to the user by changing LED colour or flashing or vibrating. Another example is the "June Bracelet or Brooch", also shown in Fig. 17, which looks like a diamond in a metal, e.g., platinum, gold, or on a leather strap or it can be worn as a brooch. The device feeds data to a smart-phone and shows a summary of the user′s exposure to the sun. It produces UV index, weather forecast etc. for sunscreen, sunglasses etc. to protect the user′s skin from sun damages or premature wrinkles.

Fig. 17 CSR and Cellini Bluetooth Pendant and Netatmo June Bracelet or Brooch[26]

4.4 Smart footwear

Smart shoe, shown in Fig. 18, generates power using two devices – a "shock harvester" and a "swing harvester" which produce power when the heel hits the ground and when the foot is swinging, respectively[27]. The generated power is three to four milliWatt (mW) and can be used to power sensors and an antenna. One of the applications of the shoe is indoor navigation and rescue operation. Similarly, Bluetooth insoles, shown in Fig. 18, are equipped with a number of sensors, accelerometers, and can monitor activity levels, walking health issues, therapy progress[28], communicate with smart-phones to give directions using vibrations[29], etc. Another area of development is smart sock which is shown in Fig. 19. The smart sock from Sensoria has embedded sensors and is able to produce feedback on the running techniques via smart-phone application for a sportsperson[30].

Fig. 18 Smart shoe capable of generating power[27] and the Bluetooth insole[28]

Fig. 19 Smart sock from Sensoria fitness[30]

5 Fitness, health and sports

5.1 Fitness tracking devices

A number of fitness tracking devices, e.g., Fitbit Charge HR, Fitbit Surge, Basis Peak, Jawbone UP Move, Swarovski Shine, are available nowadays[31]. These devices can monitor and display information about the user′s heart rate, calorie burning, e.g., running, walking, gym activities, etc. Some fitness tracking devices, e.g., Swarovski Shine, shown in Fig. 20, combines the fashion and technology together as these can track running, cycling, swimming activities and can be powered by solar energy.

Fig. 20 Fitbit Charge HR and Swarovski Shine[31]

5.2 FitGuard

FitGuard is a mouth-guard for athletes and is shown in Fig. 21. It contains accelerometers to measure linear and angular acceleration. These sensors can detect activities of the player that exceeds a safety threshold and can generate warning messages to the coach′s smart-phone or tablet computer. The device also contains LEDs which indicate a potentially low, medium or severe injury of the player with different colours, e.g., green, blue, red, respectively[32].

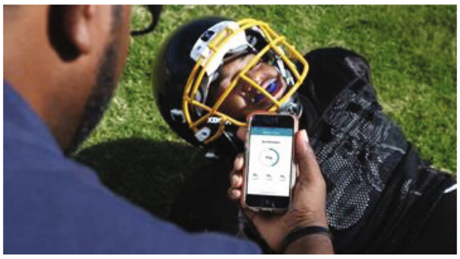

Fig. 21 FitGuard mouth-guard for athletes[32]

5.3 M-Tracer golf swing analyser

The M-Tracer can eliminate or reduce the cost to hire a golf instructor or trainer to improve a player′s performance. It is a small device as shown in Fig. 22, which can be attached to the golf club to record many samples of swings during a game. This data then can be sent to a smart-phone for further analysis, e.g., 3D movement, club speed, angle, etc[33].

Fig. 22 M-Tracer by Epson[33]

6 Biomedical and biometric applications

6.1 Smart contact lens

Google has developed a smart contact lens prototype that can measure glucose levels in tears for diabetes patients. The lens is equipped with a tiny wireless chip, a miniaturised glucose sensor and a tiny LED that lights to indicate high glucose level[34, 35] and is shown in Fig. 23.

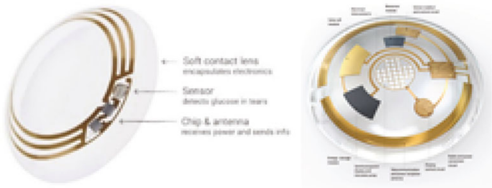

Fig. 23 Google′s smart contact lens[34] and the Bionic contact lens for augmented reality[36]

6.2 Bionic contact lens

The bionic contact lens has an antenna to collect incoming radio frequency energy from a separate portable transmitter as shown in Fig. 23. Solar energy can also be harvested to provide a boost to the lens. The total collected energy is used to power the internal circuits, e.g., display to produce the augmented reality environment, communication with an external computer, etc.[36] The user can read emails, view images, e.g., using the contact lens[37].

6.3 Ultrasound fingerprint sensor

Many mobile devices, e.g., smart-phones use a fingerprint scanner for user authentication. A new type of scanner, shown in Fig. 24, has been developed that uses ultrasonic sound waves to scan fingerprints and is able to read fingerprints through the glass, metal and plastic smart-phone covers[38]. It can even scan through sweat, hand lotion, condensation, etc.

Fig. 24 Ultrasound fingerprint sensor revealed by Qualcomm[38]

6.4 Bio stamp

Bio-stamp which is shown in Fig. 25 can be attached to human body skin to measure UV exposure, body temperature, blood pressure, etc.[39] These devices containing flexible circuits and sensors, are powered wirelessly and can stretch like human skin. Bio-stamps are like temporary tattoos which are able to replace bulky biomedical sensors.

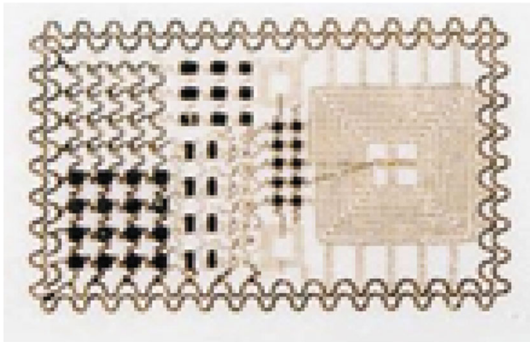

Fig. 25 Bio-stamp[39]

6.5 Closed loop insulin delivery system

It is an external autonomous closed loop system which is shown in Fig. 26 for diabetic patients. The glucose level of the body is read by a continuous glucose monitor (CGM) and sent to the insulin pump wirelessly. Based on the glucose level, the pump injects insulin into the body if needed. Model predictive or proportional and integral and derivative (PID) control, fuzzy logic, are used in the control algorithm. Such systems are already manufactured by Medtronic, Animas, etc.

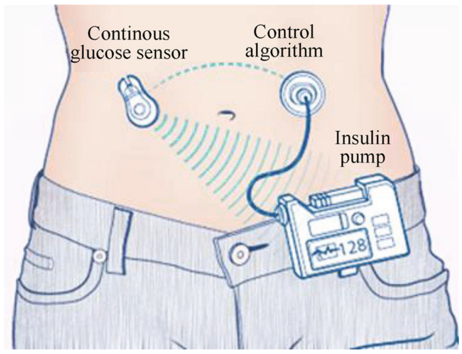

Fig. 26 A closed loop insulin delivery system[40]

6.6 Nervous system or brain-controlled robotics

It is now possible to read the nerve signals of a human body and to control an artificial leg or arm. For example, a patient who lost the lower part of his leg has been fitted with a bionic leg that is controlled by his thoughts[41] which is shown in Fig. 27. Another example is brain-controlled robotics where the brain signals are used to control a robotic body part, e.g., an arm. For example, a patient′s body is paralysed from the neck down. Two sensors implanted in his brain can now monitor the brain activities and control a robotic arm. The patient can shake hands of another person, lift a drink, control a computer mouse, etc[41].

Fig. 27 First thought-controlled prosthetic leg[42]

7 Automobile, racing

7.1 Assisted or autonomous driving

Modern cars have hardware and software to support autonomous manoeuvring, e.g., auto lane change, active cruise control with lane detection, etc. With the auto lane change feature, once the drive activates an indicator for an intended lane change, the car can detect lane marker, other vehicles around it, and change the lane when it is safe to do so. A vehicle supporting the active cruise control with lane detection feature can keep a safe distance with the vehicle in front of it while cruising on a motorway and produce a warning message in case of a lane drift so that the driver can take necessary action to avoid collision with other vehicles. Recently, Tesla has launched the "Autopilot" mode for its latest cars where the vehicle can drive itself and can interact with the driver in case of an emergency[43].

7.2 Automobile projection system

Specialised devices, e.g., Navdy′s transparent head-up display (HUD)[44], are commercially available that can project useful information (e.g., navigation, emails, text messages, etc.) on the windshield of the vehicle as shown in Fig. 28. These devices connect to a smart-phone via wireless technology, e.g., Bluetooth and the driver can interact with it using a hand gesture, voice commands, etc. Such devices ensure safe and legal driving.

Fig. 28 Navdy′s transparent head-up display (HUD)[44]

Besides specialised hardware, simple smart-phone applications can also produce the projection benefit for the drivers. For example, the HUDWAY smart-phone application turns an iPhone or Android device into a projection device as shown in Fig. 29. It can improve the driver′s safety in low visibility conditions, e.g., rain, fog, snow, darkness, etc.[45] The biggest advantage is that such applications do not need any specialised hardware to install.

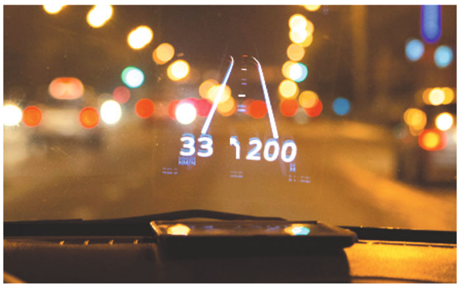

Fig. 29 HUDWAY smart-phone application for windshield projection

7.3 Safety suit for motor racing

Accidents in motorcycle racing can cause severe or life-threatening injuries to the rider. To ensure the safety, several advanced technology based suits have been developed. For example, the D-air racing suit[46] which can be seen in Fig. 30, is essentially an intelligent airbag system. It is equipped with accelerometer, gyroscopes, GPS, 2GB of internal memory to monitor the movement of the rider for accidents. In the case of a crash, it is able to deploy the airbags in 30 ms.

Fig. 30 Dainese D-air racing suit[46]

7.4 Heart attack predicting car seat

The car seat which is shown in Fig. 31 contains Electrocardiograph (ECG) technology based sensor, camera, to detect a heart attack of the driver. The ECG sensors monitor the heart activity through the cloth of the driver. The camera is used to collect the position of the driver. Once a heart attack is detected, the system can take control of the car and bring it to safety autonomously[47].

Fig. 31 Heart attack detecting car seat by Ford[47]

7.5 Safe driving application

Smart-phone applications have been developed to evaluate driving skills of a driver and to generate feedback on journeys for safe driving. Such applications use various sensors, e.g., accelerometer, GPS location, of the smart-phone to record braking, acceleration, speeding, and habits of the driver. For example, the MotorMate application developed by the car insurance provider Confused.com is shown in Fig. 32. The application can help drivers to improve their driving style. Furthermore, potential customers can get a discount on their car insurance based on the positive feedback produced by the application.

Fig. 32 Confused.com MotorMate smart-phone application[48]

8 Smart home

8.1 Smart thermostat

Saving energy has always been one of the prime concerns for a smart home environment. Specialised hardware, e.g., the nest thermostat, the hive thermostat, shown in Fig. 33, are able to actively monitor the energy use and take action if needed. Nest thermostat is able to detect human presence using motion sensors and learn the behaviour of the owner. It can be used to control the heating or hot water supply and the user can interact with it directly, using an app or via a web browser[49]. On the other hand, the hive thermostat allows the user to interact with it remotely from a phone or via a web browser, monitor energy utilisation, set and execute heating schedule, etc. However, this device does not support any learning capability.

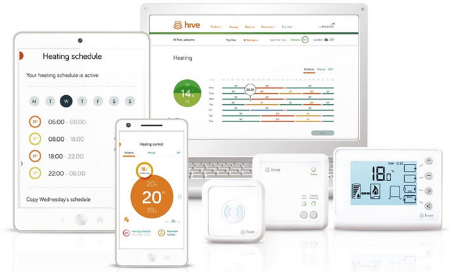

Fig. 33 Nest thermostat and the hive thermostat[49]

8.2 Smart bulbs

LED-based light bulbs are already popular because of their longer life, e.g., 30 000 hours, power efficiency, etc. Now smart LED light bulbs, e.g., STACK bulb, shown in Fig. 34, is equipped with sensors and can react to ambient light, room occupancy, etc. The bulb can turn itself off when the last person leaves the room or at sunrise, mimic daylight throughout the day, etc. It also learns the lighting behaviour or preferences of the user and can reproduce the habit while the user is away, e.g., holiday[50]. This can also improve the security of the house against burglary.

9 Miscellaneous

9.1 Personal assistant

Leading mobile device manufactures have introduced "personal assistant", e.g., Apple Siri, Google Now, Microsoft Cortana, as shown in Fig. 35. These software tools use natural language user interface to interact with the user. The personal assistants can perform various tasks, e.g., making phone calls, sending messages, scheduling meetings, launching a browser, Internet searching, getting updated traffic information, obtaining weather forecast, answering questions, etc.

Fig. 34 STACK down light starter kit[50]

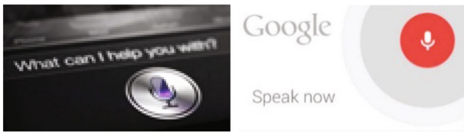

Fig. 35 Apple Siri[51] and the Google Now[52]

9.2 Baby monitors

A number of smart devices are available to monitor baby activities as shown in Fig. 36. For example, the sensible baby martOne monitor[53] and the Owlet vitals monitor[54] allow parents to monitor baby′s position, movement, body temperature, heart rate, oxygen level on a smart-phone or tablet in real time.

Fig. 36 Sensible baby SmartOne monitor[53] and the Owlet vitals monitor[54]

9.3 Real-time natural language translation tools

Many smart-phones are able to translate one language into another using translation tool. Recently, Google has developed a real-time translation tool based on images[55] which is shown in Fig. 37 and supports a number of languages.

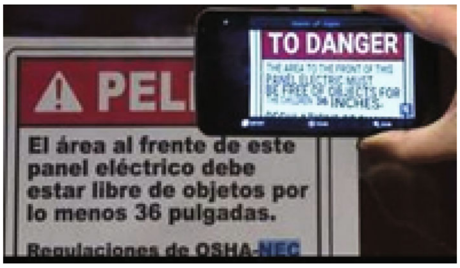

Fig. 37 Real-time natural language translation on a smart-phone[55]

9.4 Habit changing wristband

Technology can help us to get rid of bad habit as well. For example, the Pavlok, shown in Fig. 38, can be programmed, e.g., visiting time-wasting websites, launching a maximum number of tabs in the browser, and it will generate an electric shock for the user to remind of bad habit[56].

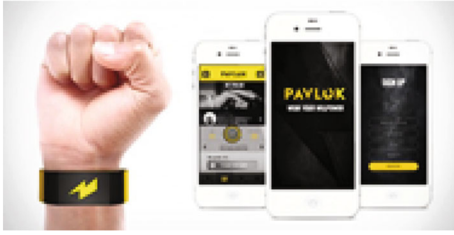

Fig. 38 Pavlok wristband[56]

10 Conclusions

Latest HCI innovations have made many technologies, e.g., virtual reality, personal digital assistant, biometric authentication, e.g., fingerprint scanner available to us and have made our lives convenient, secure etc. Nowadays, we can monitor our health, manage our daily schedules, navigate from one place to another using different forms of hardware and software HCIs. In the desktop computing HCI, many areas, e.g., real-time translation of one natural language into another, object recognition from images, low-cost virtual studio, 3D scanner to produce 3D printed models, can be identified as the future researches. On the other hand, for mobile computing, e.g., eye movement tracking, hand gesture recognition, obtaining heart rate by putting a finger on the touchscreen for some time, starting a vehicle remotely, feedback on driving behaviour, augmented reality headset for vehicle (e.g., engine maintenance, fully autonomous car, etc.) can be identified as future researches.

References

[1] M. S. Hasan, H. Yu. Innovative developments in HCI and future trends. In *Proceedings of the 21st International Conference on Automation & Computing*, ICAC, Glasgow, UK, pp. 84–89, 2015.

[2] *Curved Monitors Pros and Cons Ebuyer Blog*, Ebuyer, [Online], Available: http://www.ebuyer.com/blog/2015/01/curved-monitors-pros-and-cons/, April 1, 2015.

[3] *4k Gaming is about to become cheap, Greatness awaits on PC*, [Online], Available: http://www.gamespot.com/forums/system-wars-314159282/4k-gaming-is-about-to-become-cheap-greatness-await-31019772/, April 12, 2015.

[4] *Galaxy S6 & Galaxy S6 edge Pre-order online*, [Online], Available: http://www.samsung.com/uk/galaxys6/, April 2, 2015.

[5] S. Anthony, *LG′s flexible and transparent OLED displays are the beginning of the e-paper revolution*, ExtremeTech, [Online], Available: http://www.extremetech.com/computing/186241-lgs-flexible-and-transparent-oled-displays-are-the-beginning-of-the-e-paper-revolution, April 3, 2015.

[6] *The smallest things make the biggest impression*, Celluon, [Online], Available: http://www.celluon.com/ products_epic_overview.php, January 14, 2016.

[7] *The VK200 KEYFOB Virtual Keyboard*, CTX Virtual Technologies, [Online], Available: http://www.ctxtechnologies.com/products/vk-200-keyfob-virtual-keyboard/, January 14, 2016.

[8] *Onecue replaces all your remote controls with hand gestures*, [Online], Available: http://www.gizmag.com/onecue-gesture-control/34902/, January 19, 2016.

[9] *How to Catch Brain Waves in a Net*, IEEE Spectrum, [Online], Available: http://spectrum.ieee.org/biomedical/bionics/how-to-catch-brain-waves-in-a-net, April 1, 2015.

[10] *Look, no hands (or feet): Scientists develop car that can be driven just by THINKING*, Mail Online, [Online], Available: http://www.dailymail.co.uk/ sciencetech/article-1359512/Computer-scientists-Germany-invented-car-steered-power-thought.html, April 1, 2015.

[11] *Emotiv EPOC / EPOC+*, Emotiv, [Online], Available: http://emotiv. com/ epoc.php, April 2, 2015.

[12] *Emotiv Claims Its Brainwave Scanner Allows People to Control Wheelchairs with Their Minds*, Wearable Tech World, [Online]. Available: http://www.wearabletechworld.com/topics/ from-the-experts/articles/369076-emotiv-claims-its-brainwave-scanner-allows-people-control.htm, April 1, 2015.

[13] *Microsoft HoloLens*, Microsoft HoloLens, [Online], Available: http://www.microsoft.com/ microsoft-hololens/en-us, April 1, 2015.

[14] *The best VR headsets*, Wareable, [Online], Available: http://www.wareable.com/headgear/the-best-ar-and-vr-headsets, April 1, 2015.

[15] *Rift*, Oculus VR, [Online], Available: https://www. oculus.com/rift/, April 1, 2015.

[16] R. Preston. *Virtual mannequins promise better fit for online shoppers*, BBC News, [Online], Available: http://www.bbc.co.uk/news/technology-25812130, April 12, 2015.

[17] *Virtual Fitting Rooms-are they a gimmick or an essential tool for fashion ecommerce?*, Poq Commerce, [Online], Available: http://poqstudio.com/2013/02/virtual-fitting- rooms-are-they-a-gimmick-or-an-essential-tool-for-fashion-ecommerce/, April 12, 2015.

[18] *Virtual Fitting Room Courtesy of the Kinect*, Daily Bits, [Online], Available: http://www.dailybits.com/virtual-fitting-room-courtesy-of-kinect/, April 12, 2015.

[19] *Google Cardboard, Experience virtual reality in a simple, fun, and inexpensive way*, Google, [Online], Available: https://www.google.com/get/cardboard/index.html, April 3, 2015.

[20] *Valve reveals haptic game controller for release in 2014*, BBC News, [Online], Available: http://www.bbc.co.uk/news/technology-24304272, April 1, 2015.

[21] *Products—Tactical Haptics*, Tactical Haptics, [Online], Available: http://tacticalhaptics.com/ products/, April 1, 2015.

[22] *Google Glass UK release date, price and specs: Google Glass will go offsale on 19 January; how to buy Google Glass*, PC Advisor, [Online], Available: http://www.pcadvisor.co.uk/features/gadget/3436249/google-glass-release-date-uk-price-specs/, April 3, 2015.

[23] *Apple (United Kingdom)-Apple Watch*, Apple, [Online], Available: https://www.apple.com/uk/ watch/, April 2, 2015.

[24] *Samsung Galaxy Gear Watch (Jet Black)-1.63 Super AMOLED, 1.9MP, 4GB*, Samsung UK, [Online], Available: http://fb.uk.samsung.com/consumer/mobile-dev-ices/wearables/gear/SM-V7000ZKABTU, April 2, 2015.

[25] B. Kenney. *The Best Standalone Smartwatch Options Available*, SmartWatches.org, [Online], Available: http://smartwatches.org/learn/best-standalone-smartwatch-options/, January 19, 2016.

[26] S. Hill. *Smart jewelry is proving wearable tech doesnt have to be hideous*, Digital Trends, [Online], Available: http://www.digitaltrends.com/mobile/smart-jewelry-roundup/, April 3, 2015.

[27] P. Rincon. *Smart shoe devices generate power from walking*, BBC News, [Online], Available: http://www.bbc.co.uk/news/science-environment-30816255, April 5, 2015.

[28] *Watch your step–with a Bluetooth-connected insole*, CNET, [Online], Available: http://www.cnet.com/uk/news/watch-your-step-with-a-bluetooth-connected-insole/, April 6, 2015.

[29] L. Kelion. *CES 2015: Preview of the new tech on show in Las Vegas*, BBC News, [Online], Available: http://www.bbc.co.uk/news/technology-30643396, April 6, 2015.

[30] *Sensoria Fitness Smart Sock Preview*, CNET, [Online], Available: http://www.cnet.com/uk/products/sensoria-fitness-smart-sock/, April 6, 2015.

[31] *Best fitness trackers 2015: Jawbone, Misfit, Fitbit, Garmin and more*, Wareable, [Online], Available: http://www.wareable.com/ fitness-trackers/the-best-fitness-tracker, April 3, 2015.

[32] *FITGuard: Alerts Athletes Of Potential Head Injuries*, NXT Insight, [Online], Available: http://nxtinsight.com/fitguard-alerts-athletes-injuries/, January 16, 2016.

[33] *M-TracerTM Golf Swing Analyzer*, Epson, [Online], Available: http://www.epson.com/cgi-bin/Store/jsp/Landing/m-tracer-golf-swing-analyzer.do?ref=van_golf, January 16, 2016.

[34] *Inside Google X's Smart Contact Lens*, Recode, [Online], Available: http://www.recode.net/2014/1/16/1162-2438/inside-google-xs-smart-contact-lens, April 3, 2015.

[35] *Google unveils 'smart contact lens' to measure glucose levels*, BBC News, [Online], Available: http://www.bbc.co.uk/news/technology-25771907, April 3, 2015.

[36] *Augmented Reality in a Contact Lens*, IEEE Spectrum, [Online], Available: http://spectrum.ieee.org/biomedical/bionics/augmented-reality-in-a-contact-lens/eyesb1, April 3, 2015.

[37] M. Roberts. *Bionic contact lens to project emails before eyes*, BBC News, [Online], Available: http://www.bbc.co.uk/news/health-15817316, April 3, 2015.

[38] L. Kelion. *Fingerprint sensor revealed by Qualcomm at MWC*, BBC News, [Online], Available: http://www.bbc.co.uk/news/technology-31692988, April 7, 2015.

[39] T. Perry. *A Temporary Tattoo That Senses Through Your Skin*, [Online], Available: http://spectrum.ieee.org/biomedical/devices/a-temporary-tattoo-that-senses-through-your-skin, January 15, 2016.

[40] *It would be really great to have a closed-loop artificial pancreas device (APD) system on the market...it feels like we have been waiting for this for forever!*, Integrated Diabetis Services, [Online], Available: http://integrateddiabetes.com/closed-loop-artificial-pancreas-system-update/, January 2, 2016.

[41] J. Gallagher. *Brain-reading implant controls arm*, BBC News, [Online], Available: http://www.bbc.co.uk/news/health-32784534, June 17, 2015.

[42] *NEJM: First thought-controlled prosthetic leg*, MedCity News, [Online], Available: http://medcitynews.com/2013/09/nejm-first-thought-controlled-prosthetic-leg/, April 2, 2015.

[43] E. Ackerman. *Tesla Model S: Summer Software Update Will Enable Autonomous Driving*, [Online], Available: http://spectrum.ieee.org/cars-that-think/transportation/self-driving/tesla-model-s-to-combine-safety-sensors-to-go-autonomous, January 19, 2016.

[44] *Navdy feels like driving in the future*, Navdy, [Online], Available: https://navdy.tilt.com/start-driving-in-the- future, January 15, 2016.

[45] *Augment reality in the car, road projection on the windshield HUD Head-Up Display*, [Online], Available: http://hudwayapp.com/, January 15, 2016.

[46] *D-air Racing*, Dainese, [Online], Available: http://www.dainese.com/en_en/d-air/racing/, January 16, 2016.

[47] L. Smith. *Ford unveils a car seat which detects when a driver is having heart attack*, The Independent, [Online], Available: http://www.independent.co.uk/news/uk/home-news/ford-unveils-a-car-seat-which-detects-when-a-driver-is-having-heart-attack-9807042.html, April 7, 2015.

[48] *Using Confused.com MotorMate*, [Online], Available: http://www.honestjohn.co.uk/news/tax-insurance-and-warranties/2013-02/blog-using-confusedcom-motormate/, January 15, 2016.

[49] G. Kelly. *Smart thermostats reviewed: Which can save you the most?*, The Guardian, [Online]. Available: http://www.theguardian.com/environment/2015/jan/27/smart-thermostats-reviewed-which-can-save-you-most, January 19, 2016.

[50] *Stack Downlight Starter Kit*, store.stacklighting.com, [Online], Available: http://store.stacklighting.com// Product-Details.asp?ProductCode=BR30KIT, January 16, 2016.

[51] *Siri, Your wish is its command*, Apple, [Online], Available: https://www.apple.com/uk/ios/siri/, April 2, 2015.

[52] *Google Now. The right information at just the right time*, Google, [Online], Available: https://www.google.co.uk/landing/now/, April 2, 2015.

[53] *No more tiptoeing around*, Sensible Baby, [Online], Available: http://mysensiblebaby.com/, April 6, 2015.

[54] *Owlet Vitals Monitor*, Thing Alive, [Online], Available: http://thingalive.com/owlet-vitals-monitor, April 6, 2015.

[55] *Pardon? Testing Google's speedy translation tool*, BBC News, [Online], Available: http://www.bbc.co.uk/news/technology-30824033, April 7, 2015.

[56] *Pavlok Uses Mild Electric Shock To Help You Break Any Habit*, Pavlok, [Online], Available: http://pavlok.com/, April 6, 2015.

Mohammad S. Hasan received the B. Sc. and first M. Sc. degrees in computer science from the Department of Computer Science, University of Dhaka, Bangladesh in 1999 and 2001, respectively. He received the second M. Sc. degree in computer and network engineering from Sheffield Hallam University, UK. He received the Ph. D. degree in networked control systems over mobile ad-hoc network (MANET) at Staffordshire University, UK in 2010. Currently, he is a senior lecturer and a member of the Mobile Fusion (MF) Applied Research Centre (ARC) at Staffordshire University, UK.

His research interests include computer networks, networked control systems, remotely controllable mobile robot systems, real time systems, and wireless sensor networks.

E-mail: m.s.hasan@staffs.ac.uk (Corresponding author)
ORCID iD: 0000-0003-0458-4536

Hongnian Yu is currently a professor of computer science at Bournemouth University. He has published over 200 research papers and held several grants from EPSRC, the royal society, and other funding bodies. He is a member of the EPSRC Peer Review College and serves on various conferences and academic societies.

His research interests include modelling and control of robots and mechatronic devices and neural networks, mobile computing, modelling, scheduling, planning and simulations of large discrete event dynamic systems, RFID with applications to manufacturing systems, supply chains, transportation networks and computer networks.

E-mail: yuh@bournemouth.ac.uk