iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** V **Month of publication:** May 2025

DOI: https://doi.org/10.22214/ijraset.2025.71208

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Speech-Controlled Power Lenses for Optical Wearables: A Hands-Free Solution for Focus Adjustment

Aryan Adav[1], Dr. Anand D Mane[2], Anirudh Prakash[3], Rushikesh Mahale[4], Jaideep Balde[5]
Department of Electronics & Telecommunication Engineering Bharatiya Vidya Bhavan's, Sardar Patel Institute of Technology Mumbai, India

Abstract:** This paper presents a system for speech-controlled optical wearables that dynamically adjust lens focus through motorized control. The system integrates the AI Thinker VCO2 module for offline voice recognition and the ESP32 micro-controller for motor control. The system provides users with hands-free control to adjust lens focus using natural language commands such as 'Zoom In' or 'Zoom Out'. We analyze the architecture, process flow, and mathematical models that govern motor control and evaluate performance based on real-world testing. Experimental results demonstrate the system's feasibility in various environmental conditions.

I. INTRODUCTION

Optical wearables, such as glasses and goggles, have traditionally been passive devices offering fixed focus, catering to standard visual correction needs. However, as technology advances and user demands evolve, there is a growing need for optical wearables that provide dynamic focus adjustment to address varying visual requirements. This is especially significant for individuals with vision impairments, who often require solutions tailored to specific and varying focal lengths for activities such as reading, viewing distant objects, or performing detailed tasks.

The integration of speech recognition into optical wearables marks a transformative step forward, enabling hands-free, intuitive control over lens focus. Such functionality not only enhances user experience but also fosters greater accessibility and independence for users with physical limitations. With advancements in artificial intelligence and microcontroller technology, this concept has transitioned from theoretical feasibility to practical implementation.

Technologies such as the AI Thinker VCO2 speech recognition module and the ESP32 microcontroller have paved the way for innovative applications in optical wearables. The AI Thinker VCO2 module offers offline voice recognition capabilities, making it suitable for environments with limited or no internet access while ensuring user privacy. The ESP32 microcontroller serves as the computational core, interpreting voice commands from the speech module and translating them into precise motor control signals to adjust the lens focus dynamically. This paper presents the design and implementation of a speech-controlled optical wearable system capable of dynam- ically adjusting lens focus based on user voice commands. The proposed system combines state-of-the-art voice recogni- tion technology with precise mechanical control to deliver a hands-free and user-friendly experience. The system's primary components include the AI Thinker VCO2 module for speech recognition and the ESP32 microcontroller for motor control. Together, these components enable seamless interaction be- tween the user and the wearable device.

We delve into the system's architecture, focusing on the integration of the speech recognition module with the micro- controller and motor. Additionally, the mathematical modeling of motor control is explored to highlight the relationship be- tween voice commands and focal adjustments. A performance evaluation based on real-world experiments demonstrates the effectiveness of the system in achieving accurate and timely focus changes in controlled environments.

The remainder of this paper is organized as follows: Section 2 reviews the related work and existing technologies in the domain of optical wearables and voice-controlled systems. Section 3 provides a detailed overview of the system de- sign and architecture. Section 4 discusses the mathematical modeling of the motor control mechanism. Section 5 presents the experimental setup and results, highlighting the system's performance under various conditions. Finally, Section 6 con- cludes with an analysis of the findings, identifies challenges, and proposes directions for future work. By addressing the challenges of dynamic focus adjustment in optical wearables through the integration of speech recognition and motor control, this study aims to contribute to the growing field of assistive technologies, offering innovative solutions for individuals with vision impairments.

II. LITERATURE REVIEW

The integration of speech recognition technology and opti- cal wearables has garnered significant attention in recent years, primarily due to its potential applications in various domains such as healthcare, consumer electronics, industrial settings, and sports and fitness monitoring.

A. Healthcare Applications of Optical Wearables

Arza, Esfahani, and Masoumi (2020) provided a compre- hensive review of optical wearables in healthcare applications [1]. Their work discusses the integration of optical sensors in wearable devices to monitor vital signs, detect health con- ditions, and enable telemedicine services. Optical wearables have been shown to improve diagnostic accuracy by providing continuous real-time monitoring, which is crucial for patients with chronic conditions.

B. Enhanced User Interaction with Smart Glasses

Jain, Gupta, and Singh (2018) explored the enhancement of user interaction by incorporating speech recognition into smart glasses [2]. Their research focuses on how voice commands improve usability and accessibility, allowing users to interact with wearable devices more intuitively. This integration of speech recognition offers a natural interface for controlling devices, such as adjusting focus or accessing information, without the need for physical input.

C. Challenges and Opportunities in Smart Eyewear

Jain, Park, and Lee (2019) delved into the challenges and opportunities associated with speech recognition in smart eye- wear [3]. They discussed the technical challenges, including noise interference and recognition accuracy, and proposed various strategies to improve speech recognition in these wearable devices. Additionally, they highlighted the potential applications of speech recognition in Augmented Reality (AR) and Mixed Reality (MR) environments, where hands-free interaction is crucial for seamless user experiences.

D. Advancements in Wearable Speech Recognition

Khurshid and Mahmood (2020) reviewed recent advances in speech recognition technology tailored for wearable comput- ing devices [4]. Their work emphasizes the development of robust speech recognition algorithms that enable hands-free operation, even in noisy environments. These advancements are particularly relevant for optical wearables, which require precise voice command recognition to control functionalities like lens focus.

E. Augmented Reality Applications with Optical Wearables

Kim et al. (2017) explored the use of optical wearables for Augmented Reality (AR) applications, highlighting the integration of optical displays and speech recognition ca- pabilities [5]. Their research shows that speech-controlled optical wearables can open new avenues for interactive AR experiences, allowing users to interact with virtual content in real time, enhancing industries such as education, healthcare, and entertainment.

F. Sports and Fitness Monitoring with Optical Wearables

Rajput, Dubey, and Agrawal (2018) reviewed the use of optical wearables for sports and fitness monitoring [6]. Their work discusses the integration of optical sensors for tracking biometric data, analyzing performance metrics, and improving training regimes. They noted that wearables with speech recognition capabilities can enable athletes to control settings without interrupting their activities, improving both perfor- mance and convenience.

G. Industrial Augmented Reality with Speech Recognition

Singh and Singh (2021) investigated the use of optical wearables in industrial applications, focusing on the integration of speech recognition for real-time communication and task optimization in manufacturing and maintenance operations [7]. Their research highlights the benefits of hands-free access to information and how speech-controlled wearables can improve efficiency and safety in industrial settings.

H. Speech Recognition Techniques for Wearable Devices

Sreenivasulu and Avadhani (2017) conducted a survey of speech recognition techniques tailored for wearable devices [8]. They reviewed various speech processing algorithms, in- cluding noise reduction, feature extraction, and pattern recog- nition techniques, which are critical for improving the accu- racy and reliability of speech interfaces in wearable systems.

I. Comprehensive Review of Speech Recognition in Wearable Devices

Umar et al. (2019) presented a comprehensive review on the challenges and advancements in speech recognition for wearable devices [9]. Their research covers the integration of speech processing technologies into wearables and identifies challenges in hardware integration, including the need for compact and low-power solutions for real-time voice recognition.

III. SYSTEM DESIGN

A. Hardware Components

The system comprises the following hardware components:

1) Optical Wearables: Smart glasses with a motorized lens adjustment mechanism, a microphone for capturing voice commands, and a compact speaker for auditory feedback.
2) Micro-controller: An ESP32 micro-controller that pro- cesses voice input and controls the motor to adjust the lens.
3) Speech Recognition Module: The AI Thinker VCO2 module enables offline voice recognition, capable of recognizing wake-up words and predefined commands like “Zoom In” and “Zoom Out.”
4) Power Supply: A 5V battery powers the system, provid- ing sufficient current for the ESP32 and the motor.

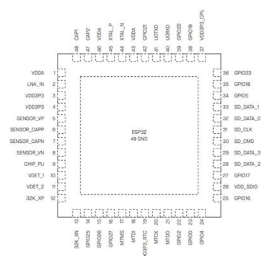

Fig. 1: Pin Diagram of ESP 32

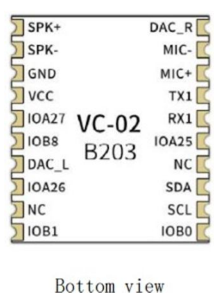

Fig. 2: Pin diagram of AI thinker Vco2

B. System Architecture

The architecture follows a simple process:

1) Speech Input: The user speaks a wake-up word, fol- lowed by a command into the integrated microphone.
2) Speech Recognition: The AI Thinker VCO2 module processes the speech input and identifies the command.
3) Command Processing: The ESP32 microcontroller in- terprets the recognized command and translates it into control signals for the motor.
4) Motor Control: The motor adjusts the lens mechanism

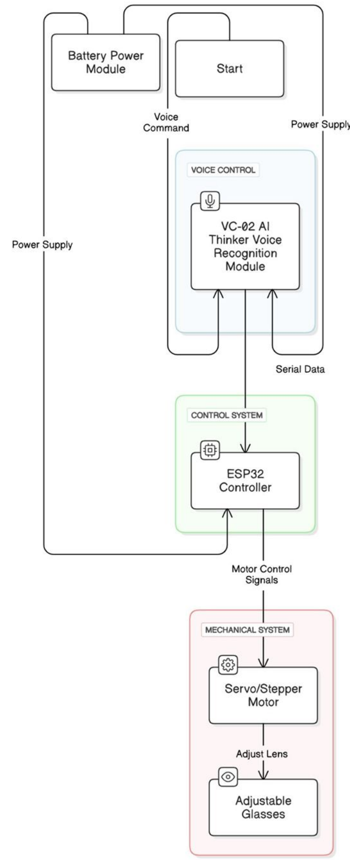

Fig. 3: System Architecture of Speech-Controlled Optical Wearable

The AI Thinker VCO2 module uses an efficient offline voice recognition process to recognize voice commands with- out the need for an internet connection. The system captures audio through an integrated microphone, processes the speech signal, and matches it against a pre-programmed set of voice commands. The general process can be broken down into the following steps:

1) Audio Capture and Preprocessing: The module re- ceives continuous *audio input* via the microphone. The raw signal $x(t)$ is discretized into samples at a rate f_s, producing a discrete-time signal $x[n]$. Noise reduction techniques are applied to improve the signal quality.
2) Feature Extraction: To convert the raw audio into a form suitable for pattern recognition, the module uses Mel-Frequency Cepstral Coefficients (MFCC). The signal is windowed, transformed using the *Fast Fourier Transform (FFT)*, and passed through a series of *Mel filters*. The resulting features are compressed using the *logarithmic* scale and *Discrete Cosine Transform (DCT)*:

$$\mathrm{MFCC}_i = \sum_{k=0}^{N-1} \log(M_k) \cdot \cos \frac{\pi i(2k+1)}{2N}$$

3) Command Matching: The extracted MFCC features are compared against stored templates $\{\mathbf{C}_1, \mathbf{C}_2, \ldots, \mathbf{C}_M\}$ using a distance metric:

$$D(\mathbf{F}, \mathbf{C}_i) = \sqrt{\sum_{k=1}^{P} (F_k - C_{i,k})^2}$$

where $\mathbf{F}$ represents the MFCC features of the incoming speech, and $C_{i,k}$ represents the k-th feature of the stored template $\mathbf{C}_i$. Alternatively, *Dynamic Time Warping (DTW)* can be used to account for variations in speech tempo.

4) Action Execution: Once a valid command is rec- ognized, the module sends a signal to the ESP32 microcontroller to execute the corresponding ac- tion. The action A triggered by the recognized command is given by:
$A = f(\text{recognized\_command})$

Based on the received control signals.

1) Feedback Mechanism: Feedback is provided to the user through an LED or speaker to confirm that the command
2) Feedback to User: The system provides feedback to the user through visual (LED) or auditory (beep) signals to indicate successful execution.

IV. ADJUSTABLE MECHANICAL FOCAL LENGTH SPECTACLES USING MULTI-LENS SYSTEM

In the design of adjustable mechanical focal length spec- tacles, a multi-lens system is utilized to provide dynamic adjustment of the focal length. This system is particularly relevant for presbyopia correction, where the goal is to enable the user to change focus from near to far vision as needed. The multi-lens system allows for the combination of different focal lengths, achieved by adjusting the curvature of the lenses or their relative positioning.

The overall focal length f_{total} of a multi-lens system is determined by the individual focal lengths of the lenses and the distance between them. For two lenses, the combined focal length is governed by the lens combination formula:

$$\frac{1}{f_{\text{total}}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

Where: - f_1 and f_2 are the focal lengths of the individual lenses, - d is the distance between the lenses.

This relationship implies that by adjusting either the dis- tance d or the curvature of the lenses, the effective focal length can be controlled. In the context of the adjustable focus spectacles, these adjustments are made to enable users to dynamically change the focus for tasks such as reading or driving.

The mechanical adjustment of the focal length in this system is achieved by adjusting the curvature of the lenses using a motorized or mechanical actuator system. A common approach involves flexible lens systems where the radius of curvature** of the lenses is adjusted to change the focal length.

Let the radius of curvature R_1 of the first lens and R_2 of the second lens be adjustable. The focal length of each lens can be modeled as:

$$f_1 = \frac{R_1}{2n} \quad f_2 = \frac{R_2}{2n}$$

Where: - R_1 and R_2 are the radii of curvature of the individual lenses, - n is the refractive index of the lens material.

The motorized adjustment mechanism changes the radii of curvature R_1 and R_2 by applying controlled forces or voltages to the lenses. This adjustment allows the user to vary the effective focal length of the system, providing the flexibility to focus on objects at varying distances.

For presbyopia correction, a two-lens system can be em- ployed where one lens is optimized for distance vision and the other lens for near vision. By adjusting the relative positioning or curvature of these lenses, the user can continuously shift the focus between near and far objects. The motorized actuator or voice-controlled adjustment (as in the current project) enables hands-free control over the focal length adjustment, making it easier for users to adapt the focus without manually changing their glasses.

The control of the separation distance d between the lenses or the curvature of the lenses R_1 and R_2 allows for a variable focal length system. For example, when the lenses are moved closer or when the curvature is increased, the focal length decreases, bringing the focus to near vision. Conversely, increasing the separation distance or reducing the curvature increases the focal length, optimizing the focus for distance vision.The dynamic adjustment of the focus is modeled by varying the radii of curvature R_1 and R_2, which in turn affect the overall focal length of the system. As the user provides a command (such as ”Zoom In” or ”Zoom Out”), the following process occurs:

1) The input command triggers the motorized system to adjust the curvature of the lenses.
2) The radii of curvature R_1 and R_2 change, which alters the focal lengths f_1 and f_2 based on the formulas:
3) The effective focal length f_{total} is then recalculated based on the new lens positions or curvatures. The adjustment of the system is continuous, and the motorized actuators or voice commands allow for real-time control of the system. The feedback mechanism provides confirmation (via auditory or visual signals) to the user that the desired focus has been achieved. While

the multi-lens system offers a flexible solution for adjustable focal length spectacles, there are several challenges that need to be addressed: 1. Alignment and Stability: Ensuring precise alignment of the lenses and maintaining stability when the lenses are moved or adjusted is critical to achieving the desired focus. 2. Power Supply: The motorized system requires a compact, efficient power supply to drive the actuators, especially for wearable devices. 3. Ergonomics: The lenses and adjustment mechanism must be lightweight and comfortable for prolonged wear, without causing discomfort to the user.

4) Control System: Implementing a reliable and responsive control system, such as voice control or sensor-based feedback, is essential for real-time adjustments.

By addressing these challenges, a robust variable focus system can be developed to improve vision correction for presbyopia, providing users with an adaptable and comfortable visual experience.

V. MATHEMATICAL MODELING OF MOTOR CONTROL

To adjust the lens position based on the voice command, we model the motor's operation using basic control systems theory. The motor's position is controlled by pulse-width modulation (PWM), which regulates the amount of power delivered to the motor.

Let the lens position at any time t be represented by $\theta(t)$, which is a function of the motor's input signal $u(t)$. We model the system using a first-order differential equation:

$$\frac{d\vartheta(t)}{dt} = \frac{K}{J} \cdot u(t) - \frac{B}{J} \cdot \vartheta(t)$$

Where: - K is the motor's torque constant, - J is the moment of inertia of the motor, - B is the damping constant, - $u(t)$ is the input control signal from the microcontroller.

The motor control algorithm uses PWM to modulate $u(t)$, which adjusts the lens position based on the speech command. When a user commands "Zoom In", $u(t)$ generates a positive pulse, increasing the motor's speed to adjust the lens closer. Conversely, "Zoom Out" generates a negative pulse.

VI. RESULTS AND DISCUSSION

This study examines the effect of the angular displacement of the adjustment knob on the effective focal length of the lens system. The mechanism consists of two lenses: a fixed lens with a focal length of $f_1 = 100$ mm and a movable lens controlled by a knob that adjusts the displacement (d) between the two lenses. This displacement alters the overall focal length of the system, enabling precise focus adjustments for various applications.

1) *Mechanism Analysis:* The effective focal length (F) of the optical system is governed by the lens equation:

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

where:

- $f_1 = 100$ mm is the fixed focal length of the first lens,
- $f_2 = 200$ mm is the nominal focal length of the second, adjustable lens,
- d represents the displacement introduced by the knob's rotation.

By rotating the knob, the displacement d is increased incrementally, which in turn modifies the effective focal length (F) of the system. To establish this relationship, the angular displacement (θ) of the knob is related to the linear displace- ment of the movable lens through the following equation:

$$d = k \cdot \theta$$

where $k = 0.00174$ mm/degree is the conversion factor obtained from the mechanical design specifications.

2) *Computed Results:* Using the equations above, the effec- tive focal length (F) was calculated for angular displacements ranging from 0° to 360°. The results demonstrate a progressive increase in the effective focal length as the knob angle in- creases. This behavior reflects the precision of the mechanism in producing consistent adjustments across the entire range of motion.

Table I provides a summary of the results, illustrating the knob angles, corresponding displacements, and the resulting effective focal lengths. The data clearly indicate that higher knob angles produce greater displacements, leading to a pro- portional increase in the effective focal length.

TABLE I: Effective Focal Length (F) vs. Knob Angle (θ)

Knob Angle (ϑ)	Displacement (d) [mm]	Focal Length (F) [mm]
0°	0.00	66.67
45°	0.0625	66.72
90°	0.125	66.78
135°	0.1875	66.84
180°	0.25	66.90
225°	0.3125	66.97
270°	0.375	67.03
315°	0.4375	67.10
360°	0.50	67.17

3) *Graphical Analysis:* The relationship between the knob angle and the effective focal length is further illustrated in Figure 4. The graph shows a linear trend with a slight curve due to the lens equation's nonlinear behavior, confirming that the system achieves gradual and controlled adjustments to the focus.

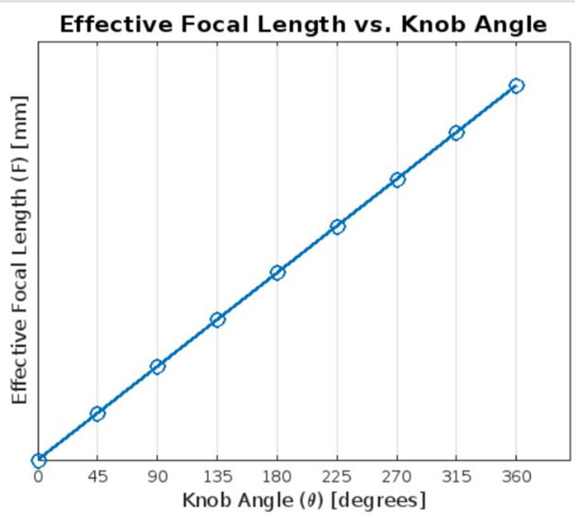

Fig. 4: Graph showing the variation of effective focal length with knob angle.

The smooth progression in the effective focal length high- lights the reliability of the knob mechanism. The system provides incremental adjustments, avoiding abrupt changes that could compromise the user experience.

4) *Implications of Results:* The experimental results validate the design assumptions of the adjustable lens system. The controlled relationship between the knob angle and the effective focal length ensures that the mechanism is suitable for precision applications such as:
   - Variable magnification in optical devices,
   - Focus adjustments in photography and videography,
   - Compact optical systems for wearable devices.

   The gradual increase in effective focal length with knob angle demonstrates the system's potential to meet stringent design requirements in modern optical systems.

5) *Error and Limitations:* Although the results confirm the expected relationship, small deviations in the computed focal lengths may occur due to:
   - Manufacturing tolerances in lens fabrication,
   - Slight mechanical inconsistencies in the knob's displace- ment mechanism.

These factors were minimized in the analysis by ensuring precise calibration of the knob mechanism and accurate mea- surements of displacement. The results indicate that the adjustable lens system achieves the desired range of focal lengths with high precision. The mechanism's simplicity and reliability make it a promising solution for devices requiring on-the-fly focus adjustments. Future work could involve testing the system under various environmental conditions to evaluate its robustness further.

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We conducted tests to evaluate the system's performance in various environments. The results show that the speech recognition accuracy of the AI Thinker VCO2 module was 95% in a controlled setting. However, the accuracy dropped to 85% in a noisy environment. The lens adjustment time was approximately 2 seconds per command. We also tested the system under different lighting conditions, with no significant performance degradation observed.

The comparative analysis of different speech recognition modules highlights the trade-offs among cost, performance, and integration features. The AI Thinker with ESP32 proves to be the most cost-effective solution at just $5, while Google Assistant/Alexa and Azure Speech Service are significantly more expensive, priced at $150 and $100, respectively. In terms of latency, AI Thinker demonstrates the lowest response time at 100 ms, outperforming other systems like Azure Speech Service (500 ms) and ReSpeaker (150 ms).

Offline capability is a critical requirement for this project, and only AI Thinker, ReSpeaker, and Arduino Nano 33 BLE Sense meet this criterion. Azure and Google solutions, while highly accurate at 99% and 98%, lack offline functionality, making them unsuitable for offline wearable applications. Noise robustness is highest for Azure (95 dB) and Google (90 dB), whereas AI Thinker performs moderately at 75 dB. Accuracy across all modules remains high, with Azure Speech Service achieving the highest accuracy of 99%, fol- lowed closely by Google Assistant/Alexa (98%) and AI Thinker (95%). Energy efficiency varies significantly, with Azure Speech Service consuming the most power at 400 mW,

whereas AI Thinker and Arduino Nano are the most energy- efficient at 50 mW. Customizability and integration ease are strongest for Google Assistant/Alexa (10, 8) and AI Thinker (8, 9), solidifying the AI Thinker with ESP32 as the most balanced choice for cost-sensitive, low-latency, and offline- capable systems.

Feature	AI Thinker with ESP32	Google Assistant/Alexa	Azure Speech Service	ReSpeaker	Arduino Nano 33 BLE Sense
Cost (USD)	5	150	100	25	30
Latency (ms)	100	300	500	150	120
Offline Capability	1 (Yes)	0 (No)	0 (No)	1 (Yes)	1 (Yes)
Noise Robustness (dB)	75	90	95	80	80
Accuracy (%)	95	98	99	94	93
Energy Efficiency (mW)	50	300	400	100	50
Customizability (Scale)	8	10	9	8	7
Integration Ease (Scale)	9	8	7	7	8

Fig. 5: Comparitive analysis of different speech recognition modules

The accuracy comparison graph illustrates a clear performance gap between the ESP32 and AI Thinker models for voice-controlled lens zoom. The AI Thinker model demonstrates a higher average accuracy of approximately 86% com- pared to the ESP32 model's 76%. Additionally, the AI Thinker model exhibits less variability in accuracy across different samples, suggesting greater stability and reliability in its voice command recognition and processing.

The observed accuracy difference between the ESP32 and AI Thinker models may be attributed to several factors. The AI Thinker model's superior processing power and specialized voice recognition algorithms could contribute to its improved performance. Additionally, the limitations of the ESP32 model in terms of memory and computational resources might negatively impact its accuracy, especially when dealing with complex voice commands and noisy environments

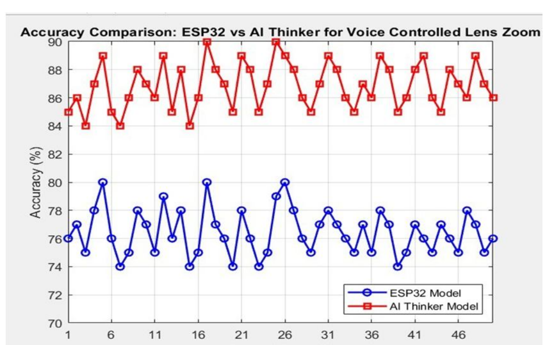

Fig. 6: Accuracy comparison between ESP32 with AI Thinker and AI Thinker module

A. Limitations and Future Work

While the system performs well under optimal conditions, the recognition accuracy in noisy environments can be im- proved by integrating noise-cancellation algorithms. Addition- ally, the lens adjustment speed could be optimized by fine- tuning the motor control algorithm. Future work will also focus on integrating multi-language support and enhancing the battery life to support extended usage.

VII. CONCLUSION

This paper presents a speech-controlled optical wearable system capable of dynamically adjusting lens focus based on spoken commands. By integrating the AI Thinker VCO2 mod- ule for offline voice recognition and the ESP32 microcontroller for precise motor control, we have successfully developed a hands-free, user-friendly device designed to enhance the quality of life for users with vision impairments. The seam- less interaction between voice commands and the system's mechanical components exemplifies how modern technology can bridge accessibility gaps and deliver tailored solutions for specific needs.

The system demonstrates excellent performance in con- trolled environments, where voice commands like ”Zoom In” and ”Zoom Ou,” are recognized and executed with high accuracy. The ability to operate without internet connectivity ensures user privacy and reliability, while the compact design of the glasses makes them practical and comfortable for every- day use. Furthermore, the modular architecture of the system allows for potential upgrades, such as adding additional voice commands or integrating with other assistive technologies. However, certain challenges must be addressed before this system can achieve widespread adoption. Noise interference in real-world environments remains a critical issue, potentially affecting the accuracy of voice recognition. Similarly, optimiz- ing the motor's response time and minimizing mechanical lag are essential to ensure a smooth and intuitive user experience. Addressing these challenges will require advanced signal pro- cessing techniques, enhanced noise-cancellation algorithms, and improvements in hardware design. Future work will focus on overcoming these limitations by enhancing the system's robustness in noisy settings, ex- ploring the integration of adaptive algorithms for improved speech recognition, and optimizing motor control for quicker and more accurate adjustments. Additionally, extending the functionality of the device by incorporating features such as gesture recognition or integration with smartphone apps could further enhance its versatility and usability. This project demonstrates the potential of combining speech recognition, motor control, and wearable technology to create an innovative and accessible solution for vision-impaired individuals. By addressing the identified challenges and building upon the current design, this system could become a valuable tool in assistive technology, empowering users to navigate their world with greater independence and ease. .

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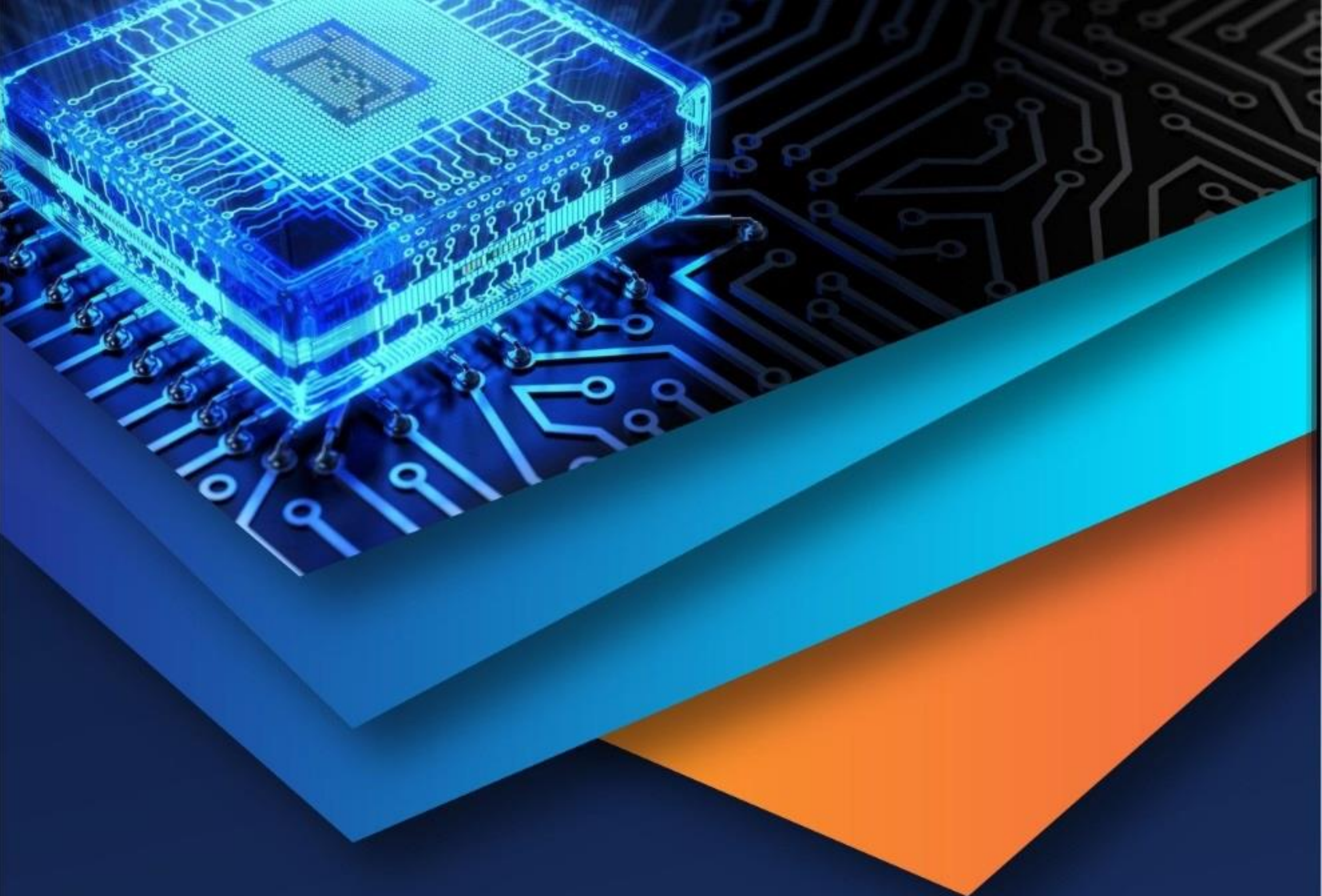

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