

DESIGN AND IMPLEMENTATION OF A SMART IOT-ENABLED AXILLARY CRUTCH FOR ENHANCED MOBILITY

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Abstract—Mobility aid equipment is fundamental to people with physical disabilities and lower-limb injury as well as elderly persons with mobility issues. Nevertheless, the traditional axillary crutches are not more than mechanical support without smart surveillance and emergency response. This paper proposes the design and implementation of a Smart IoT-Linked Axillary Crutch that will increase user safety and monitoring of rehabilitation. The suggested system is based on a lightweight, foldable aluminum crutch with integrated sensors, such as load sensors to analyze the distribution of weight and sensors based on accelerometry to sense tilting to detect the posture and falls. A microcontroller constantly runs sensor data to recognize abnormal conditions. GPS module can track the exact location in real time in case of an emergency, and GSM/Wi-Fi communication modules can send notifications and location information to the caregivers. The system guarantees the provision of medical help in time, enhances user confidence, and facilitates remote supervision. The prototype created exhibits a practical, portable, and cost-effective smart mobility platform to be applied in healthcare.

Index Terms—Smart Crutch, Internet of Things (IoT), Axillary Crutch, Fall Detection, GPS Tracking, Load Sensor, Rehabilitation Monitoring, Assistive Technology.

I. Introduction

Mobility impairment is one of the significant issues among the elderly, post-surgical patients, and physically challenged individuals in most countries of the world. Assistive aids like the axillary crutches are quite common to assist in balance and also relieve the injured lower limbs of weight. Despite the fact that the conventional crutches provide the necessary mechanical aid, they do not have the means of intelligent monitoring, real-time feedback, and the emergency communications option [1]. Poor weight balance, improper posture, or unexpected imbalance during the use would lead to the fall, and secondary injury, especially among the elderly users. Also, the remote monitoring is not only missing but also restricts the capability of caregivers to monitor the progress of rehabilitation properly [2],[3] Recent development of Internet of Things (IoT) technology has made it possible to integrate smart sensing and wireless communication with healthcare devices. With the integration of sensors, microcontrollers, and communication modules into a mobility aid, it can be improved to be much safer, track user activity, and issue real-time alerts in case of critical conditions [4]. Load sensors are able to measure weight distribution, accelerators and tilt sensors are able to detect an abnormal posture or fall. On this note, the suggested Smart IoT-Enabled Axillary Crutch will enhance user safety, independence and rehabilitation monitoring via the real-time location tracking and the emergency notification [5]. The proposed Smart IoT-Enabled Axillary Crutch will accomplish this by means of constant sensing, smart data processing, and remote

communication. The system is affordable and can be used on the go and it fills the gap between the traditional mobility aids and the modern smart healthcare technologies.

A. Objectives

- To develop and design an axillary crutch that is lightweight, foldable, and uses the IoT technology to increase mobility support.
- To measure weight distribution by load sensors to assess user balance and provide adequate rehabilitation.
- To screen posture deviations and fall incidents by use of accelerated sensor to detect tilt of the user to enhance their safety.
- To facilitate live location tracking with the help of GPS modules in case of emergency.
- To enable timely medical aid and remote monitoring by sending instant communication and alerts to caregivers via GSM/Wi-Fi modules.

B. Contribution of the Work

- Creation of IoT-based smart crutch prototype which incorporates sensing, communication and surveillance capabilities within a conventional mobility aid.
- Real time fall detection and posture analysis system implemented, with a higher level of safety than traditional mechanical crutches.
- Incorporation of GPS-based emergency tracking, which will guarantee rapid response and location exchange in the event of emergency.
- Remote health monitoring functionality which enables the caregivers to monitor rehabilitation progresses effectively.
- Development of an affordable, compact, and usable healthcare mobility platform that can accommodate aging populations and physically handicapped patients.

The remaining portion of the document is divided into significant sections, which are described as follows: Section II examines the current research efforts in Design and Implementation of a Smart IOT-Enabled Axillary Crutch for Enhanced Mobility used by different authors. Section III explains the workflow of the suggested approach in Proposed Methodology. Section IV presents the findings analysis and performance data. Section V presents the conclusion.

II. LITERATURE SURVEY

Ganokratanaa et al. (2024) developed an intelligent IoT-powered ankle brace capable of enhancing the mobility and safety of individuals with lower-limb instability. The suggested system includes motion sensors to track ankle movement and detect abnormal gait patterns in real time. The communication modules are wireless and transmit the collected information to external monitoring systems, enabling remote monitoring and rehabilitation. The device provides real-time feedback once abnormal posture or instability is detected; it helps users position themselves appropriately and reduces the risk of injury. Their study indicates that the use of wearable IoT-based assistive devices can make any rehabilitation more efficient, improve safe ambulation, and enable continuous healthcare monitoring.

Samarasam et al. (2024) presented an IoT-based, self-reliant wheelchair to support mobility and health tracking for people with physical disabilities. The system has integrated in-built sensors to monitor movement conditions and chosen physiological parameters. Information captured by the sensors is wirelessly transferred for remote observation by caregivers. The wheelchair is also designed with safety features that ensure the user can navigate it easily and remain stable and comfortable. Their contribution to the field emphasizes the value of mobility support with real-time health tracking, demonstrating that IoT-driven solutions can greatly enhance the independence, safety, and quality of life of users with long-term mobility needs.

The authors also highlighted the use of smart assistive mobility (Samarasam et al., 2024) in their IoT-based wheelchair design, emphasizing helping a person remain autonomous while under constant supervision. The design incorporates communication components and monitoring sensors that provide real-time information on users' movements and the device's operation. Safety is improved through the system because timely responses to emergencies are enabled. Moreover, it facilitates rehabilitation surveillance by recording mobility data for analysis. Their practice demonstrates the efficiency of IoT technology in transforming traditional mobility aids into smart healthcare systems that enhance operational performance, enable remote access, and build user trust.

Abdullah (2023) developed Biofeedback Stick Technology to enhance the usability and safety of walking stick users. The system incorporates sensors that measure grip pressure, posture alignment, and walking dynamics. Real-time biofeedback gives users a warning when they are detected in improper posture or balance, reducing the risk of falling and strain on their muscles over time. The study aims to increase users' awareness and encourage safer walking habits by providing corrective feedback immediately. This paper demonstrates how sensor-based assistive technologies can facilitate recovery and enhance the overall quality of life for people using walking aids.

Resch et al. (2025) performed an extensive review of smart walking aids that combine sophisticated sensor technologies with gait analysis and health monitoring. The research involved systems that used accelerometers, pressure sensors, and wireless communication modules to identify falls, monitor postural changes, and track rehabilitative progress. The authors identified issues with cost, portability, and real-time responsiveness in the existing devices. Their results highlight the necessity to develop lightweight, cost-effective, and IoT-based assistive devices that improve user security in addition to providing an effective remote provider of healthcare monitoring and rehabilitation based on data.

The comparison table 1 indicates that the earlier studies primarily focus on motion measurement technologies such as accelerometers, wearable sensors, and IoT-based monitoring systems within connected health environments. These works emphasize sensor integration, data acquisition methods, and communication frameworks but are mainly review-oriented without proposing or experimentally validating a dedicated assistive hardware prototype. One study presents similar content in an alternative citation format, offering limited additional technical contribution. Another study explores the integration of Artificial Intelligence of Things (AIoT) in assistive technologies through a systematic literature review. However, it remains largely theoretical, with minimal discussion on real-time implementation, system validation, or practical device development.

Furthermore, a notable limitation observed across the surveyed literature is the absence of a comprehensive, patient-centric design approach that simultaneously addresses portability, energy efficiency, and real-time responsiveness in a single deployable system. While certain studies propose sensor fusion techniques or cloud-based data aggregation strategies, they often overlook the constraints imposed by real-world clinical environments, such as limited connectivity, patient mobility restrictions, and the need for continuous long-term monitoring. The lack of standardized evaluation benchmarks across these works also makes direct performance comparisons difficult, thereby hindering the identification of optimal design configurations. Consequently, there exists a clear and pressing need for an integrated assistive system that not only incorporates advanced sensing and communication capabilities but also undergoes rigorous experimental testing under conditions that closely replicate actual patient care scenarios. The present work aims to bridge this gap by proposing and validating a purpose-built prototype that meets these multifaceted requirements within a structured and reproducible experimental framework.

Table 1 Comparison table for Literature survey

Ref. No	Authors & Year	Technology Focus	Application Area	Methodology
11	Daponte et al., 2019	Motion measurement technologies (accelerometers, wearable sensors, IoT-based monitoring)	Connected Health, Smart Healthcare Systems	Review of motion sensing technologies in healthcare environments
12	Daponte et al., 2019	Motion measurement technologies (conference chapter citation format)	Connected Health	Literature-based analysis
13	De Freitas et al., 2022	Artificial Intelligence of Things (AIoT), Smart Assistive Systems	Assistive Technology, Rehabilitation Monitoring	Systematic Literature Review

III. PROPOSED METHODOLOGY

The method proposed in this research is the development of a Smart IoT-Linked Axillary Crutch with the ability to gather real-time data regarding safety and monitoring within rehabilitation therapy. Sensors that can be integrated into an aluminum crutch, including load sensors and an accelerometer, will continuously measure data regarding weight distribution during use of the crutch as well as posture and motion of the user. An Arduino Uno microcontroller, which processes the received data from the entire array of sensors and detects abnormal occurrences based on thresholds such as imbalance or falls, will be used. Once an emergency occurs, the device's GPS module will determine where the user is located, and notifications will be sent to the user's healthcare providers through the GSM or Wi-Fi module of the crutch. This allows quick response times to the emergency situation by those caring for the affected individual and provides for remote monitoring. A prototype of this device will be developed and utilized to demonstrate that it will be accurate, reliable, portable, and economically feasible for use in real-world healthcare contexts.

The architecture of the Smart IoT-Linked Axillary Crutch system comprises multiple integrated elements that function cohesively to ensure user safety and provide health monitoring. The ADXL accelerometer sensor, as a motion detection sensor, measures not only motion, but also how the user is leaning and falling. Moreover, the weight distribution over the crutch is monitored with load sensors. The weight and motion information from both the accelerometer and load sensors is sent continuously to the main controller, the Arduino Uno®. The Arduino Uno processes the data from the sensor input in real time. In case of emergencies, a GPS module is integrated into the system for real-time location tracking during times of emergency. In addition, the communication modules (GSM/Wi-Fi) are built into the system as a means of

transmitting alerts to the caregiver. Lastly, a motorized mechanism on the crutch allows for height adjustment, to create optimal comfort for the user. Collectively, the components of the Smart IoT-Linked Axillary Crutch system provide real-time health monitoring, emergency detection, and fast response times to assist with improved user mobility.

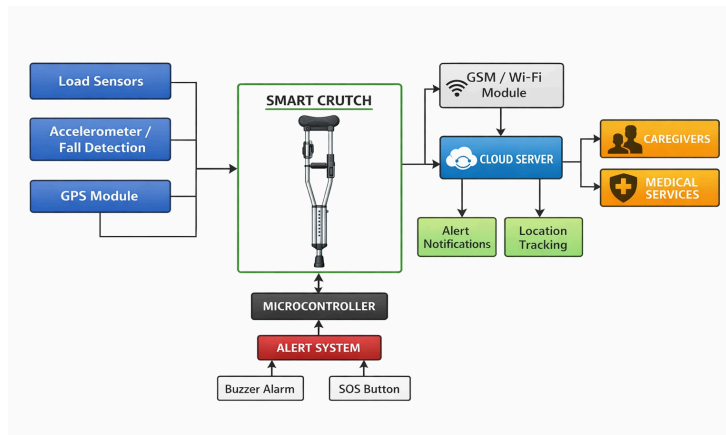


Fig.1 Proposed Overall Block Diagram

A.Data Acquisition

The process of acquiring data involves using various sensors to collect physical parameters as they occur in real-time, turning them into digital signals for further processing. In the proposed system, the first step in data acquisition is aided by an embedded sensor unit attached to an Arduino Uno in order to allow the ongoing monitoring of a user's movement, posture and weight distribution.

The system acquires data from two primary sensors:

Load Sensor:

The load sensor is used to measure the amount of force or weight applied on the crutch. It helps in analyzing the user’s balance and rehabilitation progress. The sensor converts mechanical force into an electrical signal, which is further amplified using an instrumentation amplifier before being processed by the microcontroller. The relationship between force and sensor output can be expressed as:

$$F = m \times g \tag{1}$$

Where F is force, m is mass, and g is gravitational acceleration. This data is useful for detecting uneven weight distribution, which may indicate improper usage or instability.

Accelerometer:

The accelerometer sensor (ADXL type) is used to measure acceleration along three axes (X, Y, Z). It detects tilt, motion, and sudden changes in orientation, which are essential for identifying falls or abnormal posture. The total acceleration can be calculated as:

$$A = \sqrt{X^2 + Y^2 + Z^2} \tag{2}$$

If the measured acceleration exceeds a predefined threshold, the system identifies it as a fall or sudden movement.

B. Data Processing using Arduino Uno

In the data processing phase, the sensor readings are processed and analyzed to identify deviations from normal operation. The core of the proposed system, the Arduino Uno, functions as the central processing unit. It continuously receives load sensor (via instrumentation amplifier) and accelerometer sensor signals from both sensors as input. The load and accelerometer signal are analog in nature. In order for the data to be analyzed and evaluated using pre-defined thresholds, the analog signals must be converted into digital values via an internal Analog to Digital Converter (ADC) built into the Arduino.



Fig.2. Arduino Uno Microcontroller Board

Arduino Uno is a microcontroller board that acts as a primary processing unit of the smart axillary crutch system. The board has a microcontroller chip, digital I/O pins, analog I/O pins, power supply ports, and communication ports. The analog pins are used to receive data from sensors and the digital pins are used to communicate with modules. The Arduino board processes data from incoming sensors, executes the instructions programmed into it, and controls the overall function of the system, providing important information for real-time monitoring and decision making.

C. Emergency Detection and Alert System

The Emergency Detection and Alert System of the Smart IoT linked Axillary Crutch is a critical feature for ensuring the user's safety during rehabilitation. This system performs continuous monitoring of data collected from the load sensor, accelerometer, and other sensors affixed to the crutch. The load sensor measures the weight distribution on the crutch, while the accelerometer detects sudden movements, tilts, or falls. The sensor readings are sent to the Arduino Uno microcontroller, and each reading is analyzed using pre-determined threshold values. When the system detects an unusual occurrence based on the sensor readings (i.e., weight distribution is uneven, or the accelerometer indicates a sudden impact), the system will classify it as an emergency. When the system detects an emergency situation, the Emergency Detection and Alert System will activate the alert mechanism. Once activated, the GPS module will provide the real-time location of the user and the GSM or Wi-Fi module will send an alert message and location information to registered caregivers and/or healthcare providers. Rapid notification ensures a rapid response to minimize further injury and to obtain timely medical assistance.

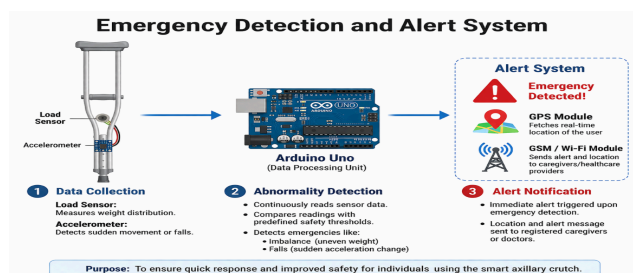


Fig.3. Emergency Detection and Alert System of Smart Axillary Crutch

The following figure displays the working of the smart axillary crutch's integrated emergency detection and alert system. It shows where there are sensors, including a load sensor and an accelerometer, on the crutch. These sensors continuously collect data (movement and weight distribution) about the user. Once collected, that data is sent to an Arduino Uno microcontroller that serves as the main processing unit. When there is an abnormal condition detected, the system sends out an alert signal, as shown by the warning indicator in the figure. The alert is then sent via GSM or Wi-Fi modules from the crutch to the user's mobile phone and to their healthcare provider; the GPS module provides real time location of the user. Through the process outlined in the diagram, you can see how the crutch collects data and sends a notification to emergency personnel, thus providing safety for the user with live monitoring and quick response time.

D. Location Tracking System

The location tracking system in the smart IoT-linked axillary crutch uses a GPS module to determine the real-time position of the user. The GPS module receives signals from multiple satellites and calculates the user's exact latitude and longitude using triangulation. This location data is then transmitted to the Arduino Uno microcontroller, which processes and forwards it through the GSM or Wi-Fi module. In case of an emergency, the system sends the user's location to caregivers or healthcare providers, enabling quick assistance and improving safety during rehabilitation.

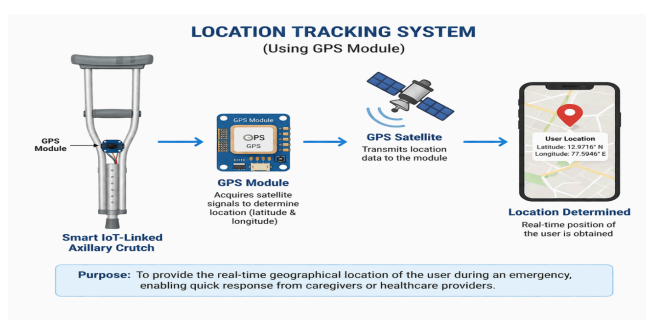


Fig.4. Location Tracking System Using GPS

In the figure above is illustrated how the location tracking system is able to function when integrated into this smart crutch. The GPS module has been added to the crutch, which allows it to receive signals from satellites (via GPS), and ultimately determine the location of the user of that crutch based on the location coordinates calculated using information received from the GPS satellites. The location coordinates are then displayed on a mobile device, showing the real-time position of the user of that crutch, providing accurate and timely tracking of the user of that crutch by way of the satellite to the location identification.

IV. RESULTS AND DISCUSSION

Improvements made in Smart IoT-Linked Axillary Crutch over other mobility aids include the addition of sensors for real-time monitoring and The developed prototype exhibited excellent efficiency in terms of its ability to monitor the activities of the user and detect any irregularities. Load sensors performed efficiently in determining weight distribution, while the accelerometer efficiently detected any tilting and falls by the user. The microcontroller processed all the data obtained from the sensors without any delay. It was easy to locate the location of the user using GPS sensors and sending of SMS alerts through GSM/Wi-Fi sensors was successful.



Fig.5.Load Sensor Data Monitoring of Smart Crutch

The following is the graph shown on the figure 5 of the real-time load measurement obtained from the load sensor present in the smart axillary crutch. As seen from the graph below, there are variations in the weights recorded at different intervals. The slight variation in weight shown in the graph represents the natural movement of the person using the crutch when moving or standing. The value currently indicated (32.5 kg) represents the most recent value. Recording such data is helpful in rehabilitation processes since one can detect cases of imbalanced weight load.

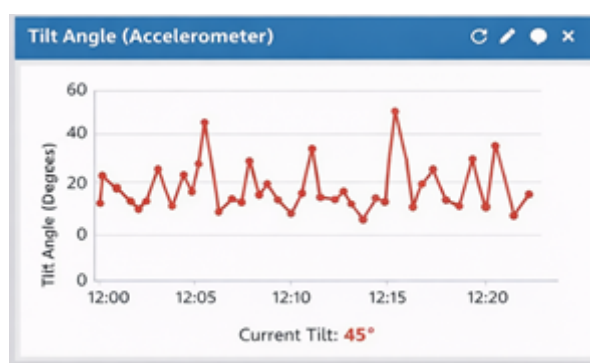


Fig.6.Tilt Angle Monitoring Using Accelerometer

The figure 6 shows the real-time angle of tilt of the smart axillary crutch with the use of the accelerometer sensor. The plot shows variation in angle of tilt on the y-axis in degrees with respect to time and shows the posture and movement pattern of the user. Peaks shown in the plot are due to sudden change in posture. The current angle of tilt (45°) is shown above the graph. Monitoring angle of tilt is very important for detecting abnormal conditions and providing timely alerts to prevent accidents.

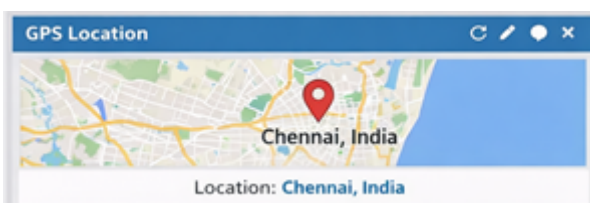


Fig.7.Real-Time GPS Location Tracking of Smart Crutch

Figure 7 depicts the live location tracking function of the smart IoT-enabled axillary crutch. It shows a map-based interface that highlights the user's present location, which is located in Chennai, India. The device continuously captures the location details via its embedded GPS chip and updates them on the interface for effective monitoring. This data can be communicated to the caregiver or any medical facility in

emergency situations. Location details allow quick detection of the user's whereabouts and provide timely help when needed. This feature greatly improves user safety, particularly for senior citizens and people with physical limitations.

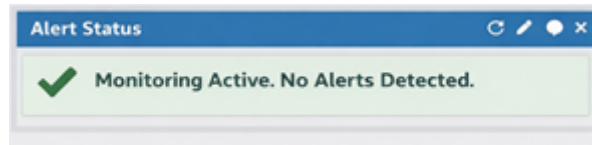


Fig.8. Alert Status Monitoring Interface of Smart Crutch

Figure 8 demonstrates the alert status display screen of the smart IoT-enabled axillary crutch device, demonstrating the fact that the monitoring is taking place and there are no alerts generated. Thus, it can be concluded that all the sensor readings are within their permissible values; otherwise, the status screen would have raised an alarm or triggered an alert. The software of the system monitors real-time data to detect anomalies like falls or imbalance issues. If no such instances arise, then it is ensured by maintaining the normal status on the screen.

V. CONCLUSION

The Smart IoT-Connected Axillary Crutch will improve upon the existing devices through the use of advanced technology such as sensors, continuous monitoring, and emergency services. Sensors that measure load and acceleration are incorporated to detect abnormalities in weight distribution, balance, and potential falls. The information is continuously processed using the microcontroller to detect any anomalies. Real-time monitoring is enabled through the use of GPS and GSM/Wi-Fi modules to determine the location of the user and notify the caregiver in case of any emergencies. The prototype is found to be light and easy to carry, as well as affordable for real-life applications. In the future, machine learning models could be employed to anticipate potential falls and monitor rehabilitation outcomes. Health sensors such as heart rate and SpO₂ monitors can also be integrated to provide comprehensive monitoring of the user's health status.

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