Development of a Cursor-Based Gaze Tracking Software using OpenCV as Control System of a Mechanical Wheelchair

Timothy M. Amado
Electronics Engineering Department
Technological University of the Philippines - Manila

Edmond N. Alvarez
Electronics Engineering Department
Technological University of the Philippines - Manila

Ivan Mar B. Badlon
Electronics Engineering Department
Technological University of the Philippines - Manila

Ma. Angela J. Delos Santos
Electronics Engineering Department
Technological University of the Philippines - Manila

Keren Keziah M. Elnar
Electronics Engineering Department
Technological University of the Philippines - Manila

Aaron James B. Jose
Electronics Engineering Department
Technological University of the Philippines - Manila

Prince John G. Principe
Electronics Engineering Department
Technological University of the Philippines – Manila

Abstract - **Quadriplegic patients and others with limb impairments lack the ability to move freely without assistance and experience difficulties in doing everyday tasks, lowering their quality of life. To move around, they need an assistive device such as wheelchairs, however, the majority of commercially available wheelchairs are either manually controlled or electrically steered using a joystick. Therefore, this study aimed to develop a user interface that can serve as primary control to a wheelchair. The researchers improved a mechanical wheelchair, equipping with a gaze-control system that utilizes eye movements to control the wheelchair's movement through an interactive interface that is shown on a screen display with a specialized algorithm. Furthermore, an obstacle detection system was included by utilizing ultrasonic sensors. Functionality testing has been conducted to assess the overall performance of the wheelchair prototype, and the results revealed that the semi-autonomous mode obtained a high accuracy rate, comparable to 100% for most commands. Therefore, it is evident that the proposed interactive interface clearly can be utilized to control a wheelchair's movement hands-free, improving the lifestyle of a quadriplegic patient and individuals with limb impairments.**

Keyword – Quadriplegia, IMU sensor, LiDAR, SLAM, Auto-navigation, gaze control

I. INTRODUCTION

Innovations in the field of assistive technology in recent years have transformed how people with disabilities interact with their environment, thus offering them more independence and freedom. Amongst these technologies, eye-tracking systems are a promising tool for improving the mobility of people with severe motor impairments. Furthermore, incorporating eye-tracking technologies into wheelchair control systems provides a compelling solution for individuals facing significant motor challenges. By exploiting the natural movement of the eyes, users can navigate their surroundings with remarkable accuracy and efficiency. Conventional eye-tracking systems often rely on specialized hardware, making them expensive and inaccessible to many users. The proposed system seeks to overcome these limitations by utilizing commercially available external webcams, improving affordability and scalability while maintaining robust performance.

This paper presents the development of a novel cursor-based eye-tracking software designed as the control system for a mechanical wheelchair, utilizing an external webcam for the gathering of input data. This research advances upon previous work in the field of eye-tracking technology, incorporating ideas from academics and industry to provide a more feasible, affordable, and practical solution. The proposed system employs computer vision algorithms and pre-trained recognition models to accurately detect and track the user's gaze in real-time, translating these movements into intuitive commands for controlling the wheelchair's movement. By employing a gaze-controlled Graphical User Interface (GUI), the users can navigate through their environments with ease, selecting different navigational commands such as forward, backward, and rotate which is achieved by simply using their eyes to interact with each designated button in the GUI to reach their desired destination.

II. Background of the Problem

Eye-tracking or gaze-tracking systems have evolved, and many researchers delve into different approaches on incorporating them as a means of controlling a wheelchair. Some studies have explored the development of a gaze tracking system utilizing external web cameras and computer vision algorithms to track the eye's movements and convert them into specific actions or commands. In 2019, Jafar et al. conducted another study that developed a gaze tracking system for a wheelchair, using a webcam and a Python-based pre-trained deep learning algorithm. The webcam acquires input data from the user, resizes the input data, and converts it to grayscale, which is later analyzed and classified by the employed classification algorithm. Moreover, the researchers applied the transfer learning approach by leveraging the Visual Geometry Group (VGG-16) model pre-trained on ImageNet dataset for eye classification and were trained using Convolutional Neural Network (CNN), which took only thirty minutes on a laptop, and one hour on the employed Raspberry Pi 3. The study produced a 98 % high accuracy in identifying different iris positions, outperforming several studies with the same approach [1].

In 2020, Dahmani et al. developed a gaze tracking system for a wheelchair designed for people with mobility disorders. The gaze tracking system was employed with a machine learning based algorithm, Convolutional Neural Network (CNN), and template matching technique for gaze estimation installed on a minicomputer for the commandeering of the wheelchair movements, and a headgear composed of two IR cameras installed on an eyeglass frame to detect the eye movements of the user. Upon testing, the study produced remarkable results, with a 99.3 % accuracy, practically 100 %, for the gaze estimation thus implying that the proposed system was suitable for real-time applications [2].

In contrast to previous prototypes of gaze-controlled wheelchairs that often depend on invasive methodologies and limited eye control, the proposed prototype, on the other hand, implements non-intrusive equipment. By eliminating the need for invasive sensors, minimizes the risk of discomfort linked to invasive procedures. Furthermore, the proposed system utilizes a cursor that can be used in any on-screen activities not limited to controlling the wheelchair.

III. OBJECTIVES

The objectives of the study includes:

1. Develop a gaze tracking system utilizing OpenCV and a pre-trained face recognition model.
2. Integrate the gaze tracking system to a graphical user interface (GUI) developed for wheelchair control

IV. RELATED STUDIES

In 2020, Anagha et. al. developed an eye-controlled wheelchair utilizing the eyes of the user as control. The invention consists of a webcam which continuously captures eye images of the user, and using the Haar Cascade algorithm and OpenCV, both the face and the eyes of the user were detected. Furthermore, edge detection, feature detection, and hough transform algorithms were implemented to further transform the captured images into desirable data. A raspberry pi module was used to process the data being sent by the camera, and Arduino UNO was used to control the dc motors. In addition, an ultrasonic sensor is placed on the prototype for it to detect obstacles, which will result in the wheelchair moving in another direction. Presented in the results, the wheelchair prototype was able to avoid obstacles because of the attached ultrasonic sensor, however, there was a delay in the movement of the wheelchair for about 4 seconds, and the difficulty in tracking the eyes of the user in a dark setting was evident [3].

In 2022, Chakraborty et al. developed a virtual keyboard and wheelchair system for people with paralysis using gaze-tracking technology. Moreover, the technology uses gaze and blinking detection algorithms to either move the wheelchair or type letters through the virtual keyboard respectively. It employs an appearance-based technique to identify the user's gaze direction and recognize blinking by analyzing pupil position and facial landmarks. In order to confirm the direction of the gaze, the gaze ratio uses the eye to provide a threshold that allows OpenCV to distinguish between the pupil, which is black in color, and the sclera, which is white. This allows OpenCV to quickly ascertain the user's point of view. The system is powered by a Raspberry Pi and a Pi camera, which are assigned to capture input frames that detect the user’s eyes. Additionally, dc motors and ultrasonic sensors are used to scan obstacles in front of the wheelchair. The study’s findings show that 98.03% of wheelchair movements are accurate, as is 97% keyboard typing [4].

In 2023, Viswanatha et. al. developed an electric eye-controlled wheelchair to be used by disabled people. The prototype is integrated with a gaze tracking system which consists of a webcam installed in front of the user which tracks the eye movements of the user, and the implemented algorithms namely the Haar Cascade algorithm and the gaze tracking algorithm which detects and records the eye movements of the user. The gathered data will then be processed by a Raspberry Pi processor which will be sent to the motor driver module in order for the wheelchair to move accordingly. Moreover, an ultrasonic sensor is implemented in the back of the prototype for safety measures. Results showed that the gaze tracking technique is accurate and efficient because the gaze tracking software can track successfully the direction of the eyes of the user [5].

V. METHODOLOGY

A. Block Diagram

The block diagram shown in figure 1 presents the development of a gaze-controlled cursor for wheelchair control. The face of the user serves as the input for the system which was captured using the external camera. From the face of the user, a pre-trained eye landmark detector (dlib) is utilized to get the estimated eye landmarks of the input.

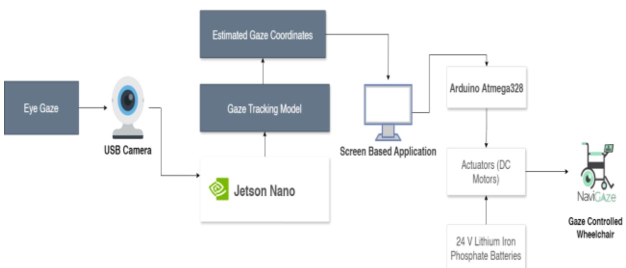

Fig. 1. Block Diagram

B. Dlib Library (Python)

Figure 2 shows the different facial landmarks that can be recognized using dlib. Each landmark is represented by a set of numbers that can be used to create functions in Python. In this case, detected eye landmarks are processed using OpenCV. This is done by processing the webcam feed frame by frame to track the position of the eyes efficiently. Image processing techniques such as grayscale and threshold can contribute to better gaze tracking. The model was further trained using internet available dataset [] to increase the accuracy of eye detection. Additionally, the newly trained model is capable of only recognizing eye landmarks instead of the whole face. Increasing the prediction speed and accuracy.

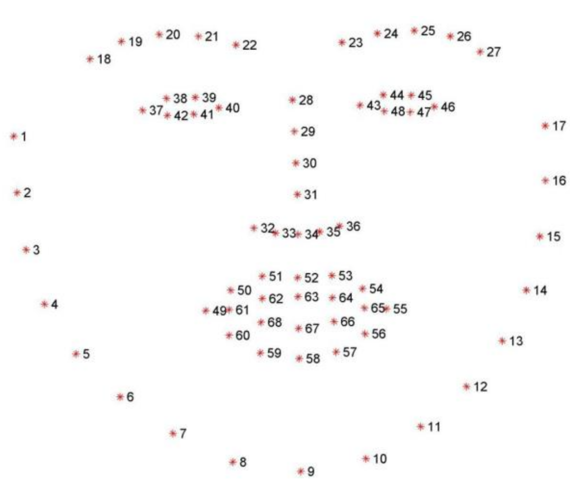

Fig. 2. DLIB Facial Landmarks

C. Gaze control through PyautoGUI and Eye Aspect Ratio (EAR)

A python-based module, PyAutoGui is used to obtain control of the operating system cursor. Integrating the gaze tracking system built using OpenCV, a cursor that can be controlled through the position of the eyes is ready to be used in a variety of applications. Additionally, the Eye Aspect Ratio (EAR) of each eye is obtained. Figure 3 shows how the EAR can be obtained using the eye landmarks that were used for the gaze tracking system. The EAR is a measurement on determining how much the eye is open or closed. The value given by the EAR is used to detect eye wink. The eye wink is used to represent the left click of a computer mouse. Finally, a threshold for defining eye closeness has been set. Calibration of the set threshold is needed every time a different user utilizes the wheelchair.

Fig. 3. EAR Formula

$$\text{EAR} = \frac{\|p_2 - p_6\| + \|p_3 - p_5\|}{2\|p_1 - p_4\|}$$

D. Screen-based application and Motor Control using Arduino

A screen-based application was developed using Tkinter, a python module that specializes in simple GUI design. Figure 4 shows the layout for application, specifically, the motor control. Directional keys were used to represent different wheelchair movements. This includes, forward, backward, right and left rotational controls. Using the Arduino mega, movements are represented through digital signals that are sent to the motor drivers at a predefined speed. Pyserial was used as a medium between the Arduino and Python. This enables sending and reading messages to the serial monitor. Messages that are sent to the serial monitor represent different functions that are defined in Arduino.

Precautionary buttons were also implemented such as an emergency stop button which halts all ongoing wheelchair control. All on-screen buttons are all controllable using the gaze-controlled cursor and each directional command only runs for a period of time before it slowly stops.

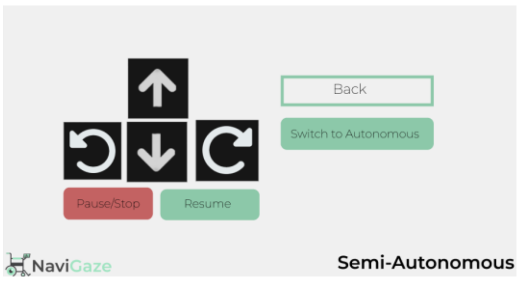

Fig. 4. User Interface of the Application

VI. RESULTS AND DISCUSSION

Based on obtained results from the functionality and field testing shown from Figure 5, the data from one of the researchers almost attained a 100% accuracy rate in terms of the forward and backward directional movements, and the right and left directional movements achieved about 86.667% - 100% accuracy, as shown in Table 2.

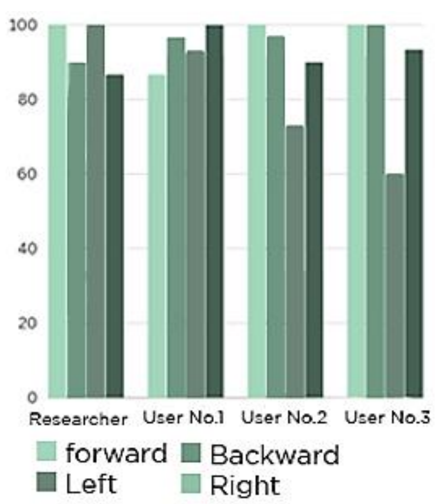

Figure 5. Field Testing Results of Gaze Tracking for Basic Commands

Researcher	Basic Commands	Wheelchair moves	Wheelchair did not move
Correct Gaze Prediction	Forward	30	0
	Backward	27	3
	Left	30	0
	Right	26	4
Incorrect/No Gaze Prediction	Forward	0	----
	Backward	0	----
	Left	0	----
	Right	0	----

Table 1. Confusion Matrix for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with the researchers

Researcher					
30 Trials each	Metrics				
On-Screen Directional Commands	No. of Successful attempts	Accuracy (%)	Precision	Recall	F1-Score
Forward	30	100%	100%	100%	100%
Backward	27	90%	100%	90%	94.737%
Rotate (left)	30	100%	100%	100%	100%
Rotate (right)	26	86.667%	100%	86.667%	92.859%

Table 2. Comparison of Confusion Matrix Metrics for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with the researchers

Meanwhile, the BBMC users were relatively precise as shown in Tables 4, 6, and 8, however, the results from the third BBMC user demonstrated low accuracy in the left directional movement. Regardless, the results supported the concept that the proposed gaze tracking system and screen-based application effectively detected the eye movements of the users, proving its potential for wheelchair navigation.

User No.1	Basic Commands	Wheelchair moves	Wheelchair did not move
Correct Gaze Prediction	Forward	26	4
	Backward	29	1
	Left	28	2
	Right	30	0
Incorrect/No Gaze Prediction	Forward	0	----
	Backward	0	----
	Left	0	----
	Right	0	----

Table 3. Confusion Matrix for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with User No.1 from BBMC

User no. 1					
30 Trials each		Metrics			
On-Screen Directional Commands	No. of Successful trials	Accuracy	Precision	Recall	F1-Score
Forward	26	86.667%	100 %	86.667%	92.857%
Backward	29	96.667%	100 %	96.667%	98.305%
Rotate (Left)	28	93.333%	100 %	93.333%	96.552%
Rotate (Right)	30	100 %	100 %	100 %	100 %

Table 4. Comparison of Confusion Matrix Metrics for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with User No. 1 from BBMC

User No.2	Basic Commands	Wheelchair moves	Wheelchair did not move
Correct Gaze Prediction	Forward	30	0
	Backward	29	1
	Left	22	8
	Right	27	3
Incorrect/No Gaze Prediction	Forward	0	----
	Backward	0	----
	Left	0	----
	Right	0	----

Table 5. Confusion Matrix for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with User No. 2 from BBMC

User no. 2					
30 Trials each		Metrics			
On-Screen Directional Commands	No. of Successful trials	Accuracy	Precision	Recall	F1-Score
Forward	30	100 %	100 %	100 %	100 %
Backward	29	96.667%	100 %	96.667%	98.305%
Rotate (Left)	22	73.333%	100 %	73.333%	84.615%
Rotate (Right)	27	90%	100 %	90%	94.737%

Table 6. Comparison of Confusion Matrix Metrics for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with User No. 2 from BBMC

User No. 3	Basic Commands	Wheelchair moves	Wheelchair did not move
Correct Gaze Prediction	Forward	30	0
	Backward	30	0
	Left	18	12
	Right	28	2
Incorrect/No Gaze Prediction	Forward	0	----
	Backward	0	----
	Left	0	----
	Right	0	----

Table 7. Confusion Matrix for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with User No. 3 from BBMC

User no. 3					
30 Trials each		Metrics			
On-Screen Directional Commands	No. of Successful trials	Accuracy	Precision	Recall	F1-Score
Forward	30	100 %	100 %	100 %	100 %
Backward	30	100 %	100 %	100 %	100 %
Rotate (Left)	18	60%	100 %	60%	75%
Rotate (Right)	28	93.333%	100 %	93.333%	96.552%

Table 8. Comparison of Confusion Matrix Metrics for Gaze Tracking for Basic Commands Trials in Semi-Autonomous Mode with User No. 3 from BBMC

VII. CONCLUSION

The researchers successfully developed a gaze-tracking system which utilized OpenCV and a pretrained face recognition model. Also, a graphical user interface was developed and integrated with the gaze tracking system intended for wheelchair control. In addition to that, the proposed gaze tracking system demonstrated favorable results, indicating its potential to be employed in real-life applications. Lastly, the obtained results from the field-testing together with actual users proved that the proposed system could cater to the specific needs of a quadriplegic patient or individuals with limb impairments.

ACKNOWLEDGMENT

The authors would like to express their gratitude to God Almighty for His guidance and provision that enabled the completion of this study. They would also like to extend their appreciation to Engr. Timothy M. Amado, their project study advisers, for his unwavering support and dedication throughout the project. Additionally, they would like to express their appreciation to Engr. Nilo M. Arago for his valuable guidance and expertise. They further convey their sincere appreciation to Young Focus for Education and Development Foundation, Inc. and Bigay Buhay Multipurpose Cooperative for allowing them to deploy the project at their respective facilities. They would also like to express their heartfelt appreciation and gratitude to their respective families and friends for the love, patience and understanding, as well as the financial and emotional support. The unwavering love, support and encouragement really played a vital role throughout the process of this study.

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