VOL. 20, NO. 2-2, 2021, 70-76
www.elektrika.utm.my
ISSN 0128-4428

ELEKTRIKA
Journal of Electrical Engineering

Development of an Autonomous IoT-Based Drone for Campus Security

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Abstract: In recent years, drone technology has gained popularity across the world because of its numerous applications, particularly in security and surveillance. This technology can be further revolutionized with the deployment of Industrial Revolution 4.0 Technology. This paper discusses the development of an IoT-based autonomous drone for more comprehensive campus security and surveillance system. The drone is featured with the capability of conducting a fully autonomous aerial surveillance, being the first responder in emergencies, streaming video while flying, avoiding obstacles, following a target and communicating with the current IoT based UTM's security patrolling system for data transfer and drone control. This has been accomplished by using the open source ArduPilot software, Pixhawk flight controller along with Dronekit python library installed on a Raspberry Pi 4. The findings show that the actual performance of the designed drone is fairly similar to the simulation results. The drone has successfully performed autonomous navigation to incident location with 1 to 2 meter accuracy as well as follow-me mode. The cellular technology utilized for drone communication also is more robust and provides promising solution to overcome short operation range and interference.

Keywords: Drone, Dronekit, Emergency Response, Pixhawk, Internet of Things

Article History: received 25 May 2021; accepted 12 June 2021; published 15 September 2021.

1. INTRODUCTION

Drones, also known as Unmanned Aerial Vehicles (UAVs), are aircrafts that can fly without the need for a pilot. They are now used in a wide range of industries, including agriculture, economics, military, and many other facets of life [1]. Among them, security and surveillance have proven to be one of the most essential uses for UAVs [2]. They have the potential to enhance security systems by performing high-risk activities, emergency response to various circumstances, and capturing and giving real-time video and photographs from the accident scene. This potential can even be expanded to new horizons with the help of Internet of Things (IoT).

In 2017, Universiti Teknologi Malaysia (UTM) launched a project called Comprehensive IoT Based Security solutions aimed to provide advanced and comprehensive security solutions to UTM campus. Figure 1 shows the scheme of Future Campus Security by Security Division. Some of these systems such as Guard Touring System (GTS), Radio Frequency Identification (RFID) Vehicle Sticker and IoT-based Office Access Solutions have been successfully implemented while, others including Smart Barrier, Internet Protocol (IP) Walkie Talkie, Body Cam, Vehicle Enforcement System and Guard Analytics are currently underway.

The IoT based ground patrolling system has significantly improved the conventional UTM security system. However, UTM Johor Bahru campus comprises a steep terrain, oil plantations, woodlands and several buildings, all of which must be constantly monitored by the UTM Security Division. Several areas aren't accessible by security guards due to possible hazards posed by the terrain itself, intruders or wild animals. In addition, fast response to emergencies is absent which may exacerbate the problem.

Figure 1. Blueprint of UTM Future Campus Security

Another disadvantage shared by the majority of similar solutions and projects is a limited communication range. The radio frequency-based telemetry that is typically utilized to communicate between the drone and ground control stations has a range of a few kilometers and becomes significantly shorter when obstacles such as buildings are present. It is also prone to interference as the frequency allocated occupies the unlicensed spectrum. In addition, the existing drone solutions for aerial patrol in the market are offered in silo and detached from the ground patrol systems.

Therefore, in this paper, we introduce a novel design of an autonomous drone for campus security, named JAGA Drone, that uses cellular communication for its control, telemetry and data transfer. Furthermore, the drone utilizes Internet-of-Things (IoT) computing infrastructure to facilitate real-time data management and also scalable application such as integration with existing UTM's IoT based Guard Touring System.

The remainder of this paper is structured as follows. Section 2 contains the project background. Section 3 and Section 4 contain the methodology for the drone design and results, respectively. Section 5 concludes the paper.

2. PROJECT BACKGROUND

2.1 Unmanned Aerial Vehicle (UAV)

Drones or unmanned aerial vehicles (UAVs) are aircrafts that can operate without onboard pilots. A typical unmanned aerial system consists of vehicle, ground control station (GTS) and communication system that links the two. UAVs can be operated remotely by human or autonomously by onboard computers [3]. UAVs are used in a wide range of applications, including security [4] and surveillance [5], detection of harmful gases, medicinal reasons, agricultural, and deliveries. Drones can be generally classified into two types, fixed wing and rotary wing. These two classifications can be further subdivided or even merged to create additional aircraft types such as vertical take-off and landing (VTOL) aircraft.

2.2 Ardupilot Software

Ardupilot is a pioneering open source unmanned vehicle autopilot system that supports a wide variety of vehicle types, including fixed-wing drones, multi-rotor helicopters, submarines, and boats. Ardupilot software was developed in response to the demand of having a stable flight as it is practically impossible to employ equal amount of thrust to each motor without a controller. The software's core concept is to read sensor inputs and modify the motor outputs as necessary to maintain a steady flight. Ardupilot is compatible with a variety of hardware, including the Pixhawk flight controller. It has embedded sensors such as an accelerometer and a barometer and may interface with additional sensors like a GPS to enable sophisticated flight.

ArduPilot software is perfect for this project because it comes with a variety of useful capabilities. It is well-documented, which simplifies the process of setting up any vehicle to meet the requirements. Secondly, it offers a wide range of flight modes, including Auto, Guided, Manual, Land and more. Another major feature is its ability to handle emergencies, such as low-battery conditions, or other system breakdowns. In short, ArduPilot firmware is widely used in the drone industry due to its advanced capabilities.

2.3 Dronekit Python Library

DroneKit-Python is an open-source python library that enables developers to create robust apps on a Drone's companion computer (e.g., Raspberry Pi) and it utilizes a low latency communication protocol to communicate with ArduPilot flight controller. Dronekit API can boost drone's application by adding a high level of intelligence to the behavior of the drone and performing time-sensitive and computationally intensive tasks, for example, path planning and image processing. Moreover, Dronekit is a cross-platform library that can run on different operating systems. DroneKit uses the Micro Air Vehicle Link (MAVLink) communication protocol to monitor a vehicle's status as well as command its movement and operations.

2.4 Internet of Things

The Internet of Things (IoT) refers to a system of linked computing devices, objects, digital and mechanical machines, people or animals with distinctive identifiers capable of transferring data over a network without the need for human interaction [6]. Figure 2 illustrates what an IoT is.

Figure 2. Internet of Things (IoT)

2.5 Related Works

Some of the relevant works and studies are discussed in Table 1. Brief descriptions of the works and their constraints are included.

Table 1: Related Works and Studies

Title and Author	Description	Limitations
IoT-Based UAV Platform for Emergency Services (2018) [7]	Developing a cloud-based software platform for emergency services using drone. This project proposed an extension of an existing IoT-based platform features.	• Lacks evidence of how realistic is the proposal • No tests or simulations are made to prove the concept
Development of an Autonomous Drone for Surveillance Application (2018) [8]	Surveillance drone detects any unauthorized entry into the deployment region and sends alerts with the GPS coordinates. Pixhawk is used as a flight controller and OpenCV library is used for image processing.	• Unable to send commands during flights • Have limited control over the drone, because of using ready-to-use flight controller • Telemetry range is short and limited • Camera quality is not good
A Cloud-based Control System Architecture for Multi-UAV (2018) [9]	A cloud-based control system with web-based ground control station to control and monitor multiple UAVs. Tested using SITL (Software In The Loop) simulator.	• No real implementation of the system, all done on simulation environment. • UAVs are not operating together to complete a mission and have to manually guide each one of them.
Multiple UAVs-based Surveillance and Reconnaissance System Utilizing IoT Platform (2019) [10]	This project aimed to develop a standardized IoT Platform for controlling multiple UAVs. As an example, the project implemented an autonomous UAV-based surveillance system using Two DJI MATRICE 100 and DIJ MAVIC is used to implement the project.	• Using commercial drones forces several limitations such as fixed flight time and objects to be carried. • Lacks in-flight commands.
Autonomous Cloud Based Drone system for Disaster Response and Mitigation (2016) [11]	A networked system of cloud-based autonomous drones cooperating in managing disaster situations. Three drones are used, the first as a pathfinder, and the second as human detection and the third as cargo drone.	• The system is too specialized and costly. • Not suitable for daily operation of aerial patrol

Surveillance Drone for Landmine Detection (2015) [12]	Development of a quad-copter capable of detecting mine. It uses IR Camera along with metal detector circuit connected to an Arduino. Once detected, it transmits the location through the GSM that is also connected to the internet.	• The prototype limits the capability of mine detection to only one meter. • The distance travelled is short • Imaging quality is low
FPV Drone with GPS used for Surveillance in Remote Areas (2017) [13]	Development of FVP quadcopter for surveillance purpose. The aim of the project was to increase the drone's flight time as well as transmitting a high-quality video. Another feature of the prototype was to make it at affordable price.	• Requires trained professionals to run the system.

3. METHODOLOGY

3.1 Hardware Implementation

To meet the project requirements, the components must be selected properly. For this purpose, a simulation of system characteristics such as flight time, power consumption, thrust-weight ratio, efficiency and many other important parameters are carried out before purchasing drone components to estimate the optimal flight performance and endurance. An online simulator called e-Calc is used to estimate the drone performance and endurance. To confirm the code's functionality, a reliable simulating drone Software In The Loop (SITL) developed by the Ardupilot community is utilized for testing. This simulation is run with several hardware parameters until one is found to be the most appropriate. The results are revealed in Figure 3, 4 and 5.

Figure 3. Simulation Results of the System characteristics

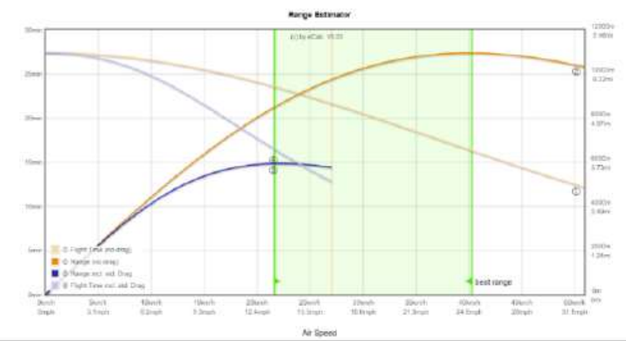

Figure 4. The Simulation Results For Range Estimation

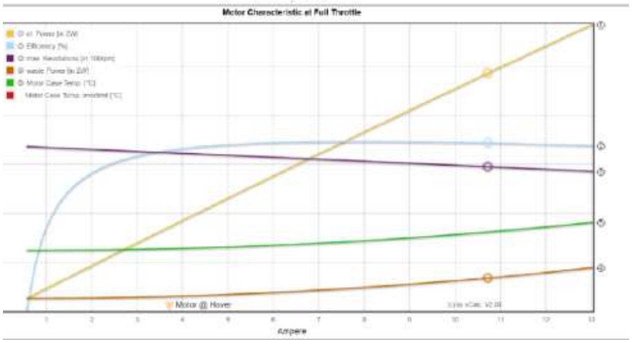

Figure 5. The Simulation Results for Motor Characteristics

From the simulation, the expected thrust-to-weight ratio is 2:1 which is good enough to produce a good flight time and payload. Hover flight time is expected to be 27.4 mins which is quite high and good for the current case. Both minimum and mixed flight time are expected to be 9.4 mins and 21.2 mins respectively. In addition, all-up-weight is computed to be 3800g with additional payload to be 2731g, and that is sufficient for carrying gambles and camera along with first-aid kit. Another important estimation is the current at maximum throttle which happened to be 10.86A. This value is vital in component selection, as it might burn some components if they do not sustain such amount of current. An estimation for best flight range is shown in Figure 10. The best expected flight speed ranges from 22 km/h to 40 km/h which results in flight time about 15 mins including drag effect. Lastly, the best estimated travelling distance with such speed is found to be from 6 km.

After conducting the simulation, the drone components are purchased. The drone specifications are shown in Table 2. It can be seen the developed drone operates on cellular technology and is equipped with sensors such as camera and obstacle avoidance sensor.

Table 2: The Real Drone Specifications

Specification	Value
Frame	Hexacopter 750 mm (diagonal size)
Frame arm thickness	16 mm
Frame kit material	3K carbon Fiber
Weight	3,800g (include battery and propeller)
Propulsion system	360kV brushless motor with 1344 carbon Fiber propeller 40A continuous current/ 60A burst current
Controller	Pixhawk 4 (Main control chip STM32F765)
Satellite positioning system	GPS/GLONASS
Battery	Lithium polymer 12,000 mah 6s 15C
Firmware	Ardupilot Copter 4.0.7
Maximum Speed	15 ms^{-1}
Maximum tilt angle	42^{o}
Ceiling service	100m AGL
Maximum wind speed resistance	10 m/s
Flight time	30 minutes
Operating temperature	0-40C^{o}
Remote controller	Computer dashboard

Communication system	Cellular technology (for telemetry, image, flight command and control) . Note: subscribed to commercial service provider for the network and data
Camera	IP camera, 4M, 1080p/ 60fps 10 mm- 300 mm focus distance 10x optical zoom 66.6-7.2° diagonal FOV Auto exposure compensation and white balance
Gimbal	-120 degree to +15 degree
Video	mp4/ MOV (AVC/H.264; HEVC/ H.265) 12V with 250mA, 365 grams
Obstacle avoidance	8 sensors in 360° around the hexacopter Range: *0.5m up to 60m Update rate: Up to 120Hz per sensor Output resolution: 0.5cm below 14m, 2cm from 14m Accuracy: ±4cm in the first 14m, 1.5% above 14m Size: 120 (D) mm x 42 (H) mm Eye safety: Yes (in accordance with IEC62471) Field of view: 2° per sensor, 45°between each sensor axis

The drone payload, which specifies how much weight the drone can carry, is one of the most critical criteria to consider. The estimated payload, as indicated in Figure 3, is 2.7 kg, which is sufficient for the project requirements such as the camera, object avoidance sensor, raspberry pi 4 and 4G modem. The significant hardware is recorded in Table 3 along with a justification for why it is chosen.

Table 3: Justification for hardware selection

Component	Reason to use
Pixhawk 4	One of the most reliable flight controllers used for custom drones.
Propulsion system.	As listed in the drone specification, the used motors and propellers can produce the required thrust and payload. Also, each ESC can handle up to 40A which is more than enough as the max current that can be produced is almost 10A
IP Camera	It is essentially used for taking pictures and videos of evidence and also to easily stream video through the internet
Object avoidance sensor	As the name reveals, it is basically used to avoid obstacles such as building and trees while flying
Raspberry Pi	It plays very important roles such as sending commands to the flight controller, connecting the drone to the internet.
4G Modem	Used to overcome the limited telemetry range by sending and receiving date through the Internet.

Figure 6 shows the developed hexa-copter from six different views.

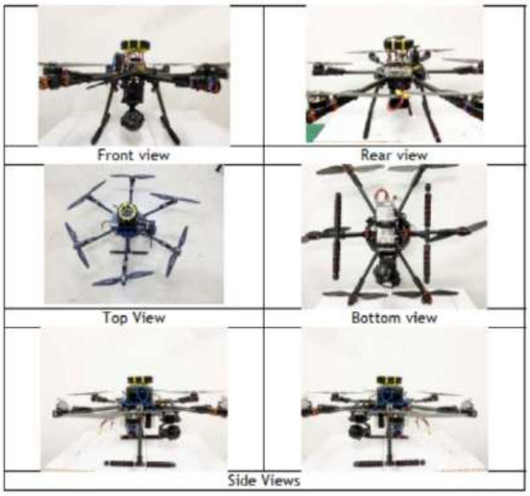

Figure 6. The Developed Hexa-Copter

3.2 Software Implementation

Dronekit python library is used to control the Pixhawk flight controller by sending MAVLink commands through the serial port between the Raspberry Pi microprocessor and the flight controller. This communication is bi-directional where Raspberry Pi can send and receive data. For example, Raspberry Pi can send commands such as takeoff, land, change mode, go to location and many more, while simultaneously receiving flight status such as altitude, position, speed and etc.

3.3 System Overall Architecture

Figure 7 depicts the total system architecture, in which the drone is linked to the server, along with the web application and the handheld device possessed by each UTM security guard.

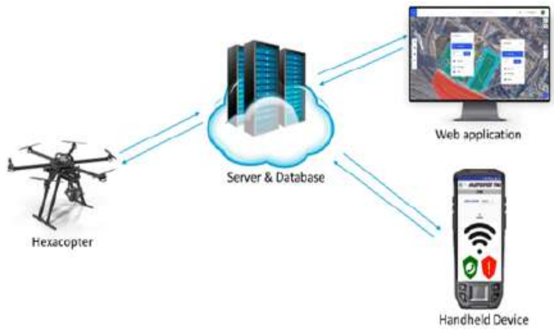

Figure 7. Overall System Architecture

Figure 8 depicts the handheld and mobile application used to alert authorities in the event of an emergency. When the panic button is pressed, a notice is sent to the command center through the dashboard (see Figure 9), and the drone will immediately fly to the incident location according to the GPS info from the device.

Figure 8. Panic Mode Activated

Figure 9. Panic Alert on the Security Dashboard

3.4 Flowchart of Emergency Response Feature

Figure 10 depicts the programming flowchart of the panic response system. Firstly, the battery is connected to power up the drone and hence will remain in standby mode waiting for incoming commands. Once a panic message is received, the drone will instantly takeoff and navigated to the incident location and starts live-streaming video during flight. Once it reaches the incident location, it will hover until further commands are received. These commands might be to land, go to another location, or return to home depending on the command center.

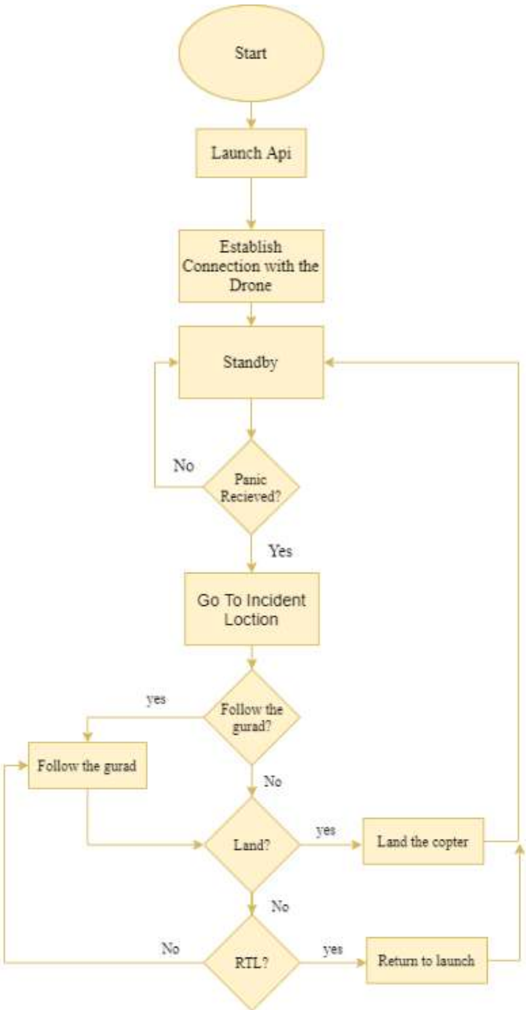

Figure 10. The Flowchart of the Drone Function

3.5 Flowchart of Surveillance Mission

One of the features of the developed drone is the ability to conduct autonomous mission for surveillance purposes. Figure 11 illustrates the flowchart of this feature.

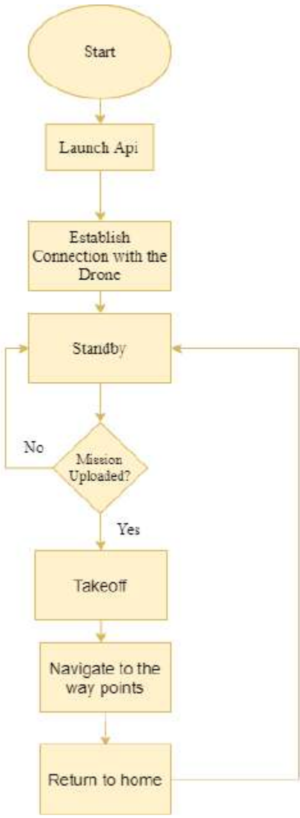

Figure 11. Flowchart for the Surveillance Mission

4. RESULTS AND DISCUSSION

This section provides a synopsis and analysis of the simulator and real-world flight results.

4.1 Simulation Results vs Actual Results

As mentioned in the methodology, the eCalc simulator is used to estimate the drone performance and important parameters such as flight time, speed, current and etc. Table 2 summarizes the performance comparison between the simulated results with the ones obtained from actual flight tests. As can be seen, the actual results are surprisingly close to the simulation results. This justifies the use of simulation tools to assist in the drone design as the simulated outcomes can be used as a baseline to achieve the desired results.

Table 4. Comparison of results' performance

Parameters	Simulation	Actual	Unit
Hover Time	27.4	30	Minute
Mixed Flight Time	25	21.2	Minute
Hover Current	22.32	20.6	Ampere
Hover Voltage	23.24	23.15	Volt
Thrust-Weight Ratio	2:01	2:01	
Max Speed	51	54	Km/h
Temperature	0-41	0-40	Celsius

4.2 Autonomous Navigation to Incident Location

Autonomous response to emergencies is tested several times, and the results shows that the drone is capable to autonomously navigate in the incident location. Figure 12 shows one of the tests in which the security guard pressed the panic button, and hence the drone took off and flew to the incident spot.

Figure 12. Implementation of Emergency Call

4.3 Auto Following Security Guard

Once the drone reaches the emergency site, it can follow the security guard using the frequent transmitted coordinates from the portable device. The functionality must be enabled from the command centre, and the drone will follow the guard automatically. This functionality has been successfully tested and implemented, as illustrated in Figure 13.


Figure 13. Follow-Me Mode

4.4 Location Accuracy

Various tests have been carried out to check the accuracy of the site of the incident. The drone usually reaches ± 2 metres from the location of the testing, which is adequate for the project objective. Figure 14 depicts the number of trials performed as well as the distance between the device and the drone.

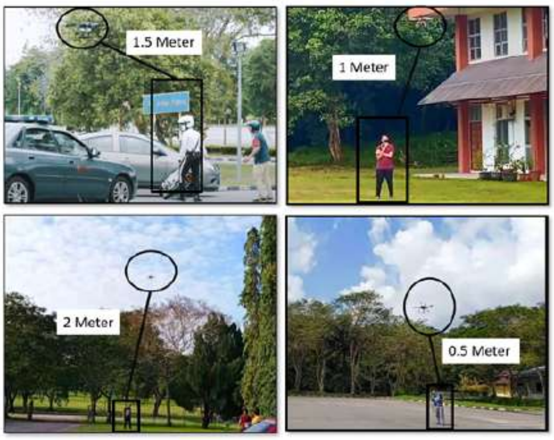

Figure 14. Results of the Accuracy of Reaching Incident Location.

4.5 Response Time

Another critical performance metric is the average time it takes the drone to arrive at the destination. Several experiments were undertaken inside UTM Campus to compare the time consumed by the drone to that of a car travelling the same distance. The studies are carried out with the use of a SITL drone and a Google estimate of automobile travel time. The findings showed that the drone is much faster than a normal car travelling the same distance. The trials done in UTM campus are presented in Figure 15. The drone's travelling time is shown in the two figures on the left and the car's travelling time is shown in the two figures on the right. Drones can travel four times quicker than cars to get to a spot that is 1.3 kilometers away. In the second experiment, the drone was five times faster than the car, travelling at a distance of 3.6 kilometers. The time it takes for both the car and the drone to travel to the same area varies depending on the nature of the environment and the length of the route.

Figure 15. Results of Response Time

5. CONCLUSION

JAGA Drone is successfully developed that complements the existing IoT based ground patrol system to provide a more comprehensive security in the form of terrestrial and aerial patrol and surveillance at UTM campus. The IoT and cellular technologies utilized in the drone design overcome the communication range limitation between the drone and the ground station as well as guaranteed quality of service for data transmission. It is capable of autonomously navigate to the incident location based on the coordinates that are sent from the developed mobile application. The drone is also equipped with multiple features such as auto following the security guard, auto landing and returning to home. Besides, the drone was able to maintain a flight of 30 mins allowing it to cover the whole university in one mission. Multiple tests on the drone's response time to reach an incident location on campus is proven to be much faster than a normal car and with location accuracy within an acceptable limit of one or two meters. It is hoped that the security deployment in both aerial and terrestrial modes will provide a significant insight for informed decision making on security policies on UTM campus.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Ministry of Higher Education (MOHE) Malaysia and Universiti Teknologi Malaysia for the financial support of this project under UTM RA ICONIC grant (Vot number Q.J130000.4351.09G69).

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