UDC 004.05
DOI https://doi.org/10.32782/2663-5941/2023.6/24

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CLOUD-BASED GPS SIGNAL PROCESSING OF THE DRONE USING RASPBERRY PI AND PIXHAWK 6C FLIGHT CONTROLLER

Unmanned Aerial Vehicles (UAVs) are rapidly evolving, finding applications across various sectors like aerial photography, agricultural monitoring, and scientific research. Central to their functionality is the precision and reliability of GPS data, crucial for accurate navigation and task execution. This article focuses on integrating two renowned hardware components – the Pixhawk 6C flight controller and the Raspberry Pi Zero W computer – for the efficient acquisition and transmission of GPS data to the Amazon Cloud environment. Emphasizing real-time data handling, this system notably enhances UAV capabilities in both scientific and commercial projects. The Pixhawk 6C is renowned for its robustness, managing different UAV types with ease, while the Raspberry Pi Zero W, despite its compact size, efficiently processes and transmits the GPS data. This combination not only ensures precise UAV positioning but also optimizes cost by reducing the need for extensive onboard processing capabilities. The utilization of Amazon Cloud for data storage and processing provides a scalable, secure, and accessible environment, crucial for analyzing flight patterns and environmental data effectively. This setup enables real-time monitoring and control of UAVs, significantly improving their operational safety and efficacy. Furthermore, this integration opens up new possibilities for advanced UAV applications. By leveraging cloud computing, it allows for more complex data analytics and machine learning algorithms to be applied to the GPS data, offering insights that can improve flight paths and operational strategies. This system's architecture, combining reliable hardware with advanced cloud-based capabilities, signifies a major step forward in UAV technology, enhancing their application in increasingly sophisticated and demanding environments.

Key words: *cloud data processing, GPS telemetry, mini-computer, unmanned aerial Vehicles, controller.*

Formulation of the problem. The technological development of robotics in recent years has led to the widespread use of mobile robots and unmanned aerial vehicles (UAVs). Among the main development trends, we should highlight: intelligent technologies, big data processing, energy saving, hardware and software, etc. [1–3]. UAVs are actively used in various fields: from commercial tasks, such as delivery of goods and aerial photography, to specific scientific research and environmental monitoring. The basis of UAVs' success lies in their reliability, autonomy, and precision in navigation, where GPS systems play a significant role. GPS data are a key element for UAVs, as they ensure the accuracy of flights, navigation safety, and efficiency in task execution. However, with the increasing amount of data comes the need for their rapid processing, analysis, and storage.

UAVs have experienced a sharp decrease in cost and improvements in technical aspects in recent years, significantly expanding their application in various fields of activity. However, regardless of the tasks set for UAVs – from simple photography to complex scientific missions – the accuracy and reliability of their movement remain paramount. The core of such accuracy is Global Positioning Systems (GPS). In this context, with the constantly increasing volume of data and the need for their processing, traditional storage and processing systems may not meet modern requirements. This has led to the need for the use of new technologies, in particular, cloud solutions for data storage and processing.

Analysis of recent research and publications. A review of the literature demonstrates the activity of researchers in this area. In the work [4] by Masataka Kan and his colleagues "Development of Drone Capable of Autonomous Flight Using GPS", the experience of creating an experimental UAV capable of autonomous flight using Raspberry Pi 2.0 (Model B) for flight control and a GPS sensor on AR.Drone 2.0 was studied. The authors conducted GPS calibration by measuring the deviation between the position where the GPS sensor was installed and the data collected using GPS. The experimental UAV was able to autonomously fly according to planned routes, demonstrating the potential and importance of further research in this area. A significant contribution to the field of autonomous Unmanned Aerial Vehicles (UAVs) was made in the article [5] "VAGADRONE: Intelligent and Fully Automatic Drone Based on Raspberry Pi and Android" by authors Saifeddine Benhadhria, Mohamed Mansouri, Ameni Benkhlifa, Imed Gharbi, and Nadhem Jlili. In this research, the authors discuss the creation of an intelligent and fully autonomous UAV based on Raspberry Pi and Android. Considerable attention in the article is given to how to ensure autonomy and intelligence in UAVs. The use of the Android operating system allows for the integration of a large number of applications that can be used directly by UAVs depending on the context of the mission. This opens up opportunities for the implementation of tasks such as object identification, facial recognition, and counting of objects (e.g., signs, people, etc.).

The literature sources listed propose numerous solutions for managing UAVs, but the combination of Pixhawk 6C with Raspberry Pi Zero W opens new possibilities for efficient collection, processing, and transmission of GPS data to cloud services. This not only allows for the optimization of local system resources but also provides access to data from any point in the world, using cloud resources for their analysis and processing. Thus, the integration of hardware components with cloud technologies in the context of UAVs is a relevant topic for research. It opens new horizons for improving the efficiency, safety, and flexibility of UAV-based systems, and provides a wide range of possibilities for commercial, scientific, and personal applications.

The goal of this work is the development of an approach for wireless transmission of GPS data from an unmanned aerial vehicle to a cloud environment in real time.

Presentation of the main research material. In this case, integration of the Pixhawk 6C flight controller, popular in the UAV community, with the Raspberry Pi Zero W mini-computer for processing and transmitting GPS data (Fig. 1) is implemented. The central aspect of the study will be the use of cloud technologies, specifically Amazon Cloud, for storage, analysis, and real-time reproduction of these data. This combination of technologies has the potential to change the approach to data processing and analysis in the UAV field, making this process more efficient, flexible, and accessible.

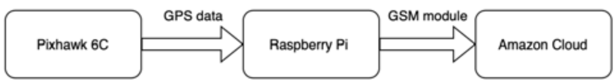

Fig. 1. Functional structure of the system

Flight controller: Pixhawk 6C: Pixhawk 6C is one of the latest models in the Pixhawk flight controller line, known for its reliability, flexibility, and openness. This controller provides advanced capabilities for managing various types of [6, 7] UAVs, including quadcopters, fixed-wing, and many others. Main features:

- Processor: H7 microcontroller (480 MHz) with high performance, ensuring fast data processing and response to commands.
- Interfaces: A set of ports for connecting various sensors, including GPS, gyroscopes, accelerometers, etc.
- External appearance: Compact size and light weight, making it ideal for use in various UAV configurations.

M8N GPS: The M8N GPS from Holybro is a high-quality GPS module that offers high precision positioning and reliability. This module provides rapid positioning and can operate in various conditions, including high-altitude and urbanized areas.

Main features:

- Accuracy: High positioning accuracy thanks to simultaneous data reception from various satellite systems.
- Compatibility: Direct compatibility with Pixhawk controllers, ensuring easy connection and integration.

Raspberry Pi Zero W: Raspberry Pi Zero W [8] is one of the most compact versions of the popular

Raspberry Pi single-board computer line. Despite its small size, it offers enough power for processing and transmitting GPS data.

Main features:

- Processor: ARM core that provides sufficient performance for data processing.
- Wireless Connection: Built-in Wi-Fi module, allowing for data transmission to the cloud or other devices.
- Interfaces: Multiple ports for connecting a variety of equipment, including USB, GPIO, etc. The fusion of Pixhawk 6C capabilities with the power of Raspberry Pi Zero W creates an efficient solution for collecting, processing, and transmitting GPS data in real-time.

Cloud environment: Cloud technologies have become an essential tool in the modern world for storing, processing, and analyzing large volumes of data. Thanks to their flexibility, scalability, and global accessibility, cloud platforms provide an ideal solution for working with UAV data.

Amazon Web Services (AWS) is one of the largest and most popular cloud platforms on the market. AWS offers a wide range of services, among which:

- Amazon S3: Object storage that can be used for storing large volumes of GPS data. S3 provides high availability, long-term storage, and easy access to data from any point in the world.
- Amazon EC2: Virtual servers that can be customized for specific needs. EC2 can be used for real-time processing of GPS data, running analysis algorithms, and other tasks.
- AWS Lambda: Serverless computing service that allows automatically running code in response to certain events, such as uploading new data to S3.
- Amazon RDS: Relational database in the cloud that can be used for structured storage and querying of GPS data. Using AWS for processing GPS data from UAVs offers numerous advantages, such as flexibility, scalability, reliability, and global accessibility. AWS also provides a wide range of tools for security, analysis, and optimization, making it an ideal choice for such tasks.

Connecting the Pixhawk 6C to the Raspberry Pi is a key step in creating an efficient system for collecting and transmitting GPS data to the cloud. This connection (Fig. 2) allows the Raspberry Pi to receive real-time data from the Pixhawk, process it, and transmit it to the cloud environment.

Physical connection:

1. UART connection: The simplest way to connect the Pixhawk to the Raspberry Pi is through UART (Universal Asynchronous Receiver-Transmitter). The Pixhawk has several UART ports that can be used for

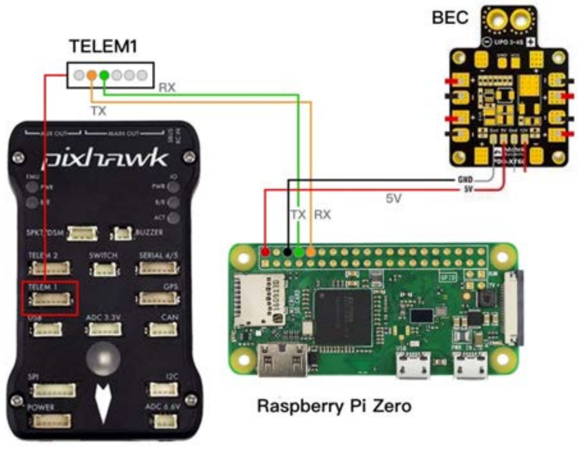

Fig. 2. Connecting the flight controller to the Raspberry Pi

this connection. Specifically, the TELEM1/2 port is commonly used for such tasks.

2. Power supply: This is an important point. The Raspberry Pi and Pixhawk must be connected to a power source that can provide sufficient power to both devices.

Software setup:

1. MAVLink protocol: The Pixhawk uses the MAVLink protocol for communication. To enable the Raspberry Pi to understand and interpret these data, an appropriate library (e.g., pymavlink) should be installed on it.

2. Pixhawk configuration: Using QGroundControl or another GCS (Ground Control Station), the Pixhawk can be configured to transmit the required data to the Raspberry Pi.

3. Data processing on Raspberry Pi: After receiving data from the Pixhawk, the Raspberry Pi can process this data (e.g., filtering, converting formats) before transmitting it to the cloud. The connection of Pixhawk 6C with Raspberry Pi forms the basis for creating a powerful system for collecting and transmitting GPS data. During this process, it is important to pay attention to the correct settings to ensure the stability and reliability of the system.

3G Modem Huawei E173: The Huawei E173 3G modem is a portable USB modem that provides connectivity to third-generation (3G) networks. It is part of the widely known Huawei product series aimed at providing mobile internet connectivity for various devices. Main features:

- Frequency range: The Huawei E173 supports various frequency bands, allowing it to work in many networks around the world.
- Data: The modem supports data transmission speeds of up to 7.2 Mbps for download and up to 5.76 Mbps for upload.

• Connection: The device connects via a standard USB interface, making it compatible with a large number of devices, including the Raspberry Pi. Using with Raspberry Pi: Thanks to the USB interface, the Huawei E173 modem can be easily connected to the Raspberry Pi. After installing the necessary drivers and configuring network settings, the Raspberry Pi can use the modem for instant data transmission to the cloud or for receiving data from the Internet.

Thus, adding the 3G Huawei E173 modem to the system not only provides instant Internet access in various locations without a stationary connection but also expands the system's capabilities, allowing for more complex real-time data scenarios.

To receive data from the M8N GPS module, it first passes through the Pixhawk 6C controller, where preliminary processing or filtering can occur. After that, the Raspberry Pi reads these data through the established connection. At this stage, the 3G Huawei E173 modem comes into play: the collected GPS data [9] can be instantly transmitted through mobile internet to the cloud environment thanks to this modem. This is particularly useful in situations where it is necessary to quickly transmit data to the cloud or when the device is in motion and does not have access to stationary networks. Once successfully transmitted to the cloud, the data are stored on services such as Amazon S3, where they can be further processed, analyzed, or used in other applications. The advantage of such a configuration is the instant data transmission provided by the 3G modem, which allows for almost real-time updating of information in the cloud and ensures the reliability of data transmission even in unstable connection conditions.

Receiving GPS data:

1. Processing on Raspberry Pi: The data received from Pixhawk through the MAVLink protocol are converted into a format convenient for further processing. For example, the data can be transformed into JSON or another standard format.

2. Data buffering: Raspberry Pi can use its built-in memory for temporary data storage before sending it to the cloud. This is useful in cases where the internet connection may be unstable.

Transmitting data to the cloud:

1. Using API: Most cloud platforms, including AWS, provide APIs for uploading data. Raspberry Pi can use these APIs to automatically transmit GPS data to the appropriate cloud storage.

2. Encryption: To ensure data security during transmission to the cloud, it is recommended to use encryption.

Storing data in the cloud:

1. Amazon S3: Amazon S3 can be used to store large volumes of GPS data. It is a reliable and scalable solution that allows easy storage, retrieval, and access to your data.

2. Storage optimization: Using cloud services such as AWS Lambda, processes of compression, archiving, and deletion of old data can be automated to optimize storage costs.

Receiving and storing GPS data in the cloud not only makes the processes of working with these data more efficient but also provides an additional level of security, accessibility, and reliability compared to traditional methods of storage on local servers or devices. In the event of unexpected hardware failure of the UAV, the collected data will be preserved for further use or analysis of the cause of the malfunction.

GPS data received from the controller are stored in the cloud database in the table "gps_telemetry" (Fig. 3). This table has the following structure:

1. id: A unique identifier for each entry. Typically, this is an auto-incrementing value that aids in managing and referencing records in the table.

2. coordinates: A geometric data type representing a point on the map with specified longitude and latitude coordinates. For example, an entry like "POINT(40.964775369364396 -99.88747515830926)" indicates a specific geographic location.

3. temperature: The temperature value at the specified location. This is a real number that indicates the temperature conditions at the GPS module's location at the time of data retrieval. For example, "29.23097597363496" indicates a temperature of 29.23°C.

4. time: Reflects the exact time of each coordinate's storage.

With this table structure, telemetric data received from the controller can be efficiently stored and managed. Each record in the table represents a separate set of GPS data, containing information about location and temperature conditions, which can be expanded and supplemented with data from any sensors and additional devices.

This study is financially supported by the National High Level Foreign Experts Introduction Project, China (G2022014116L).

Conclusions. At the current stage of technological development, real-time processing and transmission of GPS data are gaining increasing significance, especially in the context of autonomous systems, monitoring, and remote control of objects. The use of a combination of Pixhawk 6C controller, M8N

Result Grid Filter Rows: Search Export:

coordinates_text	temperature	time
POINT(40.964775369364396 -99.88747515830926)	29.23097597363496	2023-08-21 15:06:10
POINT(40.964324832374835 -99.88766344796434)	29.14113869764017	2023-08-21 15:06:10
POINT(40.96394051499084 -99.8878155230256)	29.033715574102214	2023-08-21 15:06:10
POINT(40.96435962458763 -99.88789770564027)	28.865473741074535	2023-08-21 15:06:10
POINT(40.964264963297246 -99.88836628656236)	29.306553032534712	2023-08-21 15:06:10
POINT(40.964376102551526 -99.8886338281346)	29.13542743924579	2023-08-21 15:06:10
POINT(40.96482309933252 -99.88838546741903)	29.536240704857036	2023-08-21 15:06:10
POINT(40.96458208354459 -99.88829298612477)	29.221694570706873	2023-08-21 15:06:10
POINT(40.96423190902177 -99.88860022030568)	29.236047265339685	2023-08-21 15:06:10
POINT(40.9647253750684 -99.88867594812568)	28.877010056168782	2023-08-21 15:06:10
POINT(40.96465737251328 -99.88843884924302)	28.766512165559934	2023-08-21 15:06:10
POINT(40.96489358644298 -99.88842628589192)	28.620687162616	2023-08-21 15:06:10
POINT(40.96462677140573 -99.88882288603861)	28.938131571689745	2023-08-21 15:06:10
POINT(40.96490379392188 -99.88889010665436)	29.270960975225048	2023-08-21 15:06:10
POINT(40.965269602817536 -99.88855955035591)	29.326315811207813	2023-08-21 15:06:10
POINT(40.96505470813283 -99.88830008825661)	29.768310392525336	2023-08-21 15:06:10
POINT(40.96498629477226 -99.88846813877271)	29.633297924542145	2023-08-21 15:06:10
POINT(40.96531538401134 -99.88891765514262)	29.898448388463304	2023-08-21 15:06:10
POINT(40.96548968547142 -99.88934159920325)	29.75582373585163	2023-08-21 15:06:10
POINT(40.96554839442095 -99.889120180467)	30.186790599196023	2023-08-21 15:06:10
POINT(40.96553897255967 -99.88896019033267)	30.515006885412156	2023-08-21 15:06:10
[illegible]	[illegible]	[illegible]

Fig. 3. Part of the data stored in the cloud

GPS module, Raspberry Pi Zero W, and Huawei E173 3G modem indicates new possibilities in this field. Integration of Equipment: The combination of these components not only allows for the collection and transmission of GPS data but also creates a platform for more complex data operations, such as processing, filtering, and real-time analysis. Instant Data Transmission: The Huawei E173 3G modem ensures the speed and reliability of data transmission. In situations where connectivity is critically important, this component can be a solution to ensure system stability. Cloud Storage: The advantages of cloud technologies have long been evident in many industries. In the context of GPS data, Amazon Cloud offers reliable and fast solutions for their storage, as well as for subsequent access and processing from anywhere in the world. Structured Storage: The detailed structure of the "gps_telemetry" table simplifies the process of data analysis and interpretation. The orderly and systematic organization of information always contributes to its more qualitative use. System Flexibility: Thanks to its modular structure, the system can be easily adapted or modified for different tasks. This can include adding new equipment, integrating with other systems, or adapting to new tasks. Data Security: The use of cloud technologies also provides an additional level of security. Automatic backup, data encryption, and secure transmission protocols ensure that the collected information will be protected from loss or damage. Considering these aspects, it becomes clear that the combination of these technologies creates an advanced platform for processing and transmitting GPS data. Such a system is not only efficient but also has the potential for further expansion and modernization in the future.

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ОБРОБКА GPS СИГНАЛІВ ДРОНУ У ХМАРНОМУ СЕРЕДОВИЩІ ЗА ДОПОМОГОЮ RASPBERRY PI ТА ПОЛІТНОГО КОНТРОЛЕРУ PIXHAWK 6C

Безпілотні літальні апарати (БЛА) стрімко розвиваються, знаходячи застосування в різних секторах, таких як аерофотозйомка, моніторинг сільського господарства та наукові дослідження. Основним для їх функціональності є точність та надійність GPS-даних, що є критичними для точної навігації та виконання завдань. Ця стаття зосереджується на інтеграції двох відомих апаратних компонентів – контролера польоту Pixhawk 6C та комп'ютера Raspberry Pi Zero W – для ефективного збору та передачі GPS-даних у середовище Amazon Cloud. З акцентом на обробці даних у реальному часі, ця система значно покращує можливості БЛА в наукових та комерційних проєктах. Pixhawk 6C відомий своєю надійністю, легко керуючи різними типами БЛА, в той час як Raspberry Pi Zero W, незважаючи на свій компактний розмір, ефективно обробляє та передає GPS-дані. Це поєднання не лише забезпечує точне позиціонування БЛА, але й оптимізує витрати, зменшуючи потребу у великих обчислювальних потужностях на борту. Використання Amazon Cloud для зберігання та обробки даних забезпечує масштабоване, безпечне та доступне середовище, що є важливим для ефективного аналізу польотних шляхів та екологічних даних. Це налаштування дозволяє проводити моніторинг та керування БЛА у реальному часі, значно покращуючи їхню оперативну безпеку та ефективність. Крім того, ця інтеграція відкриває нові можливості для розширеного використання БЛА. Використовуючи обчислення в хмарі, вона дозволяє застосовувати більш складні алгоритми аналітики даних та машинного навчання до GPS-даних, надаючи інсайти, які можуть покращити польотні шляхи та оперативні стратегії. Архітектура цієї системи, що поєднує надійне апаратне забезпечення з передовими хмарними можливостями, є важливим кроком уперед у технології БЛА, підвищуючи їх застосування в все більш складних та вимогливих умовах.

Ключові слова: *хмарна обробка даних, GPS-телеметрія, міні-комп'ютер, безпілотні літальні апарати, контролер.*