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Article

AutoUGV: Advanced IoT-based Smart Direction Control System for Unmanned Ground Vehicles

Santhosh Kumar Seelam[1], S Nagakishore Bhavanam[2], Vasujadevi Midasala[2], S. Sunithamani[3]

[1] Department of Computer Science and Engineering, University College of Engineering and Technology, Acharya Nagarjuna University, Guntur, Andhra Pradesh, India santhu3513@gmail.com

[2] Department of Computer Science and Engineering, Managalayatan University-Jabalpur (MUJ), Barela, Jabalpur Madhya Pradesh, India drbsnagakishore@gmail.com; vasujadevi@gmail.com

[3] Department of Electronics and Communication Engineering, College of Engineeringand Technology, katankulathur campus, SRMIST, SRM,Chengalpattu dist,India sunithabavi@gmail.com

Abstract: Abstract: UGVs are basic tools in the process of defense operations and surveillance as well as automation of industries and disaster management. Conventional UGV control systems become very popular but face challenges related to high delays and slow response as well as limited functionality in limited network environments. A direction control system based on IoT has been developed to address the performance limitations that are currently experienced with the control systems. AutoUGV as a proposed framework integrates the advanced microcontrollers with sensors and wireless communication protocols that include NodeMCU and Arduino in order to perform its functions. Control is made user friendly via a browser based interface which allows real-time feedback and accuracy. The adopted direction control system had an average latency of 0.8 seconds and has a steering accuracy limit of ± 2 degrees over a 300-meter WiFi distance range. Rigid testing provides system evaluations that confirm the high performance of the system across a wide range of essential applications such as autonomous navigation and remote control operations in adverse environments. The research results indicate the potential of the IoT technology to support effective and reliable robot systems in the industrial settings that require automated and remote control systems.

Keywords: AutoUGV, Unmanned Ground Vehicles (UGV), Internet of Things (IoT), NodeMCU, Arduino, Direction Control, Wireless Communication, Real-Time Feedback, Autonomous Navigation, Remote Operations

1. INTRODUCTION

The UGVs constitute an inseparable part that can be utilized in various ways such as defense operations as well as surveillance requirement and automation work and rescue mission. The operating environment of autonomously operated or human-controlled remotely operated vehicles consists of safety-critical or hard-access operations as well as hazardous environments. UGVs are used by the military in defense operations to conduct reconnaissance and explosive ordnance disposal and battlefield logistics missions[1]. During the natural disasters, UGVs provide assistance of great necessity in search-and-rescue missions and environmental surveillance. The existence of fashioned systems is vital to operational success as there is an upward trend in the use of UGVs given that such provide reliability in addition to precision capabilities and flexible systems to meet complex operation requirements [2].

The technological advancement of smart UGVs is achieved as the result of robotic and artificial intelligence enhancement regardless of the dissimilarity between ground vehicles and aerial Unmanned Aerial Vehicles (UAVs). The synergies produce increased mechanical and software complexity which can be vital in operation in a volatile environment[3].

The prevailing UGV control encounters several issues such as slow communication systems which is not compatible with outdated technology and plain inability to point the unit in a steady fashion. Existing remote-controlling systems (RF, Bluetooth) are traditional and delayed, which interrupt the real-time feedback and path planning in long distances.

In our study, we present AutoUGV which is a UGV direction control system based on IoT technologies as well as microcontrollers sensors and wireless connections. The system links the UGV activities to the operator through a NodeMCU and Arduino microcontroller network interface [6]. This interface displays the present status and allows users to control all the movements of the vehicle accurately. The data processing and transmission are also more effective in its system where its optimized algorithms ensure that the operator commands are sent to the system without any unnecessary delay [7].

AutoUGV shows better results in all characteristics at practice testing to be prepared to complex applications that demand autonomy and wireless connection. This study contributes to the creation of automatic IoT systems as it demonstrates how UGV technology can transform and be operational in more sectors [8].

The objectives of this research are:

1. Design and Develop an IoT-Based Control System: Designing an intelligent control system of the UGVs relying on the IoT standards to make quick and reliable operations.

2. Install Wireless Control Mechanisms: To incorporate wireless communication protocols that can support the heavy-force requirements of UGV operations such as braking, gear shifts and steering.

3. Reduce Latency: To maximize communication and processing pipelines in order to get less than one second response time on operator commands.

4. Enable Real-Time Feedback: To create real-time feedback system by using video streaming and sensor-based transmission of data to improve on the situational awareness and accuracy of control.

5. Prototype Integration and Testing: The prototype will be developed to test the functionality of advanced microcontrollers (NodeMCU, Arduino) and powerful wireless protocols to confirm the improvement of performance and scalability.

2. BACKGROUND WORK

Here, the former literature is deciphered in this theme. In [9], the authors created, assembled and tested a small UGV prototype, paying attention to the control of it using the IoT. They came up with the software and hardware architecture which has manual and autonomous operation modes. Communication and low-level control were handled by the Raspberry Pi and Arduino controllers respectively, which allowed the UGV to move and capture videos without human involvement or under operator control via the Blynk platform in [10].

The authors of [11] helped to create a comprehensive survey of the state of vehicle control technologies, which nowadays develops beyond vehicle state estimation and trajectory tracking control in Autonomous Vehicles (AVs) to collaborative control in Connected and Automated Vehicles (CAVs). They investigated the work of determining the sideslip angle of vehicles and researched on the symbolic trajectory planning of automated vehicles as well as integrated and automated vehicle management platforms. The research shows the current problems of the systems and provides potential research directions by introducing the newest vehicle control techniques.

In [14], the authors created FAUAVinSCF that utilizes Fully Automatic Unmanned Aerial Vehicles (FAUAVs) to enhance the features of Smart City (SC). This study enables them to conduct a research aimed at enhancing the work of FAUAV by applying AI techniques that process real-time data and control several autonomous agents in a distributed control architecture. The authors propose to enhance FAUAV swarm intelligence by adapting a routing solution to address operational constraints to help the FAUAVs achieve their numerous urban services in a more efficient manner. This system enables cities to become smarter through the use of automated collaboration by improving environmental protection, as well as, the quality of life in the city.

The authors analyze the integration of IoT and UAV in the inspection of the construction site and health and safety monitoring in their work[15]. They critically discuss the role of the IoT-connected UAVs in enhancing the performance of work and explain how to resolve issues with path planning and so on. This paper outlines research challenges to ensure the future research creates superior autonomous UAV solutions to various industries.

The authors of [16], introduces a survey that is founded on UAVs in smart cities and connectivity problems and it explicates the actual authors in the smart cities domain. They look at how the UAVs along with the new technologies like the IoT can enhance the urban life. Their analysis is a full review of the applications, challenges, limitations and future prospects of UAVs in smart cities. They also address sophisticated control methods to enhance UAV operation, which defeats significant challenges of control theory. Marking the barriers to integration, the innovative applications, and control strategies, the authors provide useful insights into the evolving role of UAVs in the process of building smart city infrastructures.

By conducting their studies on unstructured roads, researchers in [17] contribute to the field of UGVs by providing a state-of-the-art road terrain detection and balancecontrol scheme of UGVs. They have contributed greatly to developing a terrain identification model, which is grounded on popular multi-modal sensor fusion technology, to address the problem of computational complexity, poor anti-interference capability and poor road identification of single-sensor models. To deal with these challenges, the authors come up with a multi-sensor road classification system, which is an integration of on-board gyroscopes and velocity sensors that enhance road classification using a Back Propagation (BP) neural network.

The authors in [18] establish the parameters of sustainable development of agriculture by discussing the opportunities of using UAVs and IoT to achieve smart farming. Integrating productive IoT and autonomous system thisresearch refers to summarized applications and applications in agriculture.The authors of [19] are working on the development of SG technology as they examine future enhancements of SM systems to Smart Metering (SG) and future developments. They discuss the possibility of technology to enhance the manner in which data on energy consumption have to be gathered, and energy is distributed and deployed through the grid. This work takes into consideration various communication technologies and protocols as far as SM networks are concerned addressing their advantages and disadvantages. The authors add the flexibility and new functionality to the system with Low Power Wide Area Network (LPWAN) communication technologies. Table I provides a comparative analysis of research papers above in terms of their area of focus, features such as UGV control, autonomous vehicles, applications, IoT integration, road terrain identification and metering. It demonstrates whether or not these features are present in each paper.

Table I: Analysis of research papers and their areas of focus

Paper	UGV Control	Autonomous vehicles	Application	IoT integration	Terrain identification	Metering
[9]	✓	✗	✓	✓	✗	✗
[10]	✓	✓	✗	✓	✓	✓
[11]	✓	✗	✓	✓	✓	✓
[14]	✓	✓	✓	✓	✓	✓
[15]	✓	✓	✗	✓	✓	✗
[16]	✓	✓	✓	✗	✗	✓
[17]	✓	✗	✓	✓	✓	✓
[18]	✓	✗	✗	✓	✓	✓
[19]	✓	✓	✓	✓	✗	✗
AutoUGV	✓	✓	✓	✓	✓	✓

3. METHODOLOGY

Research designs an IoT-networked Unmanned Ground Vehicle system that can move remotely and autonomously and controlled by a web application. It is configured as an interconnected hardware and software system, through which live video surveillance and vehicle control are provided. Design process integrates experts to construct and connect hardware units to software systems that process data transfers and blocking control on a full-fledged robotic system[10].

The system consists of physical components that consists of a chassis that is connected to motors and sensors and also have inbuilt cameras and microcontrollers. The software gives the various components of the system the chance to communicate with one another and to the operator.

A. Design

Choice and incorporation of physical parts, including obstacle-detecting sensors, GPS, propulsion motors powered by DC, and microcontrollers [11]. In our group, the interface of the control system and the communication means was developed along with the hardware components of controlling output [14]. Hardware integration serves the efforts of the individual system constituents to achieve their objectives. The hardware items that are integrated in our system include:

1. Chassis: In this project, the company decided to adapt Mahindra Jeep Chassis since it supports the elements required in the vehicle including hydraulic steering motors.

2. Motors: The UGV uses two 500-RPM DC motors to drive the steering and motion [12].

3. Sensors: The car is equipped with ultrasonic sensors that check the surroundings of the vehicle and the GPS system is used to know its tracks.

4. Camera: The ESP32 camera links to the UGV system to display real time video feed straight to its operator who views the environment of the UGV.

B. Microcontrollers

The NodeMCU microcontroller is a wireless connector between the operator interface and the UGV system controls. It has one of its tasks to send the instructions given by the operator to Arduino and receive video streaming back to ESP32 camera [13]. The Arduino interprets the control signals, and converts them into steering, speed and braking control of the unmanned ground vehicle [14, 15]. The system is connected with sensors that identify obstacles and re-direct the vehicle route automatically [16]. The control software of the UGV has two distinct sections to the communication and control system:

1. NodeMCU Functions: The NodeMCU microcontroller enables communication between the operator interface and the UGV to be done through Wi-Fi. The microcontroller gets the control instructions through the web-based interface and sends them to the Arduino to execute the motor operation[17]. This communication node sends video footage to the operator interface which obtains live video streams of the ESP32 camera.

2. Arduino Functions: The Arduino interprets the commands of the NodeMCU and uses it to control UGV steering along with its mobility. The UGV relies on sensor data of the ultrasonic sensors to scan obstacles and the GPS module to show its position[18]. Sensors provide the UGV with commands and inputs that can be adjusted to steer its directional control changes and also speed adjustments.

The software system has an operator interface through its web interface to navigate the UGV, and it presents status information. The user interface sends its input commands to NodeMCU that sends them to Arduino until the UGV reacts to the motion accordingly.

C. Data Collection and Analysis Procedures

1. Data Collection: The UGV system will receive data by all the hardware components installed on it. This includes:

1. Sensor Data: The ultrasonic sensors are a real-time device that will read the distance between the UGV and any obstacle present and the GPS module will provide the position of the UGV and its direction.

2. Camera Data: Camera Data gathers the images of the ESP32 camera used and the operation interface of the device transmits the images to the operator so the view of the UGV in the real-time environment can be seen.

3. Operator Input: The web interface receives the commands provided by the operator and sends them to control the UGV movements as well as other working functions. The NodeMCU sends the inputs to the Arduino via its channel of communication.

4. Data Processing: The Arduino and NodeMCU process the raw sensor data and operator inputs. The sensor data (e.g., that of the ultrasonic sensors) is used by the Arduino to sense obstacles and change the movement of the vehicle. The NodeMCU receives the input of the web interface and converts it to control signals to the Arduino.

The sensor calibration equation is given in Eq(1)

$$s(t) = a \cdot x(t) + b \tag{1}$$

where

The scaling factor of the sensor is a.

The offset or bias in the sensor output is denoted by b.

The exact physical value is x(t)

Sensor data is stored in an array or matrix format for analysis.

$$\begin{pmatrix} X_1(t_0) & X_2(t_0) \\ X_1(t_1) & X_2(t_2) \\ X_1(t_3) & X_2(t_3) \\ X_1(t_n) & X_2(t_n) \end{pmatrix}$$

(2)

X =

where

X j (tk) is the sensor j' s data at time tk .

Sensors are recorded in time in the matrix X. X sent to user interface as GPS cooridinates and camera generated images.

1. Data Analysis: Data analysis on the response of the UGV to commands and its interface with the environment are made. They are analyzed by the following parameters:

2. Obstacle Avoidance: The obstacle avoidance capacity of ultrasonic sensors is tested when the system realizes and avoids objects by introducing obstacles to the path of the UGV.

3. Accuracy of Navigation: The GPS data collection can be used to measure the quality of the positioning of the UGV as per its predetermined route.

4. Steering Control: This is a test that evaluates the performance of the steering systems by measuring the speed and accuracy of the mechanism in performing the operator steering inputs such as left and right wheel turns.

5. System Latency: a measure of the performance of wireless communication systems is based on system latency measures which are used to comprehend the time lag between the commands keyed in on the web interface and received UGV responses.

The analysis of data can allow the evaluation of the performance of the system by checking the components that will identify hardware or software failures or poor performance. The system is provided with the outcomes of adjustments that allow improving the performance across the UGV platform.mmands entered through the web interface and obtained UGV responses.

D. System Specifications

The effective working of the UGV system requires a list of specifications. The principal specification is:

1. UGV Chassis:Mahindra Jeep was engineered to build the UGV chassis that allowed enough component holders and had a stable performance of the UGV system.

2. Electrical System:Two DC motors with a driving and camera movement (500 RPM at 12 V) and obstacle detection sensors compose the electrical system.

3. Communication:Both the remote control and video streaming between the UGV and the operator interface will be performed using a wireless indoor communication system over Wi-Fi.

4. Sensors:The ultrasonic sensors detect objects that are before it and the GPS module keeps the position of the location perfectly on track.

With its web interface operators are able to adjust the direction of the path of the UGV as well as its speed when using the UGV in real-time. This includes:

1. The ESP32 camera is employed in taking video footage.

2. The GPS circuit and compass to monitor the position and the orientation.

3. Obstacle sensors (ultrasonic).

4. A speed and direction-controlled dual drive circuit with geared DC motors.

5. Results

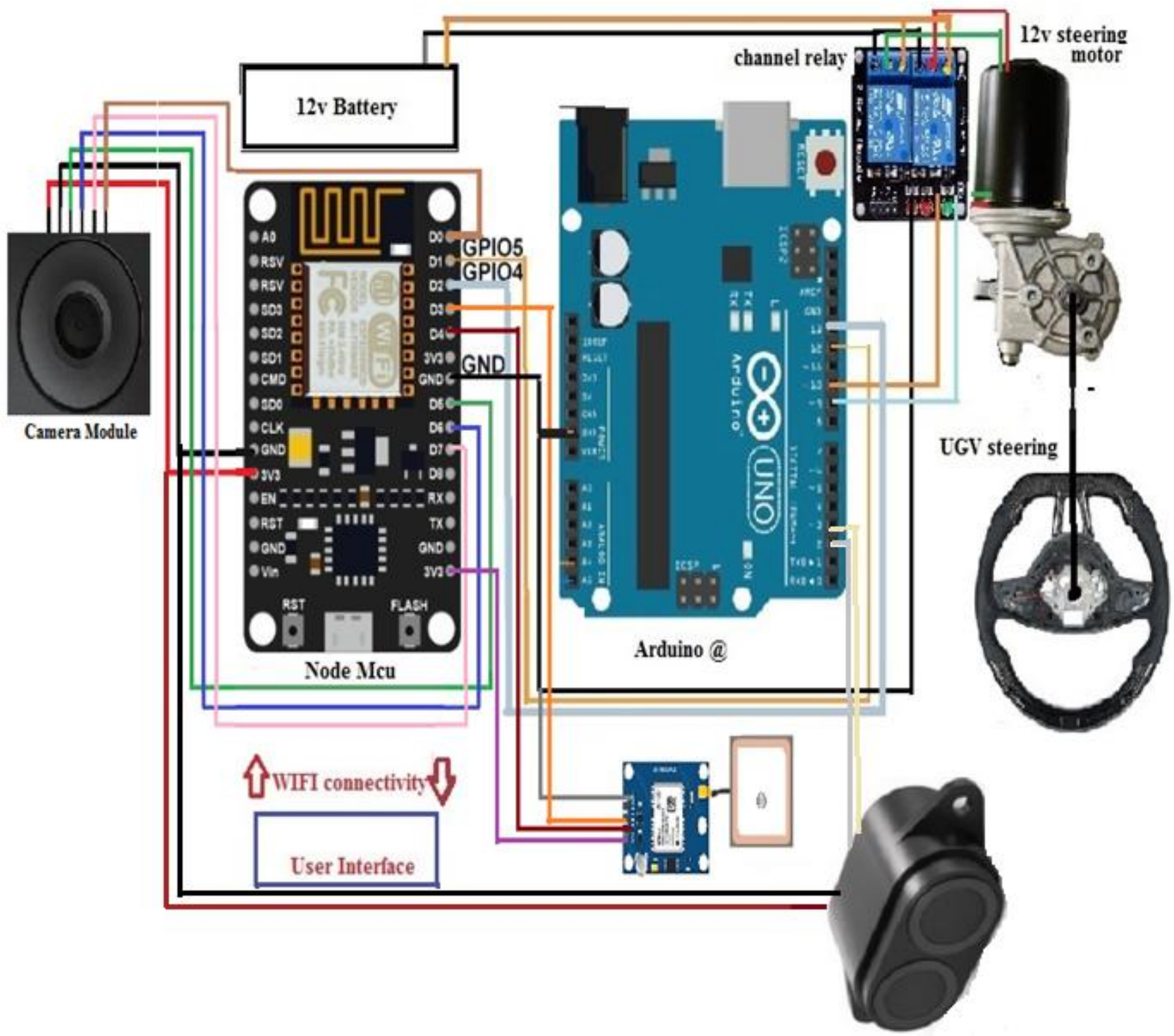

Figure 1: System Interface and Connection

Figure 1 demonstrates the UGV hardware architecture, it consists of the components such as the ESP32 camera, GPS circuit, ultrasonic sensors, and dual drive circuit with DC motors to move and detect obstacles.The software is split into various subroutines each having its own functions to perform with the system. Table II contains the most important subroutines. The schematic view of the software is represented in figure 2 and the system flow chart is in figure 3.

Table II: Primary Subroutines

NodeMCU	Arduino
Wi-Fi communication subroutine	Steering control subroutine
Command relay subroutine	Obstacle detection subroutine
Video streaming subroutine	GPS data processing subroutine

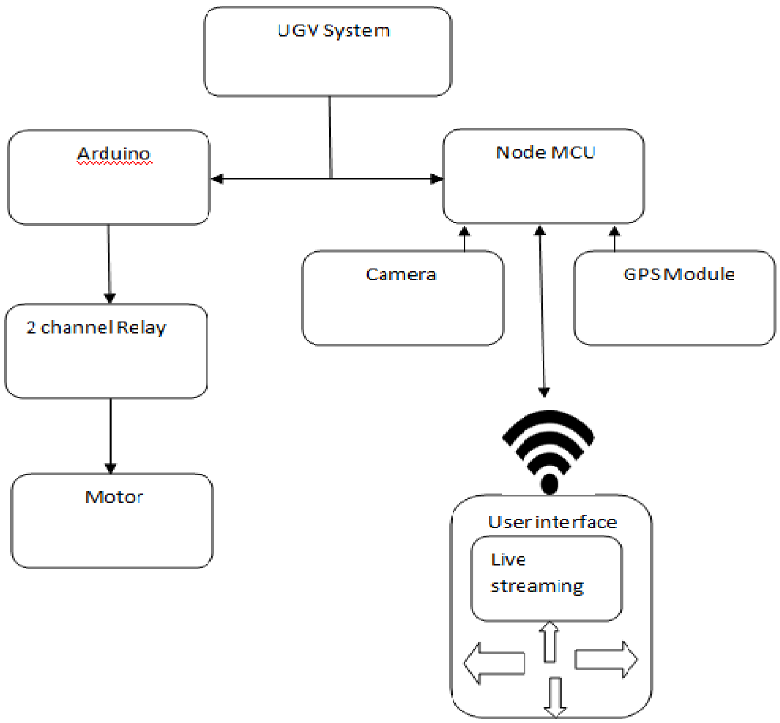

Figure 2: Software Design

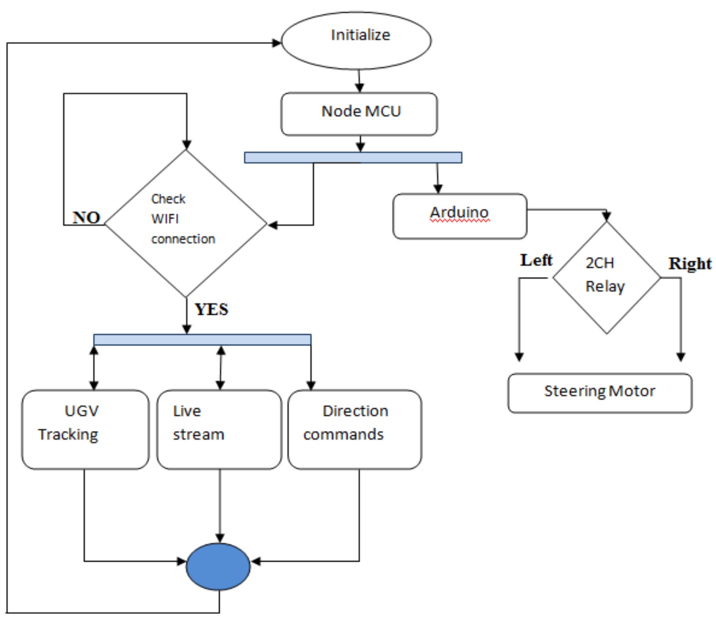

Figure 3: System Flow Chart

The Arduino-based system prototype is created in C++ and the web interface is created in HTML. Figure 4 demonstrates the System Interface.Communication between the web browser and the NodeMCU was done with ESP8266 Wi-Fi library, which enabled the UGV to be remotely operated through the internet. The system has a range of operation in the Wi-Fi network, making it possible to have long-range control [19].

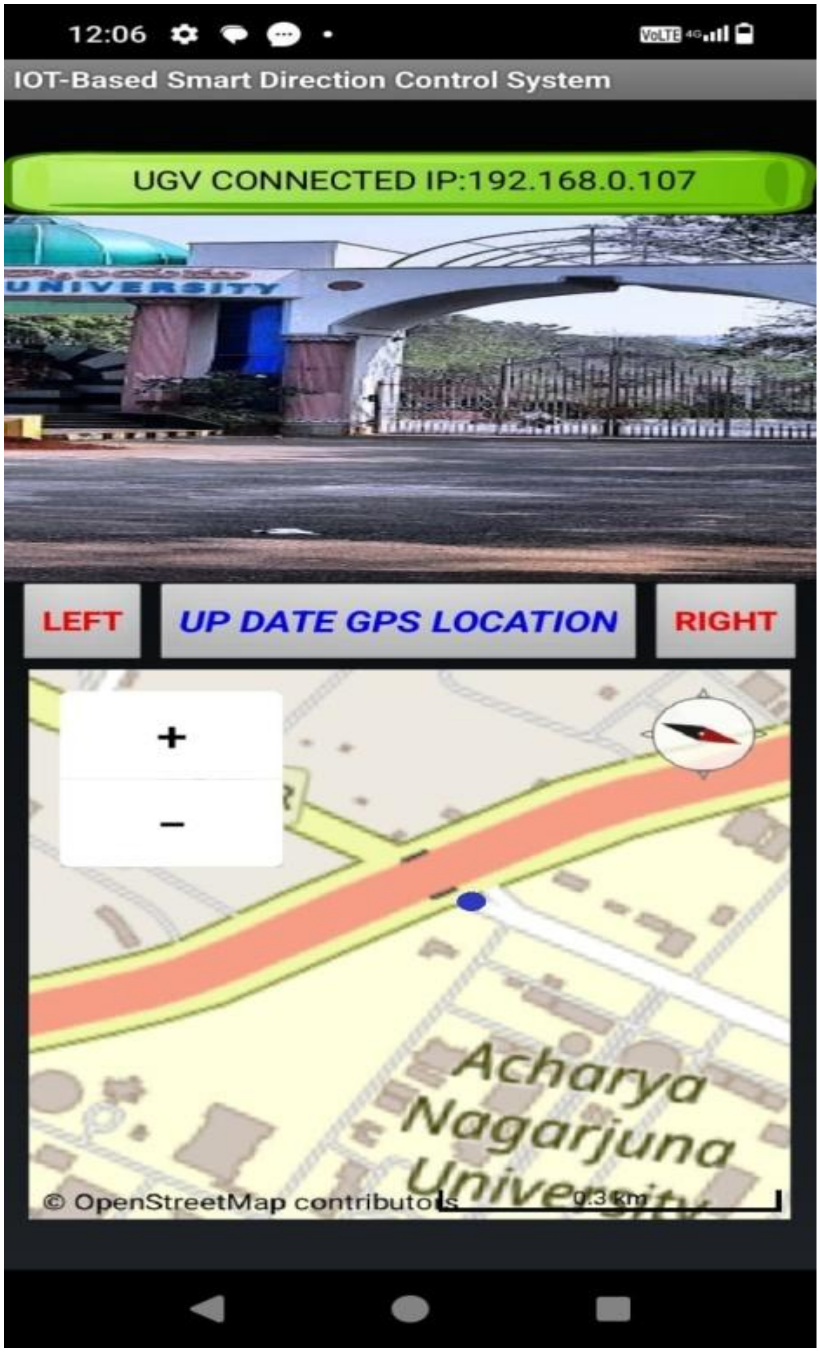

Figure 4: Web Browser System Interface

The prototype evaluation assesses its performance in terms of latency as well as accuracy and reliability criteria. Key findings include:

1. Latency: Maximum Response time of 0.8 seconds for directional commands.

2. Steering Accuracy: Precision within ±2 degrees during directional changes.

3. Operational Range: Stable operation within 300 meters of WiFi range on 2.4 GHz router .

Table III: Prototype Performance

Parameter	**Value**
Latency	0.8 seconds
Steering Accuracy	±2 degrees
WiFi Range	300 meters

Table III gives a summary of the prototype design as it demonstrates its significant performance parameters that consist of latency and steering accuracy and operational range. These metrics were used as a basis to assess the efficiency of the system in line with the effectiveness capabilities through real-world performance assessment of the system. The system latency is presented in figure 5. Table IV shows the latency in detection according to various conditions of the environment.

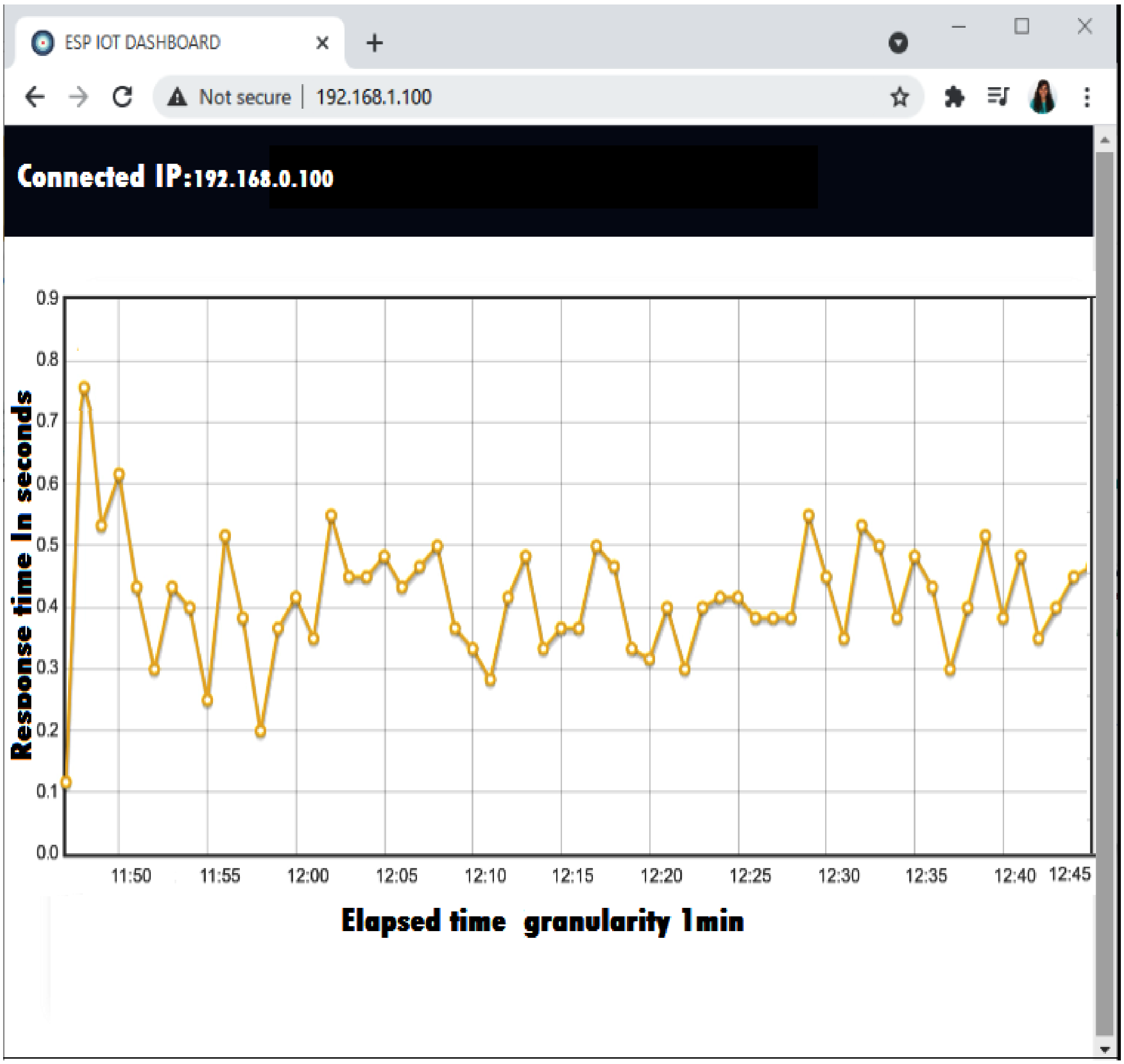

Figure 5: Web Browser System Latency

Table IV: Detection Latency Based on Different Environmental Conditions

Environment Conditions	Average Latency (seconds)	Remarks
Open Ground	0.2 seconds	Limited distance and open non-obstacles area satisfactory response
City	0.4 seconds	Increased latency due obstacles such as walls, floors, and ceilings
Maximum Load on Router	0.6 seconds	Slower detection due to maximum user load on WIFI router
Distance	0.8 seconds	Network delays causing increased Distance.
Other Network Conditions	0.5 seconds	Under optimized conditions (more heat, network hardware etc).

6. DISCUSSION

The key research aim was to develop a system of real-time direction control of Unmanned Ground Vehicles (UGVs) with the help of IoT technologies. The standardization of the use of both the NodeMCU and Arduino microcontrollers had managed to reduce the response time through the precise control of the steering capability of the UGV and the obstacle detection systems[20]. The system installed eliminated long response time that is normally enjoyed by traditional UGV systems. The implementation of an ESP32 camera and obstacles sensors provided better precision and safer real-time navigation to UGV systems.

These research results are extremely significant that can be applied to defense organizations and rescue teams besides industrial automation systems. The application of autonomous vehicles with IoT-enabled microcontrollers will allow real-time control of critical operations and the control of a vehicle. The study furthers the funds of autonomous vehicle system by exploring superior communication and quicker transmission of commands over distance [21]. The study demonstrates that the development of low-latency UGV systems is a viable approach that can be made possible using low-cost IoT devices. There are some limitations to the system since the connectivity of the Wi-Fi is a border to the operational functionality and poses challenges in unstable connection signal environments. Wi-Fi based connections are strong and sustained, therefore limiting system functionality to use in demanding or isolated environments.

7. FUTURE RESEARCH DIRECTIONS

The future quantum key distribution systems development should address a number of research proposals that will address the current limitations of the system and enhance the range of its use. The system will operate more effectively in challenging areas of operations because it will utilize 5G technology and satellite communication networks to increase the range of communication [22].4 The system will have autonomous route planning and obstacle avoidance capabilities with the help of artificial intelligence functions, reducing the need to pay full attention to the UGV. Using machine learning algorithms the platform will be able to autonomously adapt to varied environments which enhances its performance efficiency [23].

Another research step will be the development of more robust CAD-based robots that can work under extreme conditions like rough terrain and extreme weather due to the studies done on multi-vehicle coordination using vehicle-to-vehicle communication systems [24].The design of autonomous team functioning will create more efficient operations of the UGV hence extending its application to massive operations [25].

The creation of an IoT-based direction control system of UGVs researchers has established a significant step in the development of autonomous car systems with new capabilities. Such a system can be transformed across various industries by predicting advancement in technology in the communication and artificial intelligence as well as in structural design with its increase in flexibility alongside automated processes and greater reliability.

8. CONCLUSION

We developed AutoUGV, which is an IoT based UGV directional control system capable of offering real-time effective operation with low latency. IoT microcontrollers accelerated the system performance by increasing the speed of reactions and making UGV steering functions more precise and enhancing the abilities to identify obstacles. The results of the research indicate the way the IoT technologies facilitate the development of autonomous vehicle systems benefiting military activities and emergency rescues, and industrial businesses. The study produces immense value to the unmanned vehicle control since it allows rapid UGV operations. Another important invention that applies the IoT is an option that allows the UGVs to be remotely controlled and to make instant decisions that serve to foster better safety and greater efficacy and turnaround of time in critical scenarios.

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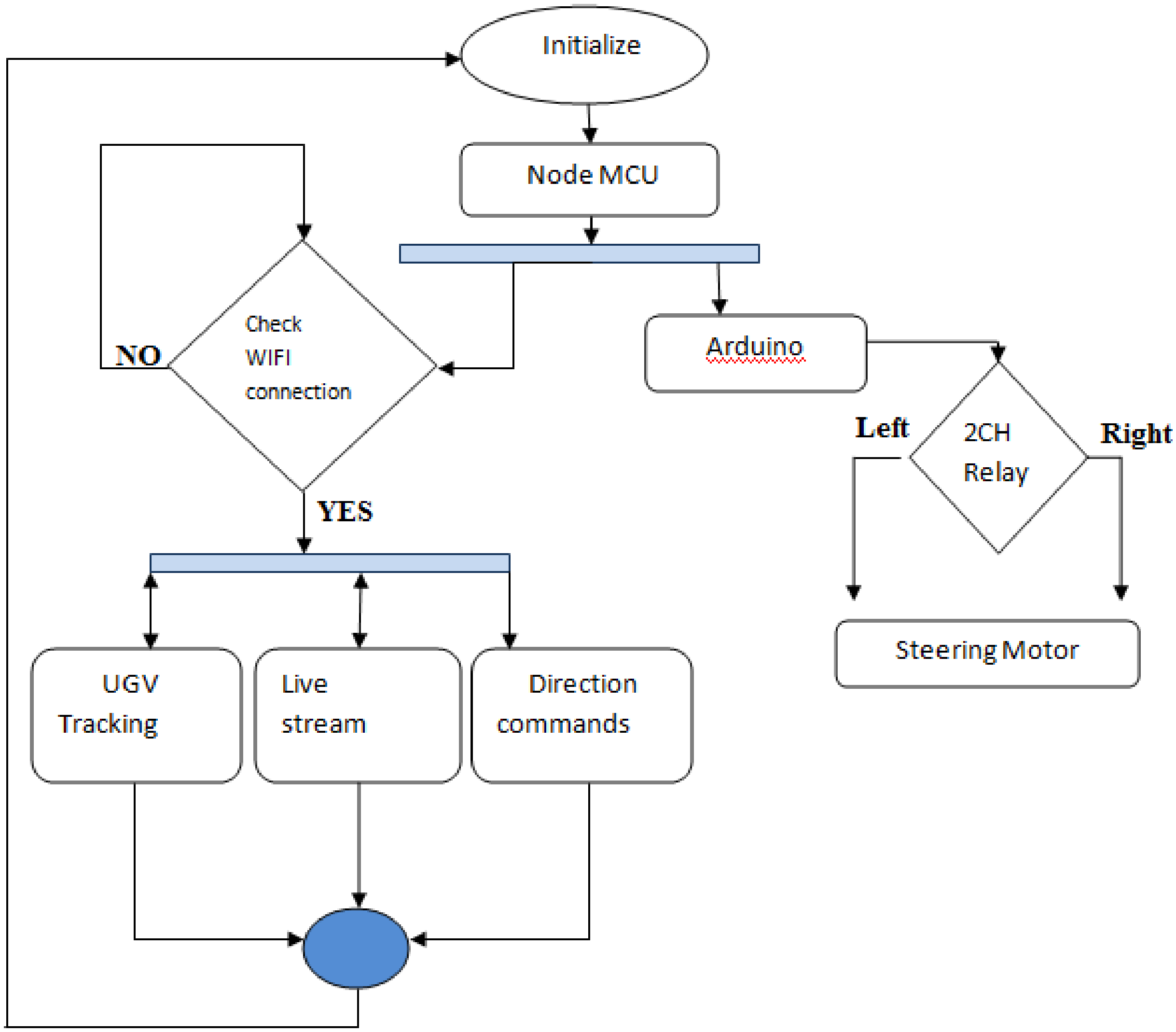

Figure 3: System Flow Chart