Man-machine Interaction System for the Paraplegics using Eye-Tracking Technique

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Abstract **- Over the years, the paraplegics have relatively found it difficult using computer systems as a result of their physical conditions, especially in Sub-Sahara Africa. They have been solely relying on third party to achieve any form of computer interactions. Meanwhile, researchers at different levels have proposed and use of different mechanisms such as: electroculogram (EOG), videooculography (VOG), video-based infrared (VIR) and sclera search coil methods overtime to assist the paraplegics. However, studies have shown that these approaches are not efficient as they were mono-directional and require other aids to complete their actions. Additionally, most of the aids are not affordable and could be dangerous to human health. Therefore, this work presents a man-machine interaction mechanism using quadrilateral eye-tracking technique, involving 3-tier eye-gaze algorithm to enhance paraplegics' interactions with any system. The pupil-center/corneal reflection method was used to determine where the user is looking on the screen. A window based system interface platform was developed and implemented on visual C# with camcorder integrated to monitor the movement of the user's eye. The system was effectively demonstrated and enabled user to read, type and make phone calls. The approach was found to be more robust when compared with existing methodologies in terms of efficiency, flexibility and time taken to process an action. Based on the good performance of the system, it is therefore recommended that the Federal government of Nigeria will sustain this development to assist the paraplegics in the country.**

Keywords: **Paraplegics, HCI, electroculogram, videooculography, human health, haptic sensors**

I. INTRODUCTION

Human-Computer Interaction (HCI) is a recent paradigm in computing that is rapidly gaining scientific attention in research and development. As reported in [1], the Association for Computing Machinery (ACM) defines HCI as a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use, and with the study of major phenomena surrounding them. The central theme of HCI focuses on human and machine interactions through a faster, natural, more convenient and less sequential means. Previous developments in computing were focused on what machines could do for man, in that wise the design was tailored towards building highly sophisticated systems that would presumably exceed user's expectation, irrespective of whether the needs are actually met or not. However, the new approach in HCI emphasizes on what man can do with the machines, this according to [2] is described as the old and new computing paradigms.

According to [3], the technological principles driving HCI designs depend on human senses, which include vision, audition and touch-based. The vision-based designs allow man-machine interaction through the eye; the audition allows interaction through vocal projection, while the touch-based interacts through generated sensations, reactions and haptic sensors [4]. For the purpose of this work, the vision-based interaction is considered. This is in search for better interfaces between the physically challenged individuals with respect to arms and the lower parts of their body, but has their eyes in order. In the work of [5], it was observed that eye movement input is faster than other existing input media in the domain. In addition, they posited that a vision-based HCI system does not require formal training for user except the need to focus on the object in view as the control-to-display relationship for this kind of a system are established in the human brain.

This research work model and developed a prototype of a man-machine interaction mechanism using quadrilateral eye-tracking technique, involving 3-tier eye-gaze algorithm to enhance interactions of the paraplegics with computer systems. The eye-tracking (gaze) technique allows a user's eye movements to be measured so as to know the direction of person's view, the object in view at a given time and the sequences of the eyes' shifting from one point to another.

II. LITERATURE REVIEW

Eye Tracking is the process of measuring eye activity. It measures either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a mechanism for measuring eye positions and eye movement to determine the user's direction at a given time and the sequence in which they are moved [6]. Gaze tracking has a number of applications that are very useful, particularly for scientists who study the movements of the eye. Eye movements can be used as control signals to enable people interacts with interfaces directly without the need for aids, mouse or keyboard. According to [7], the eye-based HCI can be used to assist not only the physically challenged persons, but also the normal persons.

According to [8], an eye tracking system is a useful form of assistive technology which supports independent use of computing technologies. In neuro-science, this technique plays a vital role in enabling doctors to monitor and interact with their patients remotely and onsite. Figure 1 depicts a sampled architecture.

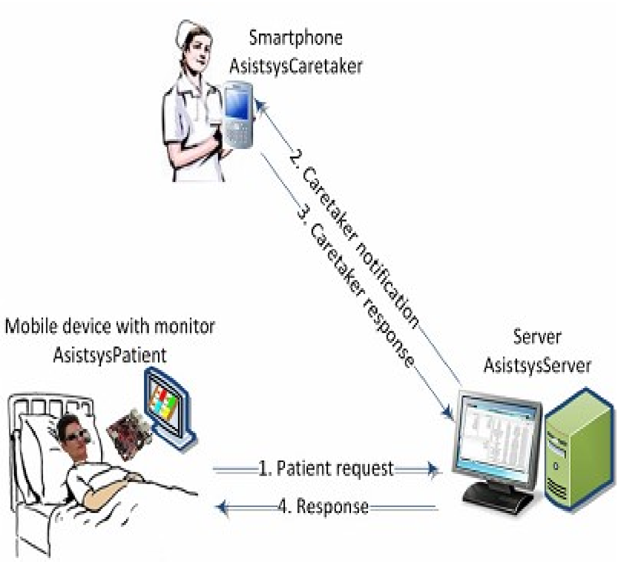
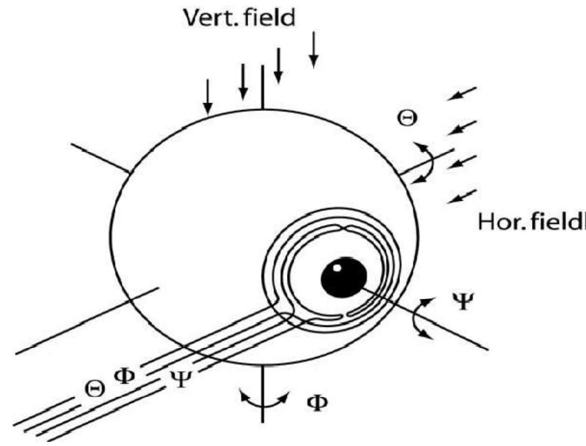


Figure 1: Patient-machine and doctor interactive system

Source: [8]

According to [9], there are two broad categories of eye tracking/gazing techniques, depending on what they measure. Those in the first category are those methods that measure the angular position of the eye relative to the head, for instance, the electro-occulography (EOG), infra red reflection oculography (IROG), and head mounted video systems. Those in the second category are those that measure the position of the user's eye with respect to the surroundings. These methods may include table-top video systems and the magnetic scleral search coil method [10].

Scleral search coil method was describes by [9] as shown in Figure 2, stating that if a coil of wire moves in a magnetic field, the field induces a voltage in the coil, and on the other hand, a signal of the position of the eye will be generated when the coil is attached to the user's eye. Therefore, in order to measure the movements of the user's eye, small coils of wire have to be embedded in a modified contact lens or annulus. To do this, local anesthetic would have been introduced before the small coils of wire will be inserted into the user's eye. Meanwhile, in order to generate the field, two coils are placed on either side of the head to permit the recording of the horizontal movements of the eye. For vertical eye movements monitoring scenario, another set of coils are arranged orthogonally against the initial setup. The separation of the two signals captured through the horizontal and vertical eye movements can be achieved using electronics designated for the purpose.



. Figure 2: Scleral search coil method [9]

The problem with this method is that, the thin wire connecting the coil with the measuring device may not be comfortable for the user since it requires an insertion of coil of wire into the user's eye. Such an invasive method is rarely used clinically, though it is an invaluable research tool.

The IROG approach, as shown in Figure 3 is based on the principle of fixed light source, directed at the eye, the amount of light directed is reflected back to a fixed detector which varies with the position of the user's eye. It uses the measurement of diffused reflection of IR light from the front surface of the eyeball. A number of IR light sources are used for illumination, and photo detectors aimed at receiving the reflected light for picking up the signal. The systems track the limbus which is the boundary between scleral and iris, or the pupil-iris-boundary, to measure relative eye rotation [10].

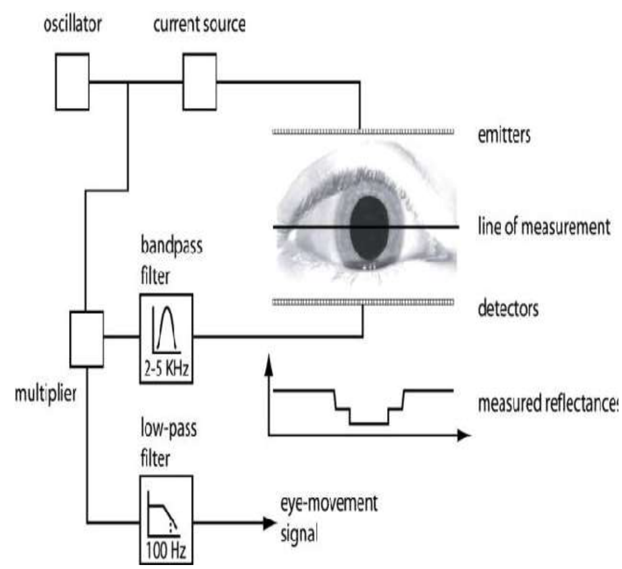


Figure 3: Eye movement measurement using IROG [10].

The EOG eye tracking system makes use of electric potentials measured with electrodes placed in the region around the eyes called electroculogram, (see figure 4). This is done to detect eye and analyse the movement of eyes. The electrode becomes steady when eyes are in their original states. Eye movements can be tracked by analysing the changes in EOG signal [11]. According to [7, 12 and 13], the user wears small electrodes around the eye to detect the eye position, thus, the EOG-based systems looks impractical for everyday use as it may not be too convenient for some users. Additionally, there could be incidences of the electrodes falling off the user's face during perspirations [14]. It is also note worthy that systems built around EOG are not, necessarily sensitive to changes in lighting conditions, especially outdoor lighting.

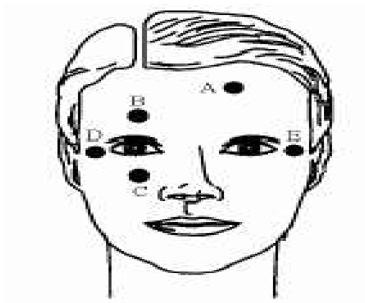


Figure 4: Placement of electrodes for EOG recording [7]

The VOG eye tracking system on the other hand works by estimating the gaze direction from a video camera. The technique measures the angular position of the user's eye with the video systems mounted on the head. It measures also the position of the eye with regards to the surroundings of the remote systems. It has been largely observed that the technique has a higher accuracy, and reduced error rate, with vast applicability in oculomotor dynamics [10]. But the issue of efficiency and mono directional remain a challenge. In [9], a 5-step process as shown in Figure 5 was identified. In the first step, a video camera records the movements of the eyes, these records are received by a connected computer for pre-processing, the face and eye localizations in steps 2 and 3 [15]. The outcome of the pupil's position detection phase becomes an input for the eye gaze computation in the last step [16].

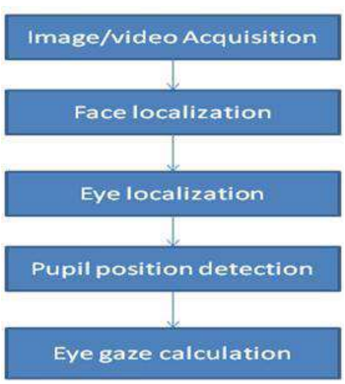


Figure 5: The process of video-occulography [9].

The eye tracking techniques discussed above have been used overtime in different applications as reported in [17, 18, 19 and 20]. However, in spite of their usage in these applications, a number of challenges still recedes the efficiency of the system. Studies have revealed that these approaches were mono-directional and require other aids to activate actions. More importantly, most of these aids are not affordable and are not suitable enough for human health. Therefore, this research work developed an archetype of a man-machine interaction mechanism using quadrilateral eye-tracking technique, involving 3-tier eye-gaze algorithm to enhance the interactions of the paraplegics with computer systems. This approach is affordable and requires no additional aids.

III. MATERIALS AND METHOD

A man-machine interaction mechanism based on quadrilateral eye-tracking technique, involving 3-tier eye-gaze algorithm was developed to enhance interactions of the paraplegics with computer systems and was implemented on visual C# with camcorder integrated to monitor the movement of the user's eye and actuate an action.

A snippet of the 3-tier eye-gaze algorithm is presented below:

```
For each user
{
    For each calibration set
    {
        For each model
        {
        Determine mapping polynomials
        Get the average accuracy over the validation
        points
        }
    }
}
```

The pupil-center/corneal reflection method was used to determine where the user is looking on the screen to provide a concise eye input action to the system by estimating the gaze position of the eye on the computer screen. Figure 6 shows the diagram of pupil/corneal reflection technique.

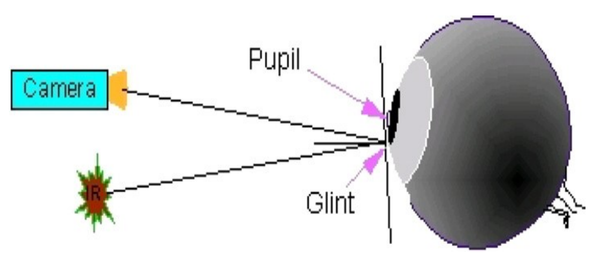


Fig. 6. Shows the diagram of pupil/corneal reflection technique. Source: [21]

Typically, a user gazes at an interface on a computer screen which provides user with visual stimulus in the form of a set of targets or a scene. Gaze tracking measurement is estimated as the average difference between the real stimuli positions and the measured gaze positions. Calculations are done separately for both eyes as presented in equation 1 and 2 respectively.

The point-of gaze (POG): *POG.Xleft, POG.Yleft, POG.Xright, POG.Yright* are the measured X,Y coordinates of the left and right eye's point of gaze are presented as follows:

$$\text{POG.X} = \text{mean}\,\frac{(\text{POG.X left} + \text{POG.X right})}{2}$$ *equation 1*

$$\text{POG.Y} = \text{mean}\,\frac{(\text{POG.Y left} + \text{POG.Y right})}{2}$$ ….*equation 2*

The *POG.X and POG.Y* are the mean gaze coordinates for both eyes. The distance between the eye from the screen and that of the eye from the tracker (camcorder) were taken using Euclidean distance as given by equation 3. For brevity, single calculations are presented and the same equation holds for both.

$$d = \sqrt{\sum_{i=1}^{n}}(q_i - p_i)^2$$ ……..… *equation 3*

Table 1 present sample gaze points and distance estimations.

Table 1: Sample gaze points and distance estimations

User	**Euclidean Measurement (inch)**		**(q_i-p_i)**	**(q_i-p_i)^2**	$d = \sqrt{\sum_{i=1}^{n}}(q_i - p_i)^2$
	p_i	q_i			
POG.X	20	23	3	9	3
POG.Y	22	24	2	4	2

The system prototype was demonstrated on five (5) different persons, which enables them to type and make phone calls. The corneal reflection and pupil outline method was used to determine the user's position on the screen and provide a concise eye input action to the system. Figure 7 and Figure 8 showed the system framework and the process design respectively.

IV. EXPERIMENTAL DESIGN

The System Architecture

The system architecture designed for this work consists of five (5) different components. The components are: the man (user), machine interface, eye gazing module, process activation and action components while the system process design consists of two (2) major components: the Menu (Activity) and the sub menu (Actions) modules. During implementation, the user selects any activity he desires and performs such in the sub menu module, as he or she focuses his or her eyes on the system. Any option, a user fixes his or her eye on is activated and the programmed action is taken place by opening the platform for the user to perform the function selected. A user can make use of the previous, next, back and exit buttons on the system platform at will. As the user sits in front of the eye gaze monitor, the webcam observes the user's eyes, while the eye tracking system analyzes the image of the eye and determines where the user is looking on the screen; no additional aid is required by the user. The user operates the eye tracking system by looking at the keys that are displayed on the control screen. As the user gazes at the key for a specified period of time, an array of menu keys is displayed which allow the user to navigate around the eye tracking programs independently and process an action.

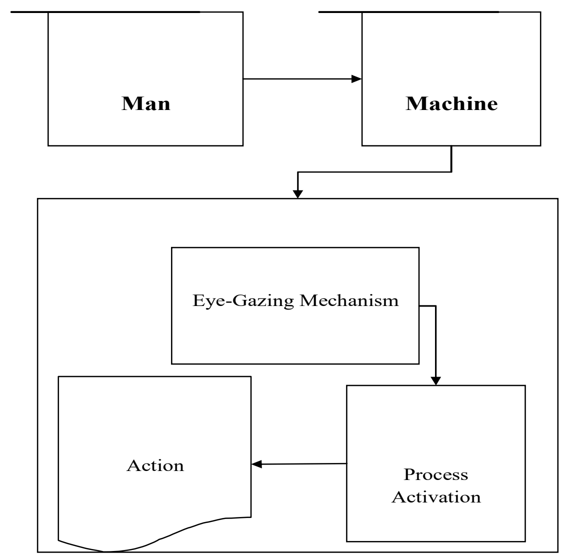


Figure 7: The System framework

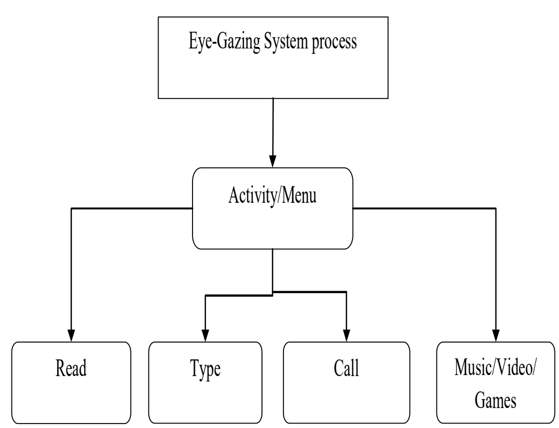


Figure 8: System process design

V. OUTPUT AND DISCUSSION

Figure 9 depicts the home screen of the eye tracking interface where users can select an action which he or she want to perform.

The interface allows users to advance to the next page using the NEXT, "SELECT" a text to read, and to return to previous or the main menu using "PREVIOUS or "BACK" buttons respectively

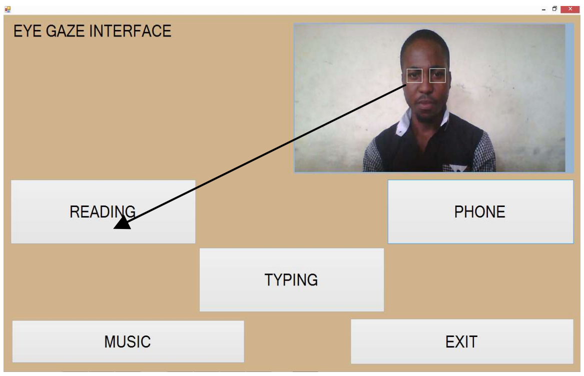


Figure 9: Home screen of eye gaze interface

Figure 10 shows the sub menu of the eye tracking reading interface and a simple typing processing can also be done using the keypad program as shown in Figure 11. The user can type by looking at keys on visual keyboards text. The user could also print or store what he or she has typed in a file to be retrieved at a later time.

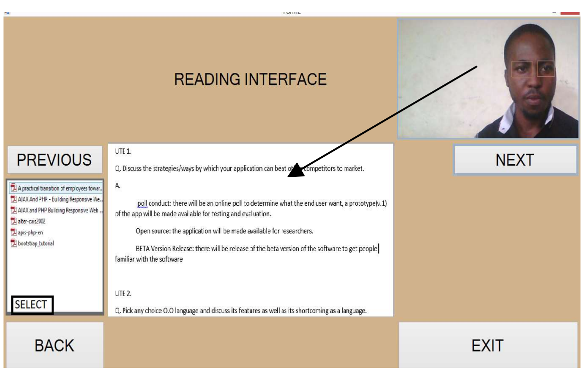


Figure 10: Sub menu of the eye tracking reading interface.

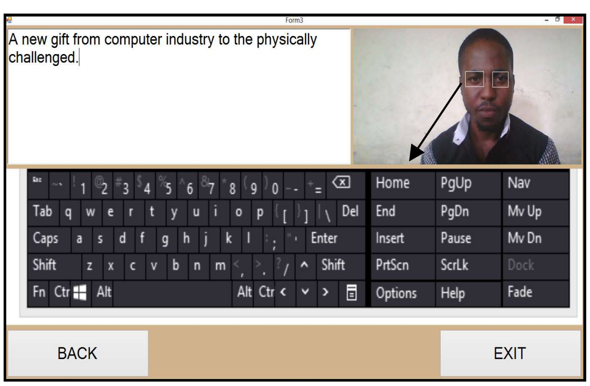


Figure 11: Keyboard control screen

In addition, the telephone program as shown in Figure 12 allows the user to place and receive calls. The user gazes his or her eye on the option he desires on the phoning pad and invoke the action.

Figure 12: Telephone Control Screen.

VI. CONCLUSIONS

This study developed an archetype of a man-machine interaction system to address the challenges encountered by the paraplegics in interacting with the computer system. It explores the techniques of human computer interaction in providing accessibility to computers for the concerned. The use of corneal reflection and the pupil outline of the user's eye provide a fast response to eye actions for the user. The system prototype was demonstrated on five (5) different persons, which enable the users to read, type and make phone calls as shown in Figure 9-12.

The performance of the system was compared with other techniques in term of efficiency and time taken to prosecute a process. The approach was more robust than the previous methodologies and can served as a valuable tool to improve the interaction of the paraplegics with computer system. Based on the performance of the system, it can be concluded that the system using the eye-tracking technique involving 3-tier eye-tracking algorithm is an effective and efficient tool to improve the interactions of the paraplegics with any systems. Therefore, it is recommended that the Federal government of Nigeria should support this development to assist the paraplegics in the country.

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