INTERNATIONAL JOURNAL OF
Telecommunications
AIR DEFENSE COLLEGE

Smart Bionic Vision: An Assistive Device System for the Visually Impaired Using Artificial Intelligence.

Badawi , M. ;Al Nagar ,E ; Mansour, R ; Ibrahim ,Kh ; Hegazy , N ; Elaskary ,S.

Citation:
Badawi , M. ;Al Nagar ,E ; Mansour, R ; Ibrahim ,Kh ; Hegazy , N ; Elaskary ,S.
Inter. Jour. of Telecommunications, ***IJT'*2023***, Vol. 03, Issue 02, pp. 01-12, 2024.*

Editor-in-Chief: Youssef Fayed.

Received: 08/01/2024.

Accepted: 21/02/2024.
Published: 24/02/2024.

Pharos University, Faculty of Applied Health Sciences Technology ,Biomedical Equipment Technology Department. Alexandria, Egypt.
mi.badawi@pua.edu.eg , 201900047@pua.edu.eg , 201900529@pua.edu.eg,
201800005@pua.edu.eg, nada.Hegazy@pua.edu.eg , safa.elaskary@pua.edu.eg

Abstract: Nowadays, Smart Glass emerges as a potential aid for individuals with visual impairments, offering the promise of enhanced quality of life. Designed for those seeking independent navigation with a sense of social ease and security, the concept revolves around the idea that visually impaired individuals prefer inconspicuous assistance tools. This paper delves into the significant advancements within wearable electronics, spotlighting additional features. This innovative glass offers a multifaceted solution for individuals with visual impairments, providing assistance in diverse scenarios. Beyond aiding in the reading of scripts, they excel at distinguishing between currencies, enabling users to navigate financial transactions with ease. The glasses also enhance color recognition, allowing wearers to perceive and appreciate the vibrant spectrum of the world around them. Additionally, the incorporation of obstacle detection technology ensures a heightened sense of safety by alerting users when they are in proximity to potential hazards. Furthermore, the glasses feature advanced facial recognition capabilities, contributing to a more inclusive and socially connected experience by detecting faces and fostering seamless interactions.

Keywords: Blind; Raspberry Pi 4 Model B; Ultra Sonic sensor; Python; Raspberry Pi CAM.

1. Introduction

The statistics mentioned in the statement are derived from the World Health Organization's (WHO) World Report on Vision 2019. This report highlighted the global prevalence of vision impairment and its impact on individuals and communities. Here are some key points related to the mentioned statistics:

The global landscape of vision impairment presents a staggering challenge, with the World Health Organization (WHO) estimating that a substantial 2.2 billion individuals worldwide grapple with near or distance vision impairments, as depicted in Figure 1.

Disturbingly, the geographical distribution of this issue reveals a stark reality—around 90% of individuals living with blindness find themselves in low- and middle-income countries. This stark contrast underscores the glaring disparities in accessing essential glasses care and vision services across various regions. The plight extends to our younger population, with the report shedding light on the vulnerability of children. A staggering statistic reveals that at least 1 billion children globally face the risk of vision impairment, emphasizing the critical need for early detection and intervention to address and prevent visual impairments among the youth. This highlights the urgency for comprehensive global efforts to ensure equitable access to glasses care and protect the vision of both adults and children worldwide.

These statistics underscore the global significance of addressing vision-related issues, emphasizing the need for increased awareness, accessibility to glasses care services, and initiatives to prevent and treat vision impairment, particularly in low-resource settings.

The World Health Organization (WHO) reports that 430 million people worldwide have hearing loss, as seen in Figure 1, and 7% of Egyptians are dumb and deaf, which affects 5% of the world's population [1]. People with special needs have received top priority in Egypt over the past seven years in an effort to address their requirements, integrate them into society, and maximize their potential.

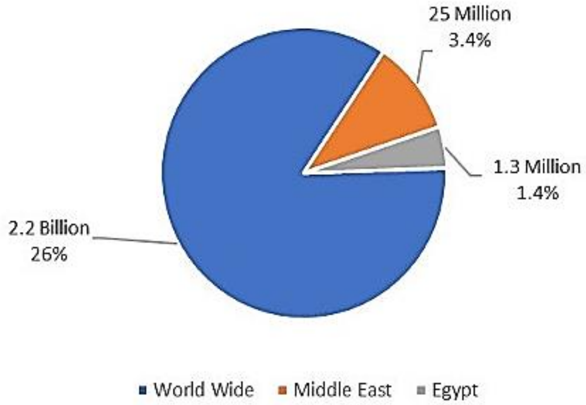


Figure 1. World Health Organization Report 2019.

The realm of wearable assistive technology is witnessing a multitude of endeavors, incorporating a myriad of features. One [2] researcher delves into the concept of minimizing hands-on interaction, advocating for wearable devices like head-mounted gear, wristbands, vests, belts, shoes, and more. The emphasis lies in allowing users to seamlessly incorporate these devices into their attire. This design approach enhances portability, rendering the devices compact, lightweight, and easily transportable. In a different innovation, the BuzzClip [3] serves as a mobility tool for the visually impaired rather than functioning as a fully autonomous device. Primarily targeting the detection of upper body and head-level obstacles, it employs sound waves for obstacle detection and conveys information to users through vibration feedback, notifying them of potential obstacles in their surroundings.

While some products in the field of wearable assistive technology lack extensive features, an alternative device [4], namely OrCam, stands out for its compact design and rich functionality. This innovative device exhibits the ability to audibly interpret text from any surface, recognize faces, and identify various items, including supermarket products and currency notes. Its unique feature of attaching to the side of glasses sets it apart. However, it falls short in certain aspects, notably the absence of obstacle detection—a key feature present in other designs.

Visual impairment significantly impacts quality of life, creating barriers to daily living. Assistive technologies provide solutions to enhance independence and inclusion. For low vision, devices like E-Sight electronic glasses use a high-speed camera to magnify objects, Optical character recognition (OCR) software is commonly integrated in devices to convert text into speech. Those with total blindness Sensory substitution devices like the Brain Port translates images to electrical stimulations on the tongue. Computer vision algorithms power handheld currency readers and other assistants like OrCam's My Eye. Spatial audio technologies are enabling for spatial awareness and 3D navigation continued innovations around multisensory interfaces, AI assistants, and neuro-integrated devices aim to create more immersive and empowering solutions for the blind [5].

The concept of developing assistive smart glasses for the visually impaired is not new, and the authors mention some existing products in the market. However, the novelty lies in the specific combination of features and the balance between cost and functionality targeted in the "Al Amal Glasses". At a cost of around $277, it offers text reading, currency recognition, color detection, obstacle detection, and facial recognition, making it affordable while retaining key capabilities needed by the visually impaired. This positioning addresses an important gap compared to more expensive commercial products.

Well-established products like Orcam, Exsight, and Pivothead Aira smart glasses are recognized in the market. Al Amal Glasses presented in this paper, distinguishes itself by striking a balance between cost and functionality, meeting user expectations for both affordability and enhanced capabilities. This positions Al Amal Glasses as a standout choice in the market compared to other available products.

2. Materials and Methods

2.1. Working Principle

Utilizing artificial intelligence and Internet of Things (IoT) methodologies empowers individuals who are blind and visually impaired (BVI) to independently engage in their essential activities, reducing the need for significant reliance on others.

Al Amal Glasses are an innovative device designed for seamless functionality. Through advanced scanning capabilities, it captures and identifies individuals by matching pictures with coded information, enabling precise recognition. Additionally, the device adeptly captures text images and reads them with the assistance of meticulously programmed codes. Leveraging an infrared sensor dependent on infrared radiation, Al Amal Glasses excel in sending messages, detecting objects, and capturing color information. Its programmable codes play a pivotal role in determining and distinguishing colors, offering a comprehensive solution for the visually impaired.

Moreover, this versatile device extends its utility to the realm of finance, skillfully aiding in the recognition and differentiation of various currencies.

2.2. System Block Diagram

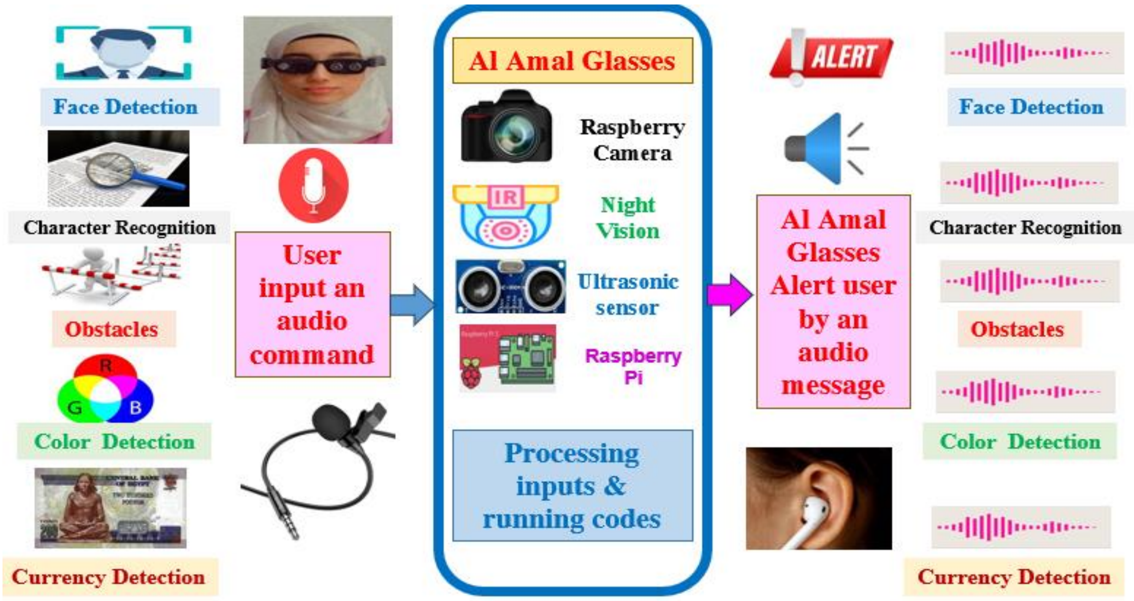


Figure 2. Al Amal Glasses Block Diagram

Figure 2. shows Al Amal Glasses block diagram, the primary stage l is to introduce a novel method of text reading for the visually impaired, aiming to enhance their communication capabilities. The glasses begin by scanning text and converting it into audio text, allowing the user to listen through headphones connected to the device. Employing technologies like OCR and OpenCV for text detection, the glasses utilize Python coding for

text-to-speech conversion. Equipped with an IR sensor, they measure the distance between the user and the object containing the image, ensuring clarity in picture capture when initiated by the user pressing a button. All computational processes are handled by the Raspberry Pi 4 B.

These glasses also feature color recognition to aid users in detecting and choosing the colors of their clothing. Additionally, they contribute to currency differentiation using Python code with the Raspberry Pi camera and employ facial recognition codes for identifying individuals through the same camera technology.

3.Explanation of System Circuit Diagram

In the next sections, we will explain each part of Al Amal Glasses hardware.

3.1. Hardware Wiring Circuit.

In Figure 3, in order to assemble Al Amal Glasses, begin by attaching the Raspberry Camera Module to the Raspberry Model B using the Raspberry Camera Cable. Securely mount the Ultrasonic Sensor to the front of the glasses, ensuring optimal positioning for accurate distance measurements. Establish audio capabilities by connecting the Microphone and Earphone to the Raspberry Model B, enhancing the device's functionality for communication. Lastly, power up the Smart Glasses by connecting the Power Bank to the Raspberry Model B, providing the necessary energy to support its various features and components, power bank powering a Raspberry Pi 4B is about 1.4 hours. This is an approximate calculation but provides an idea of the expected runtime. The actual performance will depend on the efficiency of the components and battery capacity after wear. But we can expect the power bank to power the Raspberry Pi for 1-2 hours on a full charge. This systematic assembly process ensures the seamless integration of the essential components, culminating in a fully functional and versatile device designed to assist individuals with visual impairments.

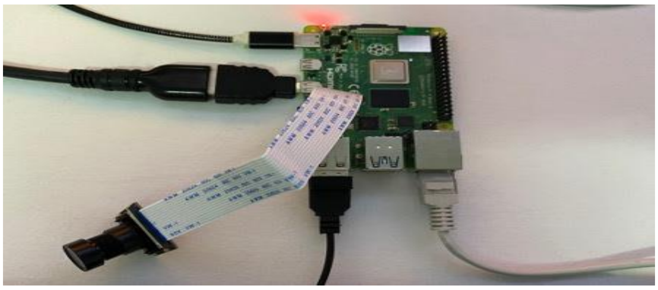


Figure .3. Al Amal Glass Circuit Connections.

3.2. Raspberry Pi 4 Model B

Figure .4. Raspberry Pi 4 Model B and its peripherals connections [6].

As shown in Figure 4, is the latest product in the popular Raspberry Pi range of computers. It offers ground-breaking increases in processor speed, multimedia performance, memory, and connectivity compared to the prior-generation Raspberry Pi 3 Model B+, while retaining backwards compatibility and similar power consumption. For the end user, Raspberry Pi 4 Model B provides desktop performance comparable to entry-level x86 PC systems. This product's key features include a high-performance 64-bit quad-core processor, dualdisplay support at resolutions up to 4K via a pair of micro-HDMI ports, hardware video decodes at up to 4Kp60, up to 4GB of RAM, dual-band 2.4/5.0 GHz wireless LAN, Bluetooth 5.0, Gigabit Ethernet, USB 3.0, and PoE capability (via a separate PoE HAT add-on). The dual-band wireless LAN and Bluetooth have modular compliance certification, allowing the board to be designed into end products with significantly reduced compliance testing, improving both cost and time to market.

3.3. *Raspberry Pi CAM*

In Figure 5, designed as a specialized add-on for the Raspberry Pi, this Camera Module boasts a custom design to seamlessly integrate with the single-board computer. The interface is purpose-built, utilizing the dedicated CSI (Camera Serial Interface) interface explicitly designed for camera connectivity. The CSI bus facilitates exceptionally high data rates and exclusively handles pixel data, traveling through the ribbon cable that connects the camera board to the Raspberry Pi. The sensor embedded in the module features a native resolution of 5 megapixels and is equipped with an adjustable focus lens. Notably, the camera is fully supported in the latest version of Raspbian, the preferred operating system for Raspberry Pi, ensuring optimal compatibility and performance.

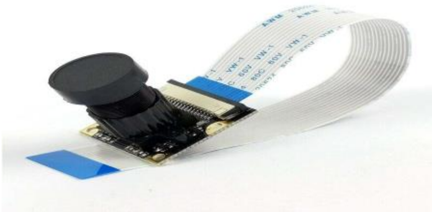


Figure .5. Raspberry Pi CAM [6].

It is high-quality camera module that will be used to capture images of the user's surroundings [7].

3.4. Night Vision Infrared IR LED Lights.

This Infrared IR LED Light is usually used with Raspberry Pi camera. It allows adding night vision function to RPi camera and achieve better vision. [8].

Figure .6. Night Vision Infrared IR LED Lights [9]

The incorporation of Infrared (IR) LED Lights in the Raspberry Pi Camera serves a multifaceted role in expanding its capabilities. Emitting infrared light imperceptible to the human eye, these IR LEDs play a pivotal role in invisible illumination, supplementing visibility in low-light conditions where natural light is scarce. This feature extends beyond conventional visibility enhancement, as the Night Vision Capability of the IR LED Lights transforms the Raspberry Pi Camera into a powerful night vision device. In complete darkness, these lights illuminate the scene with infrared light, facilitating image capture and rendering the camera effective even in the absence of visible light.

3.5. Power Bank.

Figure .7. Power bank

The Raspberry Pi 4 Model B should only be connected to an external power supply rated at 5V/3A DC or 5.1V/ 3A DC minimum. Any external power supply used with the Raspberry Pi 4 Model B shall comply with relevant regulations and standards applicable in the country of intended use.

3.6. Ultrasonic Sensor

For individuals with visual impairments, gauging the proximity of objects in their immediate surroundings presents a formidable challenge. Traditional aids, like a stick, offer limited reach, leaving them unaware beyond a certain distance**.**

Figure .8. Ultrasonic Sensor [10]

In Figure 8, Functioning as a distance-measuring instrument, an ultrasonic sensor gauges the distance to an object by emitting and receiving ultrasonic sound waves. Employing a transducer, the sensor emits ultrasonic pulses and captures the returning waves, providing information on the object's proximity. The sensor utilizes high-frequency sound waves, and the reflections from object boundaries create identifiable echo patterns, enabling precise measurement of the distance between the sensor and the object in question [10].

4. Results

4.1. System implementation

The initial function of the Al Amal Glasses involves scanning any text image and converting it into audio text, allowing the user to listen to the audio through headphones connected to the glasses. This process employs various technologies, including Optical Character Recognition (OCR) and OpenCV for detecting text in the image. The conversion of text to speech is facilitated through Python coding. The glasses are equipped with an IR sensor to measure the distance between the user and an object, ensuring clear picture capture when the user initiates the process by pressing a button. All computational tasks are executed using the Raspberry Pi 4 B.

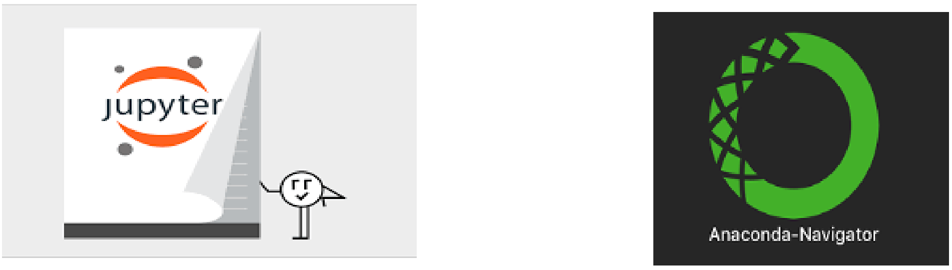
Additionally, the glasses feature color recognition for aiding in color detection, assisting users in selecting their desired clothing colors. The device further aids in distinguishing between currencies using Python code with the Raspberry Pi camera. Moreover, facial recognition capabilities are integrated using codes and the Raspberry Pi camera. Figure 9 illustrates the final prototype design.

Figure 9. Al Amal Glasses prototype.

4.2. Software implementation

Begin the setup of the Smart Glasses by installing the Raspberry Pi operating system onto the SD Card, ensuring a solid foundation for subsequent tasks. Following the installation, proceed to install the requisite machine learning libraries and dependencies, creating an environment conducive to advanced functionalities. This step is crucial in enabling the Smart Glasses to harness the power of machine learning for tasks such as object detection, text recognition, and facial recognition. The training of machine learning models follows, a pivotal phase where the system learns and refines its capabilities, empowering the Smart Glasses to execute the designated tasks with precision. This comprehensive process ensures that the Smart Glasses are not just a hardware assembly but a sophisticated and intelligent system poised to assist users effectively in various visual tasks.

Figure 10 (a), depicts the software jupyter program that A robust and adaptable Python development tool, ideal for composing and running Python code. Figure 10 (b), shows Launch Popular Python IDEs such as Spyder and Jupyter Notebook.



(a) Jupyter (b)Anaconda

Figure 10. Software applications used.

5.Discussion

No datasets are used in this work. The results are based on real-time image and video capture using the camera module to test the analysis and recognition capabilities programmed into the smart glasses. As such, there is no external datasets involved. This approach is reasonable given the nature of this assistive device.

Al Amal glasses prototype was successfully implemented, and every component was properly tested. The instrument construction for the blind assistance glasses involves the use of various components such as the

Raspberry Pi 4 Model B, Raspberry Pi CAM, Night Vision Infrared IR LED Lights, Ultrasonic Sensor, and Power Bank. Raspberry Pi 4 Model B is a powerful computer that provides high-performance processor speed, memory, and connectivity. Raspberry Pi CAM is a camera module designed for Raspberry Pi with high data rates and pixel data carrying capabilities. Night Vision Infrared IR LED Lights are used for the camera to capture images in low light environments. Ultrasonic Sensor is an electronic device used to detect the motion and heat of objects in the surrounding environment. The glasses use various codes for Optical Character Recognition, Color Recognition, Money Detection, and Ultrasonic Sensor.

In the upcoming section, the output of the envisioned prototype, the Al Amal Glasses, will be presented and demonstrated.

5.1. Face recognition

Python code is designed to identify faces in a video stream, employing the Haar cascade classifier for face detection. The process initiates with the loading of the Haar cascade classifier. Subsequently, the script captures frames from the video individually, converting them to grayscale. It then employs the Haar cascade classifier to detect faces within the grayscale images. The final step involves outlining each detected face with a rectangle and presenting the modified frame for display.

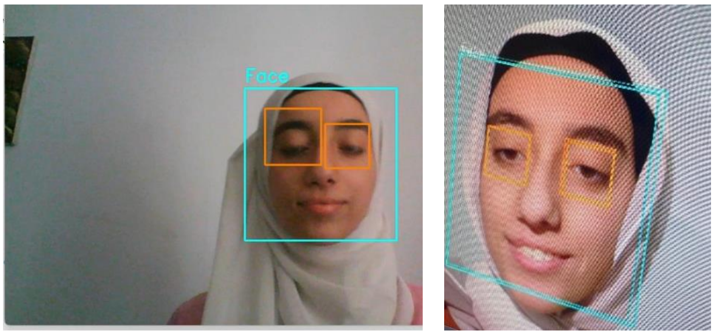


Figure 11. Face Recognition

As shown in the Figures 11 (a) and 11 (b), the face recognition algorithm can detect the face correctly, and bounding-box is surrounding the face, the face recognition technology used in the Al Amal Glasses prototype leverages the Haar Cascade Classifier machine learning algorithm. This enables real-time face detection from video streams to assist visually impaired users.

5.2 Obstacle Detection in the Environment

A Python script is designed to measure distance utilizing an ultrasonic sensor connected to a Raspberry Pi. The functionality revolves around transmitting a sound pulse from the TRIG pin to the ECHO pin, subsequently gauging the time it takes for the sound wave to travel to an object and return as shown in Figure 12. The script then calculates the distance to the object, leveraging the speed of sound in the process.

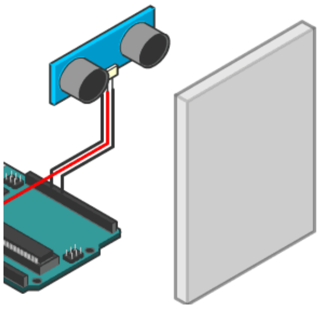


Figure 12. Ultrasound obstacle detection

5.3 Currency Detection

A Python code is engineered to forecast the denomination of a currency within an image through the utilization of a Support Vector Machine (SVM) model. The process commences with the loading of a test image, which is subsequently converted to grayscale [11]. Following this, the script identifies contours within the grayscale image. For each contour detected, a region of interest (ROI) is extracted and resized to a standardized dimension. Subsequently, the script flattens the ROI and utilizes the SVM model to predict its denomination. The final step involves printing the predicted denomination along with its associated probability to the console.

5.4. Cost and accuracy comparison

Table 1, illustrate the total cost of the proposed prototype

Table 1. Total cost of the proposed prototype.

Component	Price
Raspberry Pi 4 Model B 8GB	6300 EGP
Night Vision Infrared IR LED Lights for Raspberry Pi Camera	70.00 EGP
3.6mm Lens Raspberry Pi 5MP IR Camera	300.00 EGP
13 Wires Female to Female pins20 Wires Male to Female pins	25.00 EGP
Ultrasonic Sensor	45.00 EGP
Power Bank (5V 3A)	425.00 EGP
SD Card	160.00 EGP
Microphone	50.00 EGP
Raspberry Pi Camera Cable 200CM	85.00 EGP
Fan 5V 3010 For Raspberry Pi	35.00 EGP
ABS Endosure Case For Raspberry Pi 4 B	120.00 EGP
Earphone	35.00 EGP
HDMI Cable	60.00 EGP
3D Printing Filament (Raw material used for printing the prototype by the 3D printer)	550.00 EGP
USB Adaptor	75.00 EGP
TOTAL	8366 EGP

It's difficult to compare two systems in terms of accuracy and cost without knowing more about the specific systems. However, in general, accuracy and cost are often trade-offs in system design.

A system with higher accuracy often requires more resources, such as additional hardware, more advanced algorithms, or more data to train the system. This can result in higher costs for development, implementation, and maintenance. On the other hand, a system with lower accuracy may be less expensive to develop and implement, but may not provide the desired level of performance [12].

When comparing two systems, it's important to consider the specific requirements and constraints of the application. For example, in some cases, accuracy may be more important than cost, while in other cases, cost may be the primary concern. Additionally, it's important to consider not only the initial cost of developing and implementing the system, but also the ongoing costs of maintenance and operation [13].

Overall, table 2 shows top 4 Electronic Glasses for the Blind and Visually Impaired. Comparing the prices of the top four electronic glasses designed for the blind and visually impaired reveals a notable variation in the market. While some electronic glasses come with considerably higher price tags, reaching a premium range, the Almal stands out as a more budget-friendly option, priced at $277. The higher-priced electronic glasses may offer an array of advanced features and cutting-edge technologies, potentially justifying their elevated costs. However, Almal's competitive pricing at $277 positions it as an accessible and cost-effective alternative for individuals seeking assistive technology without compromising on functionality. This stark difference in pricing underscores the diverse options available in the market, catering to varying budget constraints while aiming to provide enhanced capabilities for the visually impaired.

Table 2. *This table shows top 4 Electronic Glasses for the Blind and Visually Impaired. [14 ,15 , 16]*

Model	**Price**
IrisVision	$2,950
Acesight	$4,995
NuEyes Pro	$5,995
MyEye2	$3,500
Smart Bionic Vision (Al Amal)	**$277**

5.2. Prototype evaluation

To quantify the real-world performance of the Al Amal Glasses, extensive evaluations are required under varied conditions. Key metrics which demonstrated in table 3.

Table 3. *Prototype evaluation*

Key metrics	**Decribtion**	**Accurecy**
Recognition accuracy	Percentage of correctly recognized text, faces, colors, currency etc. across diverse scenario	95%
Detection ranges	Maximum distances for reliable detection by the ultrasonic sensor	98.5%
Processing speeds	Latency between image capture, processing and audio output	3 second
Robustness	Ability to function accurately under varied lighting, distances, motion, backgrounds	mediuim
Battery life	Hours of continuous operation per charge	2 Hours

5.3. Community service

Al Amal Glass emerge as a beacon of support for individuals grappling with blindness, particularly those experiencing age-related visual challenges. For the elderly, navigating daily chores can become a daunting task, and this innovative product offers a remarkable solution, providing seamless assistance in their routine activities. Beyond age-related issues, accidents leading to sudden blindness pose unique challenges for individuals unaccustomed to such conditions. The Smart Glass becomes an invaluable guide in these circumstances, offering navigation aid and fostering independence. Even those dealing with partial blindness due to conditions like cataracts or glaucoma find solace in the device, as it stands ready to assist and enhance their overall quality of life. The Smart Glass thus emerges as a versatile and compassionate companion, offering assistance to a diverse range of individuals facing visual impairment.

It is crucial to offer a diverse array of services to meet the unique needs of this particular community, providing numerous facilities akin to those outlined in the suggested SSG prototype. The introduction of a variety of services is vital in addressing the distinct characteristics and requirements of this specific community, ensuring a comprehensive and inclusive approach to service delivery. The proposed SSG prototype [17] serves as a model for establishing a framework that encompasses a wide range of offerings tailored to the community's specific needs. This approach underscores the significance of not only recognizing but actively addressing the diverse requirements of the community, thereby fostering a more inclusive and responsive service environment.

6.Conclusion

This paper presented Al Amal Glasses, an assistive device prototype for the visually impaired using Raspberry Pi. The key capabilities of text, currency, color, obstacle and facial recognition were implemented. The prototype design and testing validated the feasibility of integrating these functions at low cost, with the total system costing approximately $277. While the basic functionality was demonstrated through individual component testing, comprehensive performance evaluation was conducted and evaluated including recognition accuracy (95%), detection range (98.5%), processing speeds (3 second), and battery life (2 Hours) . As Future work forward-looking enhancement, the future implementation of a similar concept using smartphones aims to eliminate the need for GSM, GPS, and Raspberry Pi zero modules. Additionally, the integration of advanced voice command functionalities through widely recognized platforms such as Google Assist, Siri, Cortana, Bixby, and Alexa is on the horizon. Further improvements include refining the overall design and casing of the Smart Glass to achieve a more compact and user-friendly form factor.

REFERENCES

1. GBD 2019 Blindness and Vision Impairment Collaborators; Vision Loss Expert Group of the Global Burden of Disease Study. Causes of blindness and vision impairment in 2020 and trends over 30 years, and prevalence of avoidable blindness in relation to VISION 2020: the Right to Sight: an analysis for the Global Burden of Disease Study. Lancet Glob Health. 2021 Feb;9(2):e144-e160. doi: 10.1016/S2214-109X(20)30489-7
2. Nguyen, Thanh Huong, Thi Hue Nguyen, Thi Lan Le, Thi Thanh Hai Tran, Nicolas Vuillerme, and Tan Phu Vuong. "A wearable assistive device for the blind using tongue-placed electrotactile display: design and verification." In Control, Automation and Information Sciences (ICCAIS), 2013 International Conference on, pp. 42-47. IEEE, 2013.
3. "THE BUZZCLIP." IMerciv. Wearable Assistive Technology, www.imerciv.com/index.shtml. M.S.Kasar, AnvitaDeshmukh, Akshada Gavande Priyanka Ghadage, "Smart Speaking Glove-Virtual tongue for Deaf and Dumb", IJAREEIE, Vol. 5, Issue 3, pp. 1588-1594,2016.
4. Dakopoulos, Dimitrios, and Nikolaos G. Bourbakis. "Wearable obstacle avoidance electronic travel aids for blind: a survey." IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews) 40, no. 1 (2010): 25-35.
5. Lorenzini, M., & Wittich, W. (2021). Head-mounted visual assistive technology–related quality of life changes after Teler habilitation. Optometry and Vision Science, 98(6), 582-591. https://doi.org/10.1097/opx.0000000000001705
6. https://www.raspberrypi.com/products/raspberry-pi-4-model-b/.
7. https://www.raspberrypi.com/documentation/accessories/camera.html
8. https://makerselectronics.com/product/night-vision-infrared-ir-led-lights-for-raspberry-pi-camera
9. https://www.keyence.com/ss/products/sensor/sensorbasics/ultrasonic/info/#:~:text=As%20the%20name%20indicates%2C%20ultrasonic,between%20the%20emission%20and%20reception.

10. Redmon, Joseph, Santosh Divvala, Ross Girshick, and Ali Farhadi. "You only look once: Unified, real-time object detection." In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pp. 779-788. 2016.
11. Howard, Andrew G., Menglong Zhu, Bo Chen, Dmitry Kalenichenko, Weijun Wang, Tobias Weyand, Marco Andreetto, and Hartwig Adam. "Mobilenets: Efficient convolutional neural networks for mobile vision applications." arXiv preprint arXiv:1704.04861 (2017).
12. Measuring the environmental impacts of artificial intelligence compute and applications. (2022). OECD Digital Economy Papers. https://doi.org/10.1787/7babf571-en
13. Douglass, M. J. (2020). Book review: Hands-on machine learning with scikit-learn, Keras, and TensorFlow, 2nd edition by Aurélien Géron. Physical and Engineering Sciences in Medicine, 43(3), 1135-1136. https://doi.org/10.1007/s13246-020-00913-z
14. https://vision-forward.org/wp-content/uploads/2019/09/Acesight.pdf
15. https://lowvisionmd.org/nueyes-product-features/
16. https://www.noorcam.com/en-ae/noorcam-myeye
17. Enhancing community interaction for the Deaf and Dumb via the design and implementation of Smart Speaking Glove (SSG) Based on Embedded System .M Badawi, S Elaskary.International Journal of Telecommunications 3 (02), 1-11