

Satellite Tracking System

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Abstract

The satellite monitoring system was developed to address the challenges associated with monitoring satellites and movements in real-time. The satellite tracking system continuously gathered information about the location and movement of the satellites. This data was then transmitted to a computer for processing and analysis. Users could access the information through a smartphone or computer web-based interface, providing them with real-time updates on satellite positions. The main objectives of the project were to create a real-time satellite tracking system that enabled users to easily monitor the movement of satellites, analyze the collected data, and display it in the user interface. The project utilises two stepper motors, two limit switches, an LCD display and an Arduino ESP32 board. The system operated based on the data received from satellite signals, utilizing it to predict the movement of the satellite using TLE (Two-line element) data sets and providing outputs to the user via Internet connectivity. The results of this project demonstrate the successful development of a fully functioning device capable of tracking the movement of a selected satellite as it passes overhead. The LCD display showcases the satellite being tracked, along with the time it will orbit overhead, and the values of azimuth, elevation, latitude, and longitude for the selected satellite. Additionally, a user-friendly web interface features buttons for selecting satellites to track. Google Sheets was employed to display satellite data and the location of the currently selected satellite on a map. Following this, a comparison was made between the project's data and information from a specialized astronomical web page, In-The-Sky.org. ISS-ZARYA was tracked, resulting in latitude and longitude values of 32.63°N and 105.27°E. In contrast, In-The-Sky.org reported latitude and longitude values of 32.7°N and 105.6°E, respectively. Upon comparison, it was found that both the latitude and longitude values from the project and the In-The-Sky webpage were identical.

1. Introduction

In an era dominated by technological progress, satellites play a pivotal role in global connectivity, impacting communication, weather forecasting, and scientific research. The satellite tracking system represents a critical advancement in efficiently monitoring these orbiting entities, addressing the escalating demand for precision in an age reliant on satellite-based services. However, current tracking systems face challenges, including limited accuracy, high costs, and accessibility issues for smaller entities. This project contributes to the discourse on space exploration and satellite utilization by spotlighting the progress of satellite tracking systems. The goal is to

overcome existing limitations and meet the escalating demand for accurate, real-time tracking. By leveraging Internet technology, cloud computing, and advanced communication infrastructure, the proposed system aims to revolutionize satellite tracking, providing timely and reliable data for proactive maintenance and optimized operations. This innovation holds promise for diverse stakeholders, offering improved tracking capabilities, resource utilization, and informed decision-making in satellite operations, thus shaping the future of space-based technologies.

Several projects related to satellite tracking systems have been developed [1]-[7]. Putra et al. [1] introduced a TLE-based tracking system utilizing software calculations and magnetic rotary encoders, achieving high accuracy. The integration of hardware, software, and a stepper motor driver circuit enables precise antenna control. Anandan et al. [2] emphasized efficient communication links between satellites and ground facilities, ensuring successful operation and addressing the need for improved antenna options. Raghu et al. [3] utilized the satellite tool kit (STK) for simulation and analysis, highlighting the continuous availability of IRNSS satellites for enhanced navigation accuracy. Tan et al. [4] explored a hexapod mechanism for satellite tracking antennas, employing a controller that communicates with AC servo motors and position sensors. The hexapod antenna accurately tracked VNREDSat-1 using real-time calculations, providing optimal positioning angles. Yassin [5] developed satellite tracking software using TLE files for orbital data distribution, featuring a user-friendly interface implemented with Visual C++. Chen et al. [6] focused on enhancing multi-satellite tracking (MST) for reliable low earth orbit (LEO) satellite communications, introducing a probabilistic multi-hypothesis tracking (PMHT) approach. The algorithm, designed for shipborne digital phased arrays, demonstrated superior performance in numerical simulations. Nugroho et al. [7] investigated the impact of updating TLEs on LAPAN-A2 and LAPAN-A3 satellite position predictions. Utilizing North American Aerospace Defense Command TLE data, the study conducted orbit simulations, revealing negligible errors within 1 week but significant errors beyond, emphasizing the importance of timely TLE updates. Mission simulations of LAPAN-A2 showcased distinct imaging outcomes, underlining the critical role of updated TLEs in optimizing satellite tracking for enhanced accuracy.

This project aims to achieve three main objectives. Firstly, the development of a satellite tracking system. Secondly, a real-time visualization of satellite positions and movements will be created. Lastly, the data will be analyzed through the satellite tracking system. The goal is to enhance the understanding of satellite movements, providing a user-friendly and real-time display for easy monitoring. By accomplishing these objectives, the project seeks to contribute to advancements in satellite tracking technology, making it more accessible and efficient for users to gather and analyze data related to satellite positions.

The project's scope involves several aspects. Firstly, Arduino ESP32 is utilized as the main hardware. Secondly, two stepper motors are employed to rotate a pointer for real-time satellite tracking. Next, five specific satellites will be tracked: ISS-ZARYA, A-SEANSAT-PG1, RAZAKSAT, STARLINK-1281, and STARLINK-2612. Finally, implement a user interface based on Google Sheets and the ESP32 web server. This comprehensive scope ensures the integration of specific hardware components, real-time tracking functionality, and a user-friendly interface for effective monitoring and analysis of the targeted satellites.

2. Methodology

The Satellite Tracking System outlines a comprehensive solution for automated satellite tracking. The system, centred around an ESP32 microcontroller, integrates various hardware components, including two 28BYJ-48 stepper motors for azimuth and elevation control, an external stepper motor driver, limit switches for calibration, and an LCD for the user interface.

A crucial aspect is the establishment of connections with internet servers, leveraging the ESP32's Wi-Fi capabilities. This connection links the system to a web server platform and Google Sheets, enabling users to select satellites for tracking and providing real-time data display.

A key objective of the project is satellite detection using TLE data, a standardized orbital parameter format. The ESP32 processes TLE data obtained from sources like Celestrak, predicting satellite positions with the SGP4 file library. The entire system enables remote tracking through a web platform, displaying real-time satellite locations and providing a user-friendly interface for satellite selection and control.

2.1 System flowchart

The Satellite Tracking System's flowchart in Fig. 1 outlines an automated process. Beginning with ESP32 internet connection, it calibrates azimuth and elevation stepper motors crucial for orientation. If uncalibrated, a limit switch check ensures safe operation. After calibration, the user selects a satellite via a web server, and the system fetches orbital data from Celestrak. Stepper motors position in standby, displaying overhead timing on an LCD. Continuously checking for the satellite within range, the motors adjust to track it overhead. Azimuth, elevation, latitude and longitude values are displayed on the user interface, along with the real-time satellite location on a map.

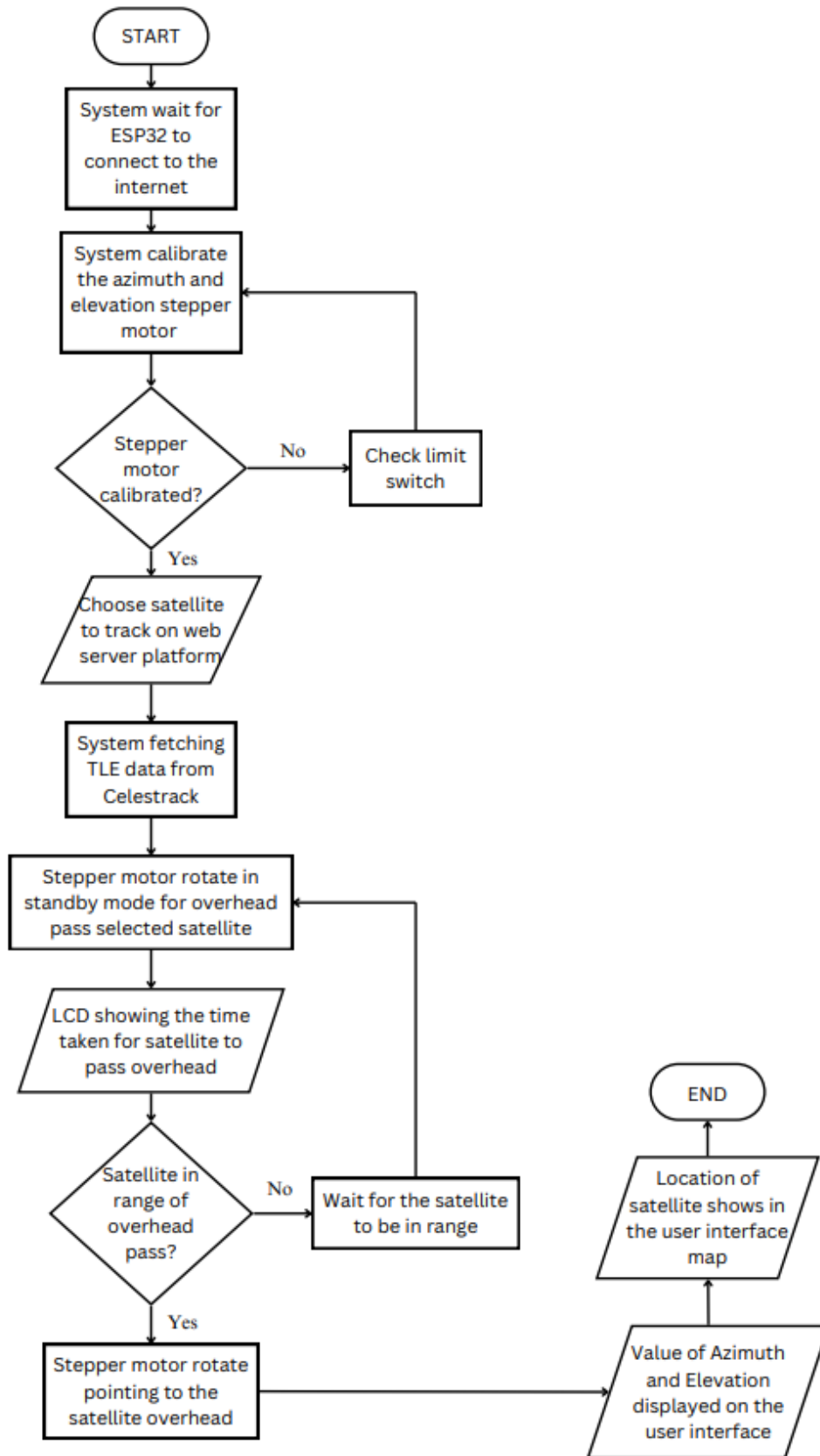


Fig. 1 Flowchart of Satellite Tracking System

The block diagram for the Satellite Tracking System depicted in Fig. 2 serves the following purposes. The primary hardware components of the system included the ESP32 and two 28BYJ-48 stepper motors. These motors enabled the rotation and positioning of the satellite, providing the system with the azimuth and elevation values.

The Google sheet and web server platform played a crucial role in both the input and output aspects of the system. It allowed users to select which satellite to track and served as a control interface. Additionally, it facilitated the display of satellite location, the azimuth, and elevation values of the tracked satellite on the platform.

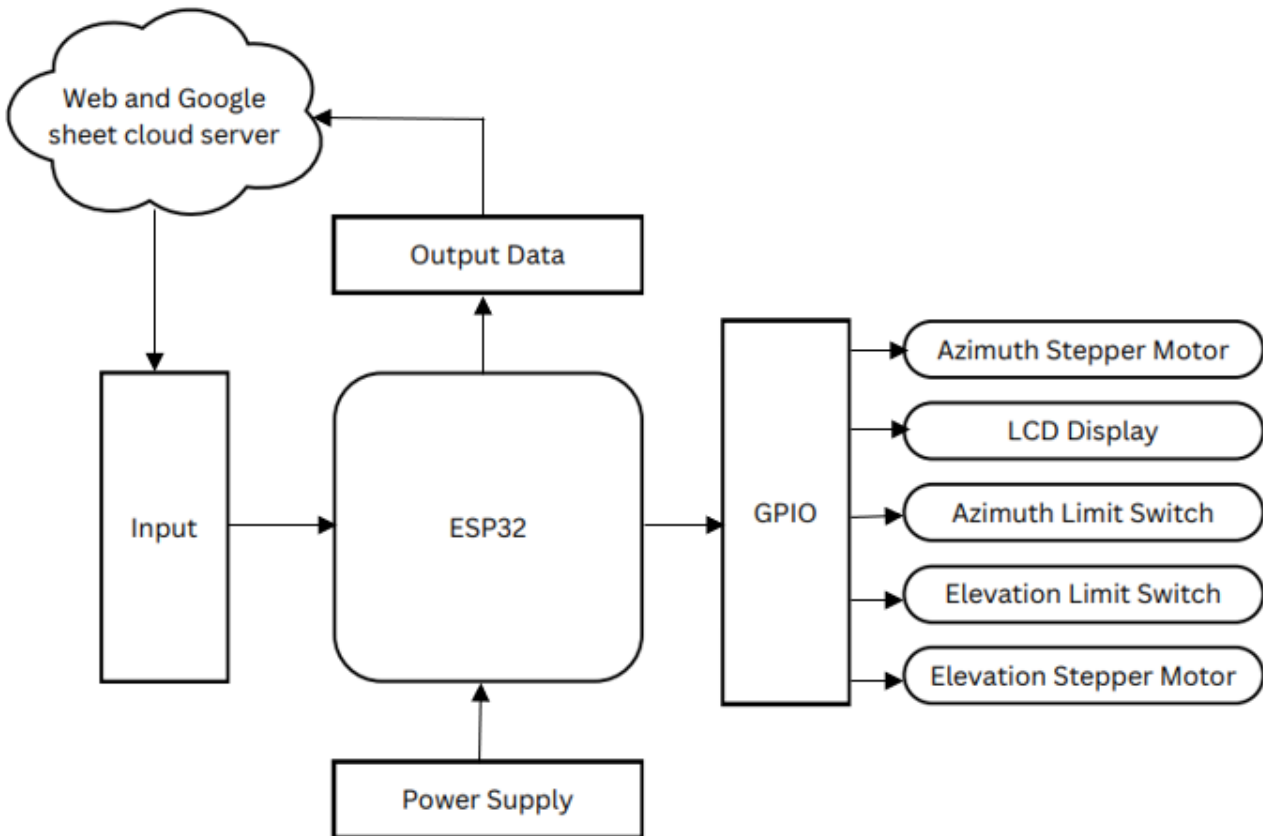


Fig. 2 Block diagram of Satellite Tracking System

2.2 Hardware Phase

To link the ESP32 microcontroller with a stepper motor, an external motor driver is connected through digital output pins, utilizing GPIO, SPI, or I2C protocols. Fig 3 illustrates this setup, detailing connections from ESP32 pins 4, 2, 17, and 16 to the first motor driver, and 26, 18, 19, and 23 to the second. Control signals, step and direction, transmitted from ESP32 were received by the motor driver, determining steps and rotation direction. ESP32 programming facilitated precise motor control, aligning it with the satellite position. Two limit switches on pins 32 and 27 prevented over-rotation. An LCD, linked to ESP32 via pins 22 and 21, displayed tracked satellite information and overpass time. Using USB-C or Micro-USB, the ESP32's expansion board allowed flexible power supply from a power adapter or power bank, enhancing project accessibility.

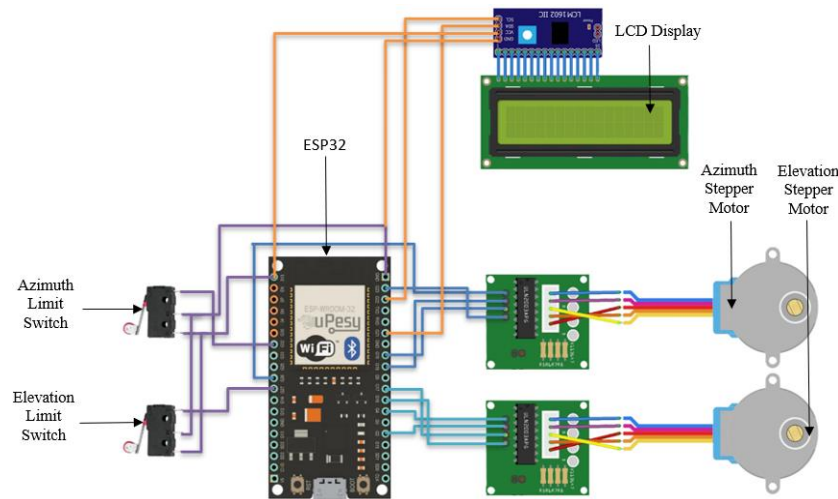


Fig. 3 Wire connection between ESP32, stepper motor, limit switch, and LCD display

2.3 Software Phase

Connecting an ESP32 to an internet server involves leveraging the ESP32's built-in Wi-Fi and implementing protocols to communicate with the server. The web server and Google Sheets were utilized in this project, where the website-controlled input by selecting and displaying the tracked satellite's location on a map. The ESP32 connected to the local Wi-Fi network, providing network credentials. Connection to the web page server required the ESP32's IP address. Creating an ESP32 web server involved configuring the Arduino IDE, integrating "WiFi.h" and "ESPAsyncWebServer.h" libraries, setting up WiFi credentials, and implementing security measures for authentication and HTTPS support. The ESP32 web server, executed through the ESPAsyncWebServer library, efficiently handled HTTP requests, ensuring a responsive and secure web-based user interface.

To connect an ESP32 to Google Sheets, a communication link was established between the ESP32 and a Google Sheets spreadsheet. This process involved setting up a Google Sheets document and a corresponding script using Google Apps Script. The script, deployed as a web app, processed HTTP POST requests from the ESP32, updating the spreadsheet. The ESP32, equipped with Wi-Fi capabilities, sent data via HTTP POST requests to the Google Sheets script, configured with necessary libraries and API keys. The Google Sheets script, written in Google Apps Script, parsed incoming data and manipulated the spreadsheet using the SpreadsheetApp method. This comprehensive setup ensured seamless communication between the ESP32 and both the web server and Google Sheets, enhancing the project's functionality and data processing capabilities.

2.4 TLE Parameter Phase

The project aimed to detect satellites by utilizing the TLE parameter data, which was a standardized format for describing a satellite's orbit. The TLE data consisted of two lines containing information such as the satellite's identification, orbital elements, and epoch time. To implement the project, the first step was to obtain the TLE data for the desired satellites. This information was publicly accessible through sources like CelesTrak satellite tracking websites. Once the TLE data was acquired, the project involved programming an ESP32 microcontroller to process and analyze the TLE parameters. The microcontroller used the TLE data to predict the satellite's position at a specific time. By combining the TLE data with received signals, the microcontroller could determine the presence and location of the satellite. The system used the SGP4 file library to calculate and forecast the satellite's movement.

3. Result and Discussion

The hardware is powered on by connecting the micro-USB to the USB cable to the laptop or any other power output, and the illumination of the LCD and ULN2003 Driver's LED indicates whether the connection is correct or not. If the LED lights up, then it indicates that the connection is correct. The full design of the project is shown in Fig. 4.

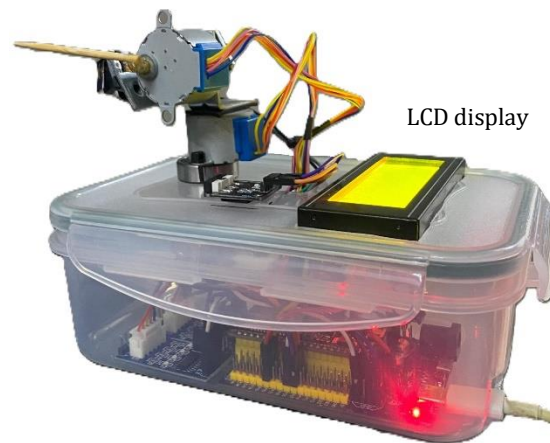


Fig. 4 Project final design

3.1 Stepper Motor Tracking Satellite

Upon activation, the project's ESP32 establishes a WiFi connection to fetch TLE data for the targeted satellite, such as ISS-ZARYA. Seamless internet access ensures efficient TLE retrieval, a crucial step for accurate satellite tracking. Subsequently, the system calibrates azimuth and elevation stepper motors, fine-tuning their rotational limits via contact with limit switches. This meticulous calibration enhances the tracking system's precision, ensuring optimal azimuth and elevation parameters. The calibrated setup guarantees stable and efficient satellite tracking, validated by successful stepper motor calibration. The serial monitor output in Fig 5(a) confirms the project locates towards ISS-ZARYA, displaying its latitude, longitude, and anticipated overhead pass time. The LCD in Fig 5(b) enters pass mode during close satellite proximity, indicating the time taken for the pass and facilitating stepper motor movement based on azimuth and elevation measurements.

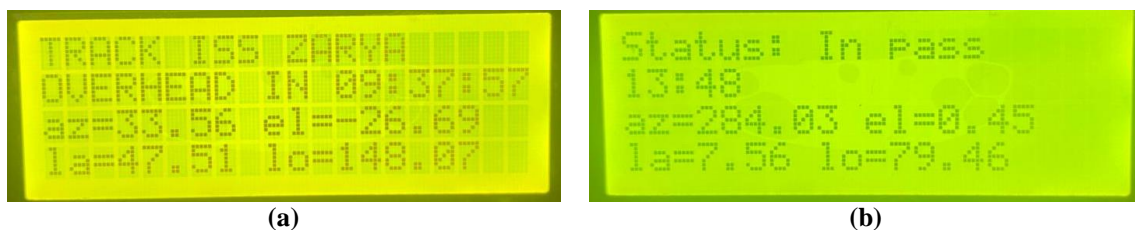


Fig. 5 LCD display (a) Standby mode; (b) In pass mode

3.2 Satellite Selection for Tracking Via Web Interface

The web interface, as shown in Fig 6, demonstrates a user-friendly platform for interacting with the satellite tracking system. This interface includes buttons for tracking various satellites, such as the ISS-ZARYA, A-SEANSAT-PG1, RAZAKSAT, STARLINK-1281, and STARLINK-2612. The web application's design is aimed at providing users with a streamlined and intuitive way to select and track various satellites.

Upon selecting a specific satellite by pressing the corresponding button, the system triggers a reset of the ESP32. This reset starts the tracking process for the selected satellite via the web application. Following that, the stepper motors responsible for azimuth and elevation are calibrated to ensure that they are precisely aligned to track the selected satellite.

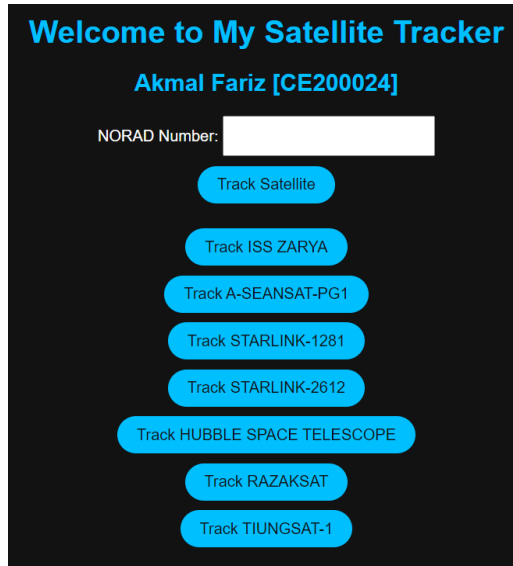





Fig. 6 Web platform interface for user to track the satellite using NORAD number

3.3 Google Sheets Satellite Data and Location on The Map

The position of the chosen satellite on the tracking map may be easily observed with the help of a Google Sheet map. The tracking map as of 2nd December 2023 properly displayed the spatial coordinates of satellite ISS-ZARYA. This information is outlined in Table 1. The table displays the satellite's position on a map. A satellite's strategic location on a map is determined by calculating its geographical coordinates, or latitude and longitude. One major benefit for users looking for immediate information is the ability to view a satellite's location in real-time.

The thorough recording of each monitored satellite extends over variable durations, ranging from thirty minutes to an hour. This extended recording period facilitates a more in-depth analysis of the satellites' intricate movements and trajectories. Google Sheets serves as a comprehensive database of satellite data. All users can interact with this Google Sheets with a given web link. It includes not only the satellite names, but also important data points such as azimuth, elevation, latitude, longitude, and altitude.

Table 1 ISS-ZARYA orbital path. Red circle shows the position of the satellite at a particular time


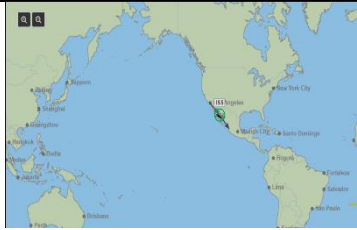




Time	Map
First minute	
Thirty minutes	
An hour	

3.4 Comparison with In The Sky webpage

To evaluate the precision of the satellite's position as shown on the map, a particular webpage that focuses mostly on astronomy was used. This enhanced the project's intended results by adding a level of thorough observation. In-The-Sky.org, a website carefully selected for its handy features and user-friendly tools intended for celestial observations and satellite tracking, was the platform of choice for this experimental comparison.

The website's interactive features were utilized to adjust the time and date settings, ensuring that the project's testing results matched the intended use. The visualization on Google Sheets maps, on the other hand, is done without refreshing the satellite path, whereas the visualization on the "In The Sky" website is done after refreshing the satellite path for a few minutes, hence the difference in the path displayed on the project and on the website. ISS-ZARYA was tracked, resulting in latitude and longitude values of 32.63°N and 105.27°E. In contrast, In-The-Sky.org reported latitude and longitude values of 32.7°N and 105.6°E, respectively. The comparison for both Google Sheets and "In The Sky" website is shown in Table 2 below.

Table 2 Comparison of ISS-ZARYA position at a particular time with In The Sky

Time	Google Sheets	In-The-Sky.org
First minute		
Thirty minutes		
An hour		

4. Conclusion

The project effectively addresses the increasing demand for efficient satellite tracking by introducing a real-time monitoring solution through Internet technology. Key findings highlight its potential to revolutionize tracking systems, providing continuous data collection, instant analysis, and proactive control. The project significantly improves satellite service performance and availability, emphasizing real-time visualization, analysis, and user insights. The integration of Arduino ESP32 and stepper motors proves successful for remote monitoring. The system exhibits adaptability to evolving satellite technologies. Future suggestions include incorporating machine learning algorithms for enhanced prediction accuracy, exploring advanced sensors for precise orientation, and expanding the database to accommodate diverse satellite types. These enhancements aim to refine tracking capabilities, ensuring the project's continued effectiveness in the dynamic landscape of satellite technologies.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Akmal Fariz Hamdi; **data collection:** Akmal Fariz Hamdi; **analysis and interpretation of results:** Akmal Fariz Hamdi; **draft manuscript preparation:** Akmal Fariz Hamdi, Mariyam Jamilah Homam. All authors reviewed the results and approved the final version of the manuscript.

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