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Internet of Things-enabled smart robotic baggage monitoring and tracking system for enhanced traveler convenience and security

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ABSTRACT

Baggage travel is a significant issue, causing inconveniences and financial losses for travellers. The rise in efficient international and domestic travel has led to the need for live baggage tracking systems. Traditional methods, such as manual tracking and locks, are inefficient and counterproductive due to power limitations. IoT has revolutionized baggage management by providing real-time tracking feedback and enhancing security. IoT-enhanced smart luggage systems use biometric locks, GPS tracking, and smart locking mechanisms to prevent theft and unauthorized usage. Geofencing allows users to draw boundaries for luggage, and smart luggage systems can adapt to airport security requirements. Some smart suitcases also have self-following features, allowing travellers to have better control over their bags. IoT-enabled baggage solutions also improve airport and travel centre efficiency. RFID and barcode identification devices enable airline employees to quickly recognize, monitor, and manage luggage, reducing waiting times and loss risks. Cloud-based systems allow users to remember their luggage and receive travel suggestions based on predicted frequency of use. IoT-enabled baggage management systems have the potential to transform airport ecosystems into smarter ones through automated tracking with minimal human involvement and errors. AI and machine learning can also proactively address concerns and improve the overall customer journey.

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1. INTRODUCTION

Luggage design changes have made it easy to transport, but vulnerable to theft. Modern smart life demands better design to address issues like baggage clearance in airports and other transportation means, also [1]. The Smart IoT Bag is a smart innovation that uses IoT functions to enhance comfort, safety, and user experience. It features sensors and connectivity modules to monitor and record real-time information about surroundings and stored objects, providing a safe and efficient way to manage and monitor baggage [2]. Misplaced, stolen, or damaged luggage is a major concern in the aviation and transport sector. To address this, smart bag tracking systems using IoT technology are being developed, combining GSM, GPS modules, and Arduino microcontrollers to monitor bag location, reducing the risk of loss or theft [3]. Smart innovation in smart suitcases includes location monitoring, security through touch identification and alphanumeric code locking mechanisms, IoT tracking for law enforcement, and biometric identification, making it more secure than typical baggage articles and impractical for unauthorized use [4]. Raspberry Pi-integrated bag tracking systems offer real-time baggage monitoring, allowing travellers to monitor their bags from anywhere, promoting safety and expediting travel by providing visual images or videos of the bag's location [5].

IoT-enabled transport technologies are transforming driving habits by assessing drivers' behaviours, providing timely advice, understanding driving patterns, and enabling automated driver assistance and smart mobility technologies [6]. The Internet has revolutionized everyday life, enabling easy connectivity between devices. The aviation industry, particularly in the area of the Internet of Things, can greatly benefit from this technology, reducing issues like delayed and lost luggage [7]. In 2018, $1.25 billion worth of airline luggage disappeared, highlighting the need for improved baggage tracking systems. The incidents included 77% delayed, 18% damaged, and 5% lost unrecovered baggage [8]. Smart tracking systems, integrating ZigBee and GSM modems, are crucial for travellers and disabled individuals. These wireless security systems monitor luggage efficiently and cost-effectively, using a multi-use wireless network and GSM communication structures to expand coverage and enhance tracking [9]. A sensor-based observation system has been developed to address security risks and manage luggage safety in travel. The system, consisting of sensor nodes, local and central controls, tracks world changes and provides instant information, enhancing travel security and aiding in disaster management [10]. People are increasingly adopting smarter, faster options due to emerging technologies like IoT-based vehicle tracking systems for modern lifestyles [11]. Transportation sectors face common issues like missing baggage, loss, and damage. To combat these, a system with a GSM/GPS module and an Arduino microcontroller is designed. The system provides real-time tracking of luggage locations, allowing passengers to see their baggage's location from anywhere. Implementing this IoT-based device can reduce stress and improve safety for passengers [12]. The paper introduces an IoT-integrated robotic baggage tracking system that improves travellers' convenience and security. It suggests integrating AI-driven autonomous navigation, path planning algorithms, computer vision, and LiDAR or depth cameras for improved obstacle detection and movement. The contribution of the study is i) to design a smart robotic system that is integrated with IoT technologies, real-time tracking, and efficient handling of the baggage; ii) to enhance the security, accuracy, and efficiency of the baggage handling with IoT devices (RFID, GPS, and sensors) for continuous monitoring and tracking; and iii) to enhance the experience of the passengers by providing real-time tracking and updates through user-friendly interfaces and notifications.

The structure of the manuscript is as follows. Section 2 provides a review of the literature. Sections 3 and 4 cover the block diagram and hardware development. The system's real-time implementation is provided under Section 5, and Section 6 provides the conclusion.

2. REVIEW OF LITERATURE

The Internet of Things (IoT) is revolutionizing management and monitoring through active population surveillance. These devices notify users via mobile when a population exceeds a certain threshold, particularly beneficial in rural areas with limited supervision. This allows for proactive measures, ensuring safety and improved performance [13]. The integration of multi-sensor IoT systems in retail is enhancing security, as the shift from manual to technology-based management systems continues [14]. Landslides in India cause property loss and fatalities. Current systems are expensive, inaccurate, and lack real-time characteristics. Challenges include time duration, slip surface depth, recurrence, sensor durability, and spatial coverage uncertainty [15]. IoT monitoring is being used for landslide detection and prevention, enhancing operational reliability and responsiveness to user requirements. Sensor-based systems monitor terrain stability, providing advanced warnings to prevent risks during heavy rains, thereby reducing infrastructure damage and cost [16]. Artificial intelligence (AI) is revolutionizing digital marketing by optimizing sales and predicting consumer behaviour. AI-driven recommendations, targeted advertisements, and automated customer engagement tools improve business efficiency and user experience. As AI advances, these developments become more efficient and cost-effective [17]. AI is revolutionizing various sectors, particularly digital marketing, with its advancements reshaping the landscape and impacting businesses' digital outreach strategies [18]. Contactless travel requires effective luggage security, using long short-term memory (LSTM) networks and IoT technologies with cloud-enabled security measures. These technologies enable real-time monitoring, anomaly detection, and data analysis, reducing loss, theft, and tampering. Cloud infrastructure improves security system scalability and dependability, while IoT and LSTM networks provide flexible security architecture [19].

IoT technology faces challenges in processing power and data security due to limited storage and computational power. Traditional cryptographic methods are impractical for IoT applications. Lightweight security methods are needed for real-time solutions without compromising system performance [20]. Smart parking systems integrate IoT cloud information, improving ownership costs and system usability. They control and allocate empty spaces, alleviating traffic congestion, and support scalability and rapid data processing, making them part of smart city infrastructure [21]. An IoT-based hyper-connected society manages resources in real-time, controlling luggage through RFID tags at airports. However, air-baggage tracking service is lacking, causing long wait times [22]. Lost baggage is a common concern among passengers, with around 5% of luggage lost due to increased air traffic. IoT-based baggage tracking systems offer real-time tracking using phones and GPS, making it affordable and user-friendly, reducing anxiety and improving the entire travel process [23]. Advancements in technology have transformed traditional baggage systems into smart ones, offering enhanced security and convenience. IoT-based tracking systems, biometric access, and cloud data management enhance user experience, making travel safer and more efficient in crowded environments [24]. IoT-enabled transport technologies are transforming driving habits through remote monitoring systems. These systems assess drivers' behaviours, preventing accidents and improving road safety. They offer timely advice, understanding driving patterns, and enable automated driver assistance and smart mobility technologies [25].

3. METHODS

The IoT-Enabled Robotic Trolley for Baggage Tracking and Monitoring is envisioned as a cohesive system with diverse components working in synchrony so as to render monitoring, tracking, and security in real-time. The interconnection of an array of sensors, modules, and actuators governed by the central microcontroller is well demonstrated in Figure 1, which ensures flawless operation and communication of data. The primary element in the system is the ESP32 microcontroller, which is fundamentally a CPU. It is responsible for data accumulation and its breakout from the diverse sensors and modules. It also provides a wireless connection to the cloud platform using Wi-Fi or GSM. The ESP32 microcontroller is a strong solution for managing robotic movement and sensor data, using IoT components like RFID, GPS, and accelerometers. However, possible security risks like location spoofing and signal interception need to be addressed. Implementing encryption and authentication using blockchain could improve the security of data. Battery life estimation, energy consumption analysis, and network scalability assessment are important for performance in high-traffic environments. Additionally, the ESP32 controls motor functions as well as enables the communication between the various hardware components so that it is possible to integrate all these components effectively. One of the unique functionalities of the microcontroller is the ability to log data and have that data forwarded to the user in real-time through remote monitoring using the Blynk mobile application. The DHT11 sensor is responsible for the monitoring of the environmental conditions, like temperature and humidity, surrounding the trolley and its payload.

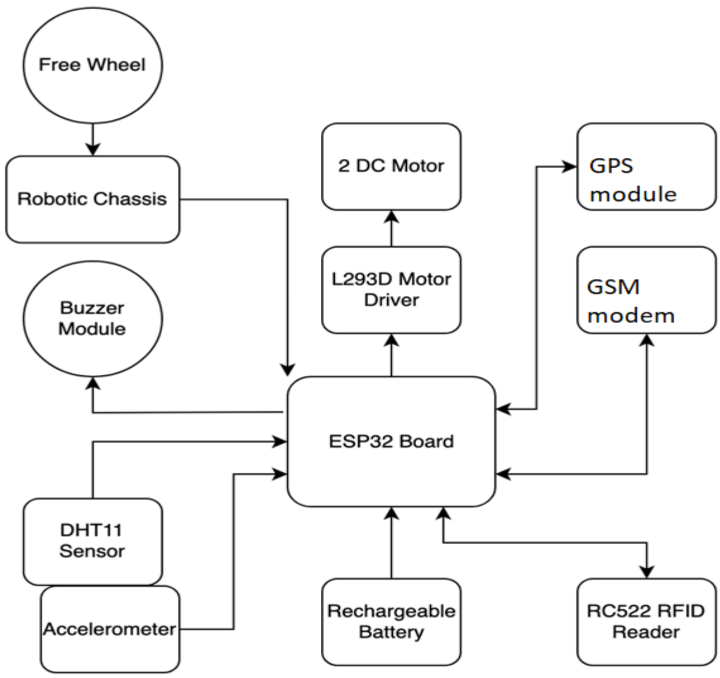

Figure 1. Block diagram of the system

This information is helpful to the end user, together with the IoT interface, because it ensures that the baggage is kept under proper conditions. In the same manner, an accelerometer serves a vital purpose in monitoring activities, such as movements or tremors that may result from attempts to alterations or wrongful use. Such data is gathered, analysed, and provided to the user instantaneously in order to maximize security. The GSM modem, together with the GPS module, allows for simultaneous placement of real-time calls and calls for the location of the trolley. While the GPS module pinpoints the current position of the trolley, the GSM modem sends the information to the cloud, where the user is assured of receiving the data. These modules guarantee that the trolley can be located at any given place, including places that do not have wireless internet coverage. To enhance system security, a user can authorize or restrict access through the use of RFID tags or cards by interfacing with the RC522 RFID reader connected to the system's trolley. With this feature, one is sure that the personnel authorized to interact with the baggage are the only ones with access to the baggage compartment. The buzzer module is also helpful as it works in conjunction with other sensors to provide audible alerts the moment tampering or unauthorized access is detected. The movement of the trolley is powered by two DC motors, which are controlled by an L293D motor driver. An ESP32 is responsible for sending commands to the motor driver, which in turn instructs the trolley to move in the required direction. The final design for the motors, free wheel, and robotic chassis allows the trolley to move and perform independently. Such a design guarantees that the movement of the trolley can be smooth and automated with little regard to the previous environment. Finally, all other components are powered by a rechargeable battery, which provides ample energy for operation, making the design range from self-contained to a minimum dependence on power sources. This battery makes it possible to move the trolley without being restricted to designated power outlets, making it ideal in environments such as airports, train stations, and other travel stations. This block diagram depicts the arranged order of a system where every part of the system has a specific purpose in achieving an intelligent, automated, and secure baggage monitoring architecture. The incorporation of IoT technologies, sensors, motors, and communication modules guarantees that the trolley offers improved convenience and safety for travellers.

The hardware connections for this innovation have the following elements, as shown in Figure 2. The ESP32 Board acts as the main controller that receives input from different sensors and modules and interfaces with the GSM modem as well as the GPS module. The respective modules are powered by the USB connection that also aids in programming the ESP32, owing to LiPo battery connectivity to ensure the ESP32 remains powered. The power and ground lines of the ESP32 are distributed on the breadboard so that other components can receive sufficient power.

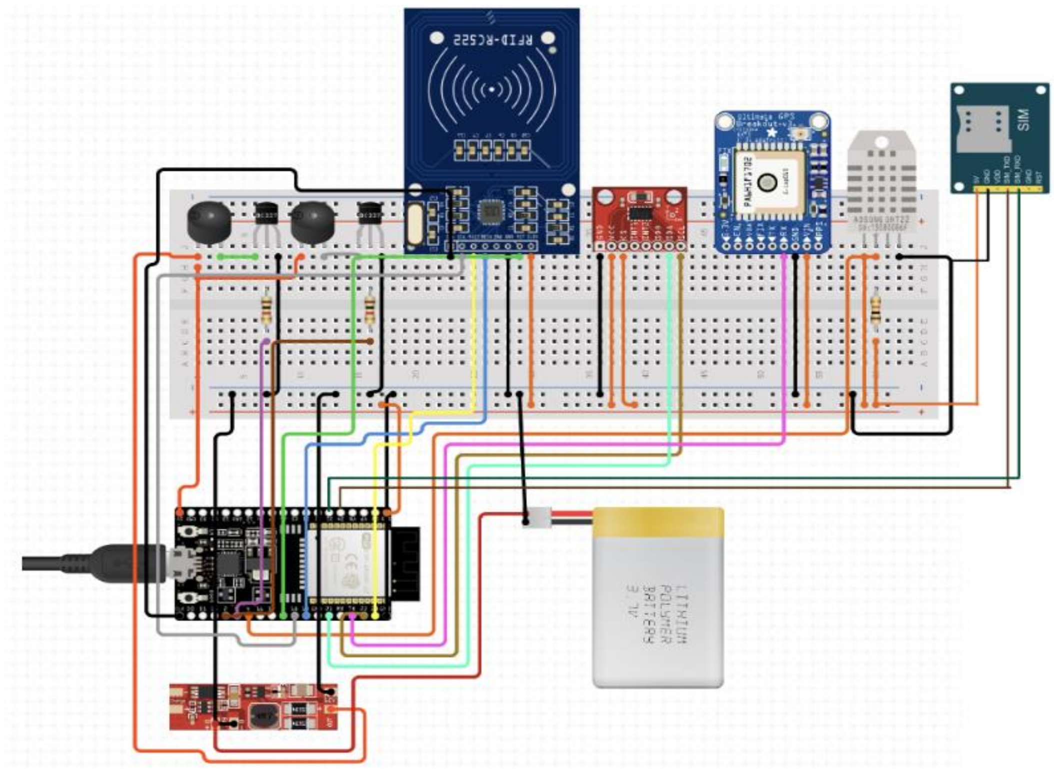

Figure 2. Connection diagram of the system

The modem does require additional power, which can be fueled at the same time as the connection to the ESP32. The GSM modem serves the purpose of cellular communication and interfaces to the ESP32 using software serial communications. The GSM modem TX (transmit) pin connects to ESP32 GPIO 34, and its RX (receive) pin connects to GPIO 35. Hence, the GSM modem can now send and receive messages such as SMS or data packets. The modem VCC pin gets powered from the 5V line set on the breadboard, whereas the modem GND pin connects to the common ground. The DHT11 Sensor is connected to the ESP32 to monitor temperature and humidity. The VCC pin of the DHT11 is connected to the 3.3V pin of the ESP32 for power, and the GND pin is connected to the ground line on the breadboard. The DHT11's Data pin has been hooked up to GPIO 27 of the ESP32 to transmit digital temperature and humidity readings. The motion or tilt monitoring feature is supplemented with an Accelerometer. Its VCC pin is connected to the 3.3V supply line, and its GND pin is connected to the breadboard's ground line. The SCL and SDA pins of the accelerometer are connected to the ESP32's GPIO 22 (SCL) and GPIO 21 (SDA) pins. This configuration enables the accelerometer to transmit motion or acceleration information to the ESP32 via the I2C protocol. For reading RFID cards or any other tags, use the RC522 RFID Reader. The VCC pin of the RFID module is connected to the 3.3V pin of the ESP32, whilst the GND pin is wired to the common ground. The RFID reader is connected to the ESP32 through SPI communication. SDA, SCK, MOSI, and MISO pins are attached to GPIO 5, GPIO 18, GPIO 23, and GPIO 19 of the ESP32, respectively. This configuration allows the ESP32 to obtain the RFID data and subsequently use it for identification. The location parameters, such as latitude and longitude, are fed into the system by the GPS Module, which is directly connected to the network. The 3.3V pin on the ESP32 is used to power the VCC pin, while the GND pin is connected to the ground of the breadboard. The GPS module operates on the TX pin, which is connected to the GPIO 16 (RX) pin of the ESP32. Directly connected to the ESP32 core, the GPS module will begin transmitting the data for the location retrieved from external sources. To facilitate the positioning of the system, the Circular Buzzer Modules seen on the breadboard can also be used, as they generate sound. The 3.3 V pin of the buzzers is also connected to the power line of the ESP32, and their GND pins are connected to the common ground. The control pins of the buzzers are wired to GPIO 26 and GPIO 25 of the ESP32. These buzzers can be activated by employing a HIGH signal from the respective control pins when specific conditions are fulfilled (e.g., RFID is detected, motion is alerted, and temperature is exceeded).

Algorithm 1. Combined algorithm for anomaly detection using LSTM
Start
- Step 1. Load the baggage movement dataset and environmental data (e.g., IoT sensors, CSV, database).
- Step 2. Preprocess datasets by removing missing or corrupted data, normalizing numerical features like velocity, position, temperature, and humidity, and combining movement and environmental data if necessary.
- Step 3. Define features (X) and target (Y):
  - a. X = {velocity x, velocity y, velocity z, position x, position y, position z, temperature, humidity}
  - b. Y = {Anomaly Label} (1 = Anomaly, 0 = Normal)
- Step 4. Create sequences from the time-series data using a sliding window approach:
  - a. For each dataset, create sequences of fixed length (e.g., 50-time steps).
  - b. Reshape the data to fit the LSTM input format (samples, timesteps, features).
- Step 5. Split the dataset into training (80%) and testing (20%) sets.
- Step 6. Initialize the LSTM model:
  - a. Add LSTM layers to capture temporal dependencies.
  - b. Add a dense layer for classification (normal or anomaly).
  - c. Compile the model using binary cross-entropy loss and accuracy as the evaluation metric.
- Step 7. Train the LSTM model on the training dataset:
  - a. Fit the model with the training sequences.
  - b. Monitor the loss and accuracy during training.
- Step 8. Test the trained model on the testing dataset.
- Step 9. Evaluate model performance:
  - a. Compute accuracy, precision, recall, and F1-score for both baggage movement anomalies and environmental change anomalies.
- Step 10. Deploy the model for real-time anomaly detection:
  - a. WHILE real-time monitoring is active:
  - i. Collect real-time sensor data (baggage movement, velocity, position, temperature, humidity).
  - ii. Create real-time sequences of sensor data.
  - iii. Use the trained model to predict anomalies: - Anomaly = model predict (real-time data)

iv. IF predicted anomaly = 1: - Alert: "Suspicious activity detected!" or "Environmental change detected!"
b. Repeat the monitoring process continuously.
End

4. RESULTS AND DISCUSSION

The IoT-Enabled Robotic Baggage Tracker Trolley is a holistic platform that aims to improve security and monitoring, tracking of a trolley in real time, and providing the maximum comfort that every traveller requires. It is designed around the idea of deploying IoT systems, sensors, actuators, communication modules, and other systems in such a manner that makes the trolley intelligent and easy to use. The paragraph below is a more detailed explanation of how it operates. The system starts working after it is activated. All systems are powered using energy from a rechargeable battery. The first step in the process is where the ESP32 microcontroller turns on all the required hardware and connects to the necessary networks. Upon the presence of Wi-Fi, the ESP32 will search for the appropriate access point to join for data transmission and reception. Wi-Fi areas that are not well covered are serviced by an activated GSM modem for cellular data transmission. This mode of operation allows for both connections to be maintained at all times. These systems enable the user's mobile phone to send and receive information from the device using the Blynk platform. The DHT11 sensor is tasked with monitoring temperature and humidity around the trolley to ensure the baggage is stored under set limits. The monitoring and sending of the signals to the cloud occur in real-time and are done via the ESP32. The accelerometer, on the other hand, notices movements, shaking, or any sudden changes to the device. If something out of the ordinary occurs, like a lot of shaking or motion, it sets off a security alert meant for the user, which increases the complexity of security breaches. The receivers furnish a location in coordinates, which is sent to the device at regular intervals. The microcontroller receives it, processes it, and then uploads it to the cloud through Wi-Fi or the GSM modem. The user's mobile application or software displays the location data so that the user can monitor their luggage wherever they travel. The assured effectiveness of this feature is that the luggage can be traced at any point, regardless of the location or distance from the rest of the people. Figure 3 shows the robot platform used for baggage handling and tracking.

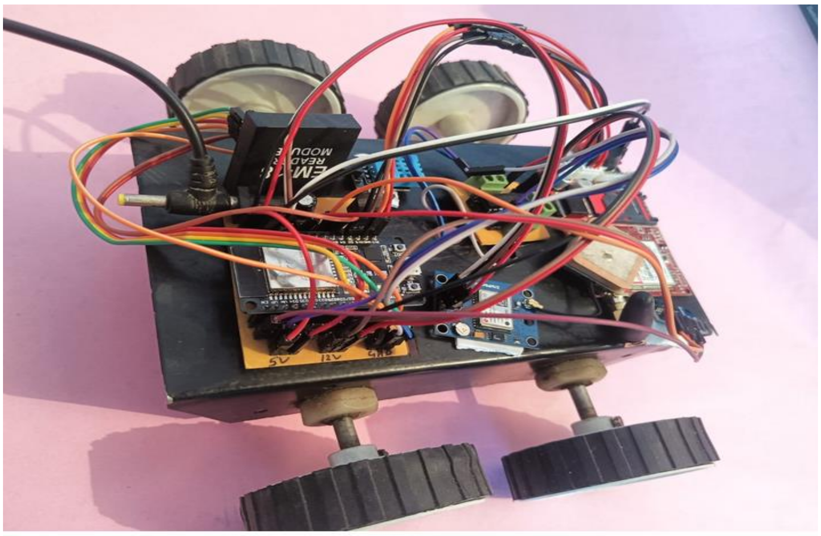

Figure 3. Robot platform for baggage handling and tracking

To improve safety, the system utilizes an RC522 RFID reader, which prevents unauthorized users from accessing or operating the trolley, as only registered RFID tags or cards can unlock it. Interactions are granted after the system scans an authorized card and validates the credentials. Any unauthorized attempt would trigger the system buzzer module, which emits an audible sound for a set amount of time to deter tampering and notify authorized personnel nearby. The movement of the trolley is aided by two DC motors with an L293D motor driver. The ESP32 receives commands in the form of user inputs or present commands and sends them to the motor driver. As the motors move the trolley, a free wheel mounted to the chassis aids in stability and ensures smooth movement. The system is capable of further use, as it can be programmed for autonomous navigation using inputs from external sensors or pre-defined user paths. The Blynk mobile application allows users real-time access to sensor readings, location server updates, and security event logs. Figure 4 shows the web dashboard of the Blynk cloud server used for the system.

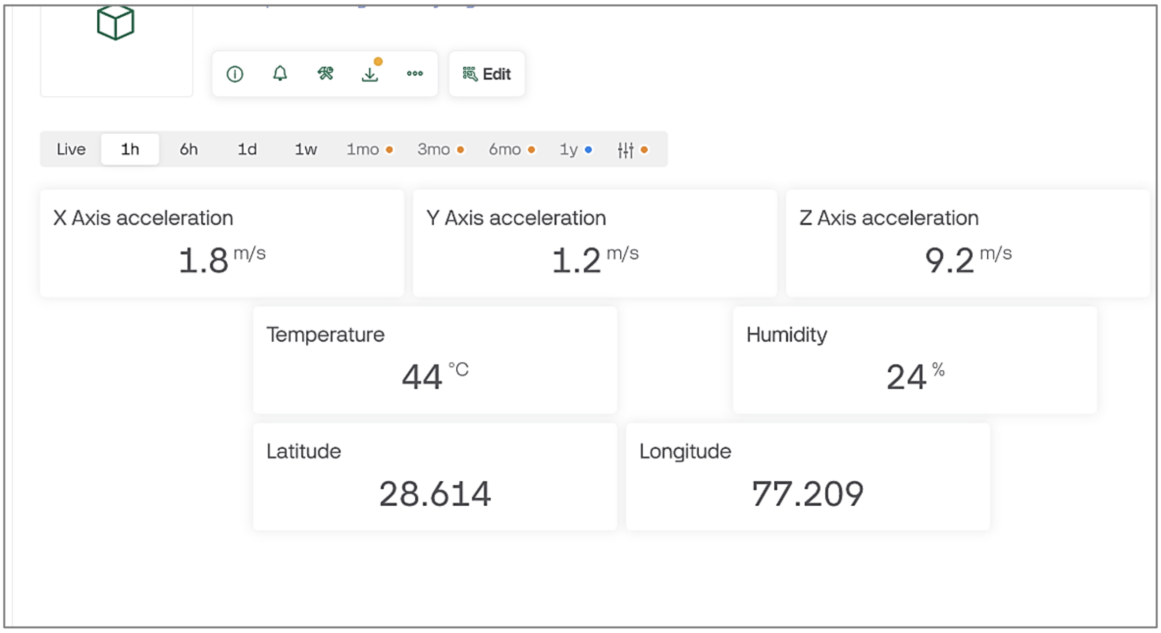

Figure 4. The web dashboard of Blynk cloud server used for this system

This feature aids the user by letting them track the status of their baggage. Likewise, alerts are generated for critical events like temperature and humidity surpassing customizable values, attempts to hack passwords, or unanticipated impacts are detected by the accelerometer. These alerts allow the user to always remain ready and act when required. In other words, the IoT-enabled robotic Baggage Tracker Trolley is equipped with a combination of IoT, robotics, and smart sensors, which makes the process of dealing with personal property more effective and safer. The system overcomes some of the issues that come with modern-day traveling by offering instant surveillance, tracking that is accurate, and dependable protection. It is not less than an innovation in smart travel technology because it brings additional comfort and security to the traveller's experience. Table 1 shows a comparative table of the existing smart baggage tracking systems like Bluesmart, Travelmate Robotics, or Samsonite Track & Go.

As an all-in-one mobile app solution, Blynk is responsible for remotely controlling and monitoring the IoT-enabled Robotic Baggage Tracker Trolley. Users are able to access real-time data from the system's sensors and modules easily and clearly with the stylish design of this application. This means that crucial information pertaining to the environmental situation, accelerometer readings, and GPS coordinates is readily available at a moment's notice. The widgets' Gauges are used to display data from the DHT11 sensors that measure the temperature and humidity. These gauges provide a dynamic overview of the parameters that surround the trolley. The insulated circular shape of the gauge is visually appealing and allows for the practicality of highlighting extreme values, increases in temperature, and decreases or increases in humidity. This informs the user of potentially dangerous conditions for sensitive items within the luggage. Like the other widgets, the Gauge widgets utilize green and red indicators for normal and extreme levels, respectively. This makes it easier for users to understand the environmental conditions without performing a detailed analysis. The Label widgets within the app also display the accelerometer or g device readings. These values contain information regarding the trolley's movement and orientation. For example, the aforementioned app can display the accelerometer's readings of whether the trolley is stationary, in a state of vigorous movement, or some form of abnormal shaking, which may suggest that the trolley is being tampered with or mishandled. The values of the three axes of the accelerometer, namely, X, Y, and Z, can each be read off as separate labels. This enables users to receive up-to-the-minute motion details, which can be helpful to track how the baggage is secured and handled while in transit. Using Label widgets to display the GPS coordinates also allows them to receive real-time location updates. As the trolley shifts positions, the label modules are able to change their coordinates, and users can tell where the trolley is positioned. In order to make this information more accessible, the app can integrate a map service that allows users to track the trolley's movements on a map. This particular function contains great value for the customers since it aids in relieving worry because they are assured that even in new places or crowded areas, the trolley can be found. Also, the Blynk application enables users to track several aspects of the trolley at a single glance as it organizes the information into dedicated widgets. These attributes improve user experience as the separation of information into motion and location labels and their gauges for environmental data makes the system simple, yet efficient. The combination of the hardware and software is indicative of how IoT technologies can bolster contemporary solutions and highlights the purpose of this project.

Table 1. Comparative table of the existing smart baggage tracking systems

Feature	Proposed System	Bluesmart	Travelmate Robotics	Samsonite Track & Go
Real-Time Tracking	Yes (GPS, RFID, GSM, Wi-Fi)	Yes (GPS, Bluetooth)	Yes (GPS, Wi-Fi)	Yes (GPS, Bluetooth)
Security Features	RFID for access control, GSM/Wi-Fi for notifications	Password protection, Bluetooth connection	App-based security, Bluetooth connection	Bluetooth security, app-based tracking
Autonomous Movement	Yes (Robotic trolley with simple sensors)	No (Manual control)	Yes (Self-driving robot)	No (Manual control)
AI-driven Navigation	No (Basic sensor-based movement)	No	No (Manual path control)	No
Obstacle Detection	No AI model for abnormal movement patterns	No	No	No
Path Planning Algorithms	Not implemented	Not implemented	Not implemented	Not implemented
Obstacle Avoidance	Simple sensor-based detection	Not available	Not available	Not available
Data Encryption	Not specified	Yes (Encryption for data transfer)	Yes (Encryption for data transfer)	Yes (Encryption for data transfer)
Battery Life	Not specified	3-5 days on a single charge	4-6 hours of battery life	5-7 days on a single charge
Integration with Mobile App	Yes (Notifications, tracking, and control)	Yes	Yes	Yes
Price	Not specified	$299	$799	$299
Web Link	N/A	Bluesmart		

5. CONCLUSION

The IoT-enabled robotic baggage tracker trolley has significantly improved the passenger experience by addressing issues of lost or damaged luggage. The system's design combines IoT and robotic systems for constant surveillance and efficient monitoring. The trolley accurately captures surrounding conditions, determines its position, and controls access to sensitive areas. The GPS module updates the location in real-time, minimizing user delays. The DHT11 sensor and accelerometer provide data critical for determining motion and environmental conditions. The Blynk mobile application sends notifications and alerts throughout the day, allowing users to act while problems like unauthorized tampering are ongoing. The trolley's autonomous movement facilitates easy movement in spaces, making it a step forward in smart travel technologies. The technology can be used in various industries, including logistics and airport baggage handling. Future improvements include the application of AI and machine learning algorithms, voice recognition, and solar-power charging. The IoT-enabled trolley could also be used in airports, train stations, and the logistics sector to facilitate efficient baggage movement. Integration with existing airport infrastructure and supply chain management could further enhance the trolley's functionality.

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No funding was received for conducting this study.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest relevant to this study.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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