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Integrated GPS Tracking and Automated Sorting: A Technological Leap for Enhanced Logistics Efficiency

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A B S T R A C T

The logistics sector, a cornerstone of the global economy, faces challenges in real-time tracking of goods and efficient sorting processes. This study introduces a dual solution: a low-cost car GPS tracker and an automated sorting system tailored for logistics companies. Utilizing the SIM808 GPS module, compatible with the Arduino ATMEGA microcontroller, the system offers live tracking of delivery vehicles, logging data continuously to a remote server via GPRS and GSM. Concurrently, RFID technology is employed for precise shipment tracking and sorting. An automated conveyor system categorizes goods based on their destination, with each package registered through a PHP-based web form, receiving a unique identifier. The centralized software solution, designed using PHP, provides various reports, including driver behavior analytics, based on geocoded data. This integrated system not only aids in vehicle recovery during thefts but also promotes worker safety, reduces labor costs, and enhances operational efficiency.

Keywords: Logistics, GPS Tracking, Automated Sorting, RFID Technology, Operational Efficiency.

1. Introduction

The logistics industry, especially the delivery sector, plays a pivotal role in the global economy. Companies such as DHL, FEDEX, and ZimPost have been instrumental in ensuring goods reach their destinations. However, the current manual system, especially in regions like Zimbabwe, is riddled with inefficiencies. Packages often pass through multiple processing centers before reaching their destination. Given the volume of packages, manual sorting becomes a tedious task, prone to errors, and time-consuming. Moreover, the misuse of delivery vehicles for personal agendas by drivers, suboptimal route selections leading to fuel wastage, and the lack of a recovery system in case of thefts further worsen the challenges faced by logistics companies (Fernie & Sparks, 2014; Li & Wang, 2010).

To address these challenges, this study embarked on designing an integrated system that combines the power of GPS tracking with an automated sorting mechanism. The GPS tracker, built around the Arduino ATMEGA microcontroller, ensures real-time tracking of delivery vehicles, thereby enhancing accountability and reducing operational costs. The tracker's data, logged continuously to a remote server, provides insights into driver behavior, route optimization, and even aids in vehicle recovery during thefts.

On the other hand, the automated sorting system, leveraging RFID technology, aims to replace the manual sorting process. Each package, upon entry into the system, is registered through a PHP-based web form and assigned a unique identifier. This identifier, when read by the RFID system, determines the package's destination, and the automated conveyor system ensures it reaches the correct compartment [3, 4]. Such automation not only reduces human errors but also significantly cuts down labor costs. This study's primary objective was to revolutionize the logistics sector by introducing technological interventions that could address its current challenges. The combined power of GPS tracking and automated sorting promises a future where logistics operations are more efficient, cost-effective, and error-free (Li & Wang, 2010; Chen & Wang, 2012).

2. Background

The Global Positioning System (GPS), formally known as the Navigation System with Timing and Ranging Global Positioning System (NAVSTARGPS), is a remarkable innovation initiated by the U.S. Department of Defense. Designed to cater to both civilian and military needs, its foundation lies in a network of satellites. The inaugural satellite was launched in 1978, and since then, the constellation has expanded to 28 satellites (Aviles & Van Dyke, 2023). This ensures that at any given point, at least four satellites can communicate with any location on Earth. Integral to their function, these satellites are equipped with atomic clocks, facilitating precise positioning, navigation, and time synchronization (Cojocaru, Birsan, Batrinca, & Arsenie, 2009).

Central to the functionality of GPS is its ability to use these satellites as reference points for terrestrial locations. For a GPS receiver to pinpoint an exact location, it calculates its distance to multiple satellites. This process involves determining each satellite's exact position, gauging the time taken for radio signals to travel from the satellite to the receiver, and adjusting for any signal delays. To achieve accurate 3D positioning, signals from a minimum of four satellites are essential (Perkasa, 2019).

However, despite the evident advantages of GPS, especially for vehicle tracking, its adoption in Zimbabwe has been slow. The primary deterrents have been the prohibitive setup costs and a limited number of service providers. Presently, a mere 11,000 vehicles in the country are equipped with GPS. This lag in adoption has led to operational inefficiencies, particularly in fleet management. With a surge in carjacking incidents in Zimbabwe, the ability to trace stolen vehicles using GPS becomes invaluable, aiding police recoveries and facilitating insurance claim processes.

Several attempts have been made to harness GPS for vehicle tracking. For instance, (Kamble, 2012; Shimizu & Sakurai, 1993) proposed a system leveraging an RF transmitter and receiver, but its operational range was restrictive. Another suggestion by (Perumal et al., 2020) was a passive system that stored data for subsequent uploads, but it lacked real-time tracking capabilities. A significant advancement came from an Indian research group that unveiled a real-time tracking application integrating GPS and GSM, allowing multiple users to access vehicle data simultaneously (Mistary & Chile, 2015).

In the logistics sector of Zimbabwe, major freight companies predominantly employ manual sorting for package distribution. While this method is straightforward, it is full of challenges such as susceptibility to human errors, inefficiencies in package retrieval, safety concerns for the workforce, and elevated labor costs due to manual operations. To enhance sorting efficiency, the introduction of conveyor belt systems is under consideration. Roller conveyors, known for being cost-effective and adaptable, unfortunately, lack durability. Chain conveyors, while powerful and efficient, demand higher maintenance and initial investment. Hinged belts, typically made of metal, are renowned for their durability but pose maintenance challenges due to their intricate mechanical design.

The background highlights the pivotal role of GPS in fleet management and the pressing need for streamlined logistics solutions in Zimbabwe. The forthcoming sections will delve into the design and development of a system addressing these challenges, with a focus on real-time location tracking, safety, continuous data logging, multi-user access, cost, and response time. In logistics, the emphasis should be on cost, maintenance, and ease of construction for conveyor systems (Sanchana et al., 2021).

3. Design and Development

The design of the GPS Tracking Hardware focused on developing a real-time GPS tracking device specifically for vehicles. As illustrated in Fig. 1, the central component of the system was the GPS tracking unit, SIM 808.

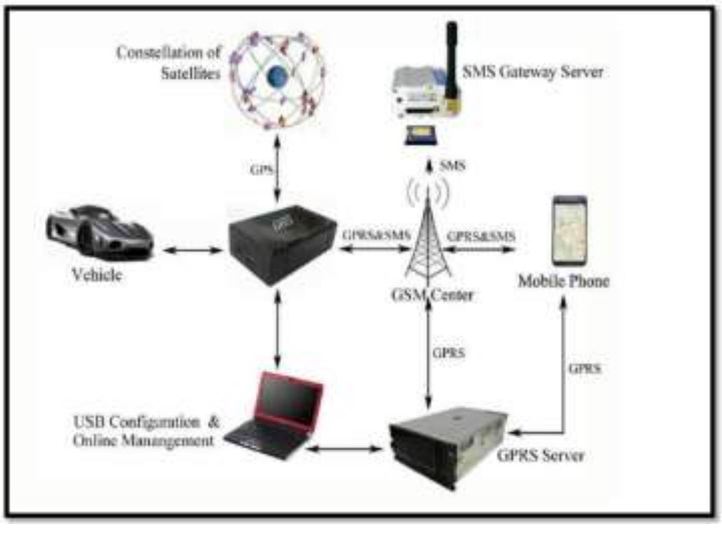


Fig. 1 GPS Tracking Block Diagram

This unit, when paired with the Arduino microcontroller and placed within a vehicle, captured GPS coordinates from the Glonass satellites. These coordinates, along with other tracking data, were then sent to the GPRS server using the GSM and GPRS network. At the server side, a geocoding process converted the raw GPS coordinates into a graphical format, which was subsequently displayed on a webpage. To optimize the GPS device's performance, configurations were implemented. These configurations, which included satellite connections and data transmission settings, were managed on a computer via a USB connection.

In the context of vehicle tracking devices, two main categories were recognized: Passive and Active tracking devices. Passive Tracking Devices stored data, such as latitude, longitude, and speed, within the device. This data was usually analyzed after the vehicle's journey was completed. Because of their communication limitations, these devices were often more affordable. In contrast, Active Tracking Devices, while recording similar data, provided the benefit of real-time data transmission. This feature, enabled through cellular or satellite networks, allowed for immediate vehicle movement monitoring. Due to these real-time capabilities, active tracking devices were the preferred option for this project.

For the GPS Tracking Hardware Design, specific components were selected based on their functionalities. The SIM808 GSM/GPRS/GPS Module was recognized for its multiple functions, capturing GPS coordinates, and sending them to a remote server. The Arduino Nano was selected as the microcontroller because of its small size and energy efficiency, ensuring the tracker could be placed discreetly, ideally inside the vehicle's dashboard. Additionally, a Rocker Switch was added, functioning both as a panic button and an engine status indicator.

The design was further extended to include both the package sorting and the GPS tracking system. This system consisted of two primary units: the package sorting unit, responsible for sorting tasks, and the delivery vehicle GPS tracking system, which provided real-time vehicle tracking. A key feature was the integration of these systems at the web application level, ensuring effective communication and data sharing.

The Sorting System Design Methodology was represented in the Sorting System Block Diagram, as shown in Fig. 2. This diagram gave an organized view of the system's components and their interactions.

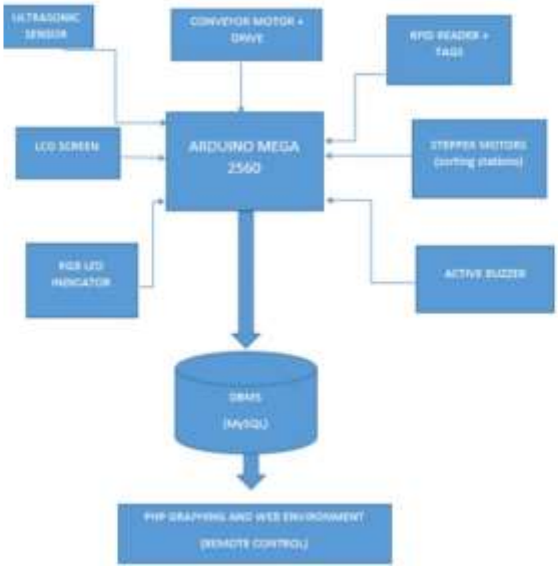


Fig. 2 Sorting System Block Diagram

After this, appropriate hardware components were chosen to enhance system efficiency. The operational sequence and module interactions were detailed in the Sorting System Flow Diagram, shown in Fig. 3. This system had three main modules: the Input Module, the Processing Module, and the Output Module. To confirm the system's functionality, practical tests and experiments were conducted.

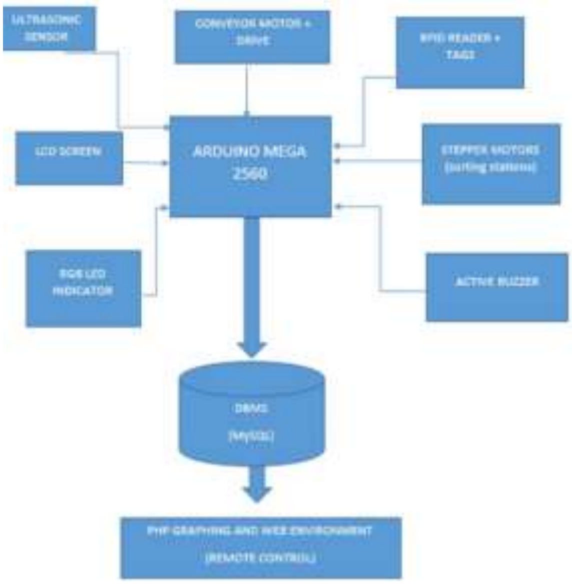


Fig. 3 System Flow Diagram

The GPS tracking system was tested through simulations. Initially, the tracker's design was simulated using Proteus Professional 8.3 to confirm its feasibility before the actual hardware setup. The first simulation, shown in Fig. 4, presented the GPS tracker's main features.

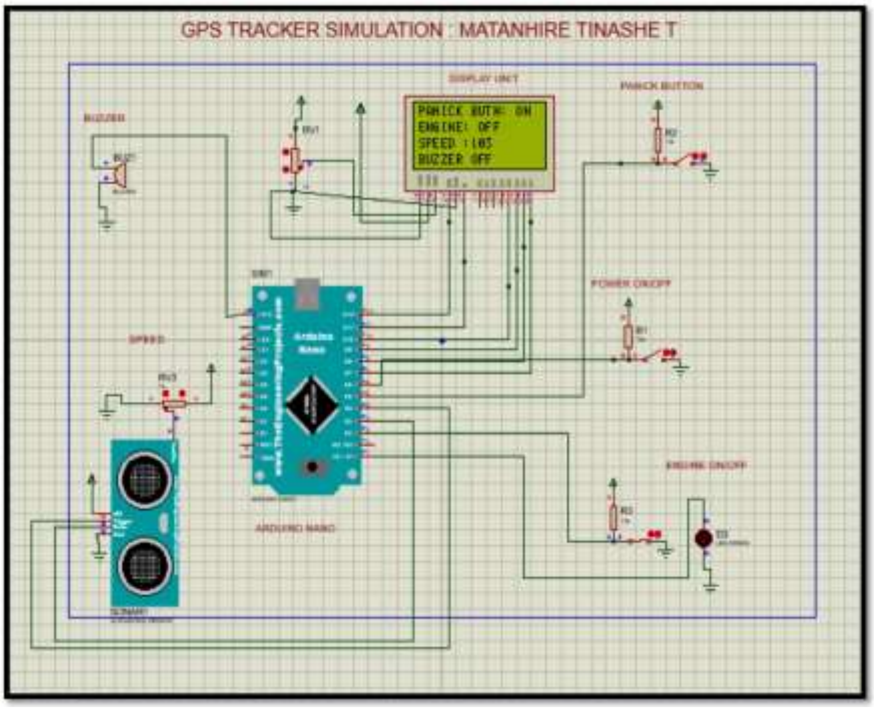


Fig. 4 GPS tracker simulation with panic button, engine switch and speed buzzer

The second simulation, shown in Fig. 5, highlighted the process of sending AT commands via the GSM/GPS module with Arduino.

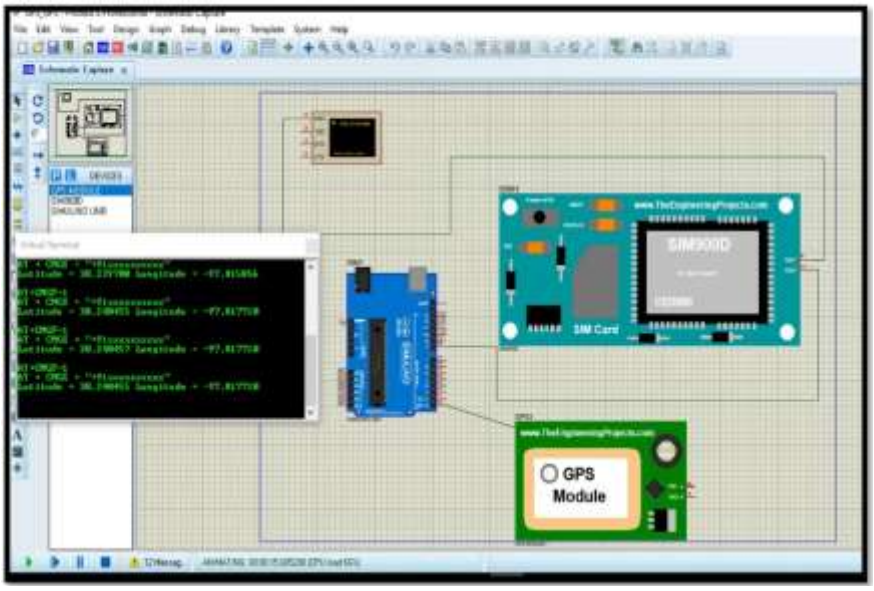


Fig. 5 Sending AT commands via GSM/GPS module with Arduino.

After the simulations, experiments were conducted. The first experiment, illustrated in Fig. 6, examined the GPS functionality of the tracker.

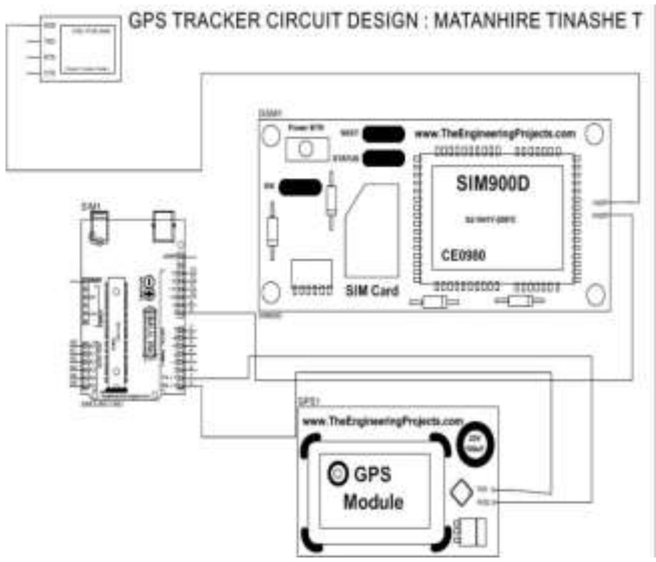


Fig. 6 GPS Lock Test Circuit Diagram.

The second experiment, shown in Fig. 7, tested the tracker's capability to collect sensor data and send it to a remote server. The third experiment evaluated the GSM functionality of the tracker.

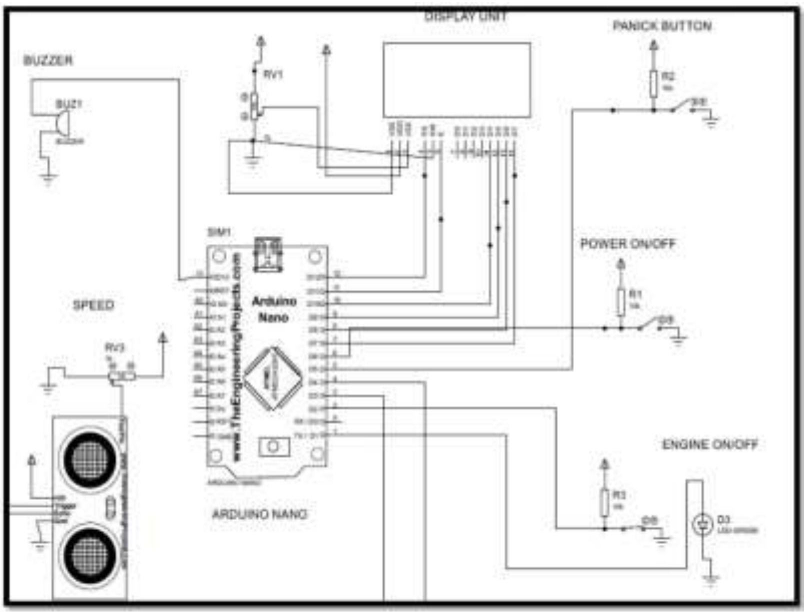


Fig. 7 Sensor Data Collection and Remote Server Connection.

The proposed system was web-based, providing a detailed graphical view of the GPS location of delivery vehicles. This design choice was made considering the adaptability of web-based systems. An essential part of the system design was shown in the UML diagram, as presented in Fig. 8. The decision to use a web-based system led to the selection of PHP, supported by HTML and JAVASCRIPT. The Google Maps API was used for geocoding due to its open-source nature.

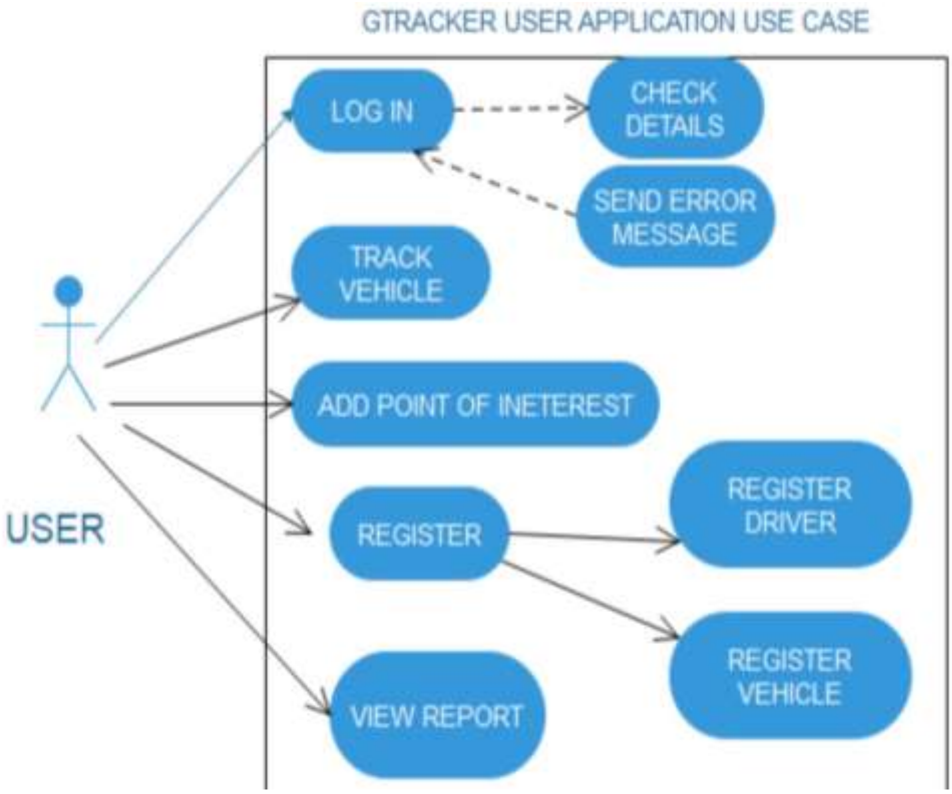


Fig. 8 UML Diagram for the Tracker Web Application

Considering the expected data volume, a strong database management system (DBMS) was set up. The chosen DBMS was the MySQL database, used within the Wamp Server. This DBMS provided several benefits, such as sequential data storage, efficient record updates, and the ability to link data.

Results

The design results of the tracker are detailed, as shown in Fig. 9a, which depicted the complete GPS Tracker Hardware. The GPS Lock Test, as illustrated in Fig. 9b, demonstrated the tracker's initialization process using AT commands.

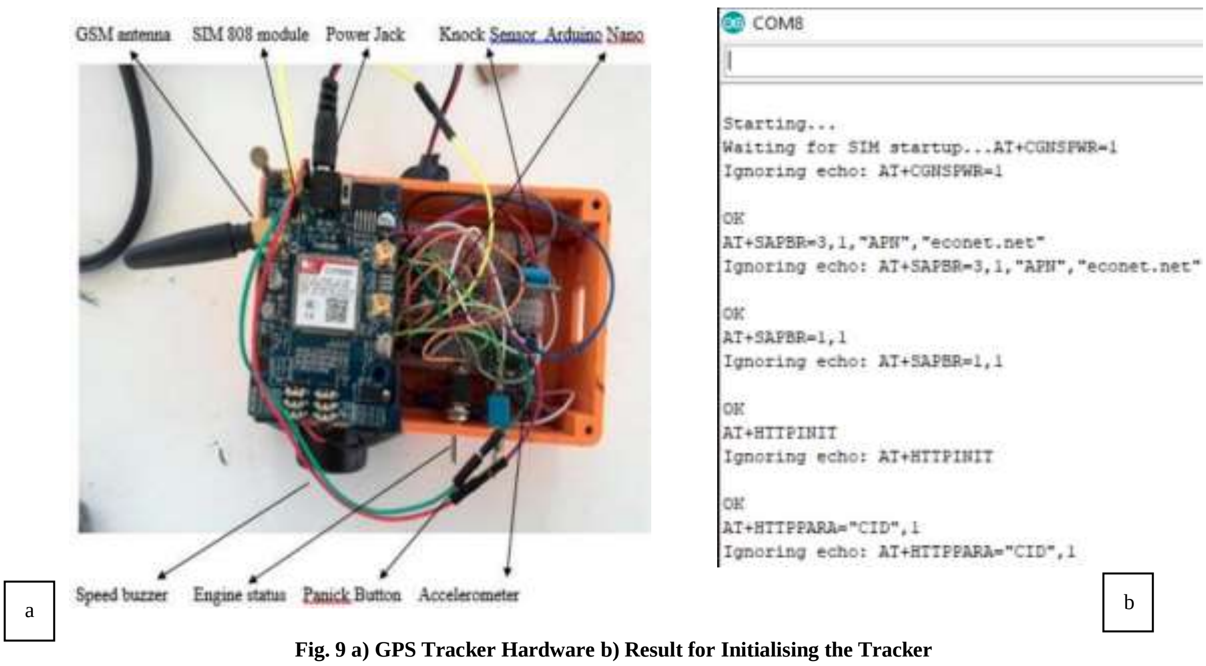


Fig. 9 a) GPS Tracker Hardware b) Result for Initialising the Tracker

The outcomes of the GPS lock acquisition are summarized in Table 1. The experiments revealed that the tracker acquired a GPS lock in 76 seconds when placed in the tracking vehicle and took 90 seconds inside a building with the antenna near a window.

Table 1 GPS Lock Results

Experiment Number	Environment Setup	GPS Lock Result	Time Taken to Get Lock
1	In the tracking vehicle	GPS lock acquired	76 seconds
2	Inside a building with antenna close to the window	GPS lock acquired	90 seconds
2	NUST basement	GPS lock failed	Never got lock

Parameter readings from the tracker, including sensor values and GPS data from the GPS module, are displayed in Fig. 10. This figure highlights the tracker's capability to collect GPS data, presenting a list of values such as UTC time, fix status, and the number of connected satellites.

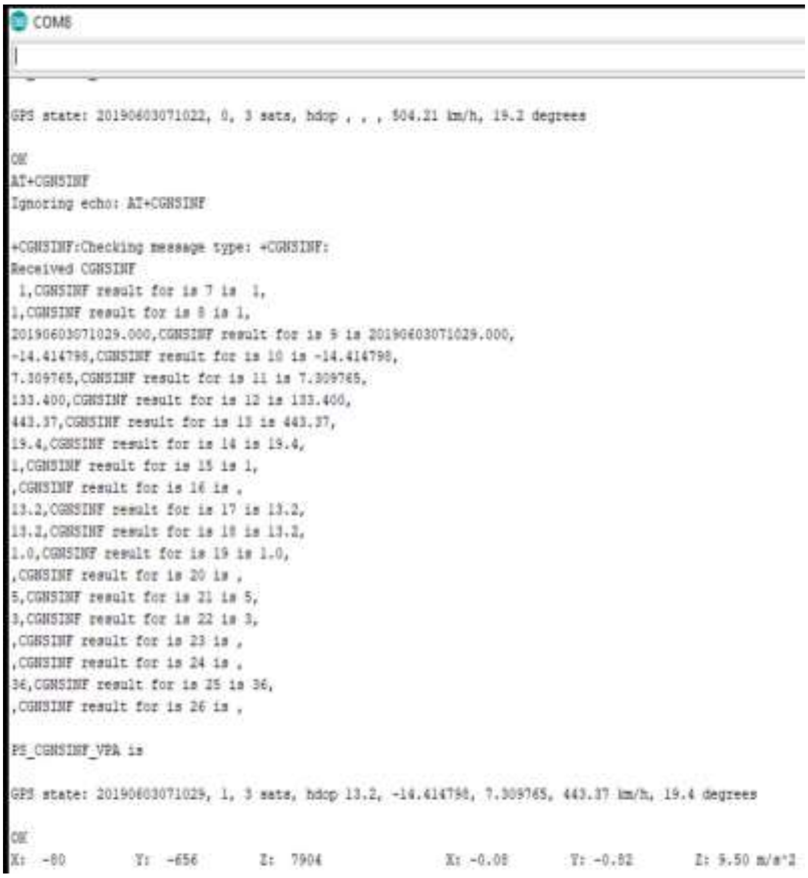


Fig. 10 Parameter Readings from the Tracker

The process of sending sensor tracker data to a remote server using GPRS is depicted in Fig. 11, which shows parameters like latitude, longitude, and acceleration data stored in the database.

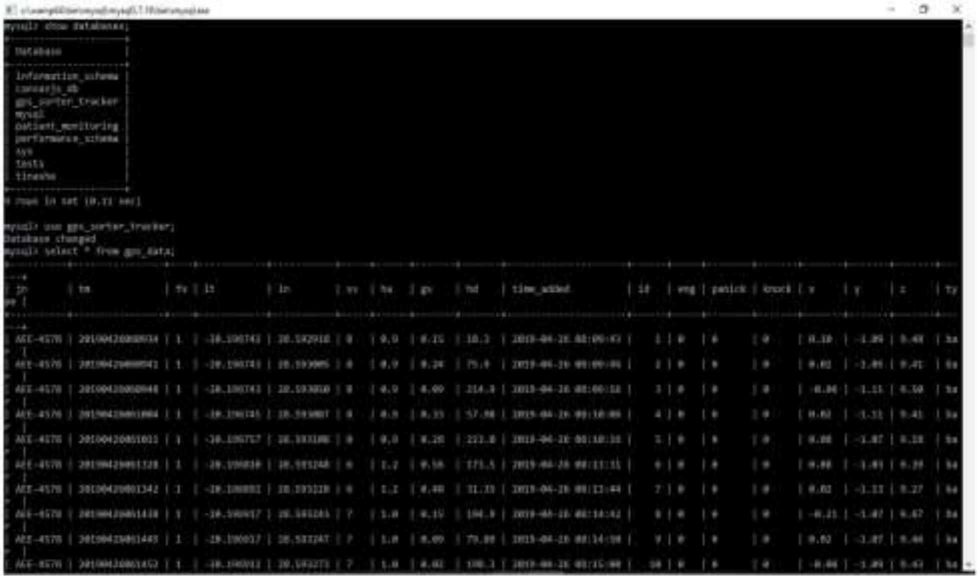
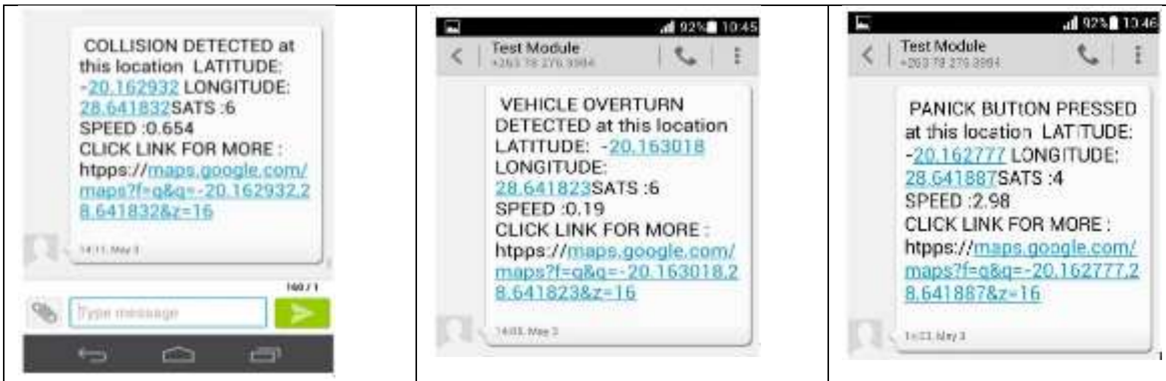


Fig. 11 Sending GPS Data to Remote Server

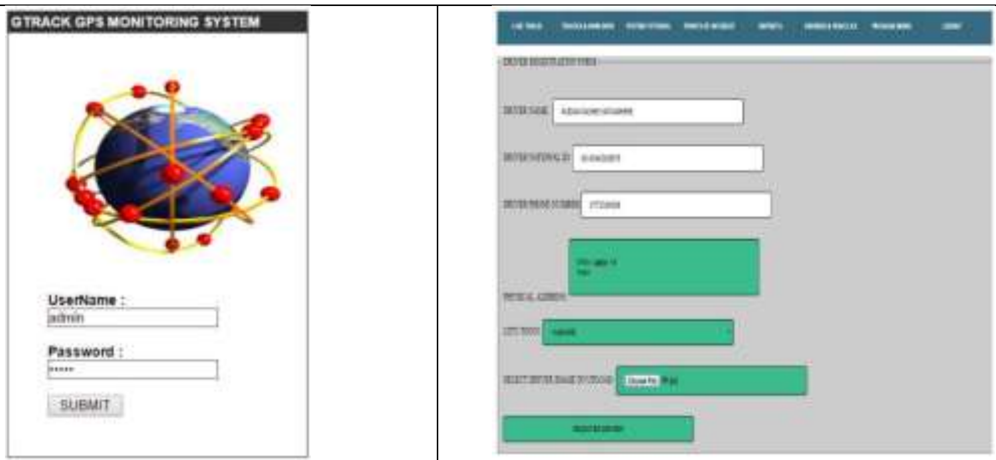
SMS alerts sent to the fleet manager for safety-related events were represented in Fig. 12 a, b, and c, showcasing collision detection, vehicle overturn, and panic button notifications, respectively.



a) Collision Detection Notification b) Vehicle Overturn Notification c) Panic Button Notification

Fig. 12 SMS Alerts Sent to the Fleet Manager

The software results are shown with the presentation of the login page in Fig. 13a, emphasizing the system's security measures. The driver registration process is illustrated in Fig. 13b, with the subsequent list of registered drivers tabled.



a) Login Page b) Driver Registration Form

Fig. 13 a) Login page b) Driver Registration Form

Upon selecting a driver's record, detailed information is displayed as seen in Fig. 14.

Fig. 14 Detailed Information of Driver's Record

The geocoding section results showcased the conversion of raw GPS data into a graphical format. The live track tab, represented in Fig. 15, provided a real-time location of the tracker on a map.

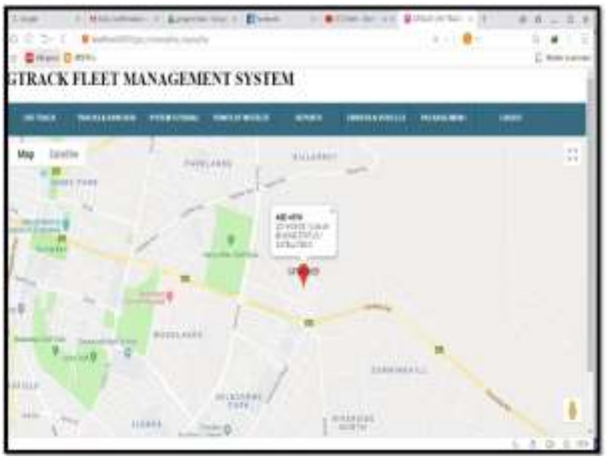
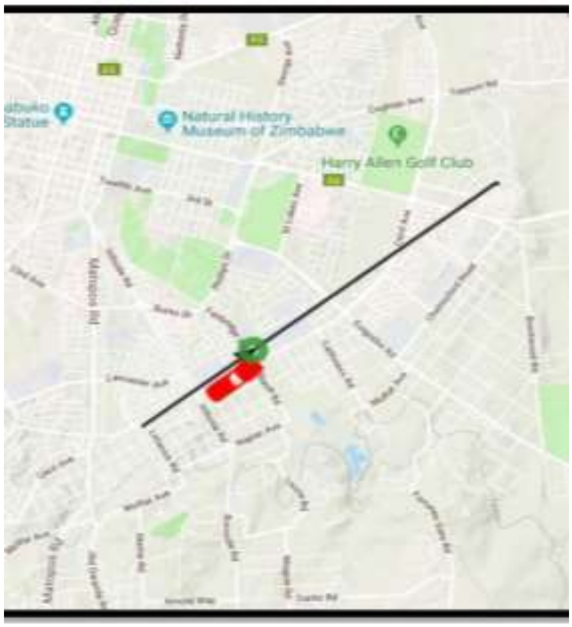


Fig. 15 Live Track Tab

The tracks and playback module testing results are displayed in Fig. 16a and Fig. 16b, highlighting the GPS data search, download, and trip playback animation.

a) GPS Data Search and Download



b) Trip Playback Animation

Fig. 16 a) The Tracks and b) Playback Module Testing Results Live Track Tab

The sorting system's design results are introduced with the conveyor belt setup in Fig. 17.

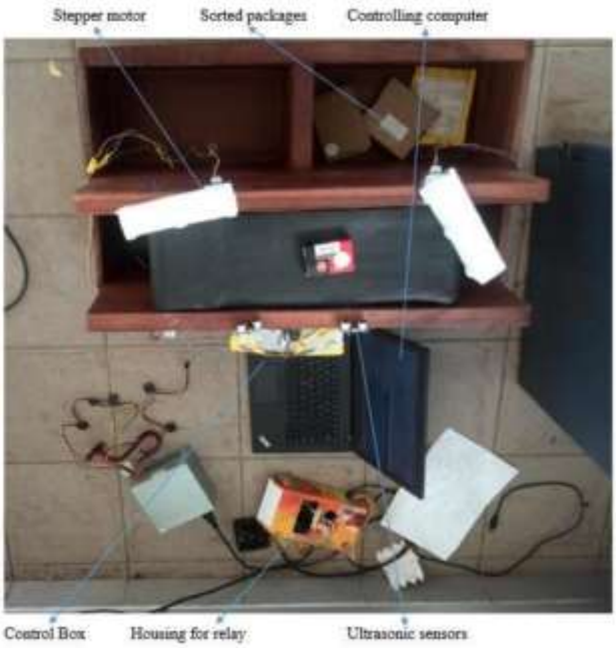


Fig. 17 Conveyor Belt

The software section of the sorting system, developed in PHP, was introduced with the package registration form in Fig. 18. Registered packages in the system are displayed in Fig. 19, and the remote-control interface was shown in Fig. 20.

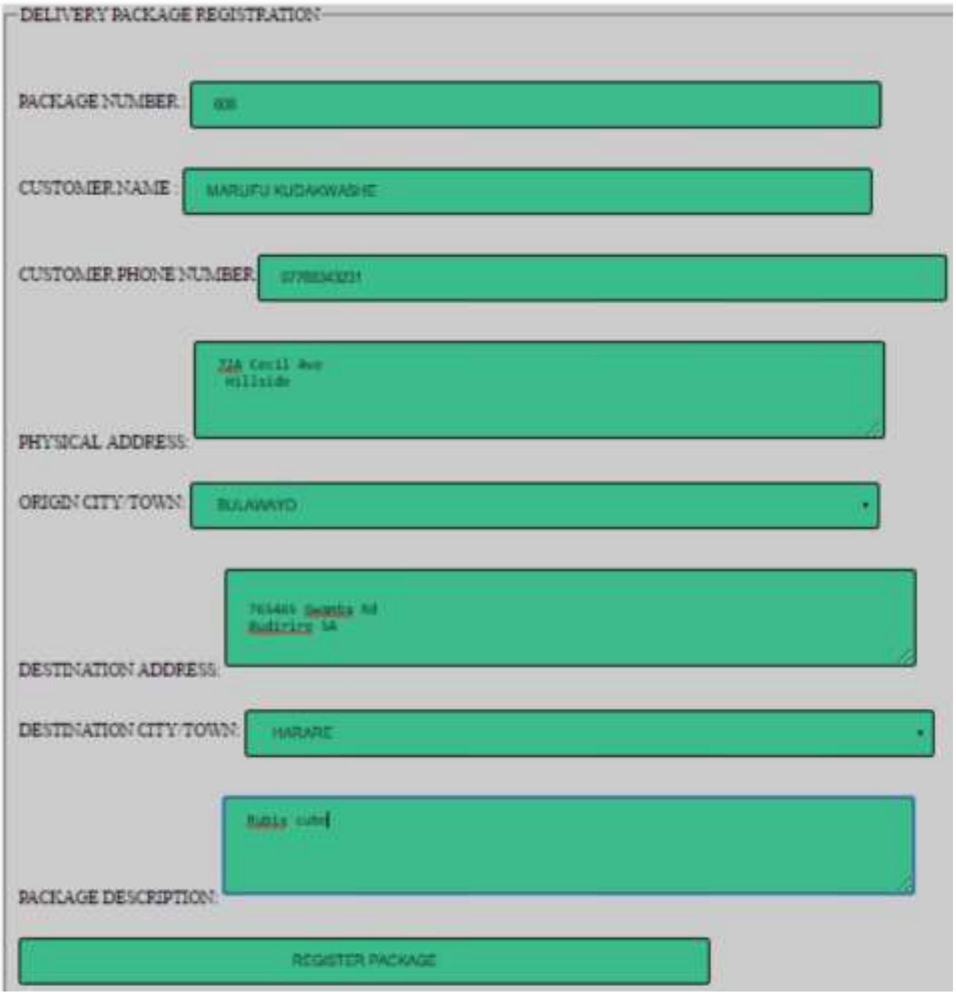


Fig. 18 Package Registration the Figure Below Shows the Package Now Captured in the System

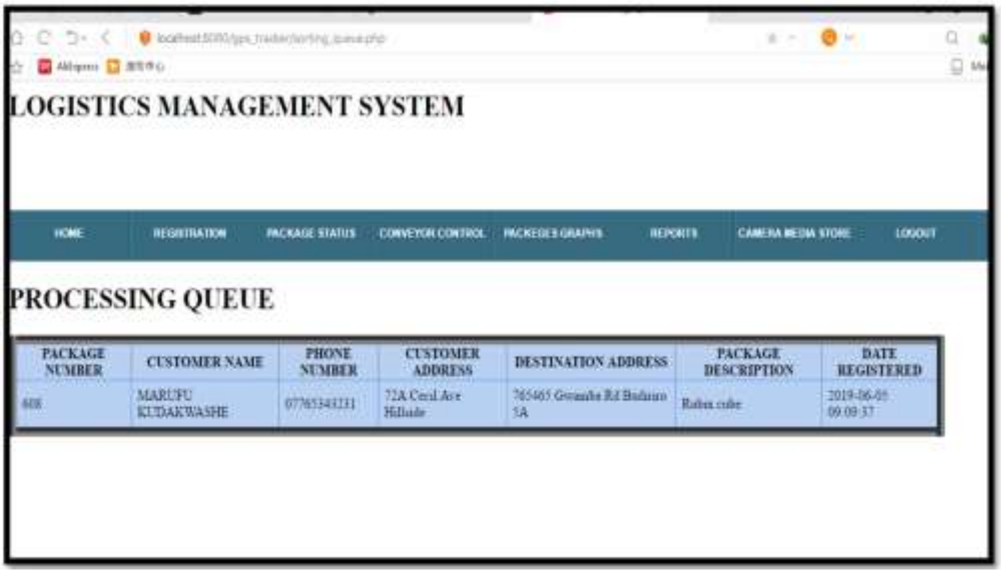


Fig. 19 Packages Registered in System

Fig. 20 Remote Control Panel

The tracker's results were analyzed with the GPS lock test analysis represented in Fig. 21. The tracker successfully acquired a GPS lock in various environments. The analysis of GPS data and sensor data acquisition results indicated an average horizontal accuracy of 2.7 meters using the prototype developed.

Fig. 21 GPS lock test analysis

The data packets delivery analysis, shown in Fig. 22, revealed a 98% success rate over a 4-hour monitoring period.

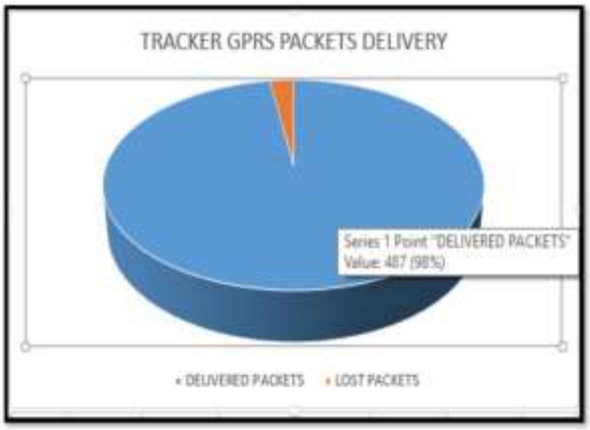


Fig. 22 Data Packets Delivery Analysis

The sorting system's results indicated smooth operation of the conveyor with web application-based remote control. The RFID tag accurately read UIDs based on the destination city. However, a latency was observed in object detection and the activation of the sorting stepper motor. The obtained results for both the tracker and sorting system were consistent with the design objectives. The tracker achieved a 98% success rate in sending data to the server every 10 seconds. The sorting system accurately identified packages using RFID and sorted them into appropriate stations.

Conclusion

This research successfully addressed the pressing challenges faced by the logistics sector, particularly in real-time tracking and efficient sorting processes. The proposed dual solution, encompassing a low-cost car GPS tracker and an automated sorting system, demonstrated significant potential for enhancing operational efficiency in logistics companies. The GPS tracker, built around the Arduino ATMEGA microcontroller, showcased a commendable 98% success rate in transmitting data to a remote server every 10 seconds. This real-time tracking capability not only ensures accountability but also offers insights into driver behavior and aids in vehicle recovery during thefts. Concurrently, the automated sorting system, leveraging RFID technology, presented a promising alternative to manual sorting. The system's ability to accurately identify packages and direct them to their respective destinations reduces human error and labor costs. The integration of these systems at the web application level further ensures seamless communication and data sharing, enhancing the overall efficiency of logistics operations. However, while the system exhibited consistent results in line with the design objectives, there were observed latencies in object detection and the activation of the sorting stepper motor. These areas present opportunities for further refinement and optimization. In summary, this study has laid the groundwork for a technologically advanced logistics sector. The combined capabilities of the GPS tracker and automated sorting system promise a future where logistics operations are more streamlined, cost-effective, and error-free, paving the way for a more efficient global economy.

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References

[1] Fernie, J., & Sparks, L. (2014). Logistics and retail management: emerging issues and new challenges in the retail supply chain. Kogan Page Publishers.

[2] Bowersox, D. J., Closs, D. J., & Cooper, M. B. (2013). Supply chain logistics management. McGraw-Hill Education.

[3] Li, X., & Wang, Y. (2010). RFID technology and its applications in Internet of Things (IoT). In 2010 International Conference on Intelligent Computing and Integrated Systems (pp. 1-4).

[4] Wang, Y., & Li, X. (2011). RFID technology and its applications in Internet of Things (IoT). Journal of Computers, 6(10), 2246-2253

[5] Chen, Y., & Wang, N. (2012). RFID technology and its applications in the logistics sector. In 2012 International Conference on Computer Science and Electronics Engineering (Vol. 3, pp. 648-651).

[6] Wang, Y., & Li, X. (2013). RFID technology and its applications in the logistics sector. Journal of Industrial Engineering and Management, 6(1), 196-209.

[7] Li, X., & Wang, Y. (2014). RFID technology and its applications in the logistics sector. International Journal of Logistics Systems and Management, 17(1), 1-18.

[8] Cojocaru, S., Birsan, E., Batrinca, G., & Arsenie, P. (2009). GPS-GLONASS-GALILEO: A Dynamical Comparison. The Journal of Navigation, 62(1), 135-150. DOI: https://doi.org/10.1017/S0373463308004980

[9] Kamble, K. (2012). SMART VEHICLE TRACKING SYSTEM. International Journal of Distributed and Parallel systems, 3, 91-98. - (Kamble, 2012)

[10] Perkasa, P. (2019). Use of Global Positioning System (gps) for basic survey on students. BALANGA: Jurnal Pendidikan Teknologi Dan Kejuruan, 7(1), 22–33. DOI: https://doi.org/10.37304/balanga.v7i1.553

[11] Aviles, J. S., & Van Dyke, K. L. (2023, October 5). U.S. department of transportation (DOT) global positioning system (GPS) interference detection and mitigation (IDM) program. Proceedings of the 36th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2023). DOI: https://doi.org/10.33012/2023.19248

[12] Shimizu, N., & Sakurai, S. (1993). Application of global positioning system (GPS) to displacement measurements in rock engineering. Shigen Sozai, 109(1), 1–7. DOI: https://doi.org/10.2473/shigentosozai.109.1

[13] Perumal, S., Tabassum, M., & Zulkipli, D. S. N. A. B. A. A. (2020). Development of a low-cost smart vehicle start up and tracking system using Android and Arduino. International Journal of Vehicle Autonomous Systems, 15(3/4), 271. DOI: https://doi.org/10.1504/ijvas.2020.116449

[14] Sanchana, S., Manjari, & Jyothi, B. N. (2021, March 25). Application development for real-time location tracking for underwater vehicles using low-cost GPS with GSM. 2021 Sixth International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET). DOI: https://doi.org/10.1109/wispnet51692.2021.9419421

[15] Zahilah, R., & Zaharan, S. Z. (2022). EyeKids: Real-time tracking and monitoring system for child safety. International Journal of Innovative Computing, 12(2), 1–8. DOI: https://doi.org/10.11113/ijic.v12n2.311

[16] Datta, N., Malik, A., Agarwal, M., & Jhunjhunwala, A. (2019, April). Real time tracking and alert system for laptop through implementation of GPS, GSM, motion sensor and cloud services for antitheft purposes. 2019 4th International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU). DOI: https://doi.org/10.1109/iot-siu.2019.8777477

[17] Morán Cabezas, A., De La Torre Macias, A., Morán Cabeza, J., & Tubay Vergara, J. (2023). Analysis and Implementation of a Satellite Tracking System applied to pets using free software with GPS and GSM technology. Espirales Revista Multidisciplinaria de Investigación, 47(7), 48–56. DOI: https://doi.org/10.31876/er.v47i7.851

[18] Mistary, P. V., & Chile, R. H. (2015, December). Real time Vehicle tracking system based on ARM7 GPS and GSM technology. 2015 Annual IEEE India Conference (INDICON). DOI: https://doi.org/10.1109/indicon.2015.7443571

[19] Bossler, J. D., Goad, C. C., & Bender, P. L. (1980). Using the Global Positioning System (GPS) for geodetic positioning. Bulletin Géodésique, 54(4), 553–563. DOI: https://doi.org/10.1007/bf02530713

[20] Capozza, P. T., Holland, B. J., Hopkinson, T. M., & Landrau, R. L. (2003). A single-chip narrowband frequency domain excisor for a Global Positioning System (GPS) receiver. Proceedings of the IEEE 1999 Custom Integrated Circuits Conference (Cat. No.99CH36327). DOI: https://doi.org/10.1109/cicc.1999.777341

[21] Kumar, S., & Moore, K. B. (2002). Journal of Science Education and Technology, 11(1), 59–80. DOI: https://doi.org/10.1023/a:1013999415003

[22] Ndlovu, N., Muusha, P., Mtunzi, B., & Ndlovu, N. (2023). Design and implementation of an industrial monitoring and control system using an android mobile application. International Research Journal of Modernization in Engineering Technology and Science. https://doi.org/10.56726/irjmets44901

[23] Parkinson, B., Spilker, J., & Elkaim, G. (2003). Global Positioning System (GPS). In Encyclopedia of Space Science and Technology. DOI: https://doi.org/10.1002/0471263869.sst069

[24] Nyathi, T. N., Nyadongo, S. T., & Muusha, P. (2023). Design and implementation of an intelligent spray-painting system for a panel beating shop: Enhancing efficiency and precision in vehicle painting. International Research Journal of Modernization in Engineering Technology and Science. https://doi.org/10.56726/irjmets44967