

# **Eye-Gaze based Communication Device for People with Disability**



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## DECLARATION

We hereby declare that the work which is being presented in the project report entitled “Eye-Gaze based Communication Device for People with Disability” is an authentic record of our own work carried out at Cognitive Systems Group, University of Bremen, Germany and at Department of Electronics and Communication. The work has been carried out at Maulana Azad National Institute of Technology, Bhopal.

Place: 30-05-2012

Date: Bhopal

Sincerely,

Arpit Srivastava  
Abhinav Asati

## Chapter 1

### INTRODUCTION

There are many people in this world, who are not able to walk, who are not able to speak, who are not able to move their hands, Why?, because unfortunately they suffer from physical and mental disabilities. According to a survey of 2006, more than 2 % of the total population of India suffers from one or other type of disability. It is important to bring such disabled people into mainstream society, making them feel useful, making them independent. One such disability is Amyotrophic Lateral Sclerosis, abbreviated as ALS in which the person is not at all able to move limbs and even head because of weakness of muscles as the disease progresses. Some other motor neuron diseases such as Cerebral Palsy may have similar implications.

However, in ALS as well as in Cerebral Palsy, the eye movements of the patient are seldom inhibited. In later stages of disease, as voluntary mobilization of fingers, hands, legs, and head etc is not possible, eye movement is the only thing that can be exploited for establishing communication between patient and the rest. In the presented work, an eye-gaze tracking based hardware device and a software interface are presented as augmentative alternative communication aid for use by persons with disability. By tracking where patient is looking on the display screen, the choice selected by patient is identified and then, communicated to the care-giver or the family members through digitized output (such as audio). By using this product, the patients can say 'Hi', 'Hello', 'How are you', 'Good Morning', 'I am thirsty', 'I want to go to toilet', 'I want to watch movie', 'I want to go outside' etc to the people around and thus express themselves to an acceptable extent. The economic viability of the product lies in the fact that the cost of the head-mounted eye tracking device is less than 1,000 INR. Commercially available gaze-based communication devices cost in several lakhs, have to be imported and are out of reach of average income Indian population. It is worth mentioning here that the software module developed in the course of this work has been made available on internet for collaborative development and user-specific customizations.

Eye-gaze tracking holds the potential of evolving as a very useful methodology for human computer interaction (HCI). Gaze tracking study was first carried out in 1967 by Yarbus in which he used invasive mechanical devices to record eye movements. Since then, Gaze tracking has come a long way and lately, it has acquired a good significance in Marketing usability research and cognitive science studies. However, integrating gaze tracking in everyday applications has been difficult for the factors ranging from invasiveness and robustness to availability and pricing. In past decade, gaze-tracking has been widely explored for usability in applications of HCI but it still has not been able to secure a place in general interface interaction in day-today life. Today, Eye-gaze tracking systems cost lakhs of Rupees, and thus their application is only limited to high-end niche products generally in research domain. It is important to note however that the bulk of this cost is not due to hardware, as the price of high-quality camera technology has dropped over the last ten years.

Rather, the costs are mostly associated with customized software development, sometimes integrated with specialized, although inexpensive, digital processors, to obtain high-speed performance.

Electro-oculography (EOG), limbus tracking and video-based tracking etc are some eye-gaze tracking techniques that have been available for many years, but they all suffer from a number of limitations. Some techniques require equipment such as special contact lenses, electrodes, chin rests or other components that must be physically intrusive to the user. These invasive techniques are uncomfortable for the user and are cumbersome to use. The expensiveness is another major issue. Recently, some video-based techniques for eye-gaze tracking have been developed that have minimized this invasiveness to some extent. Video-based techniques capture an image of the eye from a camera either mounted on head gear worn by the user or mounted remotely, process it in frames, and map the pupil movement to the gaze location on the display screen. It is clear that to reap the potential benefits of eye tracking in everyday human-computer interfaces, the development of low-cost, easy-to-use and robust eye-tracking systems will be necessary. The eye tracker developed in this work, is a low-cost, 30 frames per second (fps) head-mounted device. Although few professional companies are also making eye trackers for commercial purposes but they are very expensive and lack extensibility in terms of customized software.

## Chapter 2

### MOTIVATION

#### **ALS and other disabilities**

There are large number of people in the world who suffer from physical disabilities, and are unable to perform even basic tasks of locomotion and speaking. In severe cases, more than 75 % of the body may be affected and not even smallest of muscular movements is possible. One such disability is Amyotrophic Lateral Sclerosis (ALS). ALS also referred to as motor neuron disease in British English, is the most common form of the motor neuron diseases. The disorder is characterized by rapidly progressive weakness, muscle atrophy and spasticity, difficulty in speaking, difficulty swallowing, and difficulty in breathing. The disorder leads to muscle weakness in the whole body caused due to degeneration of the motor neurons.

The muscular weakness renders the muscles dysfunctional in time. The rate of progression can be measured using an outcome measure, a 12-item instrument administered as a clinical interview or patient-reported questionnaire that produces a score between 0 to 48 with 0 for the severe disability and 48 for normal function. Regardless of the part of the body first affected by the disease, muscle weakness spreads to other parts of the body with time. There is no known reason for this disease. In fact, in around 95% of the cases, the patient is found to have a family history of ALS. In later stages, affected individuals may ultimately lose the ability to initiate and control all voluntary movement. Although the order and rate of symptoms varies from person to person, eventually most patients are not able to walk, get out of bed on their own, not able to speak, or use their hands and arms. Some other similar disabilities are Cerebral Palsy and full-body Stroke. Depending upon the nature and extent, Cerebral Palsy patients also, in some cases, are unable to perform tasks that require even slightest of voluntary muscular force.

The people suffering from ALS, Cerebral Palsy, and Stroke etc are neither able to perform simple muscular movements of hands, legs, and even head nor are able to speak. Under these conditions, the patients suffer huge psychological outburst. It comes from the inferiority complex that they are completely dependent on care-giver, are a burden on their family and society. Not being able to express their requirements and feelings, disabled patients have to make extensive use of assistive technologies for communication. These assistive technologies help speech-language impairment patients to be lesser dependent on care-giver. At least the patient should be able to tell the care-giver or the family members that he/she is thirsty, hungry, or wants to go to the toilet etc. Augmentative and alternative communication (AAC) is the term that is used for the communication methods which can supplement or replace speech or writing for those with disability for producing or comprehending spoken or written language.

## **Available solutions and their shortcomings**

The patients suffering from severe disabilities have many assistive devices available in market, which enable them to mobilize. Some of these devices are: Personal Mobility Aids (power wheelchairs and power scooters), Transfer Aids for indoor or outdoor use (sliding board, bathtub lift etc), Personal self-care aids for bedroom, bathroom, dining room, etc. -mounted, wireless telephone and others. However, not many options are available for those suffering from speech-impairment (in later stages of ALS and cerebral palsy, speech-impairment is very common).

In mid-twentieth century, modern use of alternative communication methods began with systems for those who had lost the ability to speak. Encouraged by an increasing commitment in the world towards the inclusion of disabled individuals in mainstream society, rapid progress in technology, has paved the way for communication devices with speech output and multiple options for access to communication for those with physical impairments. Few such tools are sign language, communication board, speech synthesizing board etc which assist disabled people in communicating with others.

The main shortcomings of the above systems are that they are very expensive. In India, they are not at all affordable by a patient from low and even medium income groups. Another problem associated with them is that they are meant for very generic purposes. Customization of products is very difficult or is very expensive. For example, Speech synthesizing boards require application of physical force for operating and are useful only in earlier or middle stages of ALS. They cannot be used by patients with severe disability of more than 90 %, when the whole body is impaired and no muscular activity is possible. These methods don't take into account the individual's motor, visual, cognitive strengths and weaknesses and often require deep involvement of family members.

## **Proposed Solution**

It is worth noting that, even at higher stages of ALS, bladder and bowel sphincters, cognitive functions and the muscles responsible for eye movement are still functional. In fact, Camera Mouse is one such utility which makes use of some facial characteristics, to control computer mouse by translation of head. But unfortunately, severely disabled patients are not even able to move their head. In the presented work, exploiting the eye movement ability of ALS patients, the recently popularized technique of gaze tracking has been used for developing an alternative communication method that can be used in speech-impairment. There are two types of Gaze tracking methods: 1. Head-mounted and 2. Mobile. The patient, sitting on wheelchair or lying on bed, will focus his/her gaze on a display device kept or mounted in front of him/her and by dwelling in a particular screen region for some amount of time, he/she can make a selection. After a selection is made by eye gaze, a corresponding digitized speech will be generated which will make care-giver and family members understand what patient wants to say. The choices shown on display device are highly customizable, and may be changed as per requirements of the patient. A low-cost head-mounted gaze tracking solution and an open-source software interface have been developed for the purpose. The proposed tool is very easy-to-use, convenient for patients, economical and requires very less efforts on the part of care-giver.

## Chapter 3

### SOFTWARE MODULE

#### Algorithm

There are generally two approaches, feature based and model based. Feature-based approaches detect and localize image features related to the position of the eye whereas model-based approaches do not explicitly detect features but rather find the best fitting model that is consistent with the image. Combining both the approaches, Starbust Algorithm has been proposed by Li et al for Video-based eye-gaze tracking which makes tradeoff between run-time performance and accuracy. Figure 2. shows the step-by-step procedure of Starbust algorithm, details of which are discussed in reference [4], and need not be described here in length. Noise in incoming video signal is unavoidable when low-cost simple webcam is being used as the sensor. Although the noise is reduced, when the infrared filter is removed and visible light filter is placed, it cannot be completely neglected. To remove noise, a 5x5 gaussian filter is used with standard deviation,  $\sigma = 3$ .

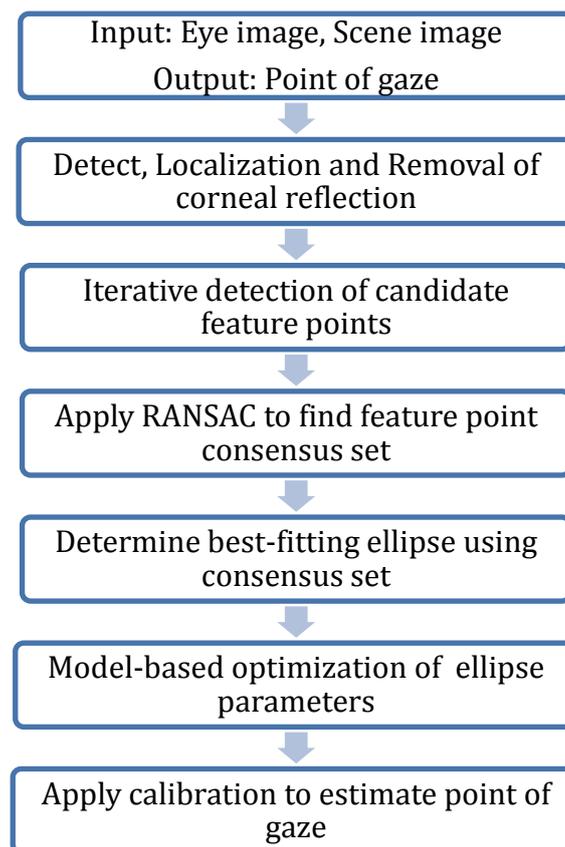


Figure 1. Flowchart of Startbust algorithm

For corneal reflection detection and localization, an adaptive thresholding technique is employed in each frame. To begin, the maximum threshold is used to produce a binary image in which only values above this threshold are taken as corneal reflection (CR) candidates. It is

likely that the largest candidate region is attributable to the corneal reflection, as any other specular reflections tend to be quite small and located off the cornea. Initially, the ratio will increase because the CR will grow in size faster than other areas. A lower threshold will, in general, also induce an increase in false candidates. The ratio will begin to drop as the false candidates become more prominent and the size of the CR region becomes large. We take the threshold that generates the highest ratio as optimal. The ratio between the area of the largest candidate region and the average area of other regions is calculated as the threshold is lowered. The location of the CR is then given by the geometric centre (x,y) of the largest region in the image using the adaptively determined threshold. Radial interpolation is then used to remove the CR. First, the central pixel of the identified CR region is set to the average of the intensities along the contour of the region. Then for each pixel between the centre and the contour, the pixel intensity is determined via linear interpolation. Figure 2. shows the step-by-step method to detect pupil contour, based on thresholding.

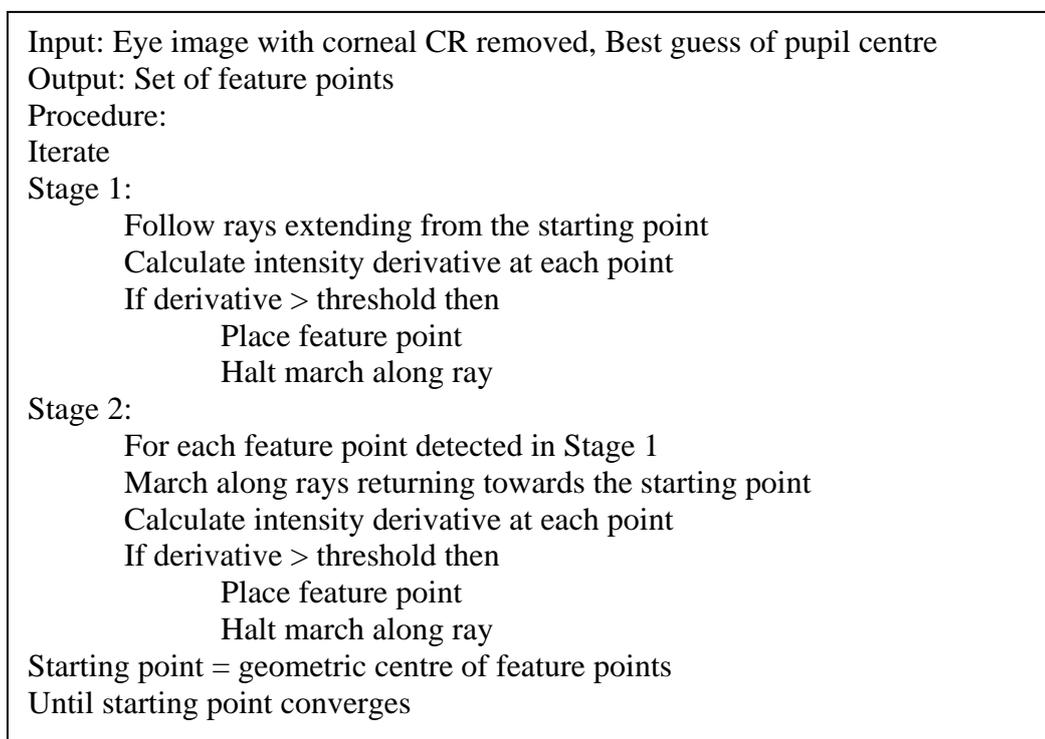


Figure 3. Pupil contour detection method

After obtaining a set of candidate feature points for pupil contour detection, the next step of the algorithm is to find the best fitting ellipse which may fit pupil model. RANSAC (Random Sample Consensus) is a popular model-fitting technique which is effective even in presence of significant amount of outliers. RANSAC algorithm has also been used in many computer-vision problems. It is an iterative procedure that selects many small but random subsets of the data, uses each subset to fit a model, and finds the model that has the most agreement with the data set as a whole. Next step is calibration. In order to calculate the point of gaze in the scene image, a mapping must be constructed between eye-position coordinates and scene-image coordinates. During calibration, the user is required to look at a 3x3 or a 5x5 grid of scene points for which the positions in the scene image are known. While the user is fixating (focussing gaze) each scene point  $s_i = (x_{si}, y_{si})$ , the eye position  $e_i = (x_{ei}, y_{ei})$  is recorded. The particular mapping used by different eye-tracker manufacturers and different research group varies widely. Therefore, we examined the optimal mapping for our head-mounted system by

examining the accuracy of the mappings derived from the first nine-point (for 3x3 grid) calibration in our validation study (see Algorithm Validation Section). The mapping that we examined was a first-order linear mapping. For each correspondence between  $s_i$  and  $e_i$ , two equations are generated that constrain the mapping:

$$x_{si} = a_{xo} + a_{x1}x_{ei} + a_{x2}y_{ei} \quad (1)$$

$$y_{si} = a_{yo} + a_{y1}x_{ei} + a_{y2}y_{ei} \quad (2)$$

where,  $a_{xi}$  and  $a_{yi}$  are undetermined coefficients of the linear mapping. This linear formulation results in six coefficients that need to be determined. Validation of the algorithm has been done in [4], and the accuracy of calibration process is  $\pm 0.77$  degrees.

## Implementation and Interface design

The open-source C++ implementation of above algorithm has been made available at <http://hcvl.hci.iastate.edu>.

This open-source C++ implementation has been used for the purpose of gaze tracking at the core of presented design interface for communication by disabled persons. For graphical visualization, audio generation and interface developments, OpenFrameworks library ([www.openframeworks.cc](http://www.openframeworks.cc)) has been used. Some snapshots of the developed software are shown in Figure 4, 5 and 6.

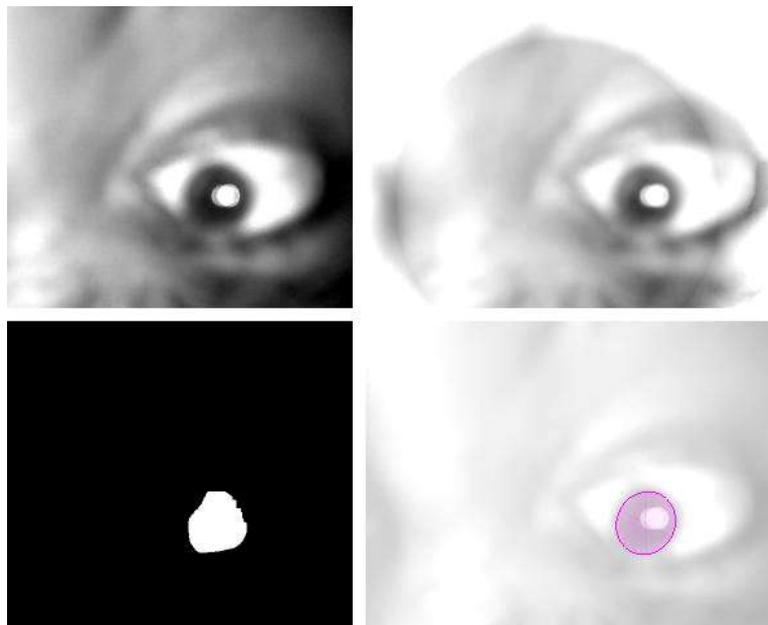


Figure 4. Different stages of algorithm (a) Original Image (b) Corrected Image (c) Thresholded binary Image (d) Ellipse-fitting

For digitized speech generation, AT&T Natural Voices® Text-to-Speech software has been used. It is worth mentioning here that the software developed by the authors for gaze-based communication has also been made available open-source to facilitate customization and collaborative development. Digitized speech corresponding to each pictorial representation and symbol are stored in the processor memory.

As shown in Figure 5, when an option (or a block) selected by the user by gazing selectively on a particular region of the display screen, that option (or the block) corresponding to that region automatically turns grey. Such kind of graphics and animations make the interface easy-to-use and beautiful. As soon as the 'OK' or the 'NO' block are selected (and are shaded grey), the digitized speech of 'Its OK' or 'No' respectively is spoken out from the speaker.

In Figure 6, two layers have been shown for menu-driven selections. On the main page, apart from some most commonly used snippets, there are some wide terms such as 'Hi-Bye', 'I need', 'I want', 'Sleep'. As the patient focuses on any one of them and makes selection, a new layer appears. For eg.

I want...to drink water  
...to take food  
...to go to toilet etc

In this way, the patient is able to frame longer expressions into speeches and communicate with care-giver or anyone else just by eye movements.

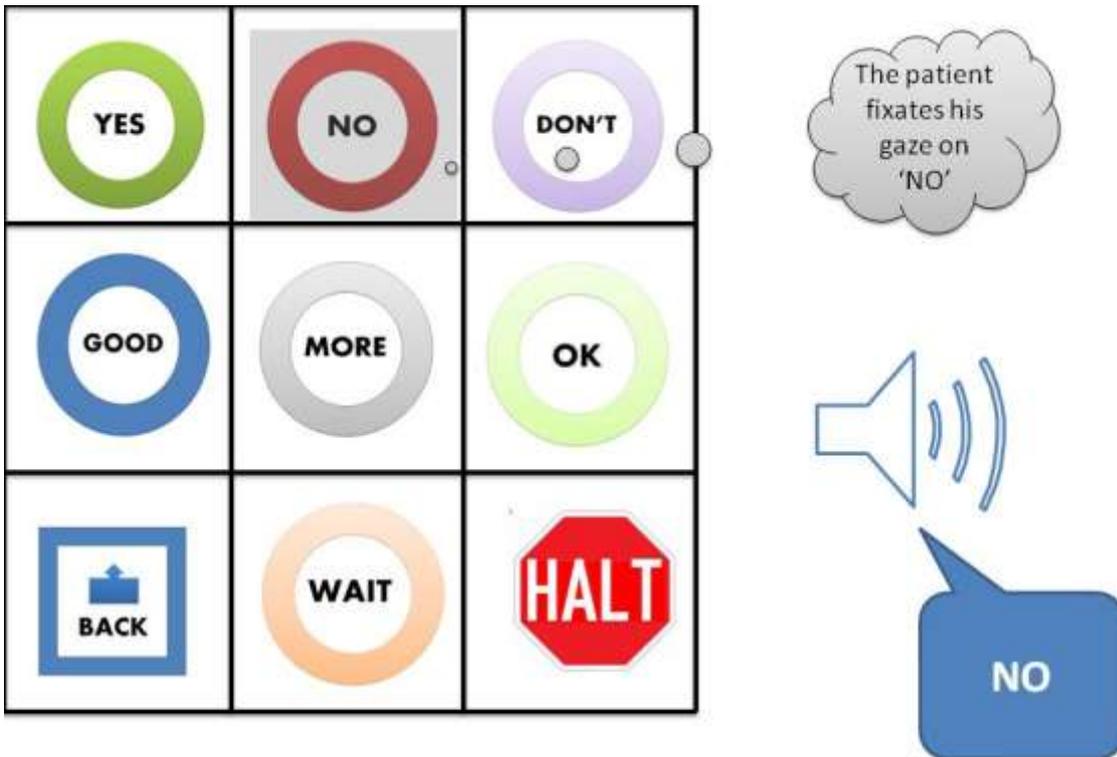
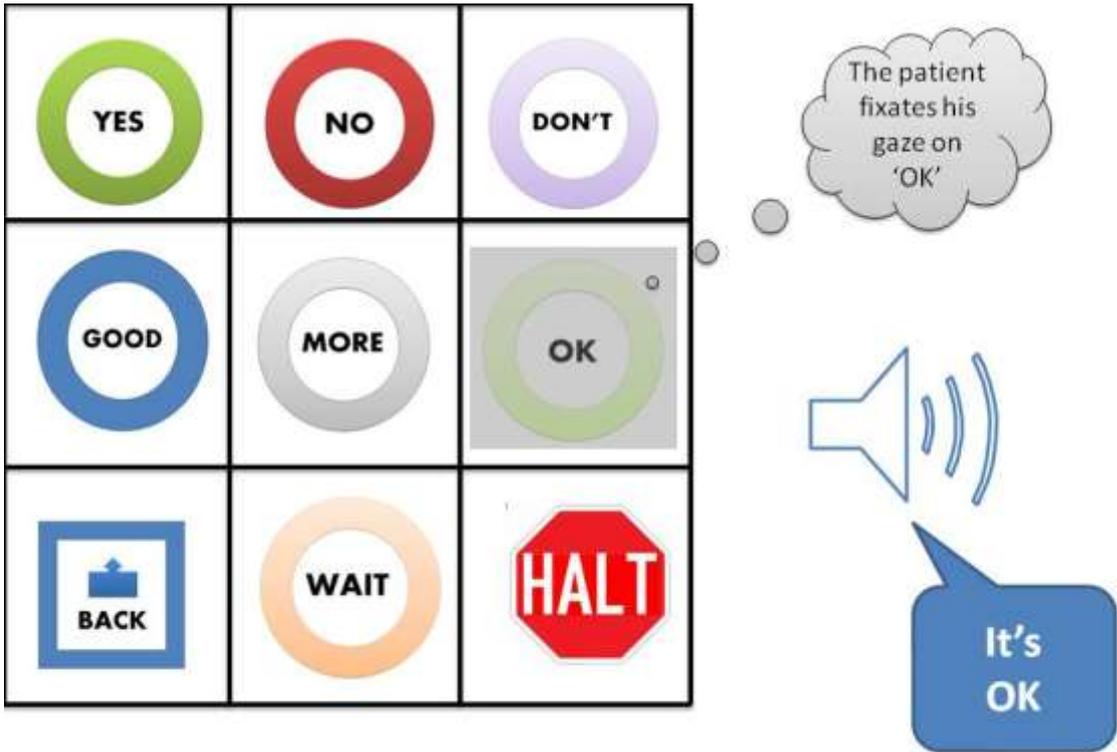


Figure 5. A Basic display interface

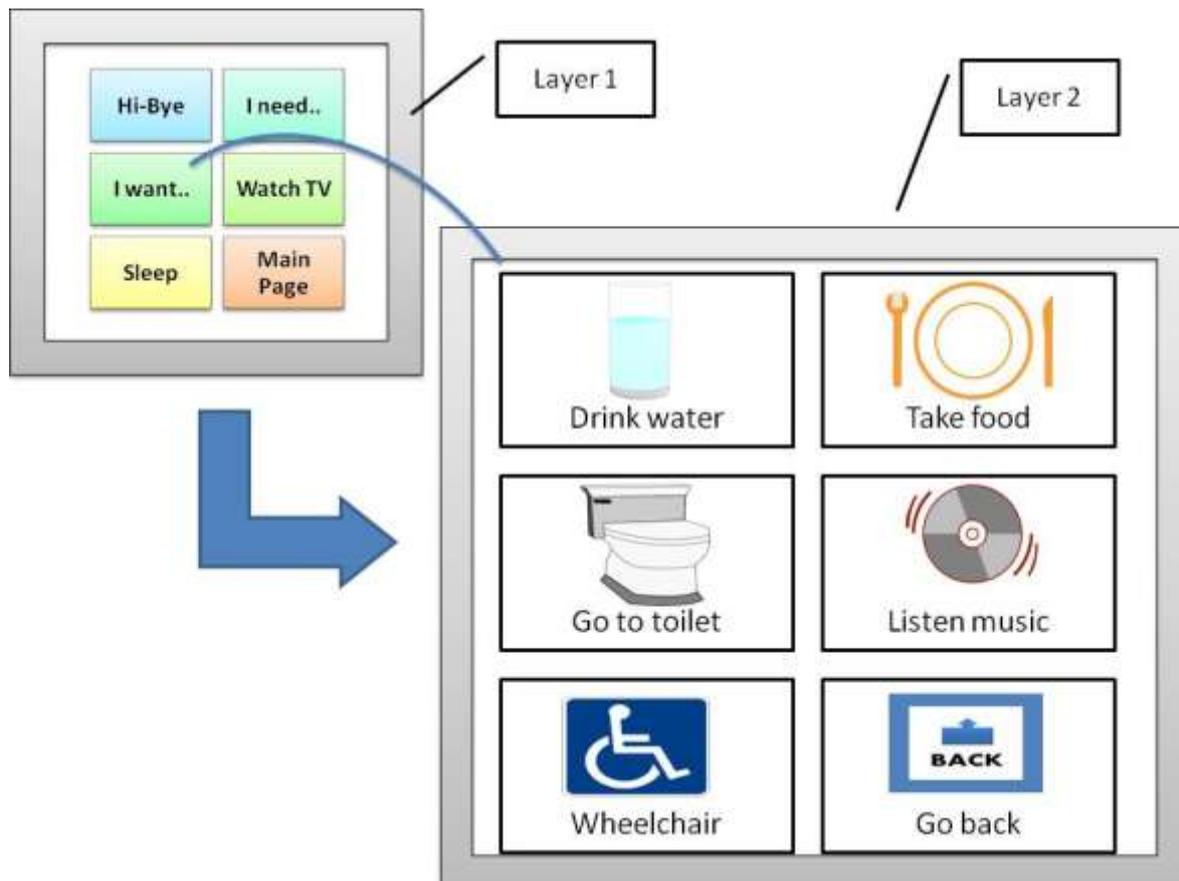


Figure 6. Menu-driven selections – From layer 1 to layer 2 by Gaze-selection

## Chapter 4

### HARDWARE MODULE

The hardware module consists of a cheap low-resolution CMOS camera for analog video output. In the presented work, an USB webcam has been hacked to act as Infrared camera. The IR filter of the webcam has been removed and replaced with a visible light filter. This is done so as to inhibit the entry of visible light into the lens system, and provide a black and white image sequence which is less noisy and computationally viable to process in real-time. In order to clearly discriminate the pupil from the rest of the eye, an even IR illumination is required which is created by placing few IR LEDs around the camera lens mount.

The camera can be mounted either on eye glasses or on a light-weight helmet to provide stability and ease of use. The camera has to be mounted as a distance of 5-6 cms from the eye in such a way that it doesn't obstruct the vision. Both types of models were built and tested for usability study and it was found out that helmet-mounted eye-tracker was more comfortable to wear for a longer time. Figures 7 and 8 contain the images of the low-cost eye-gaze trackers built during this work for testing and usability analysis. The hardware modules developed for this work were tested on number of people for usability analysis, and positive feedback was received from most of them.



Figure 7. Eye-glass mounted Eye-gaze tracker



Figure 8. A subject using helmet-mounted Eye-gaze tracker for communication

Figure 9 and 10 show how exactly a disabled person lying on bed or sitting on a wheelchair will be using the product. The ray-diagrams show the required range of pupil movement which is sufficient to cover the complete area of display screen. It is on this display screen shown in figure, the symbols and pictorial representations are shown which are comprehended and subsequently selected by the patient for audio playback of speech through speakers. Suppose, there is a 3 x 3 grid of images of various drinking and eating items (such as water, milk, juice, bread, eggs etc being displayed on the screen, the patient can fix his/her gaze (fixate) on any one of them to select that one) and this way he/she selects water, the computer will instantaneously speak out, 'I want to drink water'. By audio stimuli, the caregiver or anyone near the patient will learn that the patient wants to drink water and then help accordingly.

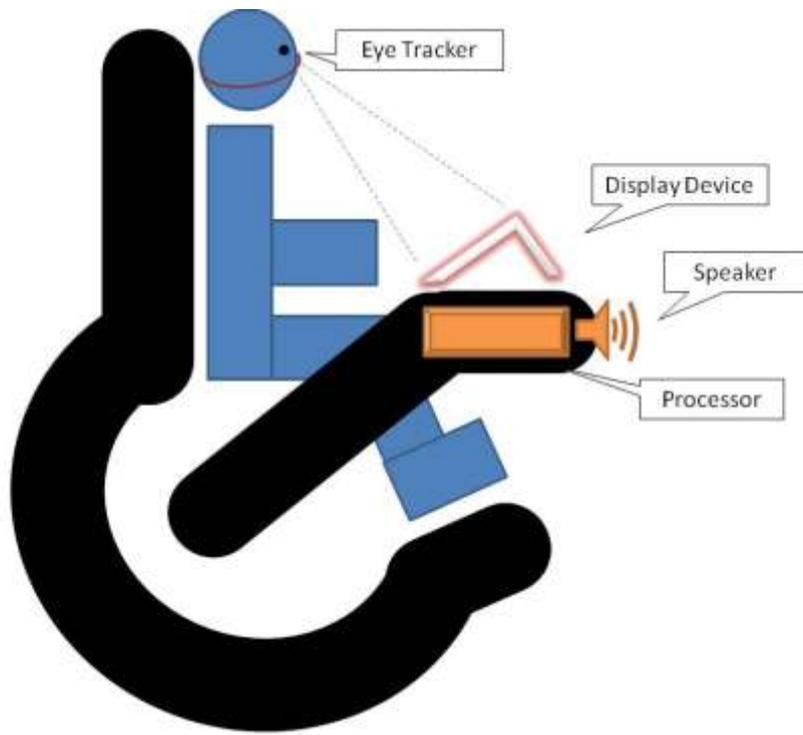


Figure 9. When patient is on Wheelchair

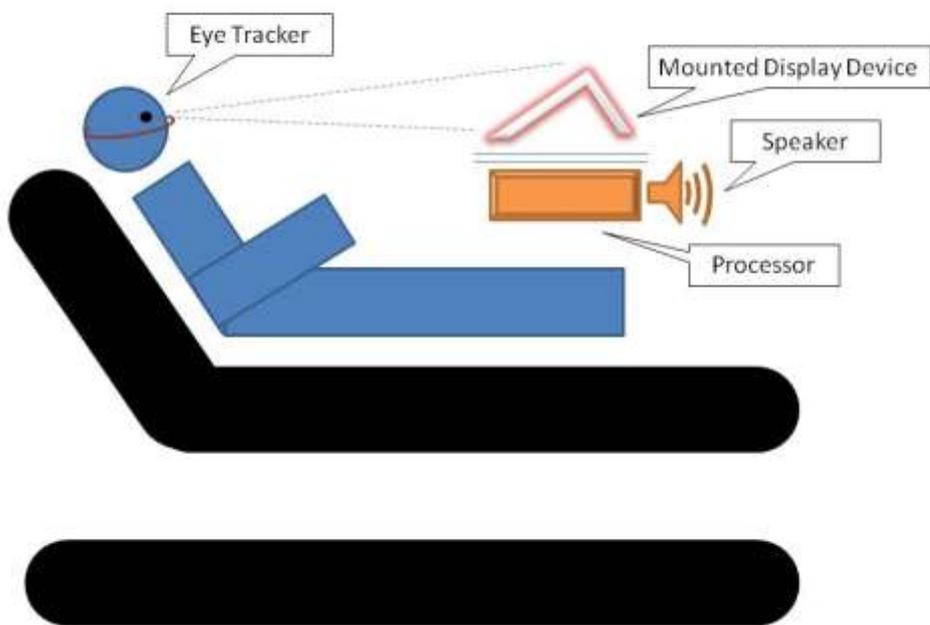


Figure 10. When patient is on bed

## Chapter 5

### USABILITY ANALYSIS

#### Design considerations

Hardware design consideration requires critical analysis of user's comfort such as maximum weight of the device that is bearable by the users should be taken into account. The camera used should have high resolution and high frames-per-second (fps). Low-cost Webcams have an fps of 30-50 whereas commercial eye-gaze trackers operate with 100-120 fps cameras. However, during experimentation on real subject, these low-cost webcams worked perfectly well. In this prototype design, a PC is required on which the communication software is installed. However, the requirement of PC can be alleviated by replacing it with Intel Atom Processors which are small in size, light-weight and compact. For improvisation, the head-mounted eye-gaze trackers can be made wireless instead of having USB connection with the computer. Display device should not be placed too far or too near the user. A distance of 1-2 meters is good enough depending on the patient's ocular defect, if any.

Software module has two components – one is eye-gaze tracking and another is communication interface. Recently, several other eye-gaze tracking algorithms have been proposed which may have better performance as compared to Starbust. The design of interface layers and selection of digitized audio is of prime importance. It is better to have a female voice digitized speech for a female patient and male voice for a male patient. A single layer must not have many pictures or symbols as it may challenge the capability of the low-cost eye-gaze tracking system and may cause error in selection. For a 15'' laptop screen, there can be a 4x4 grid, containing 16 symbols and thus providing user with 16 choices. If any new layer is added, the corresponding digitized speeches are also generated and saved in the memory of the processor. Very modular additions in the software are required to make such customizations.

#### Cost Factor Analysis

The commercially available Eye-gaze trackers are of higher precision. Several international vendors supply commercial Eye-gaze tracking system but they don't provide any platform (as in, some Standard development kit or SDK) for Eye tracking application development. As a matter of fact, the eye-tracking is expensive as the hardware only costs around 2 to 2.5 lakhs INR and application-specific or user-oriented customization may cost even more. The current market of Eye tracking research incorporates Disabled users, Universities, Hospitals, Defence institutions, and for marketing usability analysis. Given the cost factor involved, the eye tracking research, in the past decades, has been limited to applications in very niche areas. This has inhibited gaze tracking from becoming popular for HCI and other purposes. So, there is a need to promote open-source software and hardware development for gaze-tracking research and development.

The Eye-gaze trackers developed during this work were built from an off-the-shelf low-cost USB webcam (for Rs. 800), head mount (Rs. 200), some wires (for Rs. 20), IR LEDs (Rs. 50) and battery (Rs. 50). The total cost of the hardware built is around Rs. 1100-1200 only. Although this was just a prototype, an improvised version will also not cost much and many times lesser than commercialized ones. One may argue that these low-cost eye-gaze trackers are not very accurate. But the kind of application, which is being targeted here, does not require as such very high-precision or accuracy, the way some other analytical applications do. So, this low-cost not-super-accurate eye-gaze tracking system serves the purpose for block-based choice selection from a matrix of pictorial representations.

## Chapter 6

### RESULTS AND CONCLUSIONS

In the presented work, eye-gaze tracking technology has been used to address the problem that those with severe muscular disability and speech impairment. In ALS and Cerebral Palsy, there are many cases when the patients are not able to move their limbs, fingers or even head. They cannot even speak up because of inability to apply any muscular force. Many augmentative and alternative communication methods exist for such people, they all fail to prove themselves efficient in many ways. However, in spite of muscular weakness and aphasia, the eye movement is still possible.

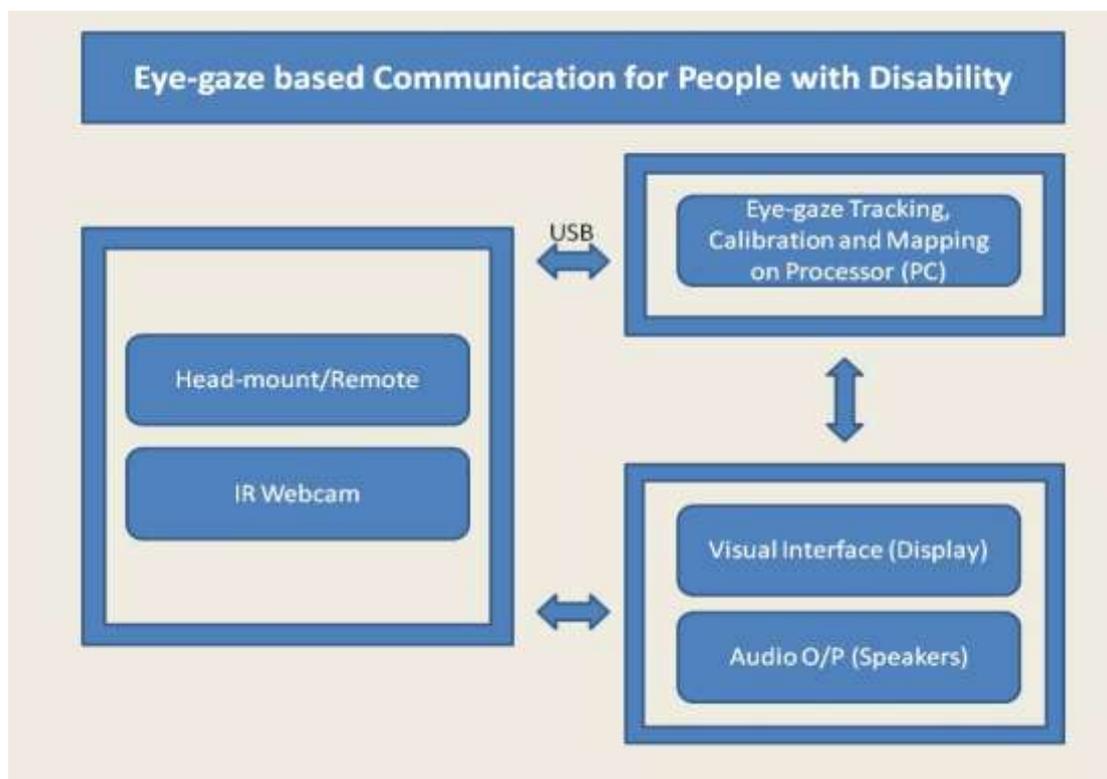


Figure 11. Block-diagram representation of the design

Eye-gaze tracking is a technique that can track our gaze and tell us where we are looking at a point of time. Figure 11. shows a block diagram of the developed project. A low-cost Webcam has been modified to work as an IR camera and is connected to the PC. The camera is mounted on the head of the user through some proper mechanism such as helmet or by using eye-glasses. This camera records the movements of pupil as the eye looks at some visual stimuli, and sends the video to the PC for processing. The software installed on PC

processes the incoming video and maps the pupil movement to the gaze fixation on the display screen. After the calibration is done, when the user looks at some point on the screen, the coordinates of that point are calculated upto  $\pm 1$  degree error, which is a pretty good accuracy. A display screen is mounted in front of the patient and several symbols are presented on the screen. The patient fixates at any symbol to select that option. As a option is selected, an audio response comes out from the speakers that can be heard by others. In this way, a person who cannot move and cannot speak can establish communication with others around him/her. Although not like natural language, the digitized speech is good enough to convey the expressions of the patient. Apart from this, a typing interface, a movie player or a web browser interface may also be developed for adding new dimension to gaze-based communication.

The method employs low-cost hardware solutions and open-source software solutions. A prototype was developed and tested thoroughly. It is an easy-to-use, economical, customizable, convenient method and non-invasive method that has the potential to solve the problem faced by many unfortunate individuals in the world today. The severely disabled people suffer dependence and hostility because they cannot talk, they cannot express themselves. This is an effort to bring back such people from alienation to inclusiveness in mainstream society for humanitarian concerns.

## Chapter 7

### FUTURE WORK

Following development work for future are planned for the improvisation of the presented product.

1. Use of Remote eye-gaze tracker - Use of remote eye-gaze tracker will not require the patient to wear any head-mounting device. It would be more comfortable, and the patient may use the communication aid for longer time periods.
2. Enhancement of accuracy – If the accuracy is improved, gaze-tracking will be efficient and chances of error will be less.
3. Calibration – Calibration is clumsy and is needed to be done at regular time intervals. Efforts are required to make calibration less time-taking or even eliminate its requirement.
4. Wide variety of customizations for patients from different geographical areas, different language speaking regions and different extents of disability.
5. Eye fatigue- The continuous use of the communication aid causes eye-fatigue. Measures have to be devised to minimize the eye-fatigue among users.

These directions for future work pave the way for betterment of this technology for the welfare of people with disabilities. It is expected that through more collaborative efforts from doctors, computer scientists, care-givers and family members of patients etc improvisation will be made in the design on the interface and a more comprehensive setup will be developed for prolonged and wider use.

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\*For downloadable C++ code implementation of the project, please visit:  
<http://tinyurl.com/augendrishti>