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USING SENSORS AND EMBEDDED IMAGE PROCESSING FOR IMPAIRED USERS' COMPUTER INTERACTION

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USING SENSORS AND EMBEDDED IMAGE PROCESSING
FOR
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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

USING SENSORS AND EMBEDDED IMAGE PROCESSING
FOR IMPAIRED USERS' COMPUTER INTERACTION

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This study is intended to create guidance on the application of Human Computer Interaction on people with disabilities to improve their computer controlling ability. We developed an assistive technology for disabled people. This assistive technology works on "disabilities related to hand using" such as quadriplegia or bomb injuries. This study aims to describe how technology can be used for disabled – computer interaction, what problems can be solved via this method and the importance of assistive technology in a disabled person's life. It would be possible to use both computer and its peripheral devices by building an assistive technology device that can help impaired to use a computer by interacting with mouse interface directly. For this aim, a Disabled – Computer Interaction (DCI) module was developed in this study with guidance of an experiment that applied on impaired people. Target audience was impaired people that are not able to use their hands for different reasons like paralysis (quadriplegia, diplegia, hemiplegia), traffic accidents, bomb injuries, combat training injuries, born defects, Multiple Sclerosis (MS), ALS, traumatic brain injury or struck damage. Technology we developed would be used by impaired people who are able to move their heads within limited angles.

Keywords : Computer – Disabled Interaction, Computer Usage for Disabled

ÖZ

ENGELLILERIN BILGISAYAR ETKILEŞIMINDE GÖMÜLÜ GÖRÜNTÜ İŞLEME VE SENSORLERIN KULLANIMI

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Bu çalışma bilgisayar engelli etkileşiminde teknolojinin nasıl kullanılabileceğini, hangi problemlerin çözülebileceğini ve yardımcı teknolojilerin bir engellinin hayatındaki önemini göstermeyi amaçlamaktadır. Bu çalışmada engellilerin bilgisayar kullanımını iyileştirmek ve kolaylaştırmak amacıyla bir engelli – bilgisayar etkileşim modülü geliştirilmiştir. Bu yardımcı teknoloji, felçliler, bomba yaralanmaları; ALS, Cerebral Palsy, MS hastalıkları gibi durumlar sonucu ellerini kullanamayan engellilerin kullanımı amacıyla geliştirilmiştir. Bu çalışma teknolojinin bilgisayar-engelli etkileşiminde ne gibi rol oynayabileceğini, bu methodla hangi problemlerin çözülebileceğini ve destek teknolojilerinin bir engellinin hayatındaki önemini tanımlamayı amaçlamaktadır. Bilgisayarın fare arayüzünü yönetebilecek bu yardımcı teknolojinin tasarlanması ile engelliler bilgisayar arayüzünün amamını ve bağlı çevresel aygıtları yönetebilir hale geleceklerdir. Bu amaç için yapılan deney ışığında bir engelli-bilgisayar etkileşim modülü geliştirilmiştir. Hedef kitlesi olarak felç (kuadrpleji, dipleji , hemipleji), trafik kazaları, bomba ve mayın yaralanmaları, doğuştan kaynaklı engeller, MS, ALS, darbeye bağlı nörolojik yaralanmalar gibi nedenlerle ellerini kullanamayan genel engelli kitlesi seçilmiştir. Geliştirdiğimiz yardımcı teknolojiyi ancak kısıtlı alanlarda baş hareketi kabiliyeti olan engelliler kullanabileceklerdir.

Anahtar Kelimeler : Bilgisayar – Engelli Etkileşimi, Engelliler için Bilgisayar Kullanımı

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INTRODUCTION

1.1 Organization of the Thesis

This study aims to describe how technology can be used for disabled – computer interaction, what problems can be solved via this method, and the importance of assistive technology in a disabled person's life. In order to reach this aim we developed a disabled – computer interaction module that can be used via head movements. The structure of thesis is given below.

- Introduction
- Literature Overview
- Development of Disabled-Computer Interaction Module
  - Hardware construction of assistive technology for a disabled person who does not have the ability to use their hands
    - This includes determination basic needs of the disabled person, how the computer – human interaction will be shaped and which protocols are most efficient within these boundaries.

    - Instant image search for the given amount of points for determining head aiming angle
        - This search creates a binary image with black pixels which means the pixel includes no IR light and white pixels which means the pixel is has IR light.
    - Standard application of morphology that includes erosion and dilation to binary image that has created previous step.
        - In general image sensors create images that have noisy pixels. Cleaning noisy pixels is the aim of this step.
        - Applying standard erosion method to the image makes the edges smaller since noisy pixels are small and they will disappear. This step will clear the noisy image gathered from image sensor.
    - After the previous step, the coordinates of white dots will be calculated within image. There will be an upper limit for point count. This limit is calculated as 4 dots for an image.
    - Points will be sent to the computer for handling usage interface such as mouse.
- Software construction of assistive technology.
    - In this step, a driver that can handle hardware will be implemented; also GUI will be implemented within needs of disabled person.

- Experiment
- Results and Conclusion
- Recommendations for Further Improvements

1.2 Background of the Study

Disabilities are statuses that cause lack of workability on people. There are many kinds of disabilities [1]. In common, they are separated into two as mental disabilities and physical disabilities. As many considered as defects, sometimes even a simple eye color can be a disability. For example, "hazel" colored eyes are a lot much more intolerable to sun light than other common colors. This gives the person a driving disability under direct sunlight. In scale such a person considered as 0.5% disabled. According to Turkish authorities even a total blind person may not be considered as %100 disabled. Disabilities such as paralysis are different kind of handicaps that affect a person's life by limiting basic needs. On the other hand there are disabilities like color blindness that does not affect a person's life in general. There are two kinds of ways that a person can be disabled. Either he is born this way or it is caused by some reason later with in their life. If a person is born with a disability, his senses will develop themselves within these boundaries. There is no possibility that a blind born person can see a visual dream. Their dreams are consisted of sound only. If the same kind of disability is occurred later in their lives, some of their senses will try to calculate with previously stored set of knowledge that is not used after disability occurs. Even if the result and the disability is the same, these kinds of disabilities must be handled separately. In both ways same disabilities bring similar kinds of discomfort to a handicapped person's life. Those that are disabled later in their life commonly lose their life quality and will to live because of lack of freedom that they used to have. This situation leads to higher levels of depression and anxiety. To stop these, they need medical treatments, therapy groups of physical therapy. Researches show that, if there is one way that offered to a disabled person that he can work, enjoy or make something useful to anyone, these symptoms are lessened [2]. As a result most commonly people with disabilities want to go on with their life as much as possible. Figure 1.1 shows one of the famous assistive technologies developed for a runner with prosthetic limbs that are specially designed for running fast.

Figure 1.1 : Oscar Pistorius, South African Paralympic runner with prosthetic legs [3]

On the other hand, people that are born with disabilities are not generally aware of the hardness that disabilities bring to their life. As like most of handicap groups, physically handicapped individuals with quadriplegia, paraplegia, and hemiplegia live their lives depending on someone else mostly.

In this situation not only the handicapped person's life is stopped, but also the one that is looking after him also cannot continue his life with in its old routine.

Though each disabled person have their own handicap, assistive technology has developed within a wide area. Figure 1.2 shows brothers with different levels of infantile paralysis.

Figure 1.2 : Different levels of same disability

This brings variety of problems. Companies are tending to develop technologies that could be sold to masses. This makes assistive technologies either limited or inadequate. Commonly an assistive technology should be developed by determining the special needs of a sample group, or should be built in a way that technology can be modified within user's needs. In this study, we developed a disabled-computer interaction module for the special needs of the impaired people that cannot use their hands.

1.3 Statement of the Problem

QWERY keyboard and standard mouse is still the best way to interact with computer. As someone loses his ability to move his hands in any case like paralysis, Cerebral Palsy (CP), Multiple Sclerosis (MS), ALS (Amyotrophic Lateral Sclerosis), traumatic brain injury or struck damage, both keyboard and mouse interaction becomes almost impossible. For those who are in the latest stages of ALS and MS none of the solutions that are stated below are usable. There are some solutions for those who cannot control computer with standard interaction modules but they are either expensive or not easy to use. For cheap side solutions there is a foot mouse solution as shown in Figure 1.3. As our feet are not as sensitive as our hands, using foot mouse limits impaired persons computer interaction capability to lower interaction standards. This solution cannot be used by paralyzed people as they generally lose their ability to use their hands and feet at the same time.

Figure 1.3 : Foot mouse

As another solution there is an eye movement based system that tracks the eyes of impaired people to guide the cursor for computer interaction. For these solutions, accuracy depends on the quality of algorithm, closeness of the camera to eyes of the user, eye openness of user and click event trigger technique. Usages of these devices are restricted by the eye movement distance. A human eye can move less than 1 cm in total to pass the computer screen within 40 cm distance [4]. This situation makes these kinds of solutions require some kind of software usage interfaces. Human eye is not motionless while looking at a fixed point as shown in Figure 1.4 [5]. This is why there is a necessity of an algorithm that stables the cursor movements during eye control. These movement patterns are different for every other human being.

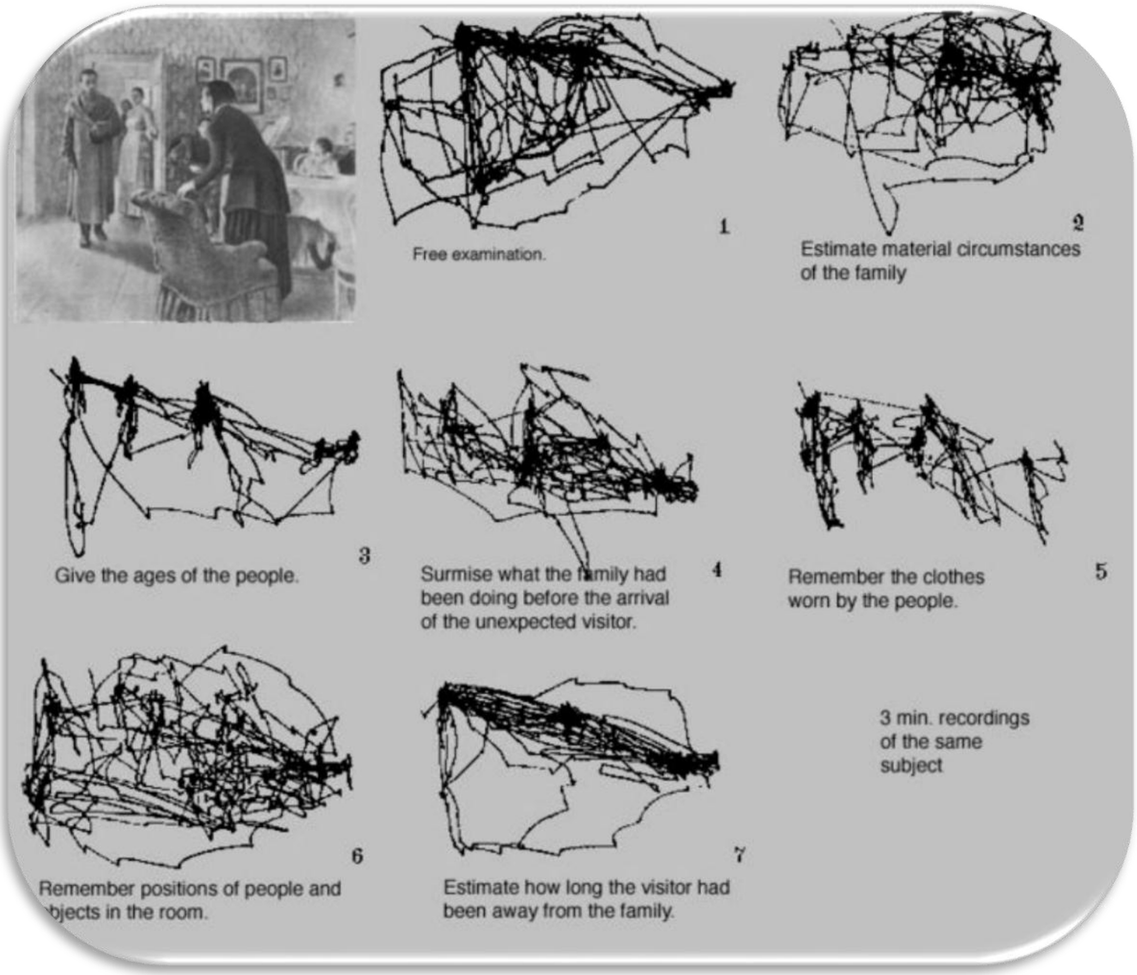

Figure 1.4 : Eye steadiness while looking at a fixed point

As these kind of solutions' quality increase their prices increase proportionally which makes them hard to be used by wider groups.

Most solutions that are built for impaired people have software interfaces to control interaction. Any kind of software that runs on computer interaction process limits the usability of standard user interface. These kinds of implementations limit the users' interaction capability in speed, accuracy, comfort or ease. Impaired people that cannot use their hands need a device that they can easily use computer interface with no restriction or loss in quality so that they can use every part of both operation system and any program that runs on it without limitations.

As these kinds of disabled people are still mentally normal (ALS, MS, Partially CP and Paralysis [6],[7]), removing their disability at computer usage area may help them being useful to society and going on with their lives doing computer related jobs, being educated over Internet and socializing over social networks such as Facebook, Twitter, Digg and Google+.

1.4 Significance of the Study

During our experiment (as described in details in Chapter 4) made on 30 impaired people with paralysis, basic needs of attendees who cannot use their hands were obtained. Most of them are unable to use any kind of devices such as remote control, cellular phone or any kind of computer. There are kind of prostatic limbs that can be used for different jobs but using electronic devices and computer are still big problems for people with no hands and those who are suffering from paralysis. Most common parts that are not affected from impairment were the eyes and then head followed. As it is pretty hard and expensive (due to long time consumption and requirement of man power) to build a device that can use eye movements for computer interaction, head movement is selected. There is also one more disadvantage of using computer with eye movements, it is too hard to make the system work as a standard mouse interface and there will be too many loses in efficiency. Most of the experimental group members were able to use their head with no problem at all.

Recently, computers and Internet has become our favorite tool in our daily life. Due to a research made by Turkish Statistical Institute (TurkStat) in April, 2011 41.6% of houses in Turkey has Internet connection [8]. PCs give one to watch whatever they want with no commercial breaks, connect with friends without any effort and play games. There are also computer related jobs such as computer engineering, remote service assistant or call-center assistant. These jobs can be done just by using a computer. Education over Internet has become possible meanwhile. There are not only high schools but also universities which give online education over Internet. Giving a disabled person, the ability to use the computer instead of a specific device, one can be educated, can work, connect with friends and use peripheral devices that can be connected to a computer. Research shown that simple mouse interface is the most preferred interface to communicate with the computer [9]. Even a 1 year old can use a mouse to interact with computer which makes it most basic computer – human interaction device. Mouse can be used with an on screen keyboard to use keyboard functions. With all this data considered, it will be wise to try helping impaired person using a computer via mouse interface. Building an assistive technology as simple as possible is the main goal of this study. This will lead to extensive usage by disabled people.

According to National Database of Impairment (In Turkish : Özürlüler Veri Tabanı (Özveri – 2011)) there are 16.677 disabled people that is impaired between 20% - 70% with known communication data and aged between 15 – 35 [10]. As they cannot use their hands, these people cannot use computer with standard interaction modules. They will be able to use complete computer interface with no boundaries, use mobile phones, TV cards and radio cards with no limitations. Also making emergency calls and sending SOS messages to predefined numbers will also be possible.

1.5 Scope and Limitations

To limit the range of target impairment mass, disabled people that do not have the ability to move their hands are selected. Target audience should also be able to move their heads within 15 degrees vertical and horizontal limits. For ALS, MS and CP impairments, level of disability must not cause unwanted head movements or stabilization issues. As most of paralyzed people are able to move their heads even if their impairment is because of a spinal cord injury from the top most part of spine. As injury reaches a higher level on the spinal cord, the ability to move decreases. At one of the worst cases, an injury from C1-C3 as shown in Figure 1.5, patient can speak, swallow and control head movements but both arms and legs are unable to move. In general these kinds of patients require a mechanical ventilator to breathe [11].

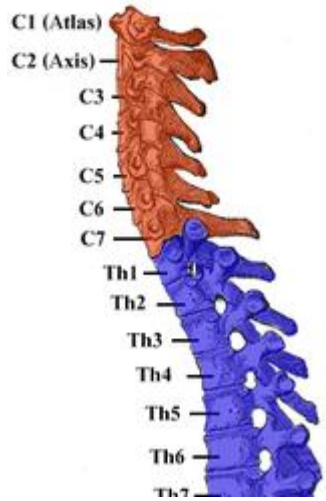

Figure 1.5 : Position of C1 and C2 spinal fragments [12]

The scope of this study was impaired people that can move their heads without some kind of vibrations in any direction. As software improvements limit users' interaction capability, no enhancements supposed to be used during this procedure. User must be able to use mouse interface without any kind of limitations. Impaired people should be able to use only their head to control entire operating system interface and software that run on it. Disabilities that come up with uncontrolled head movements or/and some kind of mental impairment are not in the scope of this study.

CHAPTER 2

LITERATURE REVIEW

This chapter provides the background information related to this study, and focuses on the following areas in the study; what is assistive technology, Definition of Terms, Hardware for Impaired, Software for Impaired, Software enriched Hardware use in Assistive Technologies, Assistive Technologies with No Hand Use.

2.1 What is Assistive Technology?

Assistive Technology is defined in [13] as: "In any kinds of means, any piece of equipment, item or product system, either off-the-shelf or acquired commercially, customized or modified, that maintains, increases, or further improves functional capabilities of individuals with impairments"

2.2 Definition of Terms

In this section, brief explanations for the important terms used within the study are provided in order to assist the reader in understanding the study.

2.2.1 Definition of ‘No Hand Use’

No hand use defines physically disabled people that cannot use their hands by any kind of handicap such as paralysis (quadriplegia loss of control in 4 quadrants of body, diplegia loss of control in 2 quadrants of body, hemiplegia loss of control in one side of body), Multiple Sclerosis (MS), ALS (Amyotrophic Lateral Sclerosis), traumatic brain injury or struck damage.

As there are so many impairment types and levels assistive technology has a large variability that include as definitions are given.

2.2.2 - Personal Emergency Response Systems

For helping vulnerable people stay independent at home longer, Personal Emergency Response System (PERS) uses an alarm system driven by sensor triggering to help caregivers manage risk. For example, the systems being put in place for senior people such as fall detectors, thermometers, flooding and unlit gas sensors. Due to person’s particular risks alerts can be customized. If an alarm is triggered, PERS sends a message to a predefined contact who can respond appropriately.

2.2.3 - Accessible Input Devices for Computers

Working through ergonomic accessories with footrests, height-adjustable furniture, arm supports and wrist rests to ensure correct posture, some assistive technology changes the situation of mouse and keyboard being still the dominant way of interacting with a standard PC.

2.2.4 - Accessibility Software

In human-computer interaction, computer accessibility means (no matter disability or severity of impairment) the accessibility of a computer system to all people.

2.2.5 - Durable Medical Equipment

Durable medical equipment is generally daily long term use devices.

・Seating products that allow comfortable and safe sitting (seating systems, cushions, therapeutic seats).

・ Standing products to support impaired people in the standing position (standing frame, standing wheelchair, active stander). Figure 2.1 shows a golf aid, and figure 2.2 shows a version of active stander.

Figure 2.1 : Standing golf wheel chair

Figure 2.2 – Active stander

· Standing and walking products for disabled people who can walk od stand with assistance like crutches, canes, gait trainers, walkers.

· Advanced technology walking products to aid people with disabilities that disable them from walking or standing, such as CP or paraplegia.(exoskeletons). Figure 2.3 shown an easy to use version of exoskeletons.

Figure 2.3 – Pony ride exoskeleton

· Wheeled mobility products which enable people with mobility impairment to move freely indoors and outdoors (wheelchairs/scooters)

Figure 2.4 – Stair climber wheel chair

▪ Height adjustable suspension modified vehicles allow wheelchair entry

▪ Developed using mechatronic technology, robot aided rehabilitation. Figure 2.4 shows an example.

2.2.6 – Mobility Impairment

In definition, mobility impairment is the situation where impaired person is not able to move by himself.

- Crutches, including assistive canes
- Walkers
- Wheelchairs

In figure 2.5 universally accessible street cross is designed for both mobility impaired and visual impaired people.

Figure 2.5 : Universally accessible street cross [14]

2.2.7 – Assistive Technology for Visual Impairment

With assistance of wide range of tools, visually impaired people can live independently. Canadian currency tactile (a system of raised dots not standard braille) based on braille cells is a well-known example. During computer use screen magnifiers, screen readers and refreshable Braille displays are most common access technologies.

Figure 2.6 : Blind stick / walking stick with seeing stick hardware

Figure 2.6 shows a blind stick with seeing stick hardware, a laser scans the point just close to the tip of stick and sends sounds as a feedback.

2.2.8 - Augmentative and Alternative Communication

Augmentative and alternative communication (AAC) term encompasses methods of communication for those with impairments or restrictions on the production or comprehension of spoken or written language. As AAC systems depend on their users' capabilities, they are extremely diverse [15]. They can be either be pictures on a board that are used to request drink, food or any other kind of care, or text to speech devices based on synthesis. In figure 2.7 here is an example of AAC device that is mounted on wheelchair.

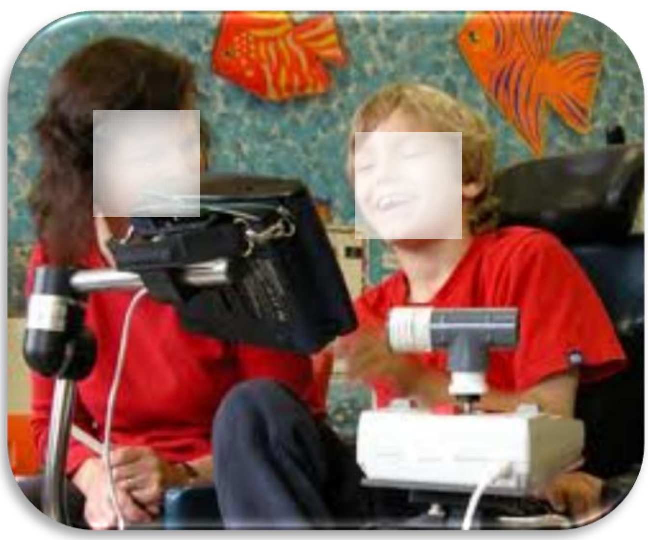

Figure 2.7 : AAC sample

2.2.9 - Deafness and hearing loss

Deafness and hearing loss are very common impairments. There are many levels of hearing loss and deafness implies 100% hearing loss.

- Radio aids and audiometers (Figure 2.8 shows a sample hearing aid)
- Doorbell lighting system, fire alarm paging system
- Portable and fixed loop systems
- Visual telecommunication devices
- Tele-text
- Subtitle recorder and reader video cassette recorders
- Fire alarm with vibration capability

Figure 2.8 : Hearing aid

2.3 – Hardware for Impaired

Hardware for impaired, has subcategories within sets of daily use devices.

- Adjustable Task Lamp: A device that holds the lamp and directs its light within given direction.
- Banknote Reader: A device that reads banknotes.
- Scanner: A device that scans the given surface. With helps of OCR software scanned document is converted into electronic text, that can be read by text to speech engine.
- Standalone reading aids that function without a PC. Such devices have integrated a scanner, optical character recognition (OCR) software, and speech software in a single machine.
- Refreshable Braille display is an electronic tactile device which is placed below the computer keyboard.
- Mountbatten Brailler: A typewriter for braille writing.
- Embedded Head Tracking and Eye Tracking Devices

2.4 – Software for Impaired

General software that is built for impaired people as assistive technologies are separated widely.

- By altering the colors and size of desktops, short-cut icons, menu bars and scroll bars; customizing of graphical user interfaces.
- Screen magnifiers that magnifies the part of the screen that mouse if over.

▪ Screen readers (In figure 2.9 Jaws is the most common SR program.)

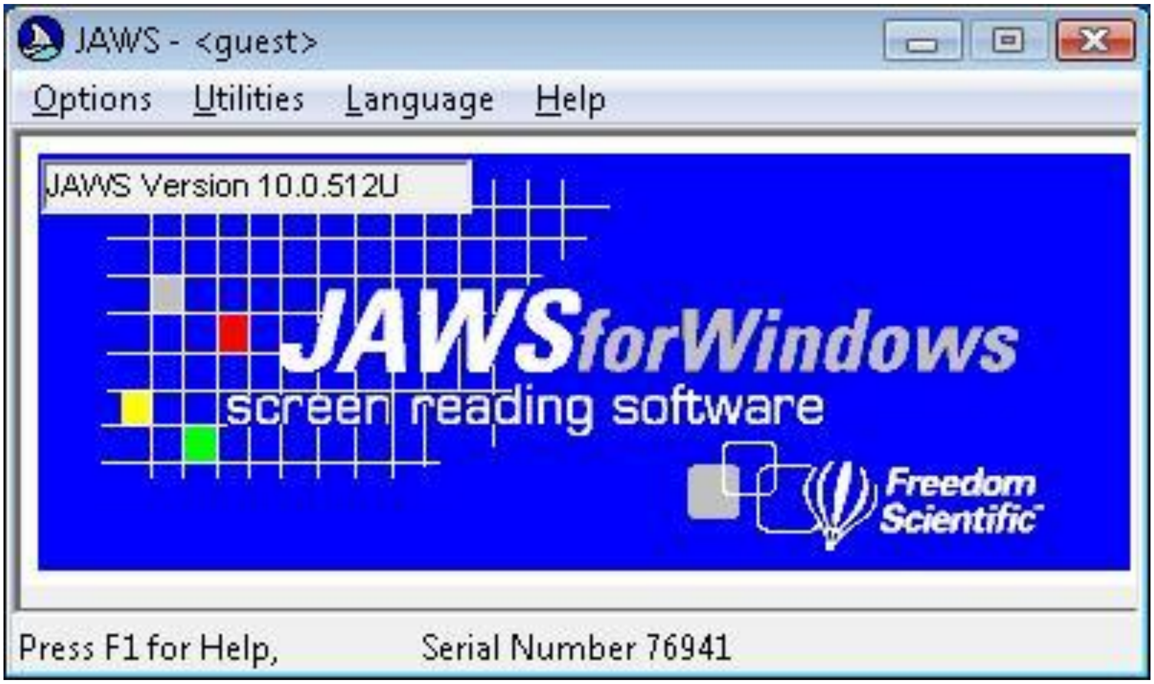

Figure 2.9 : Screen reader software [16]

▪ Applications that have self-voicing capability.

▪ Optical character recognition: Applications that convert the printed material into text, with helps of photography or scanner.

▪ Braille translator: For embossing via braille embosser, it translate given text in to braille format.

▪ Text-to-speech (TTS) and Speech-to-text (SR)

▪ Grammar checkers, Spell checkers

▪ Real-time text for people with hearing impairment

2.5 Software enriched Hardware use in Assistive Technologies

Among all assistive technologies, software enriched hardware's are most effective ones [17]. These can be easily modified for user's needs. Although there are a lot of improvements obtained with hardware, software enrichment brings assistive technology to a different level. In figure 2.10 a voter with a manual dexterity disability is making choices on a touchscreen with a head dauber.

Figure 2.10 : Touchscreen with a head dauber

Einstein stated, "Make everything as simple as possible, but not simpler."

The problem here is where to draw the line where separating the tasks that will be done on hardware and software. If hardware transfers all required data from sensors directly to computer, system will slow down because common operating systems cannot handle data in real time.

2.6 Assistive Technologies with No Hand Use for Computer Interaction

As there is no healthy information about the numbers of people in 'No Hand Use' informal numbers state that category of impaired ones has large group of numbers, thus there are a couple of devices built for their interaction with computer. Most of them use way too complicated technologies rather than necessary ones, which makes the system too complex to use for a disabled person to use.

2.6.1 No Hands Mouse

No hands mouse use foot movements to interact with mouse interface [18]. It has two button mouse functions. One pedal is for cursor control and the other one is for clicks. The function of each pedal is marked. Pedals can be switched to either combination that feels comfortable for impaired as shown in Figure 2.11.

Figure 2.11 : No hands mouse

Advantages: This device is pretty accurate considering its technology. Its simplicity makes it easy to use.

Disadvantages: As one leg sends click functions, impaired cannot put some weight on. This foot should be held by effort. It makes it hard to use. This requires strong lower abdominal muscles and can cause back pain and injury.

Biggest disadvantage of this device is that its subset is too small. People who cannot move their feet by causes like paralysis cannot use this device.

2.6.2 Adaptive Brain Interfaces - EEG Based Control Devices

This kind of assistive technology uses brain signals to control computer[20]. There are a lot of studies on this title; however, none works correctly as imagined. Most studied noninvasive interface is Electroencephalography (EEG). EEG has a nice temporal resolution, low cost and easy to use. As human beings differ from each other by their nervous mapping EEG devices require a lot of software training before use. In an experiment by Niels Birbaumer at University of Türbingen which is located in Germany, he tried to train several paralyzed people to use EEG devices in a manner that computers can understand. Birbaumer measured his techniques success by characters pressed in given time interval and users adaption to new interaction interface. This experiment was made with 10 patients that tried to move computer cursor along the screen only by brain waves. The process was so slow that in average only 100 characters could be pressed within 1 hour while training them took many months [21]. Any kind of outside interruption stopped the process during tests. Such as while patient was trying to move the cursor, if a light is switched on, system could not understand which signal is controlling computer interface and which one is produced for anything else.

Nowadays, basic EEG systems can be bought on online market by Emotiv [22]. Not like standard medical EEG, Emotiv has 14 electrodes. Emotiv headset has a long training interval to let computer learn the neural activity pattern of the user and the shape of neural network. Most users that experienced Emotiv, stated that it just measures facial expressions.

As removing a disability in an impaired person's life is main goal, one cannot state that EEG devices reached their goal. Controlling a standard computer interface is so slow that makes it almost impossible for a person to interact flawlessly. With EEG devices, impaired person cannot interact with computer fast enough compared to a normal person. Although this is an improvement considered to impaired person's previous state, if we compare a standard mouse interface with EEG devices, they commonly stay useless. Most of them are still not considered as Disabled – Computer Interaction devices. They are still in the range of HCI toys.

Some basic EEG devices are used as Disabled – Computer Interaction devices for those who do not have any kind of ability to interact with a computer other than thinking. In those cases EEG devices are one of the best choices considered to “not interacting with a computer”.

Figure 2.12 : EEG computer interaction

Advantages: This technology is the only choice for impaired who cannot move their head and cannot speak. In figure 2.13 here is a sample EEG usage.

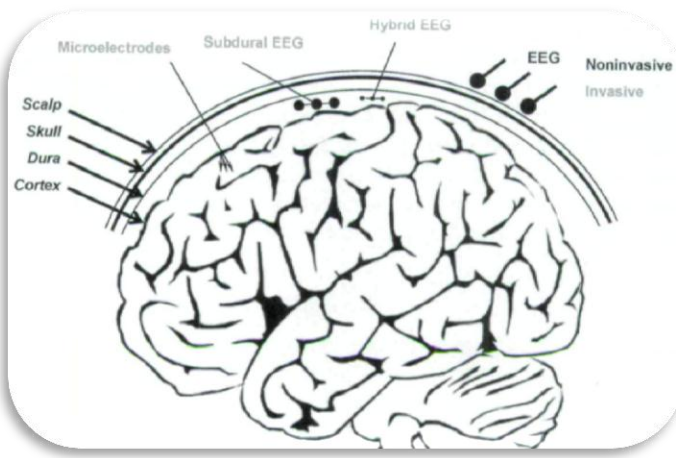

Figure 2.13 : EEG interaction system

Disadvantages: As EEG interface requires a lot of concentration, interaction can be easily spoiled by some environmental distractions. In figure 2.12 EEG interaction modules is shown. If doorbell rings during computer interaction process, control loss is inevitable. The worst part is that it is too slow to use the computer with these kinds of devices. Thus, online education and home working choices are not even possible. As a common problem among all Disabled-Computer Interaction Modules, these devices have high price range.

2.6.3 Head Mount HCI Devices

In general head mount human computer interaction devices use data obtained from basic head movements gathered by some hardware solutions [23]. Figure 2.14 shows the most common form of this device type.

Figure 2.14 : Head mount HCI device

Advantages: This device is easy to operate and easy to learn how to interact.

Disadvantages: It requires too many hardware to accomplish interaction. This makes these kinds of devices pricey. As this kind of devices are expensive, it is hard to give them to a large amount of impaired. Interaction process is slow, real time computer control is almost impossible.

2.6.4 Application Of Facial Electromyography In Computer Mouse Access For People With Disabilities

This technique aims to develop a newly facial EMG human – computer interface for people with disabilities for controlling the movement of the cursor on a computer screen by accessing the computer cursor according to different facial muscle activity patterns. As any muscle moves, it generates an electrical signal. With EMG, these kinds of movements are recorded and combined to generate control patterns. Electrical signals that are acquired from facial expressions are too weak that they can be interrupted by environmental effects. These signals are generally amplified before use [24]. As muscle movements must be used continuously during computer interaction, real time calculation and continuous wavelet transform is necessary to estimate EMG activity threshold [25]. In figure 2.15, a sample distribution of EMG sensors are shown.

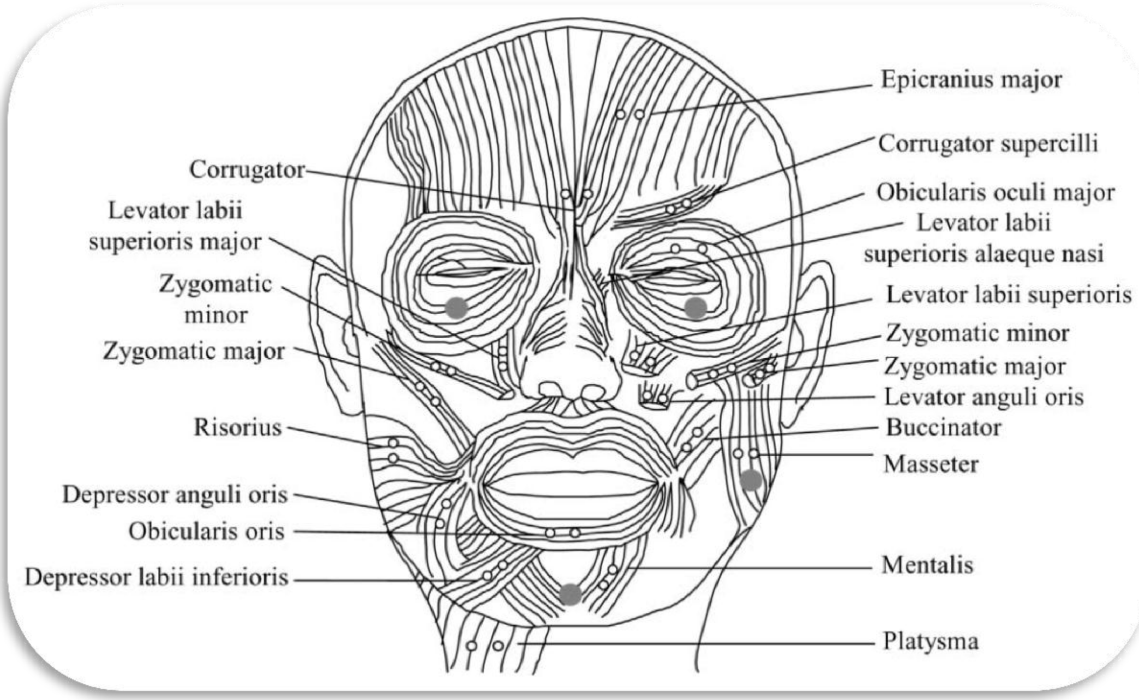

Figure 2.15 : General pattern of placement of electrodes in EMG [26]

As EMG devices generally combine data from electrodes, every single muscle movement must be handled carefully. Such as if a movement that means "move mouse to left" is acquired during evolution of a movement that means "move mouse to right" system must handle this state.

In order to exactly detect the muscle activity threshold, this study adopts continuous wavelet transformation to estimate the single motor unit action potenials dynamically.

Advantages: As a result experiments shown that the accuracy of using the facial mouse is almost 88%, and this result indicates the feasibility of the proposed system [27]. Moreover, the subject can improve performance of manipulation by repeated training. Compared with previous works, the proposed system achieves complete cursor function and provides an inexpensive solution.

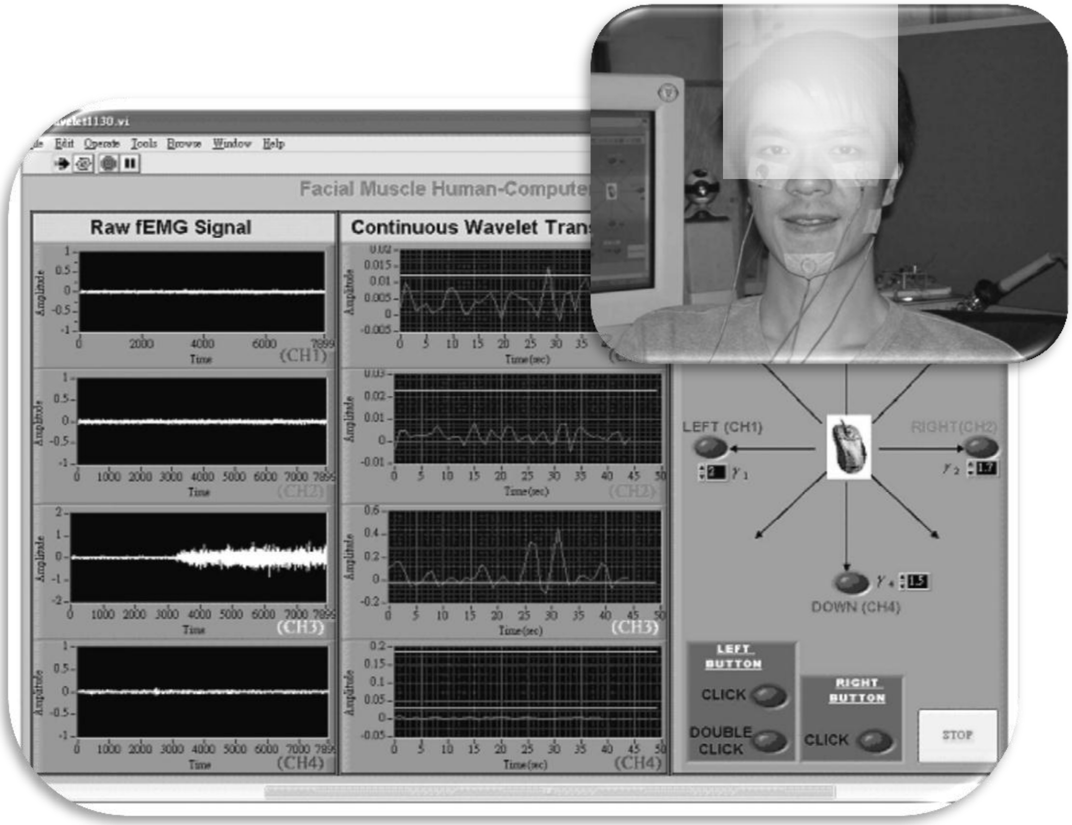

Figure 2.16 : Facial electromyography

Disadvantages: Although there are still some drawbacks in the facial EMG-based human – computer interface, the facial mouse can provide an alternative among other expensive and complicated assistive technologies. System is not 100% accurate. This situation makes it unusable for work and educational purposes. Figure 2.16 shows a sample interface of facial electromyography.

2.6.5 Eye Movement-Controlled Human-Computer Interface for the Disabled

These kind of devices work with 4 sensors sticked around the eye one above, one below, one in the right side and the last one to the left of the eye. System reads the muscle movements and controls the mouse with these data. Figure 2.17 shows a simple diagram of how eye control system works.

Advantages: Only eye movement is required. This solution is usable by disabled person that can only move his eyes.

Disadvantages: As eye is not stable during rest, it is too hard to handle mouse interface with this device. This solution is not even 50% efficient. The interface is too slow and system can be easily interacted by environmental effects.

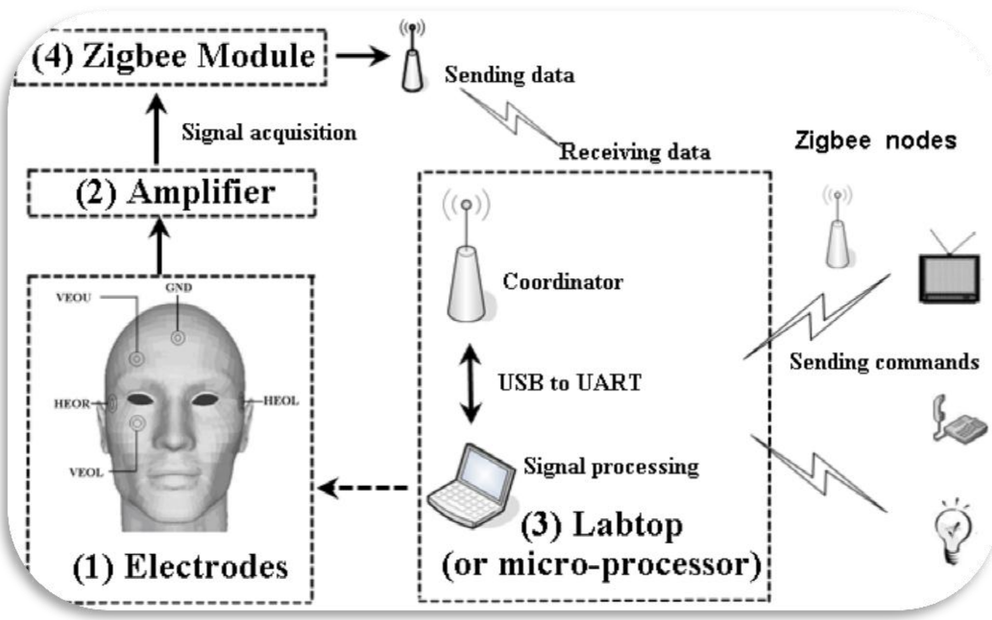

Figure 2.17 : Eye control system

2.6.6 Hands Free Vision Based Interface for Computer Accessibility

Hands-Free Vision-Based Interface is designed for impaired people who have physical disabilities or mental challenges that are an important part of today's society. They have not yet started to share our opportunities in the Information Society [28]. System is built to maintain easily accessible systems for computers to achieve their inclusion within the new technologies.

Their main subjects are is those who are disabled users with motor impairments. Program finds users face and starts to track it. Through time, it starts to recognize gestures. Subsequently, a new information fusion procedure is proposed to acquire data from computer vision algorithms and its results are used to carry out a robust recognition process.

In general, solutions under this title, detection system determines a region of the image that is acquired from image sensor, face can be used as an example. Then it finds object's location in the image. Tracking system relocates the predefined object in given images and reports the changes of its position in time. This procedure may work as a repeated frame by frame detection of the object that requires discontinuous image processing. To improve tracking process filters like Kalman[29] can be used as a temporal progression.

With helps of GPU's, preciseness and robustness is increased for these kind of techniques. Current technology does not require a specific interface so there is no restriction at impaired person's current environment. Generally Hands Free Vision Based Interfaces has no limits on static background or lightning conditions. If a well-built software is used during process, a standard webcam should be enough for a low cost system [30]. Earlier researches on head tracking were based on color distributions, head geometry or motion (1998 – Bradski, Toyoma). In 2002, Berketal brought a new approach to this title. He located visible features on the users face such as eye which is based on color tracking, nose and mouth and then he tracked face movement. This method required searching for similar looking regions in ordered frames that acquired from image sensor. At first these kinds of approaches were affected by environmental changes such as light conditions and dynamic back ground. After that most solutions used this technique. In figure 2.18 tracking of both eyes and nose tip are shown.

These kind of approaches are not still widely used on disabled – computer interaction because of lack on accuracy and preciseness.

Advantages: System only uses a standard web cam and special software. This makes it pretty cheap. As head movement depends on impairment, this solution is only usable by those who have exact head movements.

Disadvantages: User interaction is slow, gestures and eye blinks can be considered as mouse clicks so that system does not work reliable. System cannot be used for employment purposes and educational purposes.

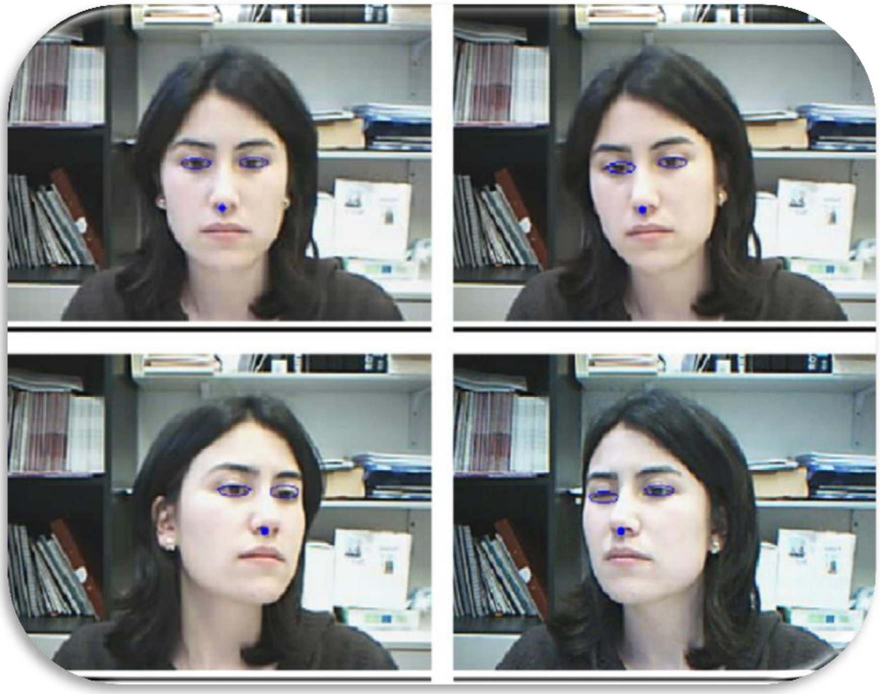

Figure 2.18 : Hands-Free vision-based interface

2.6.7 Robust Real Time Eye Tracking for Computer Interface

This system is designed for disabled people, who have of acute need for a communication system. An efficient eye tracking procedure is presented providing a non-invasive method for real time detection of a subject eyes in a sequence of frames captured by low cost equipment. The procedure can be easily adapted to any subject and is adequately insensitive to changing of the illumination. The eye identification is performed on a piece-wise constant approximation of the frames. Eye detection is generally a pupil traction procedure. It usually tries to determine the movements of the pupil relatively to the movements of the eye. As suggested in [31] 3 kinds of main methods is used generally. First one is template based in which algorithm first tries to find the shape that best fits to an eye outline. This step is usually accurate but mostly proper initialization is necessary. Proper initialization brings high cost to computing and needs almost perfect image contrast [32,33]. Appearance based methods commonly require huge amounts of data for training the software that detects photometric eye appearance for different face patterns on each subject that has different face orientations [33,34]. If classifier defined classification properties in a manner that system can use them in a high intensity, a good performance can be obtained. This depends on the training interval of the program. The last one, feature based methods generally rely on darkness of pupil, lightness of sclera, shape of iris in a circular manner, eye corners' shape,etc. for catching human eye from the given image. As picture zoning method is performed by Turk Method [35] in [36], eye blinks are easily detected with helps of Lucas Kanade's feature tracker [37] by providing feature points of eye tracking. Every step, described until now requires a high image contrast to detect and track the eye movement. After picture zoning, as semi-circle from the lower eye is detected as a curve.

In 2002, Sirorey and his colleagues used a new method to analyze irises, eye corners, blinking, eyelids and gaze direction. They applied template matching for identifying these elements, while their motion is detected by the edge segments that are associated with optical flow. During this procedure, head movements must be estimated to detect eye movements related to the head movements [38]. In figure 2.19 detection of eye in a video stream sample is shown.

After these steps, changes in eye positions can be transferred in to mouse movements. As eye movement is limited in a small range and image sensors' resolutions not enough, eye movements cannot directly control mouse interface. Instead of this, special software and user interfaces for operating systems are developed. This kinds of software limit the users' computer control with its own limits. Although this software is well built, it could never allow user to control whole computer interface.

Advantages: System uses a standard web cam and special software only. This makes it pretty cheap.

Disadvantages: User interaction is slow, uncontrolled eye movements moves the mouse unintentionally eye blinks can be considered as mouse clicks so that system does not work reliable. System cannot be used for employment purposes and educational purposes. As most of the work here is done by computer's CPU, either GPU processing of a strong CPU is necessary. As eye movements and triangularization of the eye is used by this technique, user should not have skew-eyed.

Figure 2.19 : Eye tracking system

CHAPTER 3

DEVELOPMENT OF DISABLED-COMPUTER INTERACTION MODULE

A Disabled – Computer Interaction (DCI) module for impaired people has been developed in this study. Target audience is impaired people that are not able to use their hands for different reasons like paralysis (quadriplegia, diplegia, hemiplegia), traffic accidents, bomb injuries, combat training injuries, born defects, Multiple Sclerosis (MS), ALS, traumatic brain injury or struck damage. These people are able to move their heads within limited angles.

3.1 System Architecture

DCI module includes 2 different kinds of sensors. First one is an embedded image sensor that tracks the screen and finds its center automatically; second one is a standard G-Sensor that locates head's position due to ground level. After calculation process is done system acquires center screen position and then sends it to computer via Bluetooth interface. Microsoft's HCI device driver handles the device and special software processes data input. Basic system architecture is shown in the following figure (3.1).

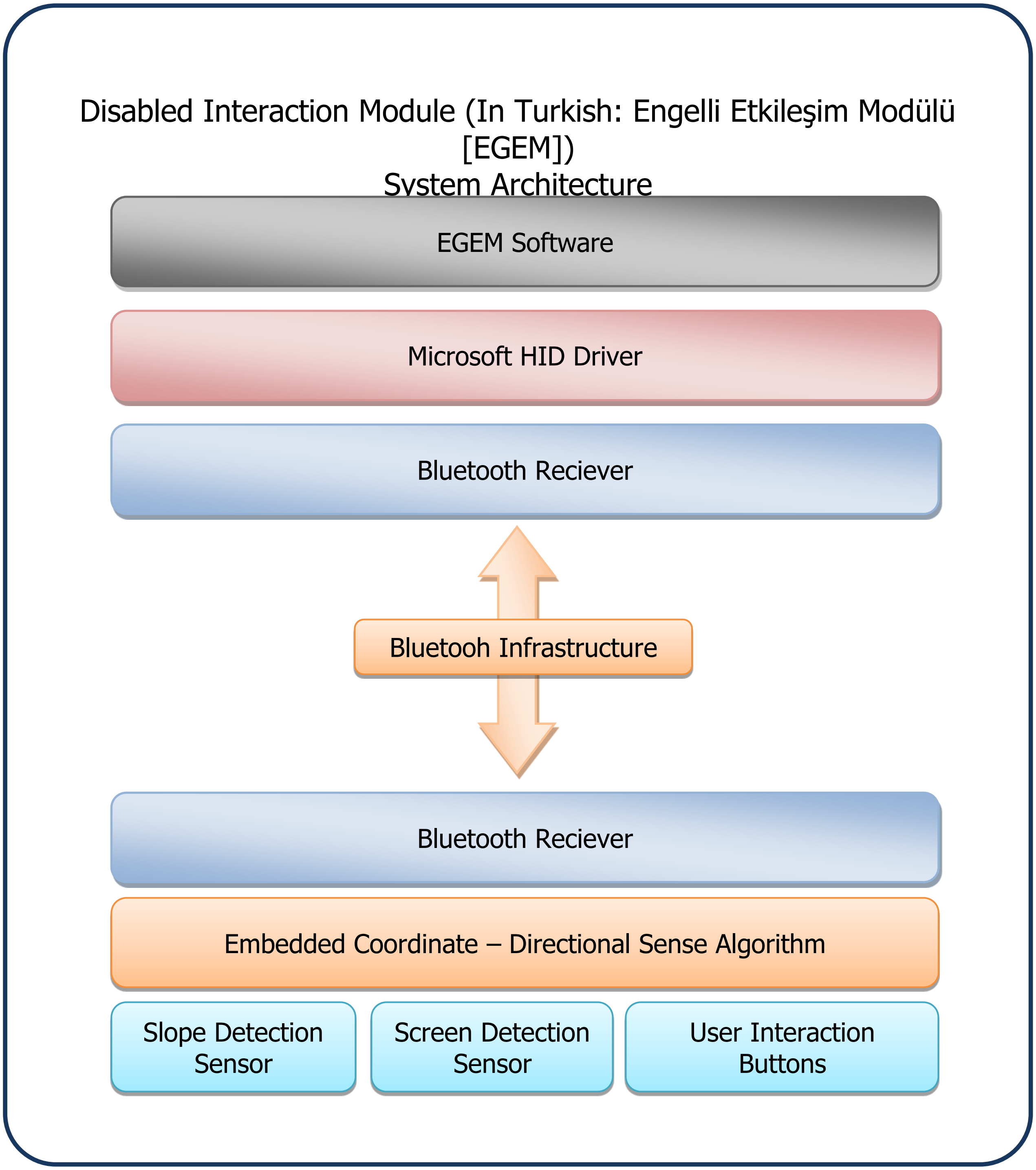

Figure 3.1 – EGEM system architecture

3.1.1 Hardware

Hardware of the module contains an image sensor, a G-sensor, and interaction buttons. Devices also use a bluetooth module to communicate with the computer.

3.1.1.1 Image Sensor

This is a special sensor that works like a normal webcam but does the entire image processing on its own so that the system itself can react in real time. It detects the IR light points within its bounds. These points are implied by 3 integer numbers that are represented by (X, Y, R). X is center of points coordinate from left side of image, Y is center of points coordinate from bottom side of image and R is its diameter. This specially designed image sensor has capability to work on its own. It only returns how many point it has got within the gathered image and their X, Y, R values in order.

3.1.1.2 G-Sensor

Basically a g-sensor is used like a digital bubble level. It is used for understanding the angular turn from gravity center. Figure 3.2 shows a simple bubble level.

Figure 3.2 : Bubble level

3.1.1.3 Interaction Buttons

As disabilities differ among every impaired person, hardware is built customizable. There are 7 inputs as buttons. Two of them are currently used for mouse interaction as right click and left click buttons. These buttons are held in mouth by user. By squeezing teeth buttons can perform mouse click actions. Design of interaction buttons is shown below in figure 3.3.

Figure 3.3 : Interaction interface buttons

3.1.1.4 Communication Interface

It is found hard to use this kind of devices with cable connections. Impaired people do not want something on their heads that draw attention. For security and financial reasons Bluetooth interface is selected for communicating via computer. Also alternatives such as wireless communication and RF usage are possible but these are easily intractable and external noises can cause malfunction.

3.1.1.5 Power Supply

Device is built to work for 8-10 hours. For this reason a powerful but light and small, rechargeable lithium battery is selected.

3.1.1.6 Head Mount

For building a prototype, a hat is selected. A simple hat does not draw attention in the crowd and does not make impaired person feel uncomfortable. Figure 3.4 shows how it is mounted and used.

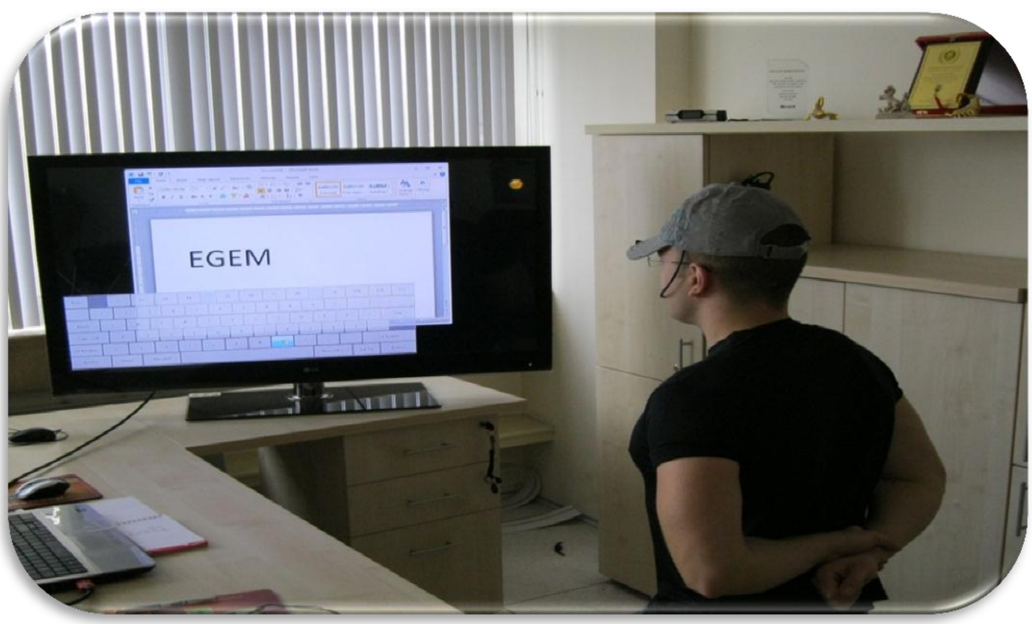

Figure 3.4 : Head mounted device

3.1.2 Software

Software side of solution consists of a device driver, and an enhancement module that works by the data supplied by this driver on the computer. On embedded software, erosion filter is applied. After erosion method, a point detection method is used to detect computer's screen's location related to the sensors pixels.

3.1.2.1 Erosion

Erosion methodology is used for removing irrelevant motions from binary images. Erosion methodology removes points from the given image under determined threshold. As the motion detected area becomes smaller than given threshold value, it disappears.

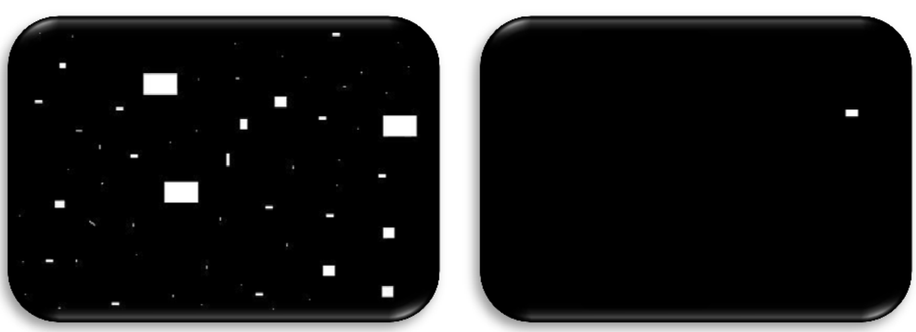

Figure 3.5 : Binary image on the left hand side, after erosion image on right

3.1.2.2 Relative Point Detection

After application of erosion method on binary image that is gathered from embedded image sensor, every row and column is sent to a serial "or" gate. This gate stops after finding the first "1" in the given serial data. After this step, two binary arrays are obtained that include the data about where the point starts and ends. From the columns' array we gather point's location's X axis by finding the middle point of the 1's. With application of the same method to the rows' array we obtain point's location's Y axis. Also finding the distance of the furthest point to the X axis location gives us the Radius of the point for further improvements. (Such as change in users distance from the computer and angle of view.) After these steps, embedded sensor sends X,Y and R values to the microprocessor to be transmitted to the computer. The usage of this algorithm on Disabled-Computer interaction is patented during this study.

3.1.2.2 Communication Structure

Every peripheral device needs a driver. For our study, we built our device to use standard Microsoft HID driver as it supports Plug and Play function. This makes the system easy to use for impaired people. Figure 3.6 shows simple working algorithm of our module EGEM (Engelli Etkileşim Modülü).

Figure 3.6 : Communication structure

3.1.2.3 Low Level Communication Interface

Due to Windows operating system restrictions HID devices are forced to communicate over COM port. Low level communication interface reads available data from COM port and sends responds to device from computer. This structure makes our system have many levels from low to high.

3.1.2.4 User Interface

As there is a wide range of impaired whom this module can be used by, system holds different user interfaces. Most common one will be explained. This interaction device directly connects to mouse interface in low level. So it does not only simulate mouse, it works just like a mouse. Program itself has a specially designed Turkish layout onscreen keyboard in order to provide easy to use keyboard interface. In default keyboard control is zipped in to a hexagonal yellow button that can be seen on Figure 3.3. On mouse over, keyboard menu appears. Menu includes hide/show button, exit button and lay out button. Figure 3.7 shows mouse leave and mouse enter events of keyboard control that is shown in figure 3.8.

Figure 3.7 : Onscreen keyboard steady state – On mouse over state

There are 4 different layouts that can easily be used. All keyboard layouts are designed to be semitransparent. The user can select which he finds easy to use.

Figure 3.8 : Onscreen keyboard

This interface also includes a Windows mobile phone interface that enables the user to use all Windows Mobile devices which are connected to computer easily. Software directly transfers visual phone screen to a window on computer screen. Mouse clicks are sent to phone via interface. Figure 3.9 shows Android interaction interface.

Figure 3.9 : Android interface

CHAPTER 4

EXPERIMENT

In order to determine the effectiveness, usability and limits of our assistive technology we conducted an experiment within a group of disabled people. A study group was formed at a rehabilitation Clinique in Ankara for nearly 45 hours in total within 2 weeks in the second quarter of 2011. Attendees were selected from people with paralysis with different levels of impairments belonging to different sub impairment categories.

In total, study group held 30 person between ages 8 to 44 (14 male and 16 female impaired people) that have paralysis (quadriplegia, diplegia, hemiplegia), Multiple Sclerosis (MS), ALS, traumatic brain injury, struck damage and cerebral palsy (CP).

Every person is examined whether they can move their head within the limits of given definition for target audience. The lowest value of head movement was ~12 degrees vertically up and down (In total 24 degrees), ~15 degrees horizontally on one side (In total 30 degrees). After examination, each subject is tested individually by his/her own under guidance of 2 observers. One of the observers keeps tracking of time for every job given, and the other one recorded the accuracy of the system and the ease of use.

Subjects used our device to complete given tasks by using cursor via EGEM. During this experiments the computers that we used were exactly the same as each other. Volume was turned on, screen resolution was at 1024x768. Computers had mate screens in size 17.3 inches. All subjects were asked to complete following 5 scenarios. In addition, free computer use for obtaining random data such as email interfaces that providers were not given.

1) Use a web browser to open a Facebook account and add someone as a friend; send a message to this person. (A dummy user was created for this step. This user was added by every subject.)
2) Use an email interface to send an email. (That has a web user interface such as Gmail, Hotmail, Yahoo. Etc. more than half of the subjects chose Gmail.)
3) Call someone by mobile phone that is connected to computer via USB. (Also ending this call and sending a message was tested. Results were recorded only by their completion, not their time consumption.)
4) Change some system settings such as brightness level. (As most subjects were not familiar with the computer interface, most of them were guided by one of the observers to change brightness level, sound level and run check disk feature.)
5) Open a movie from external disk and watch 5 minutes. (A list of

National Geographic documentaries were provided. Some users opened youtube.com and tried to open a video from there by misunderstanding. Observers were helped them to complete this step.)

As some of the users never used a computer before, their level of success was only completing these steps without any time interval. They were guided by their observer to complete these steps. For all these tasks, cursor movement accuracy was recorded by the observer. Time limitations were only given to hurry up the subject. In general after all these tasks, an onscreen keyboard was used to measure the character count per minute. In average every user wrote the sentence "EGEM – Engelli Etkileşim Modülü" under a minute. Average time consumption was 1 character per second. Female subjects those are older than 30 completed the task slower than the others.

All of 30 subjects were able to complete all the tasks with all given definitions above with no losses. As computer knowledge differed by subject to subject, success criteria for those 5 tasks mentioned up above was only completion. Cursor movement accuracy and speed were measured by counting the characters typed per minute. These results that obtained by character counting and task completion, indicated that our tool helped our target audience during computer interaction process.

CHAPTER 5

RESULTS AND CONCLUSION

As explained in the introduction part of the thesis, for those who cannot move their hands there is no way to interact to outer world by touching. Nowadays a healthy person spends most of his time in front of a computer. If a device that can make the computer useful for impaired is built, this can increase their life quality. Our device can communicate with mouse interface by analyzing head movements and turning them into data usable by computer. The device is used like a standard mouse. If user moves his head up, mouse moves upwards, if user moves his head down, mouse moves downwards. Same situations are applied while turning head left and right. Also left and right mouse button can easily be clicked via teeth. System efficiency, computer usage coverage, ease of use, and comparison with other available technologies are explained in detail below.

This study has shown that both hardware and software are built to be reliable and unlike other devices for disabled people, it is cheap enough to be spread easily. 99.9% of our test subjects easily used interaction interface.

Among all computer programs some of computer games are hard to interact with. They use peripheral device’s port directly without operating system interaction. Our system covers this kind of nonstandard usages.

Most subjects who cannot use their hands and were easily moving their heads. Some of them can do it in a limited interval; some of them do it really slow with shaking. These are previously concerned issues. So system is built ready for these kinds of usage variations.

For this thesis both hardware and software solutions are used. Comparison between appliance of the thesis and other alternatives (No Hands Mouse, Adaptive Brain Interfaces (EEG Based Control Devices), Head Mount HCI Devices, Application of facial electromyography (EMG) in computer mouse access for people with disabilities, Eye controlled Human Computer Interface for Disabled, HandsFree-VisionBased Interface for Computer Accessibility, Robust Real Time Eye Tracking for Computer Interface, Hardware and Software that are developed for this study) are given below.

As no hands mouse uses foot movements to control user interface, it cannot be used by those who also don’t have the ability to use their feet. It can be used by for those who can only and only don’t have the ability to use their hands [18]. Considered to a standard mouse, user interaction is not low. Feet are not precise as much as hands. As use needs to give less pressure to feet, strong lower abdominal muscles (muscles that are underneath belly) are necessary. Back pain and injury can be occurred. This interface is not suitable for long term use.

As an advantage this device can be used by those who cannot move their heads. On the other hand EEG devices work with brain signals [32]. Even hair length may change the interaction quality. High concentration is necessary while using this device. Interaction interface is too slow in general. This situation makes these kind of devices unsuitable for educational and employment purposes. Due to EEG sensors' price range these devices are also pretty expensive. EEG signals that are acquired from surface are pretty weak. This weakness requires amplification as correction[20]. As this amplification process also amplifies noises that are gathered from outside environment, data gathered from EEG devices become inconsistent [21]. As explained in the 2nd chapter, EEG devices are really slow that they can allow 100 characters to be typed per hour with a standard onscreen keyboard. This value is the proof that EEG devices cannot be used for real time interaction and educational, employment purposes.

Head mount devices are easy to operate and easy to interact but they are really slow [23]. They need a lot of hardware to interact with the computer. As amount of hardware increases, price line also increases. With keyboard interface, only 10 letters per minute can be written at most. If characters are selected randomly as a password, this amount is lowered down to 3 letters per minute.

Mostly, solutions under EMG title generally depend on training which makes this device person specific and unsuitable for mass use [27]. As every part of our body is specific to us like our finger prints, out nerve system is different than each other. In the hardware part every impaired must be examined for best facial sensor replacement. Due to sensor prices, these kinds of devices are expensive. After sensor placement and training is done, these kinds of devices commonly have accuracy around 80% [27]. As 80% seems to be enough for computer interaction, remote education and home employment requires more accurate interaction.

During our daily life, our eyes are always in motion. It makes eye tracking solutions hard to use and almost impossible to interact comfortably.

Eye tracking solutions that require only webcam are really cheap as they are software oriented mostly [34]. Lack of specially designed hardware equipment makes these interaction modules slow and non-reliable. Even standard gestures and eye blinks can be misinterpreted as mouse misdirection and wrong mouse clicks. For this solution, standard eye movements and blinks are mostly misinterpreted. Although prices are very low due to no hardware use, system cannot be used by impaired with high interaction quality.

Our solution is built with following specifications considered as our primary goals by our research.

- Solution must be easy to use as impaired may not get tired during interaction procedure.
- Interaction quality must be higher than a standard mouse so that impaired can use the computer interface as well as a mouse interface.

- Solution can be used for educational purposes and home employment purposes.
- Solution must be cheap so that it can easily be spreaded.

In this study as our hardware and software are built with boundaries above, the result is cheap, easy to interact and can offer high quality interaction with computer unlike other solutions defined in this project.

5.1 Recommendations for Further Improvements

System is built with 7 input buttons, 4 led lights and 1 vibration motor that work perfectly with driver and software layer. Buttons can be used for electrical wheel chair integration and robot hand control purposes. All that needs to be done is building USB interfaces for wheel chair and robot hand. As device is controlled by head movements only, with these improvements, an impaired person may be able to move himself and do some kind of basic hand related tasks such as opening doors, controlling environmental devices that do not have computer interfaces.

Using motion patterns and gestures might be required in the future for widening the target audience. After IPhone and Android devices, mouse gestures became interesting for computer interaction. Some common software comes with built in mouse gestures support. For those who will be able to benefit from these kind of software improvements will show themselves after wider field study.

Some impaired person might not be able to use drag and drop function of the mouse or click a second button by their month due to their impairment level. These kinds of simple control standards might be optional. Such as user may select whether he/she wants to use drag and drop feature. It might be easily turned on or off with a single button click.

Some impaired people may not control button with their mouths'. For those ones, another mouse click event trigger might be built.

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Appendix A: Curriculum Vitae

CURRICULUM VITAE

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EDUCATION

Degree	Institution	Year of Graduation
BS	Çankaya Univ. Computer Engineering	2008
High School	Gölbaşı Anadolu Lisesi	2000

WORK EXPERIENCE

Year	Place	Enrollment
2010 – Present	CyberTech Ltd.	Entrepreneur
2010 – Present	Başarsoft Ltd.	System Architect
2005 – Present	Courthouse of Ankara	CSI – Information Tech.
2009 – 2010	PDI - Erkom	Computer Engineer
2007 – 2008	Roboturk	Computer Engineer
2007 – 2008	Microsoft Turkey	Student Partner

FOREIGN LANGUAGES
Advanced English

HOBBIES
Free Weight Lifting, Computer Related Activities.