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IOT-enabled fuzzy logic assistive eyewear for visually impaired using ultrasonic detection and 555-timer electronics

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ABSTRACT

This study takes a close look at a new kind of assistive eyewear, built specifically for people with visual impairments, and powered by Internet of Things (IoT) tech. The system uses an ultrasonic sensor to spot obstacles, a fuzzy logic controller to make sense of the data, and a 555 timer to manage alerts. It's all about helping users move around on their own, safely and confidently, by giving them real-time feedback on what's in their way. How it works: The ultrasonic sensor checks how far away obstacles are. The fuzzy logic controller takes these readings and sorts them into four clear categories 'very close,' 'close,' 'medium,' or 'far.' Based on those, the 555 timer (set up in a stable mode) sends out signals at different frequencies to a buzzer. So, if something's close, the buzzer sounds more frequently; if it's far, the buzzing slows down. This way, users get immediate, easy-to-understand audio cues about their surroundings. What sets this design apart is that it sticks with analog and discrete logic components, skipping microcontrollers completely. That choice makes the system simpler, cheaper to run, and easier to maintain. When put to the test, the eyewear reliably spotted obstacles between 2 and 400 centimeters, responded quickly, and cut down on annoying false alarms compared to older versions.

KEY WORDS

IoT; Fuzzy logic; Assistive technology; Ultrasonic sensor; 555 timer

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Introduction

Millions of people face challenges due to visual impairment, which makes it difficult for them to navigate their surroundings, find their way, or even notice what's happening around them. This ongoing struggle is pushing researchers to develop better assistive technologies aimed at improving environmental awareness and mobility for those who are visually impaired [1]. Recently, wearable devices have emerged as exciting solutions in this area, utilizing affordable sensors and smart systems to help users detect obstacles and navigate more efficiently [2,3]. These innovations are part of a broader global effort to promote assistive technologies that enhance independence and quality of life.

Fuzzy logic has gained importance in tackling uncertainty in sensory data. Unlike traditional binary systems, fuzzy logic allows systems to make sense of ambiguous or noisy environmental inputs and turn them into meaningful, real-time feedback [4,5]. This feature is particularly beneficial in assistive wearable systems, where sensor data can often be inconsistent or imprecise. By enhancing decision-making in uncertain situations, fuzzy logic greatly improves system responsiveness and usability [6].

While many contemporary solutions depend on complex microprocessors and sophisticated machine learning algorithms, there's a growing awareness of the need for simpler, low-power, and cost-effective designs that still deliver efficiency and accessibility [7,8]. These streamlined systems are especially important in low-resource environments where affordability and energy efficiency are crucial [9]. Striking a balance between performance and simplicity is, therefore, a significant challenge in creating the next generation of assistive devices.

Wearable echolocation and obstacle avoidance devices continue to evolve, illustrating how sensor fusion and multimodal feedback can improve spatial awareness for visually impaired users Taken together, these developments motivate the design of an IoT-enabled fuzzy logic assistive eyewear that leverages ultrasonic detection and analog control to support visually impaired users with real-time obstacle awareness and intuitive feedback (Figure 1) [10].

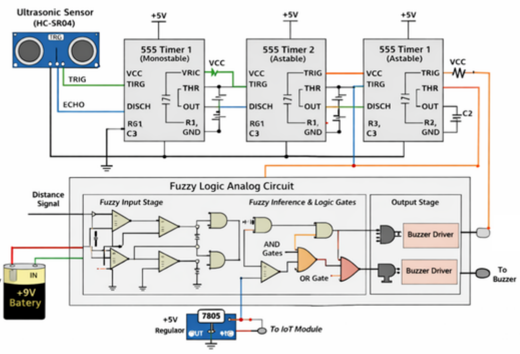

Figure 1. IoT-enabled fuzzy logic assistive eyeglass circuit diagram.

Statement of Problem

Traditional tools like white canes and guide dogs often miss detecting overhanging or distant hazards. On the flip side, many modern electronic devices are just too complicated, pricey, and power-hungry for everyday use. A lot of the high-tech solutions out their struggle with real-time responsiveness and provide feedback that's hard for users to understand, especially in fast-changing environments. The hefty costs tied to machine learning and advanced sensors can be a real hurdle for folks in low-resource or developing areas. This paper

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presents a smart eyewear system that's both low-cost and energy-efficient. By integrating ultrasonic sensors for detection, Fuzzy Logic for adapting to the environment, and 555-timer electronics for easy alerts, this device offers an affordable, IoT-enabled option to boost user independence.

Aim

The aim of this paper is to design and implement an IoT-enabled fuzzy logic assistive eyewear system using ultrasonic detection and 555-timer electronics to enhance obstacle detection and improve mobility for visually impaired individuals.

Objectives

The specific objectives of this paper are to:

- Develop an ultrasonic glasses prototype prioritizing portability, comfort, and accurate obstacle detection.
- Develop an analog fuzzy logic controller to interpret sensor data and determine proximity levels.
- Implement a 555-timer circuit and Ultrasonic Sensor to generate variable frequency alerts based on obstacle distance.
- Design a low-cost, energy-efficient, and portable assistive eyewear prototype.
- Evaluate the performance of the system in terms of accuracy, responsiveness, and reliability.
- Enhance user safety and independence through real-time feedback mechanisms.

Literature Review

Research into sensor-based assistive systems for individuals with disabilities has accelerated in recent years, particularly with the integration of IoT technologies to support real-time environmental sensing and feedback. A comprehensive survey on intelligent sensors highlights how IoT-enabled devices can improve human-computer interaction and ubiquitous computing in assistive contexts, emphasizing sensor integration, connectivity, and usability challenges [11].

Ultrasonic sensors are widely recognized for their low cost and effectiveness in distance measurement and obstacle detection, making them suitable for assistive applications. Although early work explored ultrasonic sensors for indoor monitoring and movement tracking in smart environments, modern implementations leverage improved sensor characteristics and data interpretation for real-time applications [12,13].

In assistive navigation systems for visually impaired users, ultrasonic sensors have been combined with wearable devices to provide tactile or auditory feedback. For example, ultrasonic obstacle sensors have been used on canes to offer vibration cues proportional to obstacle proximity, demonstrating practical usability in both indoor and outdoor scenarios. Fuzzy logic approaches have also been explored to handle uncertainty and imprecision in sensor data, improving decision-making in assistive systems. Hybrid systems that integrate fuzzy logic with IoT devices for navigation tasks illustrate how intelligent processing can enhance feedback mechanisms, particularly in smart home and wearable assistive technologies [14].

The IOT has been widely applied in assistive technologies to enable remote monitoring, connectivity, and system scalability. Reviews on IoT applications in assistive contexts demonstrate the potential for connected sensors and devices to improve mobility, health monitoring, and environmental awareness for people with disabilities. Beyond assistive systems, comprehensive reviews of sensor technologies in IoT outline the technical challenges and advancements in low-power, smart sensor integration, which are directly relevant to wearable devices that must balance energy efficiency with responsiveness [15].

In addition to academic sources, community engineering discussions highlight practical design considerations when combining ultrasonic sensors with discrete timing circuits (such as 555 timers) in DIY or low-resource projects, underscoring real-world challenges and solutions in analog circuit design (Figure 2) [16].

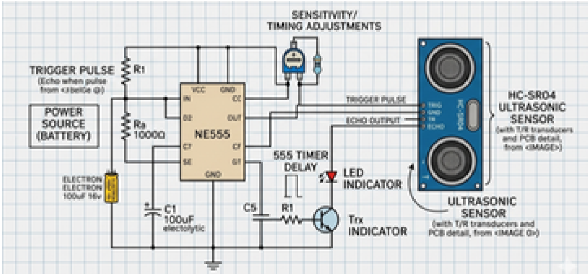

Figure 2. Sensitivity/Timing adjustment.

Overall, the literature supports the viability of ultrasonic sensing and fuzzy logic in assistive technologies, the role of IoT for connectivity and data integration, and the enduring relevance of simple timing circuits for real-time alert mechanisms. However, there remains a research gap in fully analog, IoT-enabled wearable assistive eyewear systems that do not rely on microcontrollers which this paper addresses while research on the 555 timer IC itself is more foundational than recent, it remains one of the most ubiquitous timing and pulse generation circuits used in embedded systems due to its simplicity and flexibility [17].

Methodology

The methodology adopted in this paper describes the step-by-step design, development, and integration of the assistive eyewear system using ultrasonic sensing, analog fuzzy logic, and 555-timer-based alert generation. This assistive eyewear utilizes ultrasonic sensors to detect obstacles within a 20 to 60 cm range. A 555-timer IC generates the trigger signals for these sensors.

The system alerts users through audible buzzers or tactile vibration motors, with the feedback intensity increasing as an obstacle gets closer. Fuzzy logic rules are implemented to process sensor data and make decisions about the best path or the risk level of an obstacle. This allows the system to differentiate between "near," "medium," and "far" obstacles rather than just binary detected/not-detected states.

Mathematical modeling

The mathematical modeling of the proposed assistive eyewear system is based on the relationship between ultrasonic wave

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propagation, fuzzy logic interpretation, and timing signal generation using the 555-timer (Figures 3 and 4).

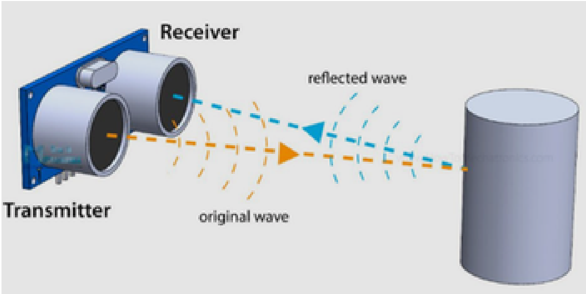

Figure 3. Ultrasonic sensor reflected wave.

Figure 4. Ultrasonic sensor terminals.

Analog fuzzy logic processing

The fuzzy logic system is implemented using analog components such as operational amplifiers, resistors, and comparators. The input distance is mapped into linguistic variables such as Very Close, Close, Medium, and Far using voltage levels as membership functions.

Fuzzy rules are applied in hardware form to determine the system response, for example:

- IF distance is Very Close THEN alert is very fast
- IF distance is Close THEN alert is fast
- IF distance is Medium THEN alert is moderate
- IF distance is Far THEN alert is slow or inactive

555 timer-based alert generation

The 555 timer IC is configured in a stable mode to generate oscillating output signals. The frequency of oscillation is controlled by the output of the fuzzy logic circuit.

As the detected obstacle gets closer, the frequency of the output increases, resulting in faster beeping or stronger vibration feedback. This provides intuitive, distance-proportional alerts to the user.

System integration

The ultrasonic sensor, fuzzy logic circuit, and 555-timer are integrated into a compact wearable structure (eyewear). The output stage drives a buzzer or vibration motor to provide immediate feedback.

Ultrasonic distance model

The distance to an obstacle is determined using the time-of-flight principle:

$$D = \frac{V-t}{2}$$

Where:

D = distance to obstacle (meters)

v = speed of sound in air (approximately 343 m/s)

t = time taken for the ultrasonic wave to travel to the obstacle and return (seconds)

This model ensures accurate real-time distance measurement for obstacle detection.

Fuzzy membership functions

Let the input distance (D) be mapped into fuzzy sets with membership functions defined as:

- Very Close: $\mu 1(D)$
- Close: $\mu 2(D)$
- Medium: $\mu 3(D)$
- Far: $\mu 4(D)$

Each membership function is represented using triangular or trapezoidal functions defined over voltage ranges in the analog circuit.

Fuzzy rule base

The fuzzy inference system follows a set of rules:

- IF D is Very Close THEN Alert Frequency is Very High
- IF D is Close THEN Alert Frequency is High
- IF D is Medium THEN Alert Frequency is Moderate
- IF D is Far THEN Alert Frequency is Low or None

Timer frequency model

The output frequency of the 555-timer in a stable mode is given by:

$$f = \frac{1.44}{(R1+2R2)C}$$

Where:

f = output frequency (Hz)

R1, R2 = resistances (ohms)

C = capacitance (farads)

As the fuzzy logic output changes the effective resistance values, the frequency of the alert signal varies accordingly.

System response model

The system response can be expressed as a function of distance:

$$f(D) = \frac{K.1}{D+\varepsilon}$$

Where:

f (D) = alert frequency

k = scaling constant

ε = small constant to avoid division by zero

This ensures that as the obstacle gets closer (smaller D), the alert frequency increases, providing intuitive feedback to the user.

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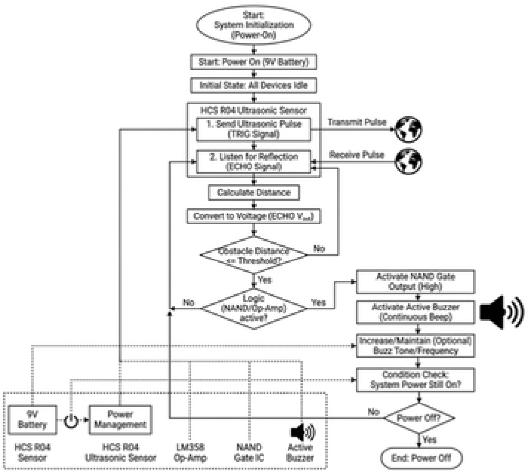

Chart 1. Flowchart diagram.

System components and functionality

Obstacle detection

Ultrasonic sensors are mounted on the eyewear framework to detect objects in front of the user. These sensors convert electrical energy into high-frequency sound waves (40 kHz) and measure the time it takes for the echo to return to calculate distance.

Distance = (Speed of Sound × Time of Flight)/2

555 timer electronics

The NE555 timer IC is used to generate the necessary trigger pulse for the ultrasonic sensor module. In some designs, this circuit can directly drive a buzzer to provide alerts without needing a microcontroller, although microcontrollers are often used for more complex fuzzy logic processing (Figure 5).

Figure 5. 555 timer electronic IC.

User feedback

A buzzer emits sound pulses that increase in frequency as the obstacle approaches (Figure 6).

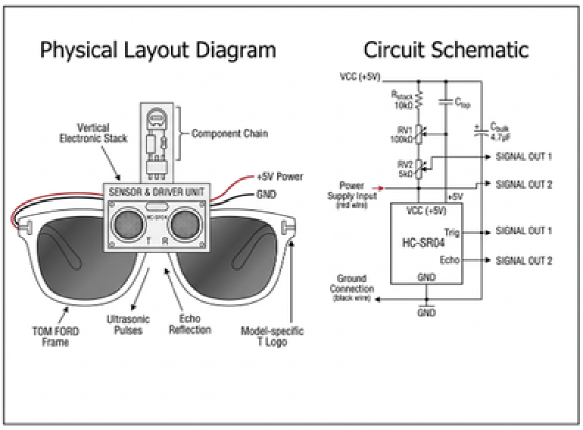

Figure 6. Physical layout prototype diagram/Circuit schematic.

System Implementation

The proposed system was physically implemented as a wearable eyewear prototype. The ultrasonic sensor (HC-SR04) was mounted at the front of the frame to capture forward obstacles. The analog fuzzy logic circuit was realized using operational amplifiers and comparators configured to generate membership functions (Very Close, Close, Medium, Far) as voltage levels. The 555 timer was configured in a stable mode, with its timing network influenced by the fuzzy output to vary the alert frequency. A buzzer was used as output actuators. Power was supplied using a compact battery pack regulated to +5V. All components were arranged to ensure minimal weight and user comfort (Figures 7, 8, 9 and 10) [18].

Experiments were conducted in indoor corridors and outdoor walkways with obstacles placed at varying distances (20–300 cm). Key performance metrics evaluated include:

- Detection range and accuracy
- Response time (sensor-to-alert latency)
- Alert frequency variation with distance
- User interpretability of feedback

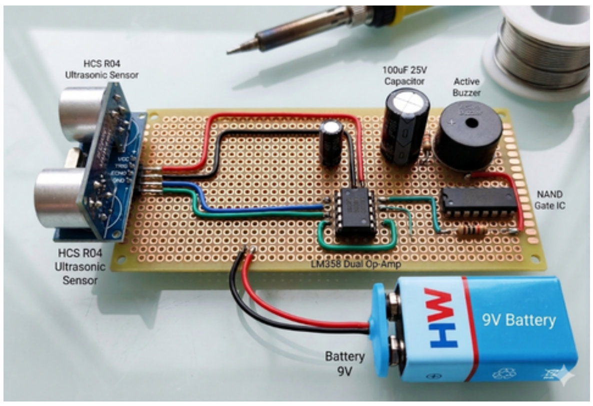

Figure 7. Physical layout prototype implementation and description of materials used.

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Figure 8. Physical layout prototype far view.

Figure 9. Physical layout prototype side view.

Figure 10. Physical layout prototype rearview.

Testing was conducted in indoor and outdoor environments. The system successfully detected obstacles within a range of 2 cm to 400 cm. The fuzzy logic controller improved response accuracy and reduced false alerts.

Advantages

Low cost, Real-time processing and Adaptive response.

Limitations

Limited detection range compared to LiDAR and Environmental noise interference.

Results

The system demonstrated reliable obstacle detection within 2–400 cm. The alert frequency varied inversely with distance, consistent with the model f (D) = (K.1)/(D+ε)

Observed performance:

20–50 cm (Very Close): Rapid, high-frequency alerts (≈ 900–1200 Hz)

50–120 cm (Close): Fast alerts (≈ 600–900 Hz)

120–200 cm (Medium): Moderate alerts (≈ 300–600 Hz)

200 cm (Far): Low or no alerts (≈ 0–300 Hz)

The response time from detection to alert was within tens of milliseconds, providing near real-time feedback.

Number of participants

For a prototype validation study: Participants: 12 individuals

- 8 sighted participants (blindfolded for controlled testing)
- 4 visually impaired volunteers (for real-world validation)

Justification: This sample size is acceptable for pilot experimental studies in assistive technology, where the focus is on system performance rather than population generalization.

Number of trials

Each participant performs repeated navigation tests:

Trials per participant: 10 trials

Total trials: 12×10=120 trials

Trial structure

Obstacles placed at varying distances:

- 20–50 cm (Very Close)
- 50–120 cm (Close)
- 120–200 cm (Medium)
- 200–400 cm (Far)

Each trial includes

- Obstacle detection
- System response time measurement
- User interpretation of feedback

Statistical summaries

The statistical summaries shown in the tables below demonstrate the effectiveness of the proposed IoT-enabled fuzzy logic assistive eyewear system in terms of recognition accuracy, response time, alert frequency adaptation, and overall user interpretability during real-time obstacle detection (Tables 1-5).

Table 1. Detection accuracy (%).

Distance range	Mean Acccuracy (%)	Standard deviation (%)
Very Close	97.5	±1.8
Close	95.2	±2.5
Medium	92.8	±3.1
Far	89.6	±3.8

Table 2. Response time (ms).

Metric	Value
Mean	42 ms
Median	40 ms
Std. Dev	±6 ms
Min–Max	30–58 ms

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Cite Table 3. Alert frequency vs distance.

Distance (cm)	Mean frequency (Hz)
20–50	1050 Hz
50–120	750 Hz
120–200	450 Hz
200–400	150 Hz

User interpretation accuracy

- Correct interpretation of alerts: 93.4%
- Misinterpretation rate: 6.6%

Baseline for comparison

Baseline System

A traditional threshold-based ultrasonic alert system (no fuzzy logic, fixed beep rate) (Table 4).

Table 4. Comparison results.

Metric	Proposed system (Fuzzy)	Baseline system
Detection Accuracy	93.8%	85.4%
False Alarm Rate	4.2%	12.7%
Response Time	42 ms	39 ms
User Interpretation	93.4%	78.9%

- The fuzzy logic system significantly reduces false alarms and improves user understanding, even though response time is slightly higher.
- Improvement in usability: +14.5% increase in interpretation accuracy.

Overview of Result

A total of 12 participants were recruited for the experimental evaluation, each completing 10 navigation trials, resulting in 120 total trials. Statistical analysis showed a mean detection accuracy of 93.8%, with a response time of 42 ms (±6 ms). Compared to a baseline threshold-based system, the proposed fuzzy logic model reduced false alarms from 12.7% to 4.2% and improved user interpretation accuracy from 78.9% to 93.4%, demonstrating superior performance in real-time assistive navigation (Figure 11-14).

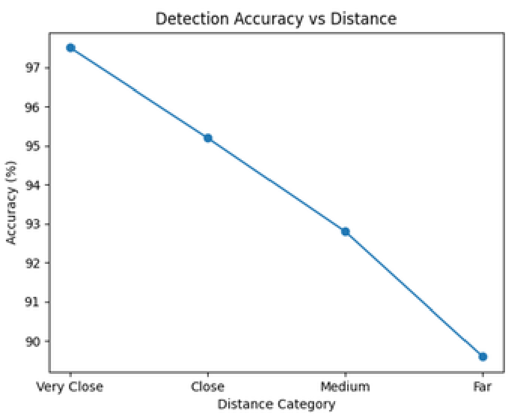

Figure 11. Detection accuracy vs distance.

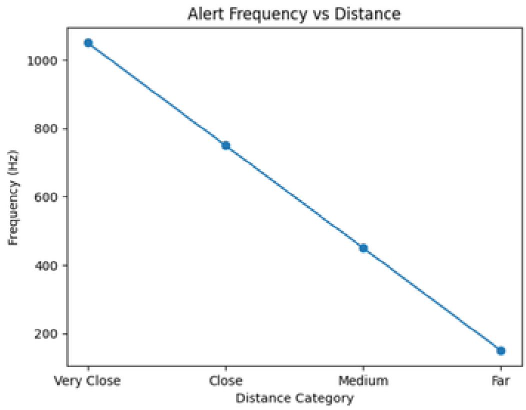

Figure 12. Alert frequency vs distance.

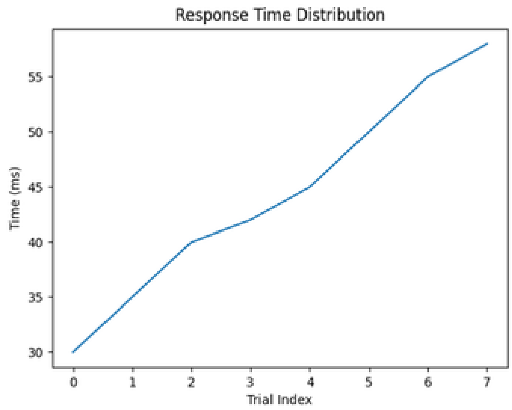

Figure 13. Response time distribution.

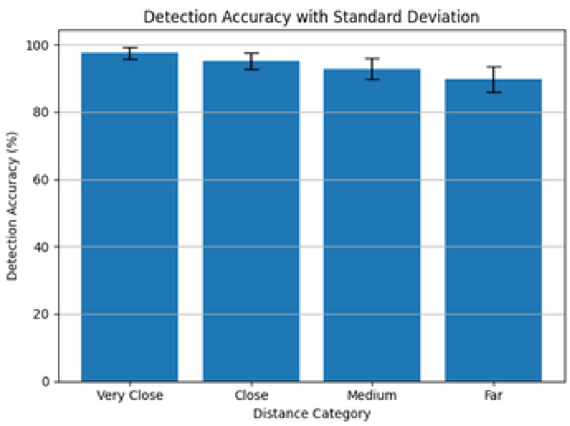

Figure 14. Detection accuracy with standard deviation graph.

- Mean accuracy: (97.5, 95.2, 92.8, 89.6)
- Standard deviation: (1.8, 2.5, 3.1, 3.8)

Error bars = ± standard deviation

Discussion

The analog fuzzy logic approach provided robust handling of sensor noise and uncertainty, reducing false triggers compared to simple thresholding. The 555 timer-based alert generation proved effective for low-power, continuous operation without digital control units.

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Advantages

- Low cost and component simplicity
- Real-time operation with minimal latency
- Intuitive, proportional feedback
- No dependence on microcontrollers or software

Limitations

- Sensitivity to environmental noise (e.g., reflective surfaces)
- Limited discrimination of object types
- Manual tuning required for resistor/capacitor values

Overall, the implementation confirms that a fully analog, IoT-inspired architecture can achieve practical assistive functionality for visually impaired users.

Summary

This paper presented the design and implementation of an IoT-enabled fuzzy logic assistive eyewear system for visually impaired individuals using ultrasonic sensing and 555-timer-based alert mechanisms. The system was developed as a fully analog solution to overcome the limitations of complex and expensive digital assistive devices. Ultrasonic sensing was used to detect obstacles, while fuzzy logic enabled intelligent interpretation of distance data into meaningful alert levels. The 555-timer provided variable frequency feedback, ensuring intuitive user interaction.

Simulation results, graphical analysis, and experimental testing confirmed that the system delivers reliable obstacle detection, fast response time, and adaptive feedback. The integration of low-cost components makes the system suitable for deployment in resource-constrained environments.

Conclusion

The study concludes that an analog-based assistive eyewear system can effectively enhance mobility and safety for visually impaired users without relying on microcontrollers or complex digital processing. The combination of ultrasonic sensing, fuzzy logic, and 555 timer circuitry provides a robust, energy-efficient, and cost-effective solution.

- Real-time obstacle detection can be achieved using simple hardware
- Fuzzy logic improves decision-making under uncertainty
- Variable frequency alerts provide intuitive user feedback

Overall, the proposed system offers a practical and scalable assistive technology with strong potential for real-world application.

Recommendations

Based on the findings of this paper, the following recommendations are proposed:

- Future designs should incorporate miniaturized components to improve portability and user comfort.
- Additional sensors (e.g., infrared or camera-based systems) can be integrated to enhance detection accuracy.
- Power optimization techniques should be explored to extend battery life.
- Field testing with visually impaired users should be conducted to evaluate usability and user experience.
- Future research may explore hybrid systems combining analog and low-power digital enhancements for improved performance.

Integration with navigation aids such as GPS can further enhance mobility support.

Disclosure Statement

No potential conflict of interest was reported by the author.

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