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REAL-TIME MONITORING AND TRAFFIC SIGNAL CONTROL BY INTELLIGENT UAV AND GENETIC ALGORITHM OPTIMIZATION

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Abstract

The rapid growth of urban populations is intensifying traffic congestion and leading to delays and accidents. This research proposes an intelligent traffic management system using UAVs equipped with advanced sensors, cameras, and real-time communication to monitor and improve traffic flow. The introduced system prioritizes emergency vehicles by detecting them within a 1.8 km range, transmitting their location, and automatically adjusting traffic signals to ensure swift passage. Normal operations resume once the vehicle clears the intersection. To reduce waiting times, the system applies Artificial Intelligence, specifically a Genetic Algorithm (GA) in MATLAB, to optimize green light durations was used. Optimized durations of 55.67, 56.70, 49.76, and 44.95 minutes reflect balanced traffic flow, with slightly longer times for higher-demand lanes. In some cases, uniform 30-second durations further improved flow. UAVs maintained stable communication and precise positioning, even in complex environments. The largest deviation in UAV target distance occurred between minutes 41-42, with a peak speed of 5.75 m/s and a 1.75 m drift due to external factors. After minute 43, the UAV realigned, showcasing the control system's ability to stabilize through speed and orientation adjustments. A successful 360-degree yaw rotation confirmed precise motor control and overall system reliability. Importantly, the system can instantly switch signals to green for emergency vehicles, effectively eliminating their waiting time.

Keywords: Artificial intelligence, Control systems, Genetic algorithm, Traffic light, Unmanned aerial vehicles.

1. Introduction

Traffic light control systems regulate vehicle movement at intersections to ensure smooth flow. However, coordinating multiple lights at nearby junctions is complex, and traditional systems are unable to adapt to fluctuating traffic volumes [1, 2]. Unpredictable population growth has increased vehicle numbers, leading to higher traffic density, longer delays, and more frequent congestion and accidents, particularly in areas without adequate oversight. Traffic light systems are essential for managing road use, controlling the right-of-way, and minimizing accidents [3, 4]. Earlier systems used direct control routines to respond to unusual events like road closures due to accidents or public gatherings [5]. They were also designed to reduce wait times, lower fuel usage, and improve road capacity and overall efficiency. Standardized colour coding (red, yellow/amber, and green) is used worldwide, with adaptations for individuals with colour blindness [6, 7].

Adaptive traffic light control systems are crucial for safer, efficient traffic flow, especially for emergency vehicles such as ambulances and fire trucks, which need to reach destinations quickly [8-10]. Heavy traffic at intersections often delays their progress. Adaptive systems address this by monitoring real-time traffic conditions and detecting emergency vehicles [11, 12]. Over time, various intelligent traffic control methods, including simple electromechanical controllers with clock-based mechanisms, have been developed to facilitate maintenance [13, 14].

Chinyere et al. [15] developed an FL-based intelligent traffic light system that outperformed manual and traditional methods by adapting to real-time traffic flow. It reduced total waiting and travel times, effectively preventing traffic deadlocks, lowering fuel consumption, and minimizing air and noise pollution.

Rao [16] improved the traffic light system using Arduino for a three-way road. The system demonstrated a simple and efficient traffic management solution for dense areas, while Preeti and Shankar [17] developed a smart traffic light control system that utilized MATLAB-based image processing, Arduino, and LED indicators. The system enhanced traffic flow, minimized wait times, conserved energy, and promoted a safer, more eco-friendly environment by reducing the risk of accidents.

Bagde [18] implemented a smart traffic system using artificial intelligence, infrared (IR) sensors, an Arduino Mega, and wireless communication modules. The system enhanced traffic management, reduced delays, and supported smart city integration. Shepelev et al. [19] implemented artificial neural networks and fuzzy logic (FL) within MATLAB Simulink to monitor traffic across 25 intersections. The research effectively forecasted traffic density and evaluated random variables influencing vehicle movement. Ikidid et al. [20] improved a traffic optimization model using Multi-Agent Systems (MAS), FL, and Java programming. The system optimized green time allocation and reduced congestion across multiple intersections.

Jafari et al. [21] applied FL, multi-agent systems, and Sugeno modelling to enhance intersection signal control. Each intersection acted independently while sharing data with others. MATLAB simulations showed reduced vehicle queues and improved traffic responsiveness. Patil et al. [22] designed a priority-based traffic light controller for emergency vehicles. The model used ATmega-328P, solar panels, IR sensors, and RF technology to prioritize emergency vehicles, ensuring timely responses and saving lives. Mohanty et al. [23] developed a system integrating environmental and health sensors with FL controllers and Simulink models, leading to improved emergency response and increased road safety. Zahwa et al. [24] used SUMO (Simulation of Urban Mobility) and Python-driven FL controllers for traffic simulation, resulting in increased vehicle speeds, shorter wait times, and smoother traffic flow at intersections.

The rapid growth of urban populations has significantly increased traffic congestion, increasing the risk of accidents and hindering the timely movement of emergency vehicles such as fire trucks and ambulances. Traditional traffic management systems often lack the responsiveness and adaptability required to handle real-time traffic dynamics, particularly in rapidly developing or infrastructure-limited regions.

This research addresses these challenges by proposing a smart, UAV-assisted traffic management system capable of real-time traffic monitoring and adaptive signal control. By integrating Unmanned Aerial Vehicles (UAVs) equipped with sensors, cameras, and communication modules, the system detects emergency vehicles within a 1.8 km range, dynamically adjusts traffic signals, and optimizes traffic flow using Artificial Intelligence techniques, a Genetic Algorithm (GA) implemented in MATLAB. The system aims to reduce overall waiting times, enhance emergency response efficiency, and operate effectively even in regions with minimal ground infrastructure.

2. Methods and Experimental Work

The design methodology included, firstly, designing a UAV control system. This system connects the ground station to the target, as shown in Fig. 1. The design also includes an intelligent traffic light system.

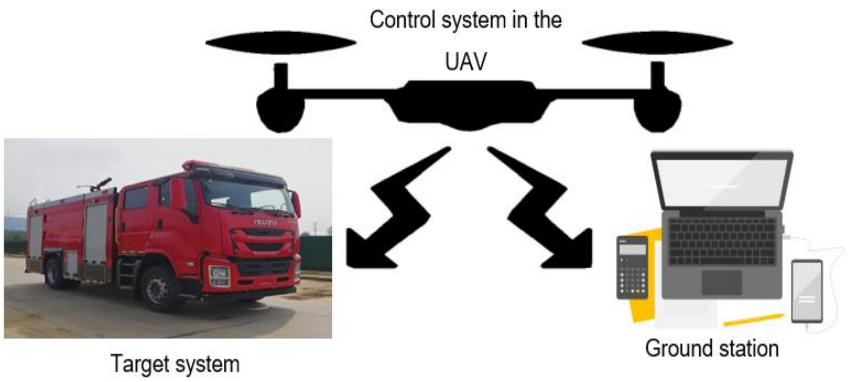

Fig. 1. Operational fundamentals of the UAV for traffic monitoring and control.

2.1. UAV control system

The angle between the two arms must be 90 degrees to achieve balance. The electrical and navigational system in the UAV is installed on the base as shown in Fig. 2.

Fig. 2. Fabricated UAV with control system.

Hardware Components: The control system in the UAV has the main electrical components as follows:

Autopilot: Autopilot is the main device as a guidance and control system in the proposed UAV. There are many tasks related to autopilots that might be performed by aircraft technicians, such as installation, inspection, troubleshooting, etc. The autopilot used in the proposed UAV is shown in Table 1.

Telemetry radio (3DR Radio V2): It is straightforward to open the communications between autopilots and grading stations in a direction with no obstacles. The telemetries 3 used in the developed system are shown in Table 1.

First Personal View (FPV) Camera: The FPV camera for UAVs is lightweight and compact, enabling real-time video transmission. It converts analogue signals to digital via an A/D converter, transmits them using digital modulation, and then demodulates and converts them back to analogue at the receiver for the display [25]. Figure 3 shows the system's block diagram.

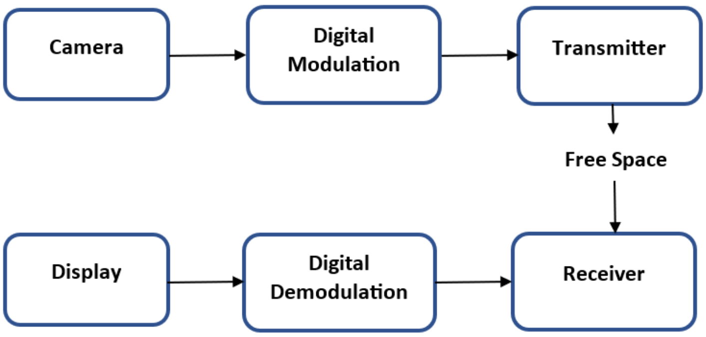

Fig. 3. Block diagram of FPV operation system.

Brushless DC electric motor: A brushless DC motor, or electronically commutated motor (ECM) is a synchronous motor powered by a DC supply. It uses an electronically controlled closed-loop system to switch current through the windings, generating a magnetic field to rotate the permanent magnet rotor. Figure 4 shows the

2300 KV BLDC motor used for a proposed UAV, which delivers up to 330 W of power and 965 mN of thrust, while Fig. 5 shows motors' control unit scheme.

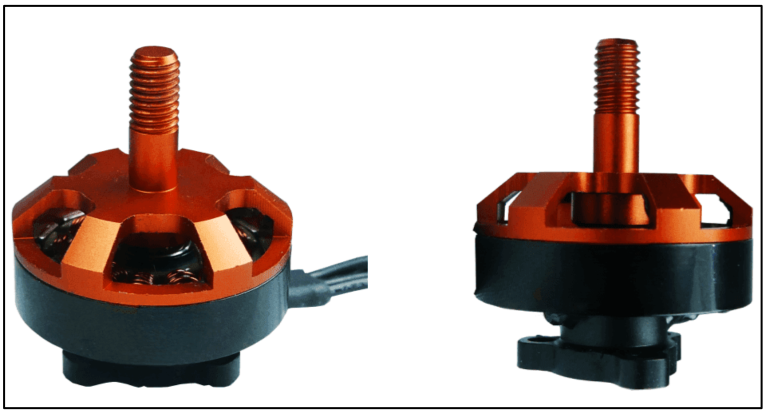

Fig. 4. 2300 KV UAV BLDC motor.

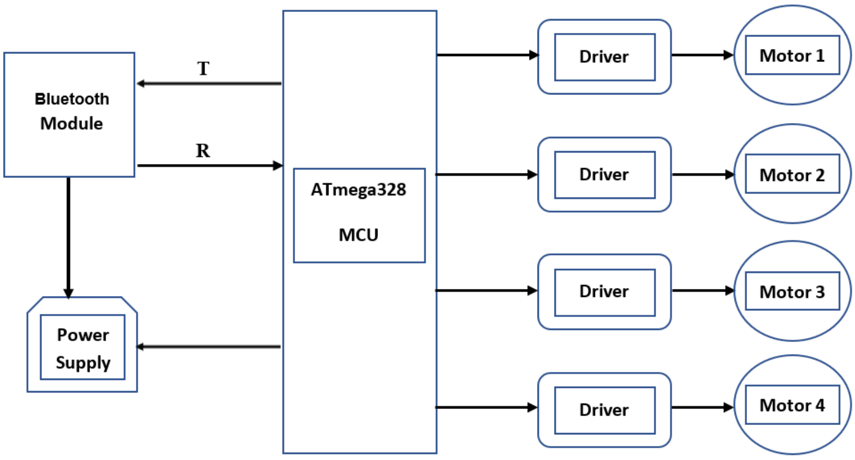

Fig. 5. Block diagram of motor control.

Electrical Speed Control (ESC) and battery: An Electronic Speed Controller (ESC) shown in Table 1, controls brushless DC (BLDC) motors in UAVs by sending high-frequency signals to the motor's three-phase windings for smooth rotation. The ESC adjusts motor speed based on signal frequency, working with the flight controller to monitor UAV orientation and maintain stability.

The Li-Po battery used in this work delivers reliable power with excellent endurance. Its key benefits include high energy density, lightweight design, high discharge rate, long lifespan, consistent voltage, and support for high current draw–making it ideal for stable, high-performance UAV operations.

Basic Operation of the Control System for UAV: The scenario for the working strategy of the control system for UAV is illustrated in the block diagram, shown in Fig. 6, that shows the electrical control system connection.

Table 1. Components operational strategy of the control system for UAV.

Component	Explanation	
Power Source & Distribution	LiPo battery connected via XT60; adapter's power module supplies autopilot & ESCs.	
ESCs	Control motor speed; connected to autopilot using servo connectors (individual or 4-in-1).	
Autopilot System	A central controller that manages motors using control signals to perform UAV actions.	
Receiver and Signal Conversion	Converts signals to PPM; communicates with a 2.4 GHz transmitter for compatibility.	
Transmitter (2.4) HZ	Sends control signal commands from the operator to the UAV.	
Telemetry MODUAL	Provides real-time data exchange with ground station software.	
GPS & Compass	Ensures navigation and orientation; the compass arrow must align with the UAV's nose.	
Safety Power Switch	Allows for a safe, quick shutdown of UAV power.	

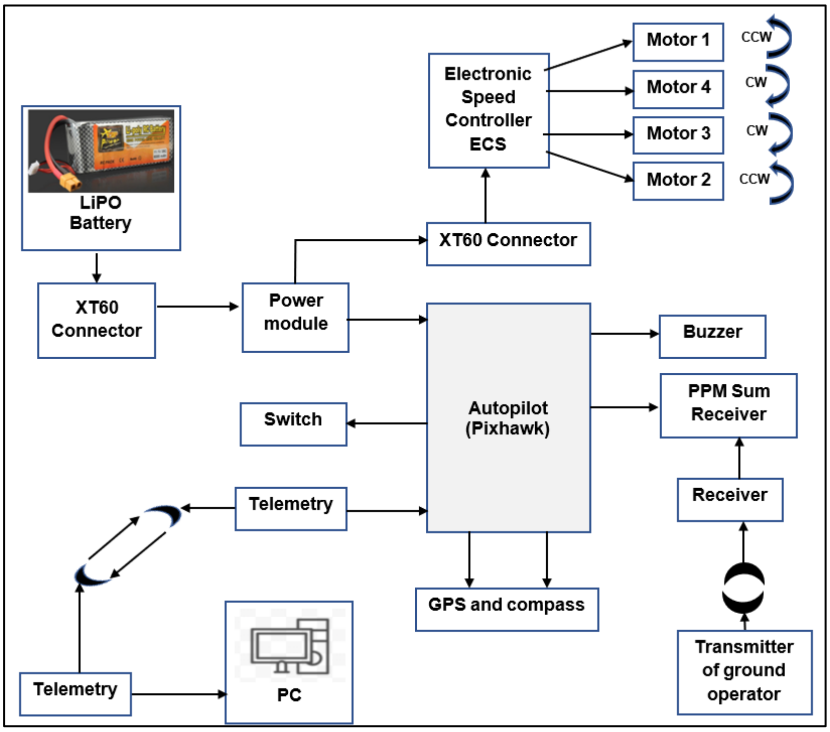

Fig. 6. Block diagram of the electrical control system.

Ground Station: Mission Planner monitors system indicators during flight. The radio is connected to a Windows PC via micro-USB, where Windows installs the driver automatically. After installing the ground station software, the correct communication (COM) port near the "Connect" button to link the autopilot is selected. Figure 7 displays the COM port interface.

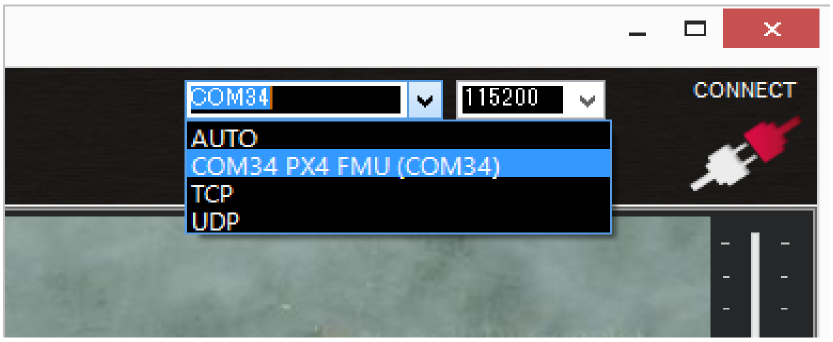

Fig. 7. Communication port (COM port).

Target System: The target is special vehicles (ambulances and fire trucks) that contain the following devices:

- Personal Mobile Phone.
- The GPS of the mobile.

- Telemetry (3DR Radio V2) with the connector.
- The proposed UAV is built to detect and track a moving target with a defined speed and direction. The implementation process includes:
- Initialization: Systems start, and altitude is set using Mission Planner.
- Target Data Transmission: GPS coordinates, speed, and direction are sent from the target to the UAV via Q Ground Control.
- Data Processing: The autopilot uses compass, gyroscope (x = 0, y = 90, z = altitude) and barometer data for navigation and stability.
- GPS Alignment: The UAV compares its GPS with the targets to align positions.
- Real-Time Tracking: Position adjusts continuously to follow the target.
- Distance/Speed Calculation: GPS data helps measure target distance and speed.

Traffic Light System Design: The proposed system used a GA to optimize the traffic light system that minimizes waiting time.

An intelligent traffic light system is designed with the following stages:

Central Traffic System: It is located at the intersection centre; it includes a microcontroller (ATmega2560) to control signals and relates to the UAV (Fig. 8).

Smart Subsystems: Recognize special mission vehicles, send their data to the UAV, which checks priority and determines the path, then relays it to the central system, as shown in Fig. 9.

System Reset: After the special vehicle passes, the UAV signals the central system to return to normal unless another priority vehicle is queued.

Operating tests for signal transmission between the traffic light system and UAV are shown in Figs. 10 and 11.

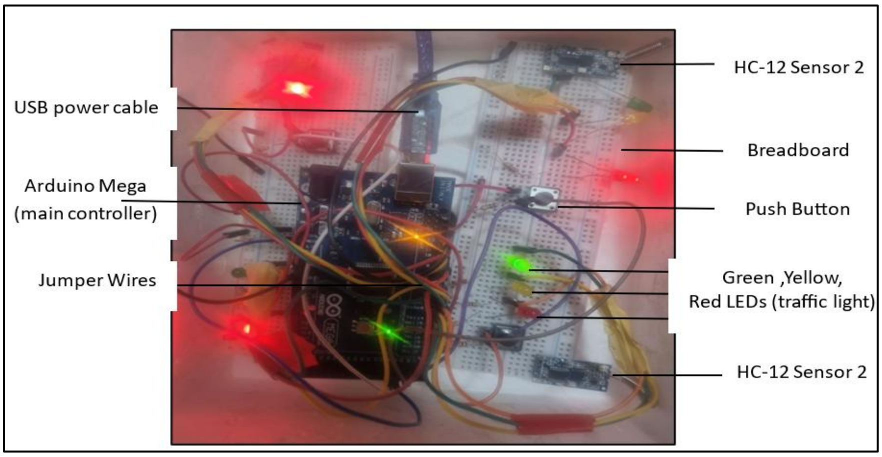

Fig. 8. Interior design of the central system in the traffic signal.

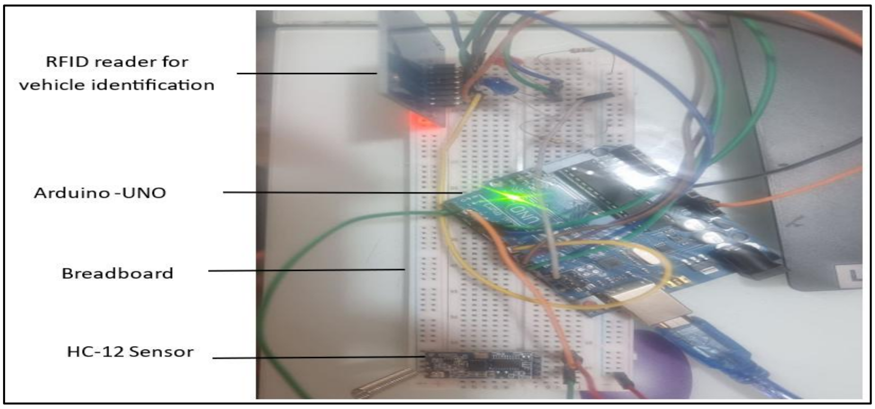

Fig. 9. Interior design of the subsystem in the traffic signal.

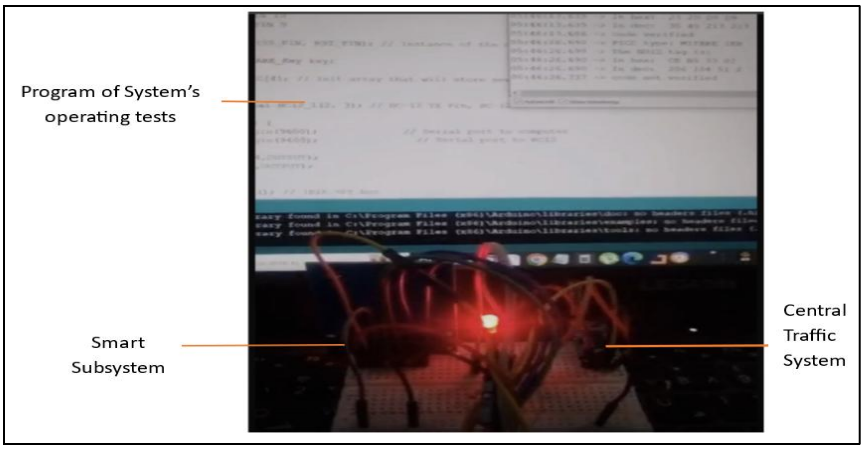

Fig. 10. System's operating tests for transmitting and receiving signals between the traffic light system and UAV.

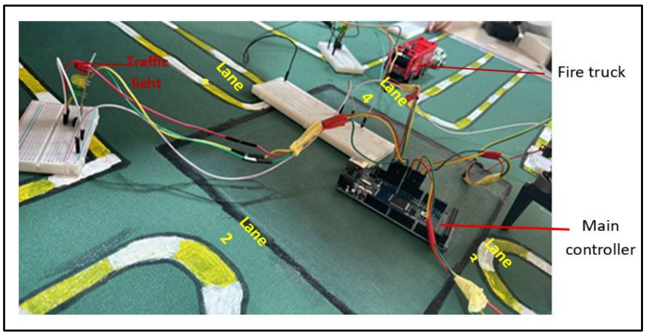

Fig. 11. The experimental model.

2.2. Genetic Algorithm optimization of the traffic light system

GA is a search-based natural selection mechanism and is among the most suitable algorithms for solving complex optimization problems that conventional methods cannot tackle [26, 27]. The aim of optimizing traffic light durations using the GA is to minimize total vehicle waiting time at an intersection. The following steps are used, and Fig. 12 shows the flow chart for the GA.

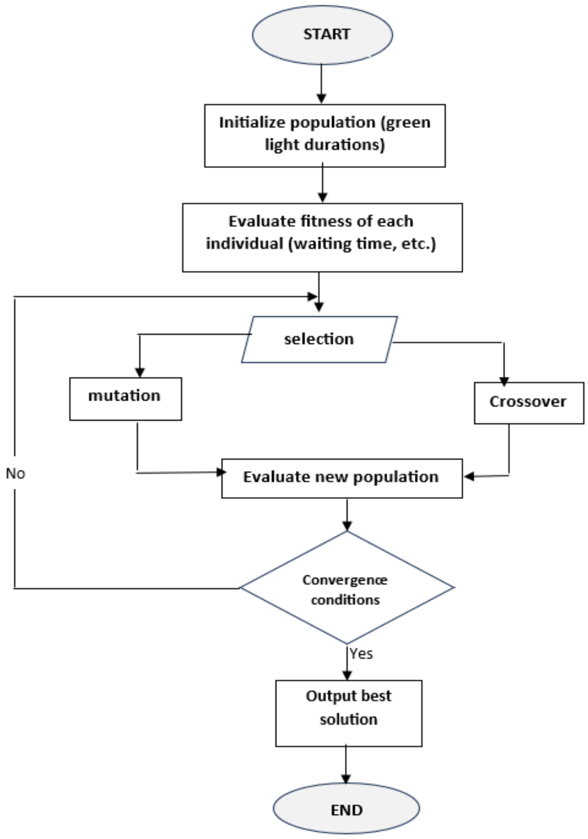

Fig. 12. Flowchart for GA.

2.2.1. Define the objective function

The objective function simulates Traffic Flow(x) and calculates the total waiting time for given green light durations. The GA will minimize this waiting time. The GA Parameters and Execution:

- Population size = 20 (number of solutions per generation).
- Max generations = 100 (iterations for optimization).
- Green light duration bounds = 10 to 60 seconds for each lane.

The GA traffic function executes selection, crossover, and mutation to find the best solution.

2.2.2. Genetic algorithm process

Initial Population: Random green light durations within limits.

- Fitness Evaluation: Uses simulate Traffic Flow to compute waiting time.
- Selection: Top 50% of solutions survive.
- Crossover: New solutions are created by combining parent solutions.
- Mutation: Random changes in offspring solutions to enhance diversity.
- Repeat Until Convergence: The algorithm runs for 100 generations.
- Visualization of Results as a Bar Chart Displays optimized green light durations per lane.
- Traffic Simulation: The function simulates Traffic Flow(x), estimates remaining vehicles and waiting time for each lane based on green durations. Assuming 2 vehicles clear per second.

3. Result and Discussion

The present work relies on the programming interfaces between the UAV, traffic system, and target system, as well as between the Arduino and MATLAB software, to achieve intelligent performance.

3.1. Results of UAV

Figure 13 shows the UAV's roll (red), pitch (green), and yaw (blue) variations [the ***changes*** or ***movements*** in the UAV's orientation (roll, pitch, yaw) during flight].

Before 11:47:

- Roll (Red): Stable with minor oscillations–indicates steady lateral balance.
- Pitch (Green): Slight variation–suggests small forward/backward adjustments; overall stable.
- Yaw (Blue): Consistent shows the UAV maintained its heading.

At 11:47:

A sharp disturbance occurs, likely due to strong winds.

- Yaw: Sudden spike indicates forced heading change.
- Roll: A significant spike means the UAV tilts laterally to counter the wind.
- Pitch: Sharp drop: UAV likely tilted backward or lost forward motion.

After the 11:47:

- Roll: Rapid drop means lateral correction during landing.
- Pitch: Further decline means reduced forward tilt.
- Yaw: Fluctuations mean difficulty maintaining direction under wind stress.

This highlights the UAV's stable flight followed by wind-induced instability during landing.

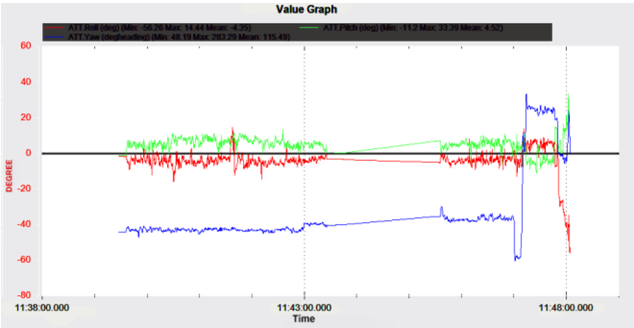

Fig. 13. UAV flight dynamics: roll, pitch, and yaw stability under wind disturbances.

Figure 14 shows variations in the UAV–target distance. The largest gap occurs between minutes 41-42, where the UAV reached a peak speed of 5.75 m/s and drifted 1.75 m from the target–likely due to wind, sudden manoeuvres, or repositioning for alignment.

After minute 43, the UAV stabilized and aligned with the target. This demonstrates the control system's effectiveness in correcting trajectory and maintaining consistent distance through speed and orientation adjustments. As shown in Fig. 15, the UAV successfully completed a 360-degree yaw rotation, demonstrating precise motor control and stability. This capability is essential for full-area scanning and realigning with targets. The UAV also showcased intelligent traffic management by identifying priority vehicles (e.g., fire trucks) using long-range sensors (up to 1.8 km). It transmits this data to the traffic system, which adjusts lights accordingly, then restores normal flow once the vehicle passes.

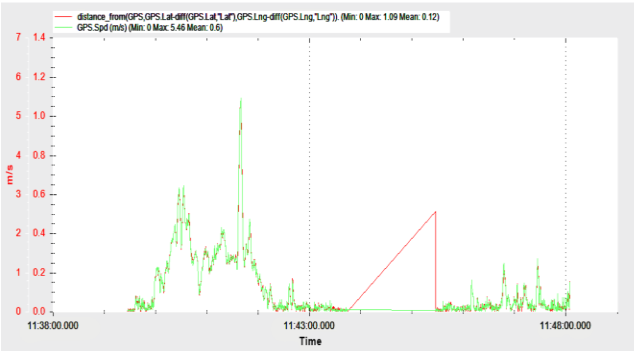

Fig. 14. Difference in distance and speed between the UAV and the target.

Fig. 15. Rotating the UAV around 360 degrees.

3.2. Results of the GA to optimize traffic light durations.

The GA optimized green light durations at an intersection, reducing total waiting time to zero. A bar chart, shown in Fig. 16, shows the optimized durations (in seconds) for four lanes: 55.67, 56.70, 49.76, and 44.95. The variation in lane durations is minimal, ensuring balanced traffic flow, with lanes 1 and 2 having longer durations, likely due to higher traffic demand.

The GA was integrated with a traffic-light control model in MATLAB, interfacing with an Arduino microcontroller to control signals. A MATLAB-based GUI was developed for traffic visualization, as shown in Fig. 17.

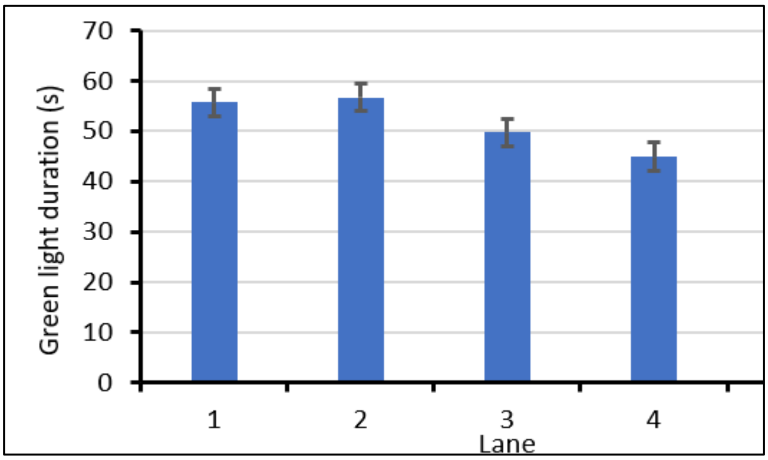

Fig. 16. Bar chart of the optimized green light durations (in seconds) for four lanes.

With this optimization, the green light duration was set to a uniform 30 seconds for each lane, improving traffic flow significantly. The system's high performance made capturing images of vehicles at red or yellow signals challenging, suggesting efficient green-light prioritization. The outcomes include optimized green light durations, minimum waiting time, and potential for real-world smart traffic signal control applications. The predicted mean standard deviation of the results is 5.47%.

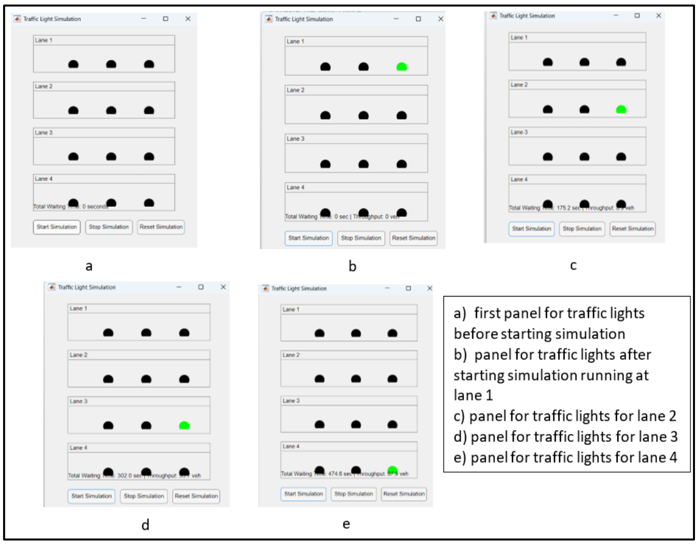

Fig. 17. Traffic performance visualization using a MATLAB-based GUI.

4. Conclusion

An intelligent signal monitoring and traffic control system is introduced in this work to prioritize emergency vehicles by identifying them within a 1.8 km radius, transmitting their positions, and automatically adjusting traffic signals to enable rapid, uninterrupted movement. To further reduce delays, the system uses Artificial Intelligence via a GA to optimize green-light durations. The UAV testing results showed strong stability in calm conditions and faced challenges in windy weather, especially during landing.

The system's high responsiveness was evident in its ability to align with targets, stabilize speed, and perform complex manoeuvres such as 360-degree rotations. While there were speed and distance fluctuations, the UAV excelled in real-time user messaging, demonstrating suitability for dynamic tasks requiring situational awareness. The introduced UAV reached a peak speed of 5.75 m/s and drifted 1.75 m from the target due to wind. After the 43rd minute, the UAV regained stability and successfully aligned with the target.

The Genetic Algorithm effectively optimized the green light durations at the intersection, achieving a total waiting time of zero. The optimized durations (in seconds) for the four lanes are 55.67, 56.70, 49.76, and 44.95. This approach prevents delays, enhancing emergency response efficiency. A key advantage is the system's cost-effectiveness, which relies on affordable sensors, embedded hardware (such as Arduino), and MATLAB interfaces. Despite its low cost, it delivers excellent results, proving that advanced traffic management can be achieved without expensive infrastructure.

Abbreviations

AI	Artificial Intelligence
BLDC	Brushless DC

COM port	Communication Port
ECM	Electronically Commutated Motor
ESC	Electrical Speed Control
FPV	First Personal View
GA	Genetic Algorithm
GPS	Global Positioning System
GUI	Graphical User Interface
PC	Personal computer
PPM	Pulse Position Modulation
SUMO	Simulation of Urban Mobility
UAV	Unmanned Aerial Vehicle

References

1. Balu, V. (2020). Smart traffic light control system. *International Journal of Advanced Research in Engineering and Technology*, 11(11), 2054-2059.
2. Sunehra, D.; and Rajasri, S. (2017). Automatic street light control system using wireless sensor networks. *Proceedings of the* 2017 *IEEE International Conference on Power*, *Control*, *Signals and Instrumentation Engineering* (*ICPCSI*), Chennai, India, 2915-2919.
3. Gayathri, R.; and Amudha, A. (2016). Solar powered traffic control system based on traffic density with emergency vehicle alert. *Middle-East Journal of Scientific Research*, 24(2), 234-238.
4. Ghazal, B.; ElKhatib, K.; Chahine, K.; and Kherfan, M. (2016). Smart traffic light control system. *Proceedings of the* 2016 *Third International Conference on Electrical*, *Electronics*, *Computer Engineering and their Applications (EECEA)*, Beirut, Lebanon, 140-145.
5. De Oliveira, L.F.P.; Manera, L.T.; and Da Luz, P.D.G. (2020). Development of a smart traffic light control system with real-time monitoring. *IEEE Internet of Things Journal*, 8(5), 3384-3393.
6. Lee, W.H.; and Chiu, C.Y. (2020). Design and implementation of a smart traffic signal control system for smart city applications. *Sensors*, 20(2), 508.
7. Oliveira, L.F.P.; Manera, L.T.; and Luz, P.D.G. (2019). Smart traffic light controller system. *Proceedings of the* 2019 *Sixth International Conference on Internet of Things*: *Systems*, *Management and Security* (*IOTSMS*), Granada, Spain, 155-160.
8. Meng, B.C.C.; Damanhuri, N.S.; and Othman, N.A. (2021). Smart traffic light control system using image processing. *IOP Conference Series*: *Materials Science and Engineering*, 1088(1), 012021.
9. Albatish, I.M.; and Abu-Naser, S.S. (2019). Modeling and controlling smart traffic light system using a rule-based system. *Proceedings of the International Conference on Promising Electronic Technologies* (*ICPET*), Gaza, Palestine, 55-60.
10. Hawi, R.; Okeyo, G.; and Kimwele, M. (2017). Smart traffic light control using fuzzy logic and wireless sensor network. *Proceedings of the* 2017 *Computing Conference*, London, UK, 450-460.
11. Safi, M.E. (2016). Smart traffic light controller based on microcontroller. *Iraqi Journal of Computers*, *Communications*, *Control*, *and Systems Engineering (IJCCCE)*, 16(1), 38-45.

12. Bhatia, M.S.; Aggarwal, A.; and Kumar, N. (2020). Smart traffic light system to control traffic congestion. *PalArch's Journal of Archaeology of Egypt/Egyptology*, 17(9), 7093-7109.
13. Aleko, D.R.; and Djahel, S. (2020). An efficient adaptive traffic light control system for urban road traffic congestion reduction in smart cities. *Information*, 11(2), 119.
14. Ahmed, A.H.; and Fragonara, L.Z. (2021). Adaptive intelligent traffic control system for improving traffic quality and congestion in smart cities. *International Journal for Quality Research*, 15(1), 139-154.
15. Chinyere, O.U.; Francisca, O.O.; and Amano, O.E. (2011). Design and simulation of an intelligent traffic control system. *International Journal of Advances in Engineering and Technology*, 1(5), 47-57.
16. Rao, N. (2019). Design and development of automatic traffic light control system. *International Journal of Innovative Research in Electrical, Electronics*, *Instrumentation and Control Engineering*, 7(6), 55-57.
17. Preeti, K.S.; and Shankar, A.R. (2020). Design of intelligent traffic light system using visible light communication. *International Journal of Engineering Applied Sciences and Technology*, 5(7), 134-139.
18. Bagde, D. (2021). Artificial intelligence-based smart traffic signal. *PARIPEX - Indian Journal of Research*, 10(6), 61-68.
19. Shepelev, V.; Glushkov, A.; Bedich, T.; Glushenko, T.; and Almitova, Z. (2021). Predicting the traffic capacity of an intersection using fuzzy logic and computer vision. *Mathematics*, 9(20), 2631.
20. Ikidid, A.; El Fazziki, A.; and Sadgal, M. (2021). Multi-agent and fuzzy inference-based framework for traffic light optimization. *International Journal of Interactive Multimedia and Artificial Intelligence*, 8(2), 88-97.
21. Jafari, S.; Shahbazi, Z.; and Byun, Y.C. (2022). Improving the road and traffic control prediction based on fuzzy logic approach in multiple intersections. *Mathematics*, 10(16), 2832.
22. Patil, B.; and Sayyed, M. (2023). Solar powered traffic control system based on traffic density with emergency vehicle alert. *International Journal of Innovations in Engineering Research and Technology (IJIERT)*, 10(4), 16-22.
23. Mohanty, A.; Mohanty, S.K.; Mohapatra, A.G.; and Nayak, S. (2024). Integrated smart accident management system for urban traffic congestion alleviation and improved road safety. *Tuijin Jishu Journal of Propulsion Technology*, 45(2), 2399-2412.
24. Zahwa, F.; Cheng, C.-T.; and Simic, M. (2024). Novel intelligent traffic light controller design. *Machines*, 12(7), 469.
25. Sun, I.; Yuan, G.; Song, L.; and Zhang, H. (2024). Unmanned aerial vehicles (UAVs) in landslide investigation and monitoring: A review. *Drones*, 8(1), 30.
26. Md Isa, F.; Ariffin, W.N.M.; Jusoh, M.S.; and Putri, E.P. (2024). A review of genetic algorithm: Operations and applications. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 40(1), 1-34.
27. Kareem, I.S. (2025). Real-time control system for mobile robot with intelligent collision avoidance. *Mathematical Modelling of Engineering Problems*, 12(8), 2732-2740.