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Acquisition of Flight Data from Mini Unmanned Aerial Systems

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Abstract

Swift progress in unmanned aerial vehicle (UAV) system technology mandates effective real-time monitoring and accurate flight data capture for building an optimum target-based cutting-edge UAVs. In the current epoch of modern-UAV era, small size and mission-oriented UAV prototypes are increasingly pervasive. This study highlights the design of a data acquisition target-based mini-UAV and introduces a novel telemetry software solution to safe and reliable communication between mini-UAV and ground control station (GCS). The primary aim is to demystify the proposed wireless communication software solution on mini-UAV capability in obtaining and managing comprehensive flight data. While creating the appropriate target-based mini-UAV prototype architecture, the features that we aim to realize for the UAV components are addressed with a system approach and the component selection is presented in detail. The integration point of the selected components is conveyed in general terms. Thus, a guiding resource for future UAV studies will be presented. Then, the processes of obtaining the flight data of mini-UAVs will be addressed. At this point, the design logic of the required commands and background software will be conveyed. Obtaining the flight data of mini-UAVs will provide important scientific contributions to the literature in terms of aviation research and safety analysis. Obtaining the flight data of mini-UAVs will meet the data set needs for flight safety improvements and air traffic management optimization studies. A general analysis of the flight parameters obtained as a result of obtaining the flight data will be performed, the predictability of the parameters will be evaluated, and the analysis of the flight phases will be performed by presenting the relationships of the parameters according to the flight scenarios and the sections taken from the parameter set in the study. This study can be considered as a concrete example of situational monitoring of UAVs.

1. Introduction

The first crewed powered takeoff had been occurred in 1903 as a milestone for aeronautics. Since that fateful day, innovators are zeroing in on their pursuits of ensuring the continuous airworthiness in the sky. Indeed, seven years before, in 1896, Aerodrome No 5’s flight have been a triumphant symbol of first powered uncrewed aviation (Schwing, 2007).

Above the centenary of elevation to prototypes, nowadays UAVS have stepped in to modern UAV age for their proficiency in addressing instantaneous and pinpoint flight data access (Wyatt, 2013). Revolution of unmanned aircraft system technology has been determined by miscellaneous significant advancements in diverse areas. Advancements in radio control systems, in conjunction with the introduction of electric motors and progress in micro-mechanical systems, micro-electronic components, and sensors, facilitated the feasibility of employing small unmanned aerial vehicles in the 1990s (Mueller,2009). These technological breakthroughs made it possible to develop more reliable and versatile UAVs.

Increasingly widespread, mini-UAVs serve as crucial tools for instant online intelligence and are projected to be central in future missions (Abershitz et al.,2005). Considered as the principal goal of UAVs are intelligence, surveillance and reconnaissance (ISR) mission. Today’s world state-of art mini-UAVs come to the forefront of the wide-range capabilities in demanding operational conditions, ISR mission, low-risk and low-cost operation compared with traditional manned flights (Butler,2001). Real time monitoring, operational area situational awareness and UAV parameter monitoring concept have a great importance for gaining superiority and handling situations.

In this point, acquiring flight data from cutting-edge mini-UAVs is one of the primary research priorities. This involves not only analyzing the performance of numerous sensors and system components but also integrating this data to accurately assess flight parameters. Effective data integration ensures that UAVs can operate safely and efficiently in diverse conditions.

A-number-of parameters have been triggered in UAV construction processes. These parameters include factors such as aerodynamic design, power efficiency, and communication capabilities (Konar, 2009; Konar,2018; Konar,2020; Erşen et. al.,2021). In this context, parameter optimization through mission-specific UAV design is of critical importance. Tailoring UAV design to meet specific mission requirements enhances performance and ensures the successful completion of tasks (Bagis 2018).

Though literature has a diverse range of methods that is appropriate for acquiring data from UAVs, especially small ones (Dantsker et al.,2019; Ho et al., 2015; Dankster et al., 2014; Tsouros et al., 2019; Brusov et al.,2011; Yang et al., 2018; Hao et al.,2022; Taha et al.,2011; Tahar et al., 2012; Luo et al.,2017; Jia et al.,2019; Popescu et al.,2019; Say et al.,2017; Schwarzbach et al.,2009)

Dankster studies on Sensor Data Acquisition System and integration of avionics UAV components (Dankster et al..,2019) Ho et al. suggested a wide-range wireless sensor network (WSN) for acquiring UAV data and evaluate the performance in the aspects of algorithms (Ho et al.,2015). Dankster et al. focuses their studies on high-frequency SDAC and evaluate the overall performance by using ground and flight tests (Dankster et al.,2014). Trosouros et al. states the UAV data acquisition methods with the axis of sensing systems and their complement the Internet of Things (IoT)-based techniques (Tsouros et al.,2019). Brusov introduces a flight data acquisition system for Small Unmanned Aerial Vehicles (SUAVs) With suggested automatic data acquisition model mini and micro-UAV flight dynamics have been monitored and understanding the characteristics of SUAV and flight data analyses have been enabled (Brusov et al.,2011). Yang et al. used sensing data acquisition technique by utilizing wide wireless UAV sensor data networks (Yang et al., 2018). Hao et al., addressed in UAV-based IoT real-time flight fata acquisition technique which aims to expand lifetime of IoT and consumed energy minimization (Hao et al., 2022). Taha et al., proposed a flight data collection technique and cumulate their efforts on utilizing flight tests for identifying the mathematical model of small- scale UAV helicopters. (Taha et al.,2011). Tahar et al., creates a 3Dmodel by using UAV images and evaluate the model usage as the source of geographical information systems data (Tahar et al.,2012). Luo et al., demonstrated cloud-based model for UAV data acquisition and processing (Luo et al.,2017). Jia et al., observe the flight modes and developed data collection strategies with the concept of age of information and observe the mathematical model for UAV data acquisition (Jia et al.,2019). Popescu et al., (Popescu et al.,2019). Say et al, put forward a collaborate partnership and data forwarding manner for UAV studied data framework chosen (Say et al.,2017). Schwarzbach et al., chose an open-source autonomous pilot assistance system for UAV mission monitoring (Schwarzbach et al.,2009).

Weighed the examinations in the literature, it is clearly observed that obtaining flight parameters from UAV integrated hardware or software have presented an imp reliable way. When the literature is examined in general terms, it is observed that wireless and sensor technologies are widely used for communication system solutions. In this study, a mini-UAV is designed for acquiring flight data. UAV components are selected to optimize target-based UAV feature monitoring, chiefly interference prevention and noise reduction. After the target-based mini-UAV construction has been built, UAV prepare for implementations of hardware and software requirements. This paper presents a novel approach in a reliable flight data acquisition process with using telemetry protocol. Along with software, the hardware structure of mini-UAV has been discussed elaborately. Ensuring the software and hardware compatibility, mini-UAV data acquisition flights are conducted. Acquired flight data from successful mini-UAV flights enables flight parameters. Flight parameters are discussed thoroughly, and the results and analyses of the mini-UAV flights represented with graphs and maps overall.

2. Methods

This section is to clarify the selection of flight data acquisition target-based mini-UAV onboard components. İn line with chosen criteria. After the special purpose mini-UAV prototype has been built, novel suggested approach for reliable data communication has been applied.

2.1. Mini-UAV Target-Based Component Selection

Mini-UAV platform configuration suggest a compromise between the prerequisites (Benito et al.,2014). Prerequisites are classified into three main criteria in general. Mini category UAV construction requirements such as size, mass, payload capability, endurance and other linked parameters comes first (Papa et al.,2014). All the on-board materials must be assessed over the size criteria.

Secondly, criteria assign for data acquisition purpose mini-UAV flight requirements. Mini-UAV should be purified from the noise and interference of signal. For this purpose, numerous enhancements have been effectuated. Vibration dampener carbon-fiber frame structure has chosen (Khan et al.,2011). The preference has been given to brushless motor due to its advantage of eliminating the surface wear and brush arching problems (van Niekerk,2009). Mini-UAV Electronic Speed Control (ESC) and motor units are regulated in compatibility to keep mini-UAV in a safety performance are (Chaput,2018). Mini-UAV propeller material has been appointed plastic ones cause of the impact of the propeller payload on energy consumption and motor performance (Rutkay et al.,2016).

Thirdly, mini-UAV systems are equipped with the effective and capable sensors to secure reliable flight parameters. In this context, predilections for superior units are being discerned.

Figure 1. UAV

2.2. Telemetry Software

This section unveils a methodical framework on robust data acquisition and handling from on-board avionics software, centering on the integration of telemetry hardware, communication systems, data logging mechanisms, and error handling protocols. The suggested framework, endeavors to augment mini-UAV operation's reliability, accessibility and maintainability factor, underpinning the mission capabilities and welfare.

2.2.1. Initialization of Communication Systems

The mini-UAV telemetry data acquisition system commences with the setting-up two critical communication links to guarantee accurate data transfer between the flight control system and ground control station. The beginning phase structures facilitating the requisite connections through the utilization of the MAVLink (Micro Air Vehicle Link) protocol. MAVLink protocol offers solutions to users in the process of creating target-oriented mini-UAVs by incorporating the requirements of wide range tracking and mapping, reliability and lightweight (Chalkiadaki, A. et al.,2021). MAVLink connection is configured by a local network address (e.g., udpin:localhost:14550), which facilitates seamless data transmission by ensuring that both endpoints are correctly addressed and synchronized.

Simultaneously, a serial communication link is established with the telemetry module. The telemetry module acts as an intermediary, transmitting data between the flight control system and the ground station. The serial interface is configured to operate at a specified baud rate, which ensures that data is transmitted at a speed suitable for real-time telemetry updates. The specific baud rate is selected based on the data throughput requirements and the capabilities of the communication hardware. This configuration is crucial for maintaining the integrity and continuity of the data stream, especially during high-speed or complex flight maneuvers.

2.2.2. Handshake Protocols

Data transmission has handshake protocols which is used before the communication agreement constructed inter-party (Peeters,2005). After communication links established between flight control card and telemetry, heartbeat messages from the flight control unit are waited for system. Heartbeat mechanism is one of the most widespread techniques among the remote nodes by sending periodic messages to inform other nodes that they are alive. If there is no heartbeat received for a certain period, the node is pronounced defunct (Johnson, 2005). Heartbeat plays an important role in the aspects of enhancing system safety. In this study, heartbeat indicator provides information about telemetry system readiness condition for data transmission. This message covers the system and component identifiers. System health monitoring is pivotal for reliable and continuous data acquisition of mini-UAV, supplied by heartbeat messages.

2.2.3. Continuous State Monitoring and Data Acquisition

After the handshaking protocols, telemetry system is ready to acquire data and write messages coming from MAVLink connection. Telemetry system continuously monitoring the messages through an infinite loop. There are two conditions. If the receiver catches a message from MAVLink, message will give us information about the operational conditions. If there is no message occurs, infinite loop will continue. Thereby, real-time flight data acquisition is put into effect.

2.2.4. Creating a Dictionary for Defining Mini-UAV Flight Parameters

Operational messages are adjusted by infinite loop. Messages are related to UAV operational parameters. Writing codes for catching messages but the telemetry system has no clear information about 'what is the message', 'which packet of input data send', 'what is the unit of this data'. To mitigate information overload and rectify informational deficiencies, data address methodology is harnessed. To evidently addressed, a dictionary has been constituted via flight data received from each sensor and unit is labeled with related scientific unit. each sensor and unit have equivalent to different types of messages. By the way, the dictionary provides their users to revise dictionary for scientific unit conversation and related types of applications.

2.2.5. Converting Data into Message

Data converted into a string from any preaddressed dictionary. Then, adding timestamp to data and hashing. One of the advantages of hashing is that it does not require index storage space. With hashing, the records are distributed to places that normally require an index (Singh, 2009).

2.2.6. Conditional File Management Based on Armed Status

A key feature of the telemetry system is its ability to conditionally log data based on the UAV's armed status. When the UAV transitions to an armed state, a new log file is created. This file is uniquely named based on the current timestamp, ensuring chronological organization of flight data. This naming convention facilitates easy retrieval and analysis of the data, allowing for detailed post-flight analysis and performance assessment.

Conversely, when the UAV disarms, the open log file is promptly closed. This practice ensures that all data is properly saved and prevents potential data corruption that could occur if the file remained open. The systematic management of log files based on the armed status is critical for maintaining data integrity and reliability. Additionally, the use of time-based file naming allows for automated data processing and integration with other flight data management systems.

2.2.7. Processing and Logging of Telemetry Data

The proposed communication system is operated by laying down the relevant units and evaluating the data coming from the sensors. In addition, the processed data is recorded and the flight data set is obtained. In the mini-UAV prototype, the sensors that will provide data on flight changes are positioned on the battery and GPS modules.

2.2.7.1 GPS Data Handling

GPS data contains the latitude, longitude and altitude information of the mini-UAV. Using this information, it is possible to obtain ground speed information. The file is opened by checking the power status. Messages from the sensors are displayed as different message types. In the MAVLink protocol architecture, GPS messages are assigned as the GPS_RAW_INT message type. Data is processed and sent via ports. After sending, the messages are written to the file and given meaning.The system extracts essential parameters such as latitude, longitude, altitude, and velocity from the GPS messages. The altitude value, for instance, is converted from millimeters to meters for standardization. This conversion is necessary to align with commonly used units in flight data analysis.

2.2.7.2 Battery Status Monitoring

UAV battery sensors play a critical role in monitoring and managing battery performance. Battery sensors carry information such as voltage and current monitoring and remaining battery percentage. The battery message type assigned for the MAVLink data communication protocol is BATTERY_STATUS. This message type acts as a BMS in a sense and provides safety critical data such as the SoC. When the mini-UAV is powered up, the file is opened and the message that the battery wants to transmit is received by determining the BATTERY_STATUS message type. It is determined which flight parameter related to the battery provided by the sensor data is included in the received message and the message is written to the file.

2.2.8. Error Handling Mechanisms and System Resilience

To ensure robustness, the telemetry acquisition system incorporates comprehensive error handling mechanisms. Exceptions are caught and logged, allowing the system to continue operation despite encountering errors via try-except blocks (Alvarez et al.,2024). This resilience is crucial for maintaining continuous data acquisition during the UAV's operation. The error handling routines are designed to minimize downtime and ensure that the system can recover gracefully from unexpected issues. This includes handling communication timeouts, data corruption, and unexpected disconnections, all of which are critical for maintaining system reliability.

2.2.9. Autonomous Boot-up Procedures for mini-UAV Telemetry Systems

The proposed communication system model includes an operating system (OS) design within itself. OS executes the command in the string at the OS level. With the OS command, MAVProxy, which is the MAVLink Proxy service, is automatically started. This automatic start facilitates the data flow between the UAV and the UAV. Another advantage of the proxy system is that the data is cached and accessed faster (Zeng et al., 2004). This automatic procedure receives the mini-UAV flight data via the MAVProxy software and transmits this data to the UAV via the UDP port. The use of a mini-UAV communication system with autonomous start-up procedures ensures that the system is commissioned quickly and consistently even under difficult operating conditions.

3. Mini-UAV On-Board Avionics Integration

In this section, the interface units of mini-UAV which is used for data acquisition process are detailed. Figure 3 shows that the schematic architecture of system components.

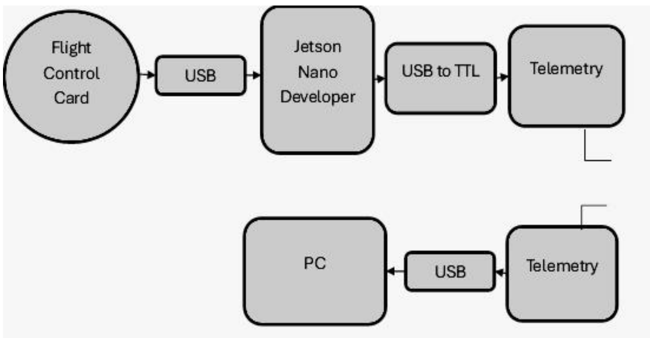

Figure 2. System Architecture

The flight control unit integrated into the UAV is a crucial component engineered for the acquisition and transmission of flight data. The data generated by this unit is conveyed to the Jetson Nano Development Kit through a USB connection. The Jetson Nano Development Kit is a high-performance artificial intelligence unit renowned for its substantial computational power and AI processing capabilities. Once the USB connection is established, the raw data obtained from the flight control unit is transmitted to the Jetson Nano Development Kit, where it undergoes processing.

Subsequent to the data processing, the processed data is transmitted to the ground station. This data transmission is facilitated by a USB-to-TTL converter, which allows the data to be sent using the UART protocol. The telemetry device then transmits the data to the ground telemetry device via a wireless connection, ensuring reliable data transfer within a wireless environment. The data format utilized in this process is JSON.

The ground control station serves as a software interface for the processing and analysis of the received data. When the telemetry device is connected to the computer via USB, it streams data to the ground control station interface. This configuration enables users to monitor and analyze flight data in real-time. Ensuring the accuracy of data transmission is essential for the effective operation of the ground control station. Figure 4 illustrates a visual representation of the data acquisition process from the ground control station.

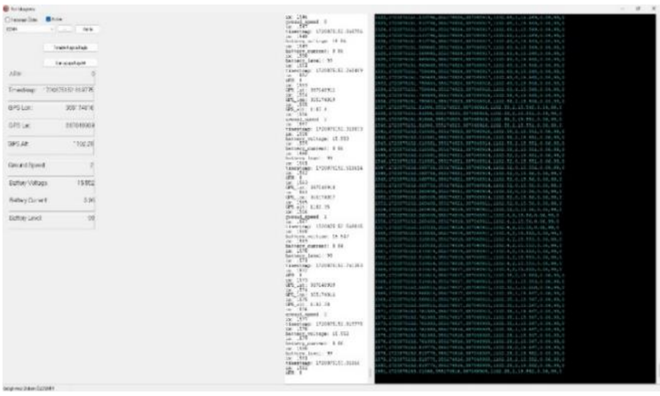

Figure 3. Ground Control Station

Figure 4 demonstrates the mini-UAV system components for flight data acquisition.

Figure 4. Mini-UAV

4. Results

This section elucidates the results of mini-UAV flights conducted specifically for the purpose of acquiring detailed flight data. This section elucidates the outcomes from mini-UAV flights, based on the data acquisition purpose flights.

Following the completion of hardware and software integration, mini-UAV flights were conducted to achieve flight data acquisition, and the flight data was successfully captured. Figure 6 illustrates the waypoints assigned for the mini-UAV flight conducted.

Figure 5. Mini-UAV Path Planning

The flight is structured into the phases of takeoff, navigation, and landing. In this context, the flight dataset was analyzed and found to encompass 12,572 data rows corresponding to a flight duration of 3 minutes and 35 seconds. The navigation phase selected for examination includes instantaneous flight data spanning from row 6,421 to row 11,740, representing a 3-minute segment of the flight. The dataset comprises 5,321 observation units and 9 variables across its columns.

To data analysis, the navigation phase selected extends from waypoint 2 to waypoint 26. Graphs depicting the parameter data pertinent to the navigation phase of the flight have been constructed. Figures 6 through 16 present these graphs.

During the analysis, there is an arm feature indicating the engage/disengage status of the UAV. The UAV's operational status has been monitored through this parameter. Each electronic device is equipped with an internal counter. The number of incoming data packets and the information from the electronic device's counter have been assigned as separate features within the dataset. This allows for the analysis of the sampling rate of incoming data packets and the associated transmission delays within the dataset. Figure 9 presents a graph related to this analysis.

The process of acquiring flight data enables users to perform real-time monitoring and gain access to comprehensive flight details. It facilitates the monitoring of real-time data during the flight and allows for a detailed analysis of flight performance. The data obtained is a critical resource for evaluating the UAV's performance, verifying the reliability of the system, and optimizing flight operations. Moreover, this data collection process provides a valuable reference for future research and can contribute to the development of strategies aimed at enhancing data accuracy and system efficiency in forthcoming applications.

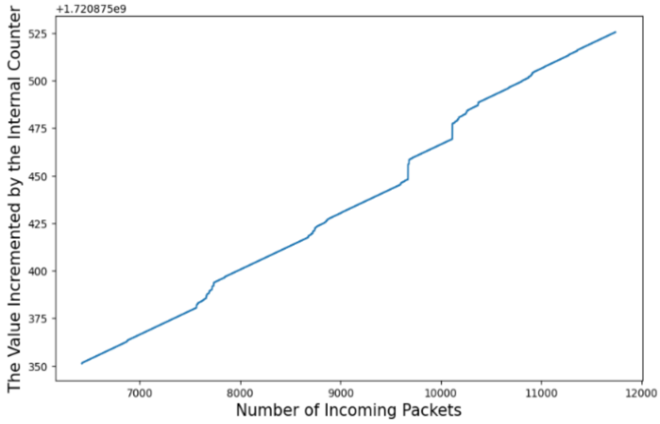

Figure 6. Relations Between Timestamp vs Internal Counter Value

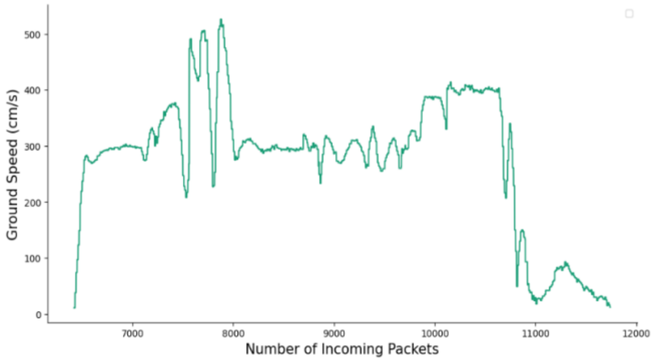

Figure 7. Ground Speed Change Over Time

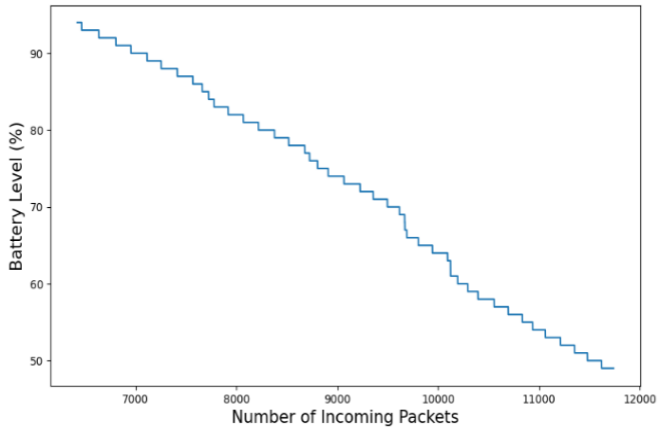

Figure 8. Battery Level Change Over Time

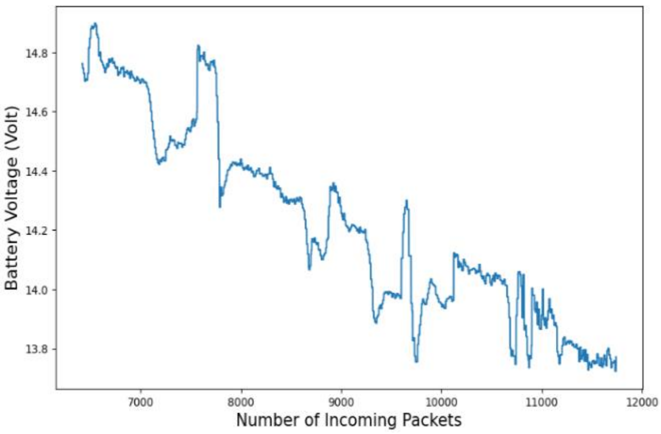

Figure 9. Battery Voltage Change Over Time

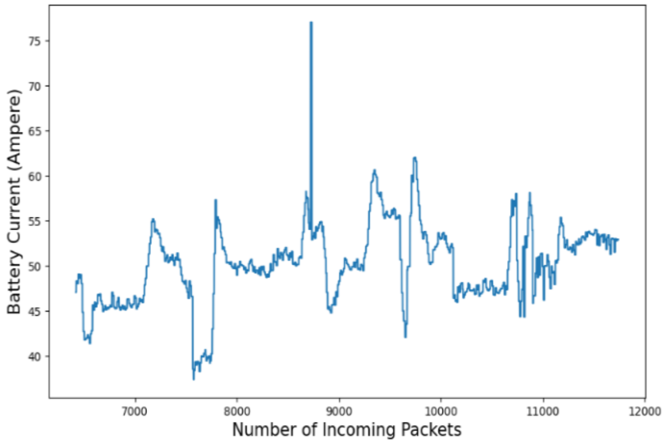

Figure 10. Battery Current Change Over Time

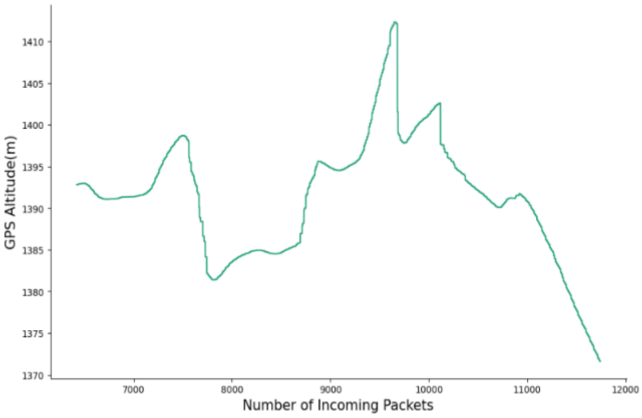

Figure 11. GPS Altitude Change Over Time

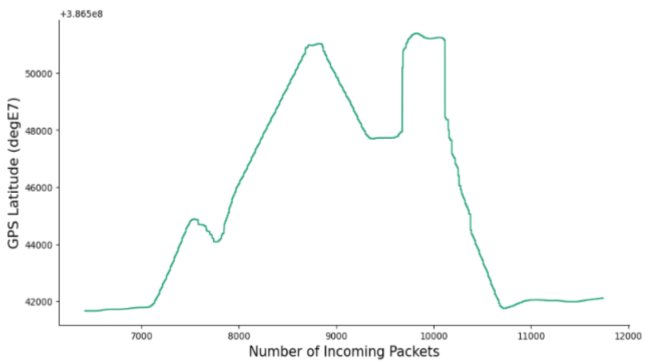

Figure 12. GPS Latitude Change Over Time

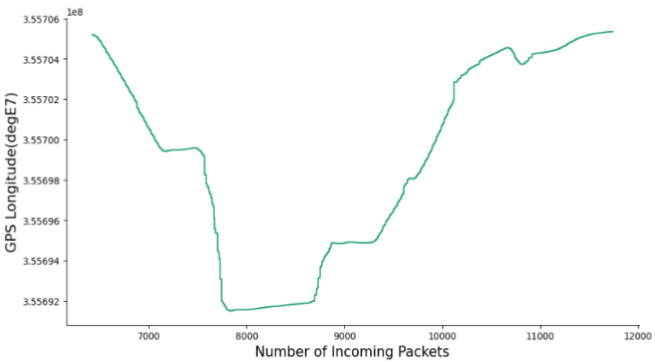

Figure 13. GPS Longitude Change Over Time

For the analyzing between the flight parameters correlation heat map is used. The term of correlation signifies to define quantitively in the aspect of degree of interdependence between two or more than two variables (Roggers,1959). Map designed for represent relations in the range of -1 to 1. -1 and 1 are the maximum relation parameters respectively negatively relation and positively relation. Heat map colors indicate the flight parameters relations with warm and cool colors. Figure 14 indicates the flight parameters' relations. Correlation heat map in accordance with flight data set's flight parameters empowered users to make informed decisions.

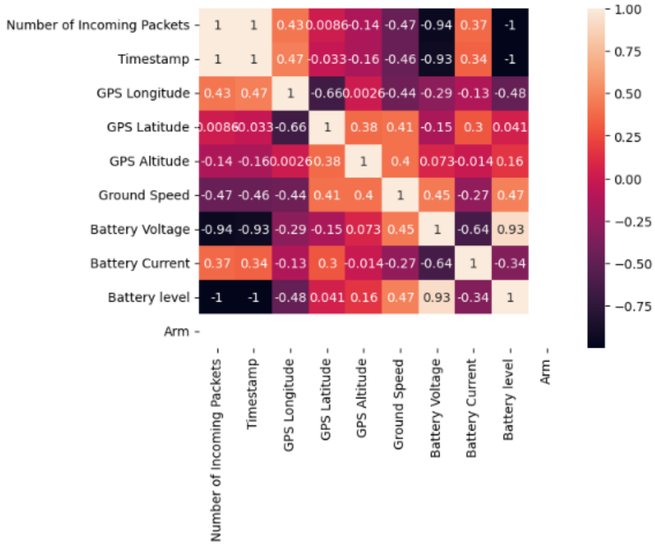

Figure 14. Flight Parameters Correlation Heat Map

Three-Dimensional flight pattern graphs present users to evaluate flight in the aspect of phase mode maneuver etc. Figure 15 and 16 shows flight pattern graphs. To review the map in detailed, we determine the non-colored right upper area to compare with Figure5 flight pattern, understand that mini-UAV is maybe in the hover mode. On the other hand, non-colored area can represent unscaled space. Although this situation is not definitive, it demonstrates the effectiveness of the data set in estimating the flight phase and maneuver.

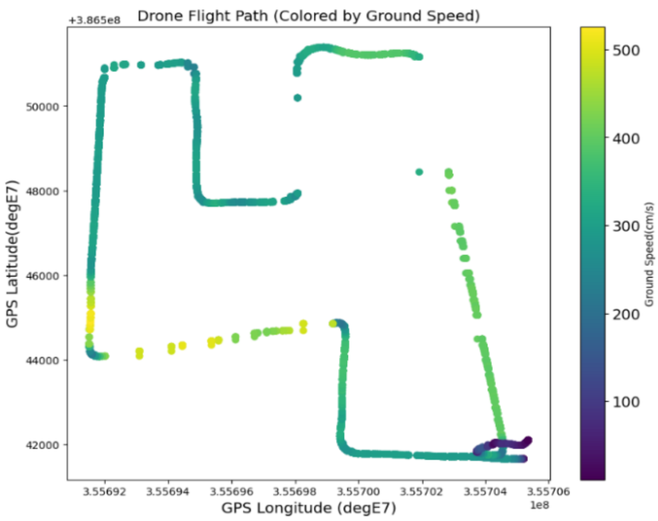

Figure 15. Flight Pattern Colored by Ground Speed

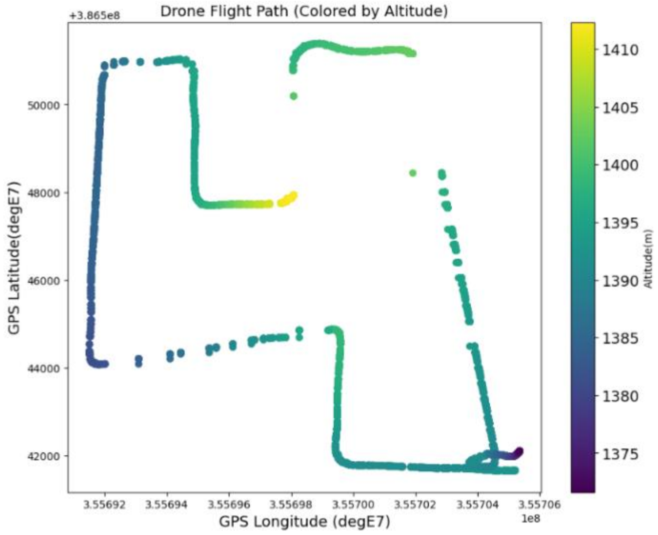

Figure 16. Three-Dimensional Flight Pattern Colored

5. Conclusion

In this study, a mini-UAV prototype was meticulously designed to facilitate the acquisition of flight data through conducted UAV flights. The prototype has been optimized to effectively capture flight data from UAV components. Throughout this process, custom-developed software for telemetry communication was employed to ensure the secure and accurate transmission of data. The data retrieved from the ground control station was successfully processed, enabling both real-time monitoring and comprehensive analysis.

In conclusion, this study offers an innovative and effective approach to data collection and processing for mini-UAVs. The implemented system has significantly improved the accuracy and efficiency of flight data, while also ensuring the reliability of data transmission. The software and telemetry communication strategies utilized may serve as valuable references for other UAV projects. Future research could focus on areas such as predictive analysis of flight data, monitoring system performance and parameters according to varying flight scenarios, enhancing UAV performance through AI-supported decision-making processes, and refining system design for diverse operation scenarios.

This study will be a resource for the integration of route-based parameter analyses into the autopilot in future studies and the pre-flight analysis of the effects of the obtained flight parameters on the UAV configuration; and for determining how the UAV parameters will be observed before, after and during the flight. In future studies, it is envisaged to improve the prototype configuration, make parameter-based improvements and design the parameters given as input according to the desired output parameters. By examining the flight phases in detail, estimating the relevant flight parameters in the flight phase of UAVs and determining how a maneuver will affect the UAV parameters will be made possible by obtaining and evaluating flight data sets from mini-UAVs.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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