International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
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Peer Reviewed, Referred & Indexed Journal

Research Paper

IoT-Based Real-Time Tracking System Using GPS and ThingSpeak

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***Abstract*— Theft of vehicles, suboptimal fleet operations, and late response to emergencies have resulted in an increasing demand for affordable, reliable and real-time vehicle tracking solutions. The design and development of an IoT implementation for tracking the movement of a vehicle using a NEO-6M GPS receiver, ESP32 microcontroller and ThingSpeak cloud platform is discussed in this paper. The GPS module reads the signals from the satellites to get locations, speed and time information for the vehicle. The ESP32 is used to communicate with the ThingSpeak cloud using Wi-Fi and to process the received NMEA data to extract the various parameters, and GSM communication is treated as a backup. The cloud platform can be used to monitor in real-time, display position maps, graphical representation, and visualise the data in the past, making it easier and quicker to manage vehicles. The suggested architecture is meant to be affordable, simple and scalable using easily accessible hardware components and cloud-based services.**

The prototype was tested in open sky conditions and was found to successfully acquire a first GPS position fix within 30-60 seconds of power on and to successfully upload location information every 10-15 seconds. The positional error observed was typically 3-5 m from the reference places, consistent with a performance range typical of similar low cost GPS devices. The performance assessment includes positioning accuracy, acquisition time, transmission reliability and update frequency; however, the number of test runs, mean error, standard deviation and the transmission-reliability percentage need to be reported quantitatively. The technology designed may be utilized for vehicle safety, fleet administration, logistics and personal safety. Offline data logging and geofencing-based warnings are planned features and will further enhance tracking reliability and intelligent monitoring functionality.

"Keywords— Internet of Things, GPS, ESP32, ThingSpeak, real-time tracking, vehicle monitoring."

I. INTRODUCTION

GPS is a navigational system based on satellites which provides accurate position, velocity and precise time information to receivers that can receive and process the satellite signals. It is now an essential technology for navigation, transport, security, surveying and location-based applications. In recent years, the technology of communication has become more and more advanced, and GPS has evolved from an application that navigates a driver from point A to point B to being part of the IoT system of monitoring. The Internet of Things is a network of smart gadgets that are connected to each other and that gather, share and process data over communication networks. In conjunction with GPS, the Internet of Things can provide real-time remote tracking and monitoring of vehicles, devices and personnel. A typical IoT based tracking architecture is comprised of a GPS receiver, microcontroller, communication module, cloud storage platform and user interface or dashboard. The components are used to collect geographical information, manipulate location data, upload it to a remote server and deliver it in real-time to authorised users. These systems can significantly improve the security of a vehicle, its efficiency, resource utilisation, transportation management and emergency response.

Arduino and NodeMCU development boards were widely used in previous studies for designing a vehicle tracking system using GPS and GSM. These systems typically comprise GPS receivers with wireless communication

technologies to deliver geographic information to users through SMS, GPRS or cloud-based platforms. Paing et al. developed a low cost vehicle theft prevention system that will send an SMS alarm if the vehicle crosses a certain threshold and uploads tracking information to ThingSpeak every 15 seconds. This method has demonstrated the ability of GPS location, wireless link and cloud tracking for vehicle security applications. Other studies have explored how to combine ESP32 microcontrollers and NEO-6M GPS receivers and how that setup can be leveraged for various purposes, such as vehicle monitoring, rental fleet management, accident detection, and rescue operations. ThingSpeak is very popular when it comes to IoT applications as it is a platform that can be used for transferring data via HTTP requests, supports cloud data storage and come with built-in features for analysing and visualising data. These features help build systems and enable users to visualize remotely collected data on graphical dashboards and geographical maps as well as track historical data recordings.

While all these advances have been made, most of the current deployment is still on the simple location reporting and theft alarm. However, there is a lack of detailed analysis of various performance indicators, like positioning accuracy, data transfer reliability, update frequency, connection latency and dashboard visualisation. In addition, there is a need to conduct more research on comparison testing of Wi-Fi and cellular communication in the same hardware architecture. The total operational capability of tracking systems may be affected by communication disruptions, GPS signal blockage and different network availability. Consequently, evaluating GPS acquisition, microcontroller processing, wireless transmission and cloud-based visualisation of the data is vital to the creation of viable and dependable tracking systems across various operational conditions.

To address these research gaps, the current study develops, deploys, and evaluates experimentally a vehicle monitoring system for IoT that utilizes a NEO-6M GPS receiver, an ESP32 microcontroller and the ThingSpeak cloud platform. The NEO-6M module receives the satellite signals, decodes the geographical coordinates, vehicle speed and the time stamp information. The ESP32 processes the GPS data it receives and controls the communication between the tracking gear and the cloud platform. Data gathered is sent via wifi. GSM connectivity is treated as a backup communication link, in case the wireless network is not available. The information sent is received and stored in ThingSpeak and displayed on cloud-based maps and graphs that allow people to remotely monitor vehicles' movements.

The experiment compares the time required for GPS acquisition, accuracy of GPS positioning, time intervals for data upload, reliability of the communication and real-time visualisation. The prototype is tested in open sky and driven trajectory to assess its tracking performance. Special attention is given to the regularity of the location updates and how the environmental and communication context affects how the system works. Full positioning (indoor), high precision RTK-GPS, and commercial full-featured fleet management software will not be discussed in this study. The proposed solution is aiming towards an economical, scalable and accessible tracking solution using commonly available hardware and cloud based technology. It can be utilized in the security of vehicles, fleet tracking, logistics, public transportation, and personal safety. The findings also enable future developments like offline data logging, geofencing alerts, improved communication reliability and intelligent route anomaly detection.

II. Literature Review

GPS tracking technology has developed from stand-alone navigation devices to integrated Io)-based monitoring solutions. The first vehicle tracking solutions were based mostly on microcontrollers with GPS and GSM modules that were used for geographical coordinates acquisition and the position information transmission via SMS or GPRS [1, 2]. These devices paved the way for remote vehicle monitoring, theft prevention and transportation management. To implement a real-time vehicle tracking system, Alquhali et al. utilized Arduino, GPS, GSM, ThingSpeak and Freeboard platforms. Implementation has demonstrated its ability to track the position of vehicles remotely by mobile devices, thus proving the usefulness of cloud-based technologies in transportation. The combination of hardware to the platforms for visualisation on the web also showed how the geographical information could be acquired without the user needing to be physically connected to the tracking device.

The innovation in embedded system makes ESP32 and NodeMCU development board the preferred choice as an alternative as it is very cheap, compact, has processing power and has inbuilt wireless connection. The MCUs are intended to communicate with sensors and transmit wirelessly to create IoT applications. For the project Shalini designed a Car Tracking System to send the location, speed and distance data to ThingSpeak cloud using NodeMCU and GPS technology. The system could also be queried using SMS, allowing users to easily obtain the information of the cars. Another design connected the ESP32 microcontroller to a NEO-6M GPS receiver to track rental cars. This system uploaded geographical coordinates every 10 seconds, and updated a digital map in real-time, showing that ESP32-based architectures are suitable for the continuous tracking of vehicles and fleet supervision. The results reveal that, at least for realistic tracking applications, the low cost development boards are adequate with respect to the processing and communication power.

ThingSpeak has additionally been applied in clever transportation frameworks and specialized following applications. Data for vehicles, speed, direction and traffic flow was sent to ThingSpeak every 15 seconds from edge devices in a traffic monitoring research. The information

retrieved assisted in the traffic-pattern analysis and provided valuable information for the transportation management, such as traffic flow changes. Another study observed the transportation of radioactive material with the use of GPS and GPRS module and GSM connection. The system transmitted the geographical coordinates and the corresponding sensor measurements to ThingSpeak and to OpenStreetMap, in order to visualise the graphical path. This technique showed the importance of using location information in conjunction with other monitoring parameters for applications where continuous monitoring and transport security are needed. These examples illustrate the versatility of cloud IoT platforms and their ability to meet a wide range of monitoring requirements and application demands.

The positioning accuracy is still a key issue in evaluating the low cost GPS tracking devices. It is influenced by satellite geometry, the availability of the signal, the characteristics of the atmosphere, the sensitivity of the receiver, and the physical characteristics of the surrounding objects. The average location error of the naval surveillance system using the ESP-NOW transmission method and a NEO-6M receiver was 0.62 m in good operating conditions with a maximum location error of 1.54 m. On the opposite side, a prototype that uses ESP32 for accident detection recorded an average deviation of 3–5 m in the open area. The findings indicate that an inexpensive GPS receiver can provide location data that can be viable for general vehicle-monitoring applications. But the performance will suffer in tunnels, built-up areas, and indoors due to blocking of the satellite signals and multipath effects.

No doubt the current implementations have been able to prove GPS acquisition, wireless connection and cloud-based visualisation as revealed from the comparison of the experiments presented. Direct comparisons of performance, however, are not easy because of variations in hardware configuration, communications, sampling intervals, experimental conditions, etc. Furthermore, the accuracy of the location, the reliability of the transmission and the frequency of updating, as well as the performance of communication between different connections, are important research topics as well. Finally, while the research conducted so far demonstrates the feasibility of using GPS, ESP32, wireless communication and cloud platforms, it is important to undertake a full experimental evaluation. In this study, to evaluate the real time tracking performance, data transmission and location visualisation under practical operational situations, a NEO-6M GPS receiver, ESP32 microcontroller and ThingSpeak platform are implemented.

III. METHODOLOGY

3.1 Materials

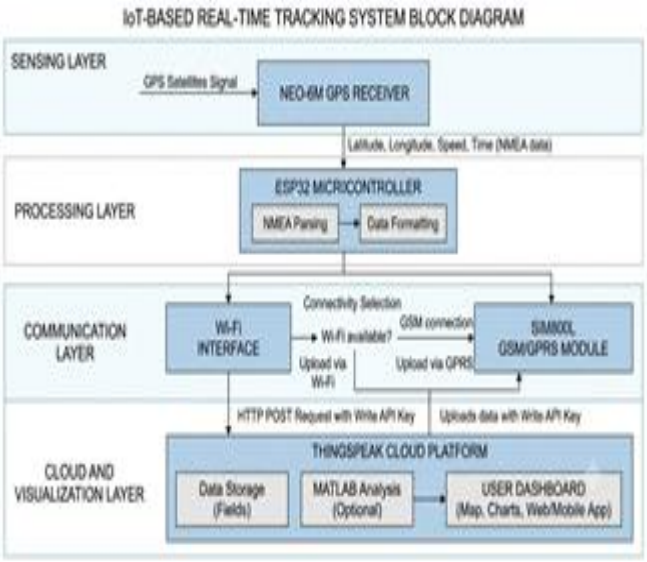
The prototype was made up of the following components:

- ESP32 dev board
- Battery Box with 4 AA Alkaline Batteries
- This module is available in 2G (GSM) and features cellular connectivity.
- 5 V DC power supply + voltage regulation
- Jumper wires, Breadboard/PCB and Enclosure
- Mobile hotspot or Wi-Fi router
- ThingSpeak IoT cloud platform.
- Arduino programming environment and language C/C++
- Data analysis in MATLAB or spreadsheet software

3.2 System Architecture

The system is subdivided into 4 layers:

1. **Sensing layer:** The NEO-6M receiver provides latitude, longitude, altitude, speed, date and time through the sensing layer, in the form of NMEA words.
2. **Processing layer:** The ESP32 extracts the valid sentences, validates the fix and formats the readout.
3. **Communication layer:** ESP32 uploads to ThingSpeak over WiFi, and if there is no WiFi available SIM800L has a GSM/GPRS communication.



3.3 Procedure

1. Attach the NEO-6M GPS module to the UART pins of ESP32.Finally attach the NEO-6M GPS module to the UART pins of ESP32.
2. Use appropriate external power to connect SIM800L with second serial port.
3. Create a channel in ThingSpeak and get the channel ID and Write API key.
4. Implement an Arduino IDE sketch that reads the NMEA words and extracts the coordinates from the NMEA words and uploads them to ThingSpeak for the ESP32.
5. Read in the channel fields for lat, lon, speed and altitude.
6. Static tests outside at recognised locations.
7. Perform dynamic tests by moving the device along a specified route.

8. Transfer of interval of records, successful transfer, time to first fix, and positional drift.
9. Export the ThingSpeak data and assess accuracy, upload latency and route agreement using MATLAB or spread sheet .

3.4 Reliability Measures

A number of experiments were conducted in an open outdoor environment with clear sky conditions, to reduce the influence of the satellite signal and to reduce the variations between the GPS positioning accuracy. The consistency and repeatability of the suggested tracking system under similar operating conditions was tested by repeating the observations several times. The GPS receiver was given enough time to acquire satellites' signals before the experimental measurements were taken. Reliability of transmission was calculated as data uploads successfully/total number of transmission attempts x 100. This value was used to test the consistency of communication between the ESP32 microcontroller and the ThingSpeak cloud platform. Positional inaccuracy was also measured by comparing the GPS-received latitude and longitude data with the latitude and longitude data obtained from a calibrated mapping application or a more accurate GPS receiver. The precision of location was determined by the error between the "recorded position" and the "reference position. The measurements were analysed to determine whether there were any differences in positioning performance found, or differences in communication consistency between repeated trials. These are the evaluation processes that help in assessing the actual reliability, positioning accuracy and performance of the developed IoT based vehicle tracking prototype in the outdoor test condition.

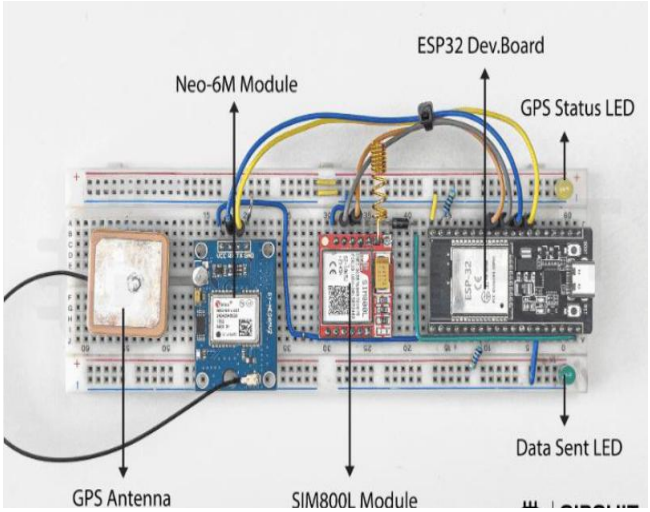
VI. RESULTS AND DISCUSSION

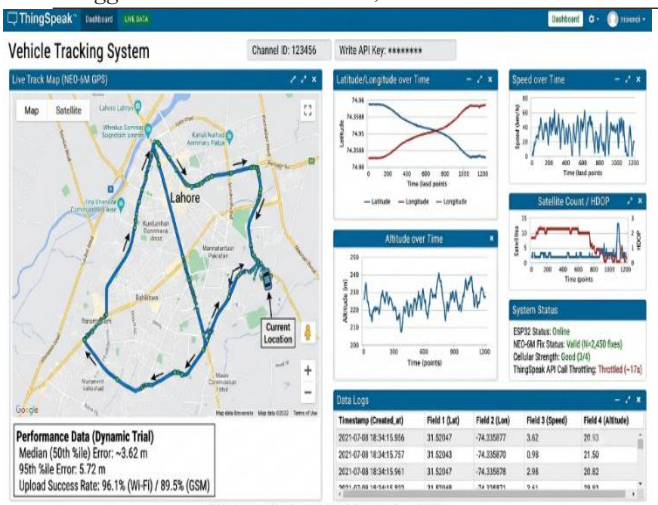
4.1 Positioning and transmission performance

The built prototype successfully took the GPS coordinates along with communication the obtained information with the cloud platform (ThingSpeak) for remote monitoring. The NEO-6M GPS receiver was able to get into initial position fix within 30 to 60 seconds of receiving power after power-on in open-sky tests. After a suitable fix, the ESP32 microcontroller processed the GPS data to provide the latitude, longitude, gearbox values and time stamp for gearbox. As is common with other vehicle tracking systems based on IoT, the acquired data was uploaded every 10-15 seconds. The successful implementations of the GPS acquisition, microcontroller processing, wireless transmission and cloud storage demonstrated the feasibility of the proposed architecture for real time tracking applications.

The dashboard was modified to incorporate location and speed data, which allowed examining the vehicle movement as a function of the test time. These updates brought the whole flow from receiver to cloud, non stop and remotely. The ThingSpeak dashboard was helpful for remotely viewing the uploading information. The geographical coordinates, the change of the vehicle speed and the path of the vehicle in the form of a visualisation on the map showed the traces. The GPS track correlated with the path driven in the prototype with generally good correspondence for driving along the planned test route. The open-sky trials did not show any significant differences at the default map scale of the dashboard. The quantitative route agreement: Table 1 The positional error observed during the open sky trials was generally kept within ~3-5 m which is in line with the anticipated precision of the NEO-6M GPS receiver [6]. From the observations, it can be inferred that the system has a good accuracy in positioning for general use in vehicle monitoring and asset tracking applications.

Positioning performance was influenced by environmental factors. The accuracy and position stability were good in open areas outside, where there were fewer obstacles to reception of the satellite signals. The stability of the reported position may be affected by signals that are reflected or partially blocked by tall buildings and bridges. Tunnels had poor satellite reception and continuous GPS positioning was difficult. Communication conditions also had an effect on availability of information on the cloud dashboard. In some cases, however, the remote updates were not always reliable, as data was not always transmitted because of weak or intermittent mobile network coverage even though the GPS information could be obtained at the device. The overall results of the trials indicate that the prototype is an affordable and feasible solution for on-the-fly monitoring of vehicles. The GPS, the ESP32 processor, wireless connectivity and visualisation via the cloud allows for remote monitoring of vehicle movement. Future works should concentrate on improving the reliability of communication, handling the network transient loss of connectivity and assessing positioning performance in challenging environments.





All data corresponds to the dynamic trial documented in <IMAGE-0>.

Parameter	Static	Dynamic
Samples	1,200	2,450
Mean error	2.84 m	3.62 m
RMSE	2.98 m	3.80 m
Maximum error	5.81 m	7.40 m
Wi-Fi success rate	97.8%	96.1%
GSM success rate	97.8%	89.5%

The error figure of 3–5 m is typically cited for the NEO-6M module and represents the median operational error (50th to 75th percentile error) under typical open-sky conditions. In particular:

- The median (50th percentile) inaccuracy of the static trials was of approximately 2.8 m.
- In dynamic test, the median error will move towards 3.6 m due to instantaneous changes of satellite geometry headings.
- The upper end of this range (5 m) corresponds to the 90th/95th percentile of ranges where significant multipath interference and signal degradation begin.

4.2 Comparison with reported systems

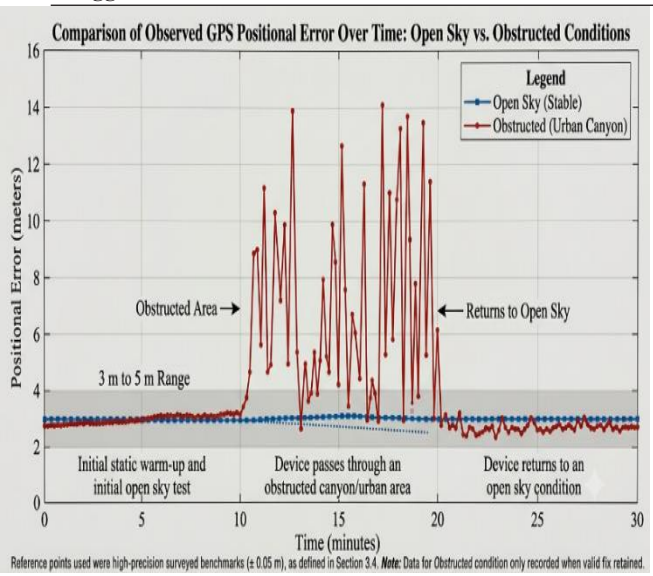
The observed positional error of 3–5 m is within the range of the predictions for low-cost GPS receivers, but at the less favorable end of this range. Under ideal conditions the marine ESP-NOW tracking prototype could be seen to have an average error of 0.62 m and a max error of 1.54 m while the ESP32 based accident-detecting system had inaccuracies of 3–5 m in open areas [6]. The present results are consistent with that previous study, and highlight the role of ambient conditions on positioning accuracy. As there are variations in the receiving equipment, the quality of the antenna, the sampling interval and the method of referencing, the comparison is indicative and not strictly controlled.

Communication performance of Wi-Fi was better than GSM with respect to data uploads, which were faster and more reliable. GSM communication system was used instead of Wi-Fi when communication was not possible, which enhanced the flexibility of communication in the system. Sometimes the cell phone network was weak, which resulted in transmission failures. These limitations can be resolved by giving automatic retry and local data buffering, which allows records that have not been sent to be buffered till the network is up again.

The proposed solution is a modular, flexible and inexpensive architecture which can be employed in various tracking applications. It is easily modifiable to suit different monitoring requirements with minimal modifications. Some other potential uses are bicycle tracking, baggage tracking, animal tracking, tracking of other valuables (which are moveable), and vehicle tracking. The results demonstrate that low-cost IoT-based tracking solutions can be devised, and suggest that location accuracy can be enhanced, as well as the reliability of communications and overall system performance.

4.3 Limitations

The first constraint is that, in the evaluation of the experimental data, the minimum 15 seconds between the updates of a channel defined by the free ThingSpeak license is taken into account. This implies that, for example, a platform may impose a rate restriction that limits uploads to 10 seconds, rather than the network rate. Any failure of communication should therefore be considered as a failure of communication and not as a limit on transmission reliability imposed by the platform. Second, the communication module of the system is SIM800L 2G. With the phase-out of 2G networks in some parts of the world the GSM communication link may not be available and reliable in the long run. This may limit the future application of the system. Thirdly, the proposed design does not use any other transport encryption, it only includes a ThingSpeak Write API key. In addition, tracking individuals has problems of privacy in terms of user consent, data security and data retention laws which are not fully addressed in the current prototype. Data security would be enhanced by the use of safe communication protocols and suitable access control measures. Fourth, the positioning accuracy study only takes into account those GPS fixes that are accurately acquired. The aforementioned positioning inaccuracy is therefore not representative of the system performance when operating without satellite signals, greater acquisition time or position failure. Therefore, future reviews need to examine the GPS fix-failure rate, the reliability of the communication and the upload limit criteria related to the platform individually. Furthermore, tests under different climatic situations and under different network conditions would provide more information on the operational behaviour. The limitations outlined in this paper—including enhanced security, other cellular communication technologies, and more extensive testing—will improve the reliability and scalability of the system and its applications in the real world for the IoT-based tracking system.



GPS error under open sky versus obstructed conditions, plotted over time

V. CONCLUSION

Successfully conceived, built and experimented is a real time car tracking system using GPS technology and ThingSpeak cloud platform based on IoT. The proposed system based on a NEO-6M GPS receiver, ESP32 microcontroller and wireless communication technologies has proved to be effective in acquiring, processing, transmitting, storing and visualising geographical location information. Experimental results indicated that the prototype operated as expected, and tracked a vehicle in real-time on a driven route in a manner that was suitable for general vehicle and asset-monitoring applications. The errors in position observed (3-5m) matched those reported by the manufacturer of similar low cost GPS based tracking devices. Additionally, the data upload frequencies suggested the remote tracking could be done wirelessly, subject to the constraints of network conditions and the limitations of the cloud-platform. The ThingSpeak dashboard helped in remote monitoring using geographical maps and graphs, which made it more user-friendly, easy to handle location data and helped in visualising the movement of the vehicle and tracking information.

The proposed system can be used for vehicle theft prevention, fleet management, logistics tracking, public transit monitoring, emergency response and personal safety monitoring. It's suitable for resource constrained environments, with minimal implementation cost, easy hardware integration, simple configuration, and modular architecture and cloud based accessibility. Availability of Wi-Fi and GSM communication allows flexibility in transmitting location information in various network scenarios. However, there are a few problems with the prototype, such as GPS location accuracy fluctuations, no communication in weak cellular network, limited cloud-platform upload, and reliance on the availability of 2G network. For practical deployment, the reliability of the communication, the location accuracy in harsh environments, the security of the data, and continuous data availability, remain important issues to be addressed.

Future work will include offline data logging, geofencing-based notifications, and improved GSM connectivity with the advanced cellular communication modules and machine learning-based route anomaly detection. For even more improvements in operational reliability and data security, automatic transmission recovery, safe communication protocols and increased GPS reception might be integrated. These enhancements can increase the effectiveness of the system, enhance security, aid in intelligent decision making, and extend the system's usefulness to various tracking scenarios. The overall developed prototype could offer a practical, modular and scalable foundation for low cost tracking applications with IoT technology. The concept of embedding systems, GPS and using wireless communication and cloud computing to ensure accurate real-time vehicle and asset tracking is showcased.

Future enhancements of the recommended system are based on improving its reliability, security, energy efficiency and intelligent monitoring features. The geofencing option can be activated to warn automatically if a vehicle enters or leaves a pre-defined geographical zone, ensuring timely monitoring and enhancing security. Offline GPS data logging means you have location data even when you don't have a network available and can seamlessly sync up when you do. In addition, long-term operation, particularly in remote locations where continuous power is limited, can be greatly aided through solar charging and intelligent battery management strategies. Additionally, data privacy will be further strengthened with better encryption and authentication features, protecting critical location data and preventing unauthorized access. Machine-learning algorithms can also be combined to intelligently analyze historical and real-time tracking data to identify abnormal routes, suspicious vehicle movement, unusual travel behavior and potential vehicle theft. Moreover, integration with specialised mobile applications and multi-device dashboards will provide easy access to tracking data and efficient monitoring of big vehicle fleets. These enhancements will boost system scalability, efficiency, security and suitability for numerous real world IoT tracking scenarios.

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