Human-Machine Interaction (HMI): A Survey

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Abstract

This document provides a literature survey of papers published in the area of Human Machine Interaction(HMI), mainly focusing on state of the art technology that has or will have a major influence on the future direction of HMI. Through a glimpse of what the current technical achievements are and what the future might hold, it becomes clear that advanced HMI technologies will begin to converge, HMI devices will combine functionality, new levels of sensor fusions will be created, and all this for one purpose, to bring intelligent machines and robots more close to humans. HMI plays a key role for robots and machines to be used in the general public who have no knowledge of software and hardware, in particular bringing benefit to the elderly and disabled.

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Acronym's

HMI - Human Machine Interaction / Human Machine Interface
MMI - Man Machine Interface
HCI - Human Computer Interface
BCI - Brain Computer Interface
EEG - Electroencephalography
EMG - Electromyography
EOG - Electrooculography
ECG/EKG - Electrocardiogram

1 Introduction

We usually interact with machines through an interface, so in this paper we can assume that HMI stands for Human Machine Interaction as well as Human Machine Interface and has the same meaning as Man Machine Interface (MMI) and Human Computer Interface (HCI). There is also a list of acronyms at the top of this paper if you get lost. Human Machine Interaction (HMI) has the most general definition. It describes how we as humans interact with machines, and we define a machine as 'any mechanical or electrical device that transmits or modifies energy to perform or assist in the performance of human tasks'[1]. This review is going to focus more on the latter, electrically devices. Unfortunately no single reviewer can cover the entire field of HMI without missing one or two things, but at least a good overview of the topic is possible. There are a whole range of HMI devices: kitchen appliances, medically devices, manufacturing machinery, entertainment equipment, computer gadgets, and many more but we are going to center on relatively new and current technology such as: the brain computer interfaces(BCI), exoskeletons and state of the art interfaces.

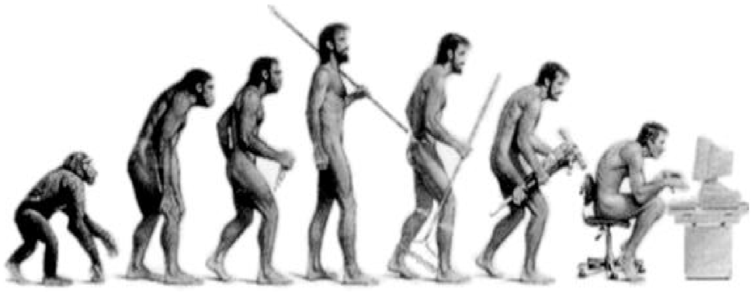


Figure 1: Human Evolution[Cato A. Bjorkli Presentation 2003]

The evolution of man dates back a few millions years, i.e. started off as chimps, eventually evolved into hunter gathers and then finally moved into the computer era, as shown in Figure 1. Earlier computers punched holes into a piece of card to input data. It was only around the mid 20th century that a new HMI device, based on the typewriter was created, which led to the creation of the 1st computer keyboards. Computers used to be text only, no graphic user interface. It was only when computers became more graphical the need for a mouse arose. When we reached the computer boom, starting in the 1980's, a whole range of new HMI devices began to appear, including a whole assortment of joysticks, graphics tablets, single handed keyboards, a whole range of joy pads and sticks, which are still being used today. Nowadays it seems we are slowly moving away from the more traditional mouse and keyboard interface, and the rest of this paper will show you how.

As shown in Figure 2, ergonomics is the design of equipment with the user in mind. In terms of HMI it relates to how the user will interact with a machine and how easy that interaction will be. The main goals are to reduce the risk of injury, fatigue, error and discomfort, as well as improve productivity and the quality of the interaction. There is a great deal of evidence showing that ergonomics works, and can make a users work and perform better, which is why it is an important factor to consider, and worth just a quick note here. Research and practical experience show that systems which neglect ergonomics, particularly in HMI, are more likely to give rise to occupational injuries, operating errors and accidents[2]. Although we have had the mouse and keyboard for decades, the future seems to be leading us towards more natural interfaces that are more intuitive to use, and shouldn't impose any restrictions on natural movements.

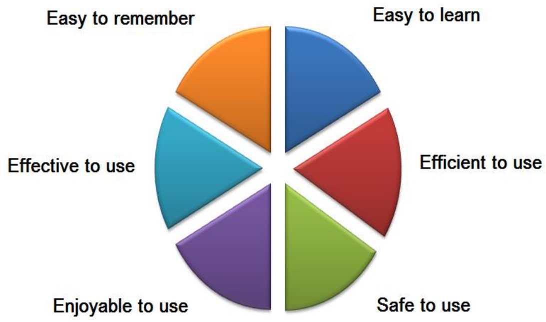


Figure 2: Ergonomics

2 Background of HMI

It was only after the advent of small low cost, low power microcomputers, which propelled electronics forward, that has allowed us to open the door to such varying HMI technology. A video camera which used to be over a foot long, can now fit into the palm of your hand, microphones which used to be noisy are now clear, sensors have shrunk, new technologies have been invented, and thus we believe that 5 broad categories of HMI have been created as shown in Figure 3. Each has a unique human machine interaction, and will be discussed in more detail in the following sections.

(a) Acoustic (Sound) (b) Optics (Light) (c) Bionics (d) Motion (e) Tactile (Touch)

Figure 3: Types of HMI

2.1 Optic(Light) based technology

In Optic based technology the primary hardware used in usually a Camera, HMI utilizes this hardware for Computer Vision. Lasers and LED's also fit under the optic heading, but are used in a slightly different way. Optic HMI does not usually require the user to physically touch anything, simple hand motions and gestures can easily be used to interact with the device, which allows it to become a very effective public interface.

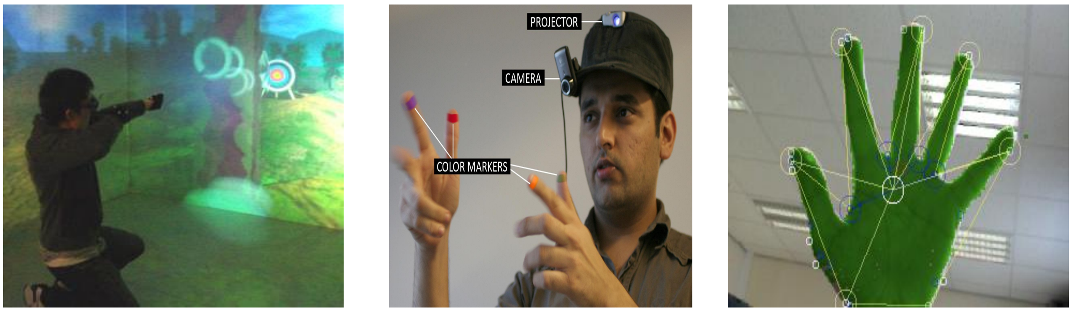
2.1.1 Camera - Computer Vision

Computer Vision is related to HMI, such as object detection and tracking in [4]- which relates to gesture control whether that would be determining a hand, arm, leg or head motion. It can also detect intent from body language such as those that a criminal might portray before committing a crime or before a suiside[5], this also links to emotions that can be detected - are you happy, sad, worried?

Computer vision allows machines to see, and sometimes see things that even we cannot see. The process behind computer vision is quite simple. You have a camera which is attached to an electronic device, usually something similar to a computer or a mobile phone. All the data from the camera is transmitted to this device for processing. To process the data, requires you to go through every pixels in the frame and perform some altering/anaylising function, which is quite intensive considering cameras can now have upwards of millions of pixels, just trying simple functions is going to take considerable processing time, and that is just one frame. When you want to detect motion you have to use multiple frames.

The approach to motion detection is quite simple, it requires you to take one image and then compare it with the next to verify if anything has moved. This is fine for stationary camera's but once you start moving around, more complex tracking is required. Hand gesture recognition and tracking is one of the most popular applications of Computer Vision in HMI, due to the freedom of interaction that is achievable. The main goal is to try and get similar robustness to biological vision, but we are still a long way off this.

There are a lot of computer vision based applications available, but the ones that focus heavily on HMI are based around recognition and motion analysis. Figure 4 shows three applications. Others include Self parking car [6], Head gesture controlled wheel chair [7], eye blink control interface [8], the ability to control music software with hand gestures [9], table top interaction [10], eye tracking used for computer input control [11], Multi touch interfaces[12], not to mention the potential that could be achieved in virtual reality applications[13].



(a) Computer Vision Game[13]

(b) Sixth Sense[16]

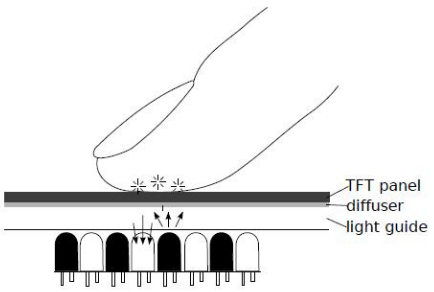
(c) Computer Vision Hand detection [9]

Figure 4: Computer Vision HMI

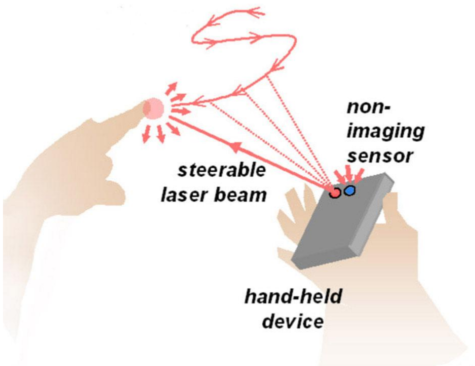
Computer vision has a lot of future potential, you just have to look at Microsofts interactive tables[14], project Natal[15] - which is Microsoft's answer to controller free gaming, and the 6th Sense[16] project - which is an impressive wearable gesture based interface, and you should start to see where the future of computer vision is taking us. Camera based control shows a lot of promise, however it does have some problems, for instance, if the camera gets dirty errors can quickly mount, and if there is no way around this it can somewhat limit outdoor applications. Otherwise computer vision can easily be coupled with other technologies to make it more error resistant.

2.1.2 Laser and LED's

Laser and LED's can be used in conjunction or as an alternative to camera based HMI. Generally they are not as complex but this can be both a advantage and a disadvantage: simpler smaller hardware, but less complex operations can be performed. This is not to say that Lasers and LEDs can't perform complex operations. Just by combining multiple Infra Red(IR) LEDs with IR sensors, and you can create a LED-based Multitouch Sensor, as used in a interactive LCD Screen[17]. The basic working concept is simple: You have your IR LEDS and sensors packed close together, then as you place your fingers closer to the LED's the IR light shines on them, which is reflected back and captured by the sensors, as can be seen in Figure 5a. It is this HMI interaction that is recorded and used as input to the interface.



(a) LED Interface



(b) Laser Interface

Figure 5: Optic Interfaces

A laser system would work in a similar way, light would be emitted and a sensor would track the light. However this could be done with just one laser and one sensor, rather than multiple LED's. Figure 5b will give you a clearer picture. Laser and LED HMI can be both touch and non-touch based, it purely depends on the application. Lasers and LED systems have similar problems to camera's, as soon as you get dirt on the sensor, detecting the reflected light becomes more difficult, its not such an issue if you have multiply sensors, but when you have relatively few, a little dirt can cause a lot of problems. Senors also have the annoying habit of varying slightly from one another even in the same batch, general wear and tear also influences readings, but it is not such an issue if the error is negligible.

The applications you can get with this technology are limited, and usually involve laser gesture interfaces like the one described above, which allow bare-handed gesture control to be incorporated into portable devices[18]. When combining this technology with a projector, it would completely remove the need for a physical interaction area. You could interface with this device at any time and any place, it would truly become an Anywhere Interactive Device (AID). There is also the virtual projected keyboards[19] application, that uses a laser to project a keyboard onto a flat surface and uses sensors to monitor key presses. There might be future potential as part of holographic interface however that is about it.

The main function of Laser and LED based technology is for distance detection, and commonly used on robots as a backup or a collaborator with other technology like computer vision. The main future potential lies with collaborating with other technologies to enhance the user experience.

2.2 Acoustic(sound) based technology

Acoustic or sound based technology mainly focuses on speech recognition, and can be used to convert spoken words to text, manipulate or control a device, or communicate with a machine. The goal of voice recognition is to accurately recognize every persons voice with minimal error, no matter how different you may sound. Speech recognition has great potential, and many phones have built in voice recognition software. Voice recognition has always been popular, ever since science fiction writers and movie producers made it interesting.

The way voice recognition works is: as you speak, your voice is projected towards a microphone, which converts your voices sound waves into an electrical signal, which a computer or a microcontroller can then use, this is the easy part. The hard part comes in trying to analyze your voice. Using pattern recognition techniques a computer extracts important features from your voice to recognize a word. This is a lot more complicated than it sounds, and requires many other processing techniques to improve the signal, such as noise reduction and background separation.

If voice recognition can work accurately there are plenty of applications, controlling your TV or computer, instructing your house to turn the lights on, machine automation, robotics control. These have all been tried before, and it is only over the last decade that accuracy has improved enough to make these more viable. Typical applications include voice controlled wheel chairs[20], voice controlled home appliances[21], or even voice enabled in-car entertainment system[22].

Another interesting area of acoustic HMI technology is acoustic myography, which is basically measuring the acoustic properties of muscles as they contract[23]. The more a muscle contracts the greater the sound. To simply demonstrate this, put your fingers in your ears and then make a fist, you should just be able to hear a slight difference in sound. A novel system, Skinput [24], uses a similar approach to acoustic myography. It combines the natural conduction properties of the human body, such as the complex assemblage of bones to increases acoustic distinctiveness, which allows any part of human body to potentially become part of the interface. Say you tap your fingers on your skin, this causes distinct forms of acoustic energy and causes waves to move across the skin as can be seen in Figure 6(a). As you tap your fingers on your skin, you should see the surrounding area move. Skinput captures that data and uses it to determine where you have pressed. When this system is used in conjunction with a portable projector it becomes an even cleaver piece of technology, as shown in Figure 6(b).

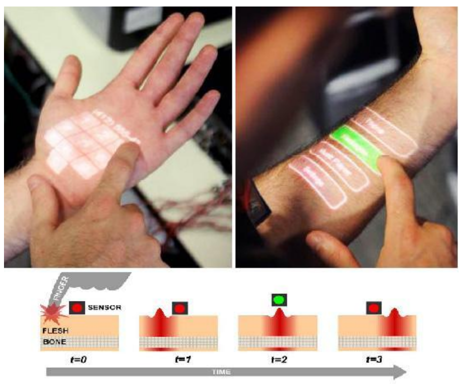


Figure 6: Skinput[24]

So to conclude, Acoustic based technology has a lot of potential, speech recognition isn't perfect but holds a lot of opportunity for the future, one day we will simply ask our cars to take us home and it will do it, the dream of a universal language translator is no longer a dream but will one day become reality, we will speak in one language and output another.

2.3 Bionic technology

Bionic's is an impressive area and provides a lot of cutting edge technology. It is one of those areas that is inspired by science fiction, and over the lasts couple of decades has really started to come alive. Bionic technology has been around for a number of years but relatively few people have heard of it. It is a combination of biology, robotics and computer science, and can be seen as any technology that uses or monitors the biological aspects of the body, in order to perform a function. You can have bionic eyes, ears, legs, arms, toes, feet and hands.

In order to use biological signals we need to gather useful information from our bodies, which is done via electrodes. All the following HMI techniques in this section use electrodes to gather electrical data. In most cases we can use the same electrodes for different aspects of Bionics, you just need to alter the frequencies you monitor and change the level amplification.

All the techniques in this section originated from medical practices, EEG was used to measure the brain for conditions such as sleep deprivation, insomnia etc..., EMG and EOG are used to check if the muscles and the nerves are working correctly, and of course ECG is used to measure the heart. All of them are still used in hospitals today. Bionics breaks down into 2 major categories: EEG based Brain Computer Interfacing(BCI) and EMG Myoelectric control, however there are smaller areas in Electrocardiogram(ECG) and Electrooculography (EOG), but we will focus on the newest technology such as the Brain Computer Interface, which only really started showing potential in the last decade or so.

2.3.1 Brain Computer Interfacing(BCI)

Neuroscience, which is the study of the nervous system, including the spinal cord, nerves and of course the brain [25] is thought to have started as far back as ancient Egypt. It is this discipline that created the necessary foundations for BCI to grow into what it has become today. Our brain is made up of billions of nerve cells which are called neurons. Neurons have the amazing ability to gather and transmit electrochemical signals. Electroencephalography (EEG) is the recording of this electrical activity and this is what is used in BCI. Every animal has a brain, but the human brain is unique, it gives us a sense of who we are and what we feel. It allows us to think, smell, taste, listen and plan.

Generally there are two forms of BCI, invasive and non-invasive. Invasive BCI requires you to have electrodes (which facilitate acquiring the electrical signal) surgically implanted through the skull and onto the brain, in order to monitor the activity. Why do people do this? Well one amazing application of this technology is to allow the blinded to partially recover their sight, with the aid of a bionic eye. Previously it was only possible to monitor the neural activity but now it is actually possible to communicate with existing brain tissue, with the potential of replacing brain damaged regions with microchips[26], which would be an extreme form of bionic HMI that is heading towards a future of cyborg's. We already have BCI applications that can control robotic arms and hands[27] so a cyborg civilization is too far fetched.

The less intrusive form of BCI simply places surface electrodes onto the head at

Figure 7: Brain Controlled Hand [www.singularityu.org]

specific points, however the electrical signal is difficult to monitor, as its only a few microvolts, which is why it is necessary to amplify the signal 1000 to 100,000 times. In theory with implanted electrodes you can monitor and communicate with any part of the brain, but with surface electrodes you can only receive information from the surface of the brain, which does somewhat limit non intrusive BCI, but you can still achieve impressive accomplishments like controlling a computer mouse [28] or manoeuvering a wheelchair [29].

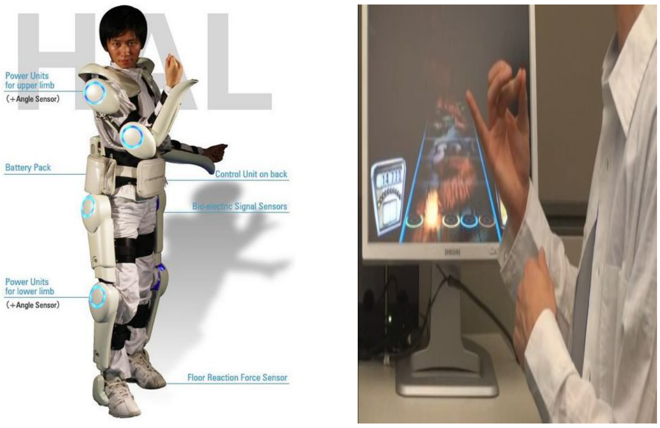
Newspapers claim we can read your mind, which is partly true, but mostly rubbish. We can detect certain functions for instance, if you move your arms or legs, but we can't tell what your thinking ... yet. There are an endless amount of possible applications if we could truly read peoples minds, you could control anything with just a thought - car, phone, dish washer, tv, computer. It is the ultimate interface but with a lot of sophisticated problems.

2.3.2 Myoelectric Interaction (EMG)

Myoelectric Control uses a very similar technique to the BCI, except instead of using electrodes to monitor the electrically signal from the brain, we are instead interested in the electrically characteristics of our muscles. The process of monitoring this electrically signal is called Electromyography (EMG). The hardware used for BCI can be used to work with EMG, as they use much of the same frequency band, but EMG operates in milliVolts which is much stronger then EEG, so doesn't require as much amplification.

When we look at our muscles we don't consider them to have any electrical properties, but they do, and it comes from an electro chemical reaction. The basic way is works is: The brain sends commands down through the nervous system using our nerves, and these activate the electro chemical reaction that causes your muscles to contract. This is picked up through electrodes. As previous mentioned these can be intrusive and non-intrusive, however intrusive electrodes not only include surgically implantation, but also the injection of needle and wire electrodes directly into the muscle. Once we have acquired the signal then a complex signal processing procedure is used to make sense of the data, and then perform some operation based on the results.

Myoelectric(EMG) HMI is quite feasible as an interface, and consequently a number of applications have been developed. Most notably as a source of control for a prosthetic limb like an arm or a leg. There are also full bodied exoskeleton suits that can enhance a users strength, such the Human Assisted Limb (HAL) exoskeleton[30] shown in Figure 8a. Just like Camera Gesture recognition there is also EMG Gesture recognition[31],



(a) Exoskeleton (b) EMG Interface

Figure 8: EMG Interfaces: a) HAL - Hybrid assitive limb Exoskeleton b) EMG controlled Guitar Hero [www.gizmowatch.com]

which can be used as a rich source of input to control a hands free portable music player[32], it can be used to play guitar hero, control a simulated aeroplane[33] or prosthetic hand[34]. Anything you can do with your muscles or your limbs could be converted into an electrically signal and used to control any electrical device.

Another interesting area is EMG motionless gestures [35], which gives the user a more private experience. A motionless gesture requires no movement or very minor movement such as tensing the bicep, the only limitation is that you are restricted by the level of control you can have. However the idea that no one will be able to notice or see you interacting with a device is quite unique, and yet a little sinister. EMG is particularly useful for accurately detecting the level of force a muscle is producing, which is especially important for fine control of prosthetics, if you want to pick up an egg you don't want to necessarily crush it every time.

The future of myoelectric control lies in trying to accurately determine muscle movement, in terms of prosthetics this means trying to closely mimic the functionality of a lost limb. Prosthetic arms and legs generally have quite good function, it is more the hands which require work. In terms of a myoelectric computer input device, similar work needs to be done on the hands, to allow the user to truly be able to interact freely.

2.3.3 Electrocardiogram(ECG or EKG)

Electrocardiogram(ECG or EKG) measures electrical heart activity and although we don't interact with an ECG devices voluntarily they are still partially included in HMI. ECG applications outside of the medical sector are rather limited due to the lack of voluntary interaction, however over the last several years they have been incorporated into smart clothing to monitor your health, which the fashion industry briefly sampled to create heart beat varying colored clothes, other than that ECG HMI potential applications are limited.

2.3.4 Electrooculography (EOG)

Electrooculography (EOG) - measures eye muscle movements, by placing electrodes above the eye. It can be used for eye tracking, in applications like an EOG-based remote-control TV[36]. It is a very useful technology for providing support to those with disabilities which happen to restrict them from using other HMI devices. EOG can be used to control a wheel chair[37], to help those who cannot walk, a virtual keyboard [38] which would restore some communication to those who cannot speak, or it has potential applications as a un-obtrusive bionic eye interface, even military potential as a camera control interface on a robot droid.

The last thing to note about Biological signal technology is it's not perfect. It is very difficult to get 100% accuracy, which is why it is often found with multiple HMI technologies, and integrated together to enhance performance such as: combining EOG and EMG into a wheel chair[39], or the teleoperation of a robotic hand and eyes - with potential security applications, or EMG and computer visions, such as on a interactive table[40], and EMG, EOG and EEG all combined together for sleep monitoring and analysis[41]. It is often the case that even if one type of technology works well independently it can work even better, or provide improved functionality and a better user experience if combined with another.

Biological signal technology has much future potential, from helping the disabled regain their lost independency to interacting with our environment. This is one area that could really enhance how we interact with technology and seamlessly integrate it into our lives.

2.4 Tactile(touch) technology

Tactile based technology is the only technology that physically requires you to touch something, all the others in some sense can operate hands free. The most classically touch technology is the button, as used on the keyboard, which is the most popular HMI device ever created, we use it in an incredible amount of applications ranging from the computer keyboard, mobile phones, to personal entertainment devices. They are so popular that we have even woven small versions(using conductive materials) into our clothing, now called smart clothing (Figure 9) or smart textiles [42], so that we can control our entertainment devices no matter where we are and what we are doing.

Figure 9: Smart Clothing [www.hight3ch.com]

In the optics section we came across touch screen interfaces that use light based technology to recognisee if the screen is touched. However there are also tactile systems[43], by pressing on the screen, you physically connect two wires together forming a circuit which can then identify the touch. It has the advantage of being simple and low cost but loses out on functionality and resolution. Light based interfaces normally just detect finger touches, however tactile systems require you to apply pressure and press on the interface[44], this means that some level of force might be detectable.

Some HMI devices are quite unique and imaginative, Digital clay[45] for instance, is clay that can be molded, and the shape digitally transferred to a computer, it has great future potential if a truly 3d application can be developed and then combined with a 3d printer. Interestingly enough motion sensing gloves, which you might have thought fit in the Motion section, actually fits under the tactile category, although their main function is to provide motion feedback they are still mostly operated through tactile interaction.

Motion sensing gloves can be very accurate which is why they are a good option for teleoperating robotic hands[46], computers and games control. There are other tactile devices like the haptic feedback device, which is now used in some surgical procedures[47]. It fundamentally works as a high resolution 3 dimensional mouse, and hence is effective at manipulating objects within a 3D environment, it also provides tactile feedback making manipulation feel more natural and therefore becoming more effective, so it also works well with 3d graphics and games[48].

One quite impressive piece of tactile technology is the textural interface, Super Cilia Skin (SCS)[49] which has potential as an artificial skin with sensory feedback. Currently it allows two people to communicate over a distance by manipulating the orientations of what you could describe as oversized follicles(such as hair follicles) that you might find on the skin, so as you can imagine it could provide a whole new level of prosthetic feedback, and if the entertainment industry get there hands on it, we could see some very interesting applications.

Figure 10: Textural Interface: Super Cilia Skin [49]

2.5 Motion technology

Motion technology includes all HMI that in some way can detect motion, gyroscopes and accelerometer's are the main technologies used. However they are not often used alone, but mostly combined with other sensors. In theory all the previous technologies mentioned can detect some form of motion, and some versions of gyroscopes and accelerometer's are actually light based, but in hope of keeping this section as simple as possible, we will define this section as any technology which requires you to physically move part of the hardware and whose primary purpose is in some way to detect motion.

Gyroscopes and accelerometer's, or even when combined together, offer very reasonable motion sensitivity, which is why you can find them in a large array of different applications, such as a motion sensitive mouse interface[50] which operates as you move and tilt your hand, or being used in gesture following, for example, teaching a musician how to conduct an orchastra[51] or teleoperating a humanoid robot [52]. They are even quite useful for determining head rotations[53], and have been implemented in wheel chair controllers[54].

Some of the most notable motion sensing technology is in the wii controller, which a good example of sensor fusion, infra red sensors are used together with an accelerometer to detect motion. Another popular example of a motion sensitive device is the iphone which can use both gyro's and accelerometer's. The use of Gyro's and accelerometer's are not the only available Motion sensing technology, it is possible to use magnetic fields to determine the position of a magnet, which has potential as a 3d hand positioning system[55], however there is the issue with how other electrically devices might operate in close proximity to such an environment, as quite a few should avoid being near magnetic fields.

Motion technology is quite a big area on its own, optic based motion, you can detect bodily motion using bionics and some acoustic technology, even a touch interfaces can detect motion, but once you remove all those you are left with relatively little. So although the technology listed in this section is unlikely to grow massively, overall its probable that motion technology will improve and expand into many aspects of our lives. T.V's, cars, mobile phones, computers, games consoles are all likely to have some form of motion integrated into them in the future.

3 Conclusion And Future Work

This document has provided an overview of what HMI has to offer, and has shown you a glimpse of what the future might hold. One thing that is certain is that technologies will begin to converge, devices will combine functionality, new levels of sensor fusions will be created, and all this for one purpose, to enhance our Human Machine Interaction. The technology involved in HMI is quite incredible.

However, HMI still has a long way to go, for example, Nano technology has provided a new waive of advancements, but these have yet to be fully utilized in HMI, Nano technology has an important future role to play. Nano machines and super batteries haven't fully materialized, so we have something to look forward to. There is also the potential of Quantum Computing which will unleash an entirely new level of processor, with amazing speeds. HMI technology is impressive now, but in the future there will be nothing like it. It won't matter who you are, what language you speak, or what disability you have, the variety of technology will cater for everyone.

In the near future we will see higher function prosthetics, brain computer interfaces with more control, voice recognition and camera gesture recognition being used more. Although not quite the death of the every day mouse and keyboard, we will definitely start to see new types of technology integrated into our everyday lives. Portable devices are becoming smaller and more complex, so we should start seeing growth in wearable interfaces. Robots, and the way we interact with them is already beginning to change, we are in the computer era, but soon we will be in the robotic era.

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