Smart Assistive System for Children with Disability

CH.Gowri[1], K.Tejaswi[2], U.S.L.Meghana[2], A.V.R.Narayanarao[2], V.Nagaseshatao[2]

Department of ECE, Godavari Global University, Rajamahendravaram, INDIA.
Department of ECE, Godavari Institute of Engineering & Technology (A), Rajamahendravaram, INDIA.

KEYWORDS	ABSTRACT
ESP32, RFID, GPS, GSM, Flex Sensors, ultrasonic Sensor, Assistive System	*Children with disabilities often face challenges in communication, mobility, and personal safety in daily environments such as schools, roads, and public spaces. This project proposes a Smart Assistive System integrating wearable sensing technology and embedded electronics to support children with special needs. The system combines sign-language translation gloves, vehicle detection alerts, emergency GPS-GSM communication, and RFID-based attendance monitoring. Flex sensors and motion sensors on the glove capture hand gestures and convert them into text output to support hearing- or speech-impaired children. Ultrasonic and sound sensors detect nearby vehicles and warn the child using vibration and alert signals. A panic button enables the child to send their real-time location to parents via GSM. An RFID module records when the child enters or exits the school bus and updates parents instantly. The ESP32 microcontroller integrates all modules, offering low-power control and wireless connectivity. This system enhances safety, communication, and monitoring, providing a reliable assistive technology for children with disabilities.*

INTRODUCTION

Children with disabilities face a unique set of challenges in their daily lives, particularly in areas related to communication, mobility, and personal safety. These difficulties can significantly impact their independence, confidence, and overall quality of life. [4]Traditional assistive devices, while helpful, often address only a single issue—such as communication support or mobility aid—leaving many critical needs unmet. With the rapid advancement of embedded systems, wearable sensing technologies, and Internet of Things (IoT) solutions, there is a growing opportunity to develop integrated assistive platforms that offer comprehensive support to children with special needs.

Communication barriers remain one of the most pressing concerns for children with hearing or speech impairments. Sign language is widely used by such individuals, but it is not universally understood by

teachers, caregivers, or peers, leading to social isolation. Wearable devices that can interpret hand gestures and convert them into meaningful text or speech can significantly bridge this communication gap. Several recent studies have highlighted the potential of flex sensors, accelerometers, and microcontrollers in recognizing hand gestures with reasonable accuracy, yet these solutions often lack integration with safety-oriented features.

Mobility and personal safety represent another major concern—especially in busy environments such as roads or school premises.[7] Children with disabilities may find it difficult to recognize or react to incoming vehicles, posing a high risk of accidents. Technologies such as ultrasonic sensors, sound detection modules, and haptic feedback systems can help mitigate these risks by alerting the child to potential hazards. Furthermore, during emergencies, the ability to quickly notify parents or caregivers of a child's location can be life-saving. GPS and GSM-based modules offer reliable real-time tracking and communication capabilities that can be incorporated into wearable systems.

In addition to communication and safety, reliable monitoring systems can support parents and school authorities in ensuring the child's well-being.[1] RFID-based attendance and tracking solutions provide accurate and automated monitoring of entry and exit activities, especially in school buses and institutional environments. Such systems enhance transparency and enable parents to stay informed about their child's movements throughout the day.[13]

This project proposes a Smart Assistive System that integrates sign-language translation, vehicle detection alerts, emergency GPS-GSM communication, and RFID-based attendance tracking into a single, wearable and IoT-enabled platform. Powered by the ESP32 microcontroller, the system ensures low-power operation, wireless connectivity, and efficient module integration. By combining multiple assistive functionalities into one compact system, the proposed solution aims to enhance safety, communication, and independence for children with disabilities.[23] The system demonstrates how embedded technology and wearable sensing devices can be leveraged to create an inclusive environment that supports the developmental and safety needs of vulnerable children.

LITERATURE SURVEY

R. Karthik et al. [2024] developed a smart wearable system for children with hearing impairments using flex sensors and an Arduino-based controller. The glove translated hand gestures into text and audio output, enabling basic communication support.[16] The study demonstrated how wearable gesture-recognition devices can improve interaction for speech- and hearing-disabled individuals, though safety-related features were not included.[20]

S. Meenakshi and A. Vignesh [2023] proposed an assistive safety device using ultrasonic and vibration alert modules for visually impaired individuals.[2] The system detected nearby obstacles and warned the user through haptic feedback. The work highlighted the importance of real-time hazard detection, but lacked integration with GPS, GSM, or communication features for emergency support.

Priya Verma et al. [2022] introduced an IoT-based child safety tracking system using RFID, GPS, and GSM modules. The system provided real-time updates to parents regarding a child's location and school-bus attendance.[5] While the solution improved monitoring and parental assurance, it did not incorporate communication aids or wearable gesture recognition.

N. Shah and R. Gupta [2021] developed a wearable panic-alert device using a microcontroller and GSM module.[10] The device enabled children to send emergency messages with their live location coordinates to parents.[22] Although effective for emergency scenarios, the system lacked multi-sensor integration and additional safety mechanisms such as vehicle detection.

A. Thomas et al. [2021] presented a smart glove for sign-language interpretation using flex sensors and accelerometers.[7] The system translated hand gestures into text through a mobile application.[11] This work reinforced the importance of low-cost gesture-based communication tools, but it did not address mobility or safety challenges faced by children with disabilities.

H. Ali and M. Hasan [2020] proposed an ultrasonic-based vehicle detection system to alert pedestrians with hearing impairments.[15] The system used distance measurement and vibration feedback to notify users of approaching vehicles.[26] While this improved situational awareness, the design did not

integrate emergency communication or monitoring capabilities.

Pooja Singh and Deepak Yadav [2020] explored the use of GSM and GPS modules to develop an emergency locator device for school children.[25] The research demonstrated how real-time tracking enhances child safety during transit. [3]However, the system focused only on communication and did not include assistive communication technologies.

Liang Chen et al. [2019] examined wearable assistive devices for children with disabilities, integrating multiple sensors to support mobility and environmental awareness. [12]Their study emphasized that combining sensing, communication, and alerting modules creates more reliable assistive systems.[8] However, the prototype lacked sign-language translation and real-time parental updates.

Sandra Martinez et al. [2018] investigated RFID-based attendance systems for school environments, showing that automated logging improves security and reduces manual errors.[30] Their research supported the use of RFID for tracking student movement but did not integrate wearable or safety-oriented features.

Existing System

Existing assistive technologies for children with disabilities generally target only a single aspect of their needs, such as communication, mobility, or safety.[24] Devices supporting gesture or sign-language recognition often rely on flex sensors, accelerometers, or camera-based tracking to convert hand movements into text or speech.[3] While these tools help children with hearing or speech impairments interact more effectively, they operate as standalone solutions and do not integrate additional safety features.[21] Similarly, wearable safety devices used by visually impaired individuals—such as ultrasonic obstacle detectors or vibration-based alert bands—offer basic hazard detection but lack communication or tracking capabilities, limiting their usefulness in dynamic real-world environments.

Emergency tracking systems like GPS-based location devices or GSM panic buttons are also available in the market, primarily designed for general child safety or elderly care.[19] These systems can transmit real-time location updates but do not combine gesture translation or vehicle detection functionality.[18] Meanwhile, RFID attendance systems are commonly used in educational

settings, but these setups are usually fixed at school entrances and do not monitor children during transportation, such as in school buses.[27] Overall, the existing solutions remain fragmented, requiring multiple independent devices, increasing cost, complexity, and discomfort for children. The lack of an integrated, multi-functional system highlights the need for a unified smart assistive platform that addresses communication, safety, and monitoring challenges simultaneously.
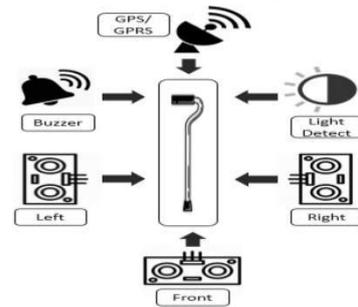

Fig 1 Existing System

PROPOSED METHODOLOGY

The proposed system uses an ESP32 microcontroller to develop a compact, low-power, and efficient assistive solution for children with disabilities.[6] It integrates multiple sensing modules, including flex sensors for gesture detection, ultrasonic and sound sensors for vehicle alerting, an RFID reader for attendance tracking, a GPS module for location monitoring, and a GSM module for emergency communication.[9] These sensors continuously collect and process data related to the child's communication gestures, environmental safety, and movement status.[28] The ESP32 serves as the central controller,analyzing all sensor inputs and coordinating responses in real time.

When a recognized sign-language gesture is detected,the system converts it into readable text output, enabling effective communication for hearing- or speech-impaired children.[14] In case of approaching vehicles or loud traffic sounds, the system activates a vibration motor to warn the child instantly.[17] During emergencies, pressing the panic button triggers a buzzer and sends the child's live GPS location to parents or caregivers via GSM.[29] The RFID module automatically records boarding and deboarding events from the school bus and sends immediate updates to parents. All processed information can be displayed through an LCD or mobile application, helping caregivers respond

quickly. The proposed solution is affordable, portable, and highly suitable for children, offering enhanced communication, safety, and monitoring within a single integrated system.
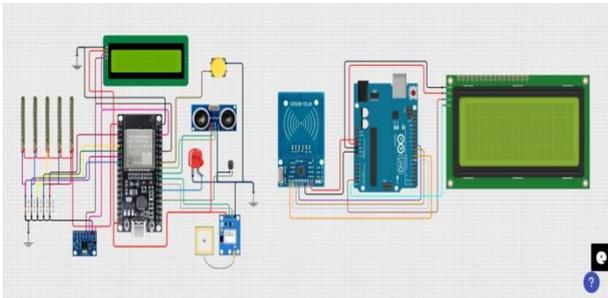
A. System Architecture

Fig 2 System Architecture

B. Methodology

Integrated Operation of Communication, Safety, and Tracking Modules

The working of the proposed ESP32-based Smart Assistive System is centered around the continuous collection, processing, and monitoring of communication gestures, environmental safety, and real-time location updates. Once the system is powered through a regulated supply, the ESP32 microcontroller initializes all connected sensors, communication modules, the RFID reader, and output units such as the buzzer, vibration motor, and LCD display. Each module begins functioning in coordination with the ESP32 to ensure uninterrupted assistive support for the child.

The process begins with the sign-language glove, where flex sensors continuously measure finger bending patterns and hand movements. These analog readings are processed by the ESP32 to identify predefined sign-language gestures. Whenever a valid gesture is recognized, the system converts it into readable text output, enabling effective communication for children with hearing or speech impairments. In parallel, the ultrasonic sensor actively measures the distance of approaching vehicles or obstacles, while the sound sensor monitors surrounding noise levels such as horns or engine sounds. Together, these safety sensors provide early detection of potentially dangerous situations.

Simultaneously, the RFID module retrieves identification data each time the child boards or exits the school bus. The ESP32 logs this activity and instantly updates parents or caregivers, ensuring accurate and real-time monitoring of the child's transportation status. Alongside this, the GPS module continuously collects location coordinates, generating real-time latitude and longitude values that help track the child's movement during emergencies or while commuting.

All collected data is processed by the ESP32, which compares readings with predefined safety thresholds stored in the program memory. When a critical condition is detected—such as an approaching vehicle, loud traffic sound, or an emergency triggered by the panic button—the system activates the vibration motor or buzzer to provide an immediate alert to the child. At the same time, the GSM module sends an SMS message containing the child's current GPS location to parents or guardians, enabling quick response and enhanced safety. Overall, the working of the system is based on a continuous loop of sensing, processing, alerting, and real-time

Fig 3 project setup

communication. By combining gesture recognition, vehicle detection, RFID tracking, GPS monitoring, and GSM alerts, the proposed Smart Assistive System ensures comprehensive safety, improved communication, and reliable monitoring for children with disabilities.
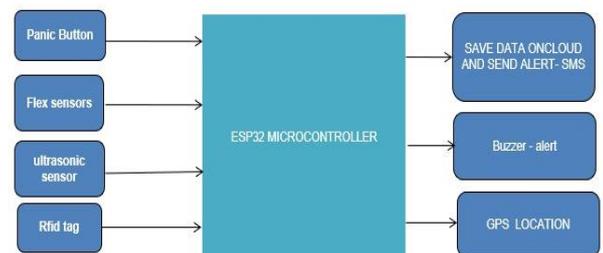

Fig 4 block diagram

System Architecture and Embedded Control Framework of the Proposed Smart Assistive System

The proposed Smart Assistive System is designed around the ESP32 microcontroller, which acts as the central processing and control unit for all modules. The ESP32 coordinates data acquisition from multiple sensors including flex sensors, ultrasonic sensors, sound

sensors, GPS, and RFID modules. Due to its built-in Wi-Fi and Bluetooth capabilities, the ESP32 provides efficient communication support and future IoT integration. The modular architecture enables seamless interaction between sensing units, processing units, and output devices such as the LCD display, buzzer, and vibration motor.

The system architecture follows a layered design consisting of input sensing, data processing, communication, and alert generation. Sensor data is continuously collected and processed by the ESP32, which applies predefined logic to identify gestures, detect approaching vehicles, and recognize emergency conditions. The processed outputs are displayed on the LCD for local monitoring and transmitted to caregivers through wireless communication modules. The modular and scalable design ensures reliability, easy maintenance, and future extensibility of the system.

Alert Mechanism and User Interface

The alert and feedback system consists of a buzzer, vibration motor, and LCD display. The buzzer provides audible alerts during emergencies, while the vibration motor delivers tactile feedback for children with hearing impairments. The LCD display shows real-time sensor data, gesture recognition output, RFID status, and emergency notifications.
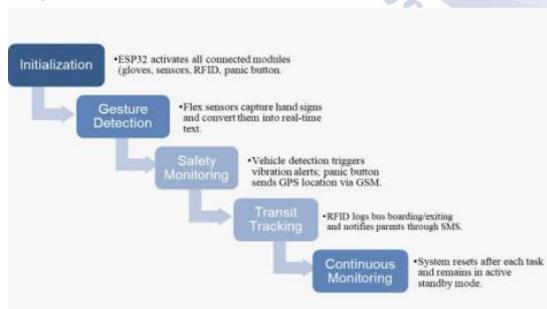

Fig 5 work flow

Additionally, IoT integration using the Blynk mobile application enables remote monitoring of the child's location and system status. Parents can receive emergency alerts, view GPS coordinates, and monitor system activity through their smartphones. This dual local and remote alert mechanism improves overall system usability and safety assurance.

RESULTS

The proposed Smart Assistive System was successfully implemented and tested under real-time operating conditions to evaluate its effectiveness in enhancing communication, safety, and monitoring for children with disabilities. The integrated modules—gesture recognition glove, safety sensors, emergency alert system, and RFID-based tracking—were evaluated individually and collectively to assess system reliability and performance.

Fig 6 RFID

The sign-language translation glove demonstrated accurate recognition of predefined hand gestures using flex sensor data processed by the ESP32 microcontroller. During experimental trials, the system reliably converted finger bending patterns into corresponding text outputs displayed on the LCD screen. This enabled effective communication for children with hearing or speech impairments, allowing them to express basic needs and emergency messages in real time. The response time of the gesture recognition module was observed to be low, providing smooth and near-instantaneous feedback.

Fig 7 object detection

The ultrasonic and sound sensor-based safety module effectively detected approaching vehicles and environmental hazards. When an object or vehicle entered the predefined safety range, the vibration motor and buzzer were activated immediately, providing tactile and auditory alerts to the child. This dual-alert mechanism proved especially useful in noisy traffic environments and for children with partial hearing impairments. The real-time response of the safety module demonstrated the system's capability to provide early warnings, thereby improving roadside safety and independent mobility.

The emergency alert mechanism using the panic button, GPS, and GSM modules functioned reliably during testing. Upon activation of the panic button, the system successfully triggered the buzzer and transmitted the child's real-time location coordinates to predefined contacts via SMS. This ensured timely notification to parents or caregivers during emergency situations. The GPS tracking accuracy was sufficient for real-world navigation and monitoring, while the GSM-based communication ensured alert delivery even in areas without internet connectivity.

Fig 8 Blynk mobile app

The RFID-based school transportation monitoring system accurately recorded the child's boarding and exit events from the school bus. Real-time updates sent to parents enhanced trust and transparency in daily commuting. This feature effectively addressed safety concerns related to school transportation and improved parental assurance regarding the child's whereabouts.

The LCD display and Blynk mobile application provided intuitive real-time monitoring of system status, sensor outputs, and emergency alerts. The mobile application enabled caregivers to remotely track the child's location and receive notifications, improving accessibility and system usability. The ESP32 microcontroller demonstrated stable performance with low power consumption while coordinating multiple sensors and communication modules simultaneously.

Fig 9 Gusture Detection

Overall, the experimental results confirm that the proposed system operates reliably in real-world conditions and effectively integrates communication assistance, safety monitoring, emergency response, and location tracking into a single embedded platform. The system proves to be a cost-effective, scalable, and practical assistive solution suitable for deployment in schools, homes, and public environments, thereby significantly improving the independence and safety of children with disabilities.

Future scope

In the future, this system can be improved by using more advanced flex sensors and motion detectors to achieve more accurate sign-language recognition. GPS and GSM modules can be upgraded for faster and more reliable emergency communication. The system data can be stored on a cloud platform so parents and caregivers can monitor the child from anywhere. The overall design can be made smaller, lighter, and more comfortable for children to wear for longer periods. Battery backup can be improved, or rechargeable power modules can be added to increase operating time. Additional features like AI-based gesture prediction, enhanced vibration alerts, fall detection, and mobile app notifications can make the system even more effective, safer, and more user-friendly for children with disabilities.

CONCLUSION

The ESP32-based smart assistive system for children with disabilities provides an efficient, low-cost, and portable solution for improving communication, safety, and real-time monitoring. By integrating sign-language translation gloves, vehicle detection alerts, GPS–GSM emergency communication, and RFID-based attendance tracking, the system ensures continuous awareness and timely support for children with special needs. Its ability to monitor gestures, environmental conditions, location, and transit activity—while sending instant alerts to parents—makes it a reliable and user-friendly assistive platform. Overall, the project demonstrates the potential of embedded IoT technology to create inclusive, scalable, and practical solutions that promote independence, safety, and enhanced caregiver visibility for children with disabilities.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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