2025 IEEE 5th International Conference on Smart Information Systems and Technologies (SIST)
14-16 May, 2025, Astana, Kazakhstan

2025 IEEE 5th International Conference on Smart Information Systems and Technologies (SIST) | 979-8-3315-1514-0/25/$31.00 ©2025 IEEE | DOI: 10.1109/SIST61657.2025.11139290

Simulation and Optimization of UAV Group Control Strategies

Gulim Jobalayeva
Electronics, Telecommunications, and Space Technologies Department
Satbayev University
Almaty, Kazakhstan
g.jobalayeva@satbayev.university

Sara Kengesbayeva*
Electronics, Telecommunications, and Space Technologies Department
Satbayev University
Almaty, Kazakhstan
sarakengesbayeva@gmail.com

Yerlan Tashtay
Electronics, Telecommunications, and Space Technologies Department
Satbayev University
Almaty, Kazakhstan
y.tashtay@satbayev.university

Kuanysh Mussilimov
Automation and Control Department
Satbayev University
Almaty, Kazakhstan
k.mussilimov@satbayev.university

Inkar Issakozhayeva
Automation and Control Department
Satbayev University
Almaty, Kazakhstan
inkar.n@mail.ru

Aidana Torekul
Information and Communication Technologies Department
ALT University
Almaty, Kazakhstan
a.torekul@alt.edu.kz

***Abstract*—In recent years, extensive research has been conducted to develop methods and algorithms for controlling the coordinated motion and interaction of autonomous unmanned aerial vehicles (UAVs). The issue of UAV control in real-world conditions, especially when controlling autonomous unmanned vehicles like airplanes, remains relevant. The complexity of such control is due to the high dynamics and input constraints of real-world autopilots. This paper presents an adaptive control strategy for unmanned aerial vehicle (UAV) group coordination, integrating integral control laws and fuzzy logic to improve dynamic formation stability and energy efficiency. A simulation environment was developed in MATLAB/Simulink to evaluate the proposed strategy. Simulation experiments demonstrated superior responsiveness, reduced trajectory deviation, and increased robustness against external disturbances compared to traditional methods. The results validate the viability of the proposed control scheme in real-time multi-agent UAV systems operating under dynamic and uncertain conditions.**

***Keywords*—UAV; adaptive control; fuzzy logic; formation stability; rotor; energy efficiency.**

I. INTRODUCTION

Currently, the use of unmanned aerial vehicles (UAVs) is rapidly expanding in the military and civilian spheres. They are often used for such tasks as oil and gas pipeline diagnostics, early detection of forest fires, search and rescue operations in emergency situations, terrain mapping and patrolling [1]. The group application of UAVs significantly increases their efficiency and speed of execution, so the study of group control methods remains relevant.

The primary challenge in UAV control arises from their high dynamic nature, nonlinear constraints, and environmental disturbances, which make traditional control approaches less effective. The development of robust control methodologies that enhance UAV autonomy, adaptability, and energy efficiency remains an urgent research priority. Advanced hybrid controllers, such as combinations of SMC and LADRC enhanced with PSO tuning, have demonstrated strong disturbance rejection and improved attitude control in quadrotors [2]. Unlike conventional control methods, which rely on centralized planning or static trajectories, integral and fuzzy logic-based control allows decentralized, real-time adaptation. This makes it especially suitable for unpredictable environments such as disaster response zones, urban obstacle fields, and search and rescue missions.

This research proposes a novel decentralized algorithm to enhance UAV group coordination under disturbances, focusing on real-time adaptation and local responsiveness. The integration of integral laws allows the system to minimize steady-state errors, while fuzzy logic enhances its ability to manage uncertainties and nonlinear behaviors without requiring precise mathematical modeling. The objective of this study is to develop and optimize control strategies for UAV groups operating in coordinated flight formations. Enhanced formation flight strategies based on improved consistency principles and adaptive PSO have been proposed. These methods aim to ensure stability and collision avoidance in multi-UAV operations [3]. The research focuses on designing a control system that ensures dynamic trajectory tracking and stability while accounting for real-world constraints. The simulation model is developed in the MATLAB/Simulink environment to evaluate the performance of the proposed approach under varying conditions.

[1] Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP19679602).

Authorized licensed use limited to: Satbayev University. Downloaded on April 03,2026 at 13:14:57 UTC from IEEE Xplore. Restrictions apply.

The novelty of this research lies in the application of parametric adaptation algorithms based on integral control laws and fuzzy logic for UAV coordination. Swarm robotics takes inspiration from collective behaviors in nature, such as bird flocks and insect swarms, and its applications in surveillance, agriculture, and military domains are rapidly growing [4]. The application of swarm intelligence algorithms like ACO, PSO, and ABC enables UAV groups to autonomously handle complex tasks such as path planning and task allocation in dynamic environments [5]. Unlike conventional control methods, which often rely on pre-programmed paths or centralized decision-making, the proposed approach enables adaptive self-tuning of UAVs in real time, improving their resilience to external disturbances and operational uncertainties. This includes challenges in wireless communication, where UAV systems must operate reliably under multi-jammer attacks and imperfect CSI, as addressed in recent optimization-based strategies [6]. The significance of this work is twofold: first, it contributes to the advancement of UAV group control strategies, which are crucial for applications such as swarm robotics, disaster management, and autonomous reconnaissance; second, the proposed simulation model provides a robust framework for evaluating UAV dynamics and optimizing control algorithms before real-world deployment.

II. Literature Review

Recently, collision-avoidance control for UAV swarms has received significant attention due to its industrial and commercial applications. Traditional collision-avoidance models primarily focus on individual UAV-level avoidance, often failing to address multi-group UAV interactions, which can lead to deadlock situations in constrained environments. Luo et al. [7] proposed a multi-group UAV collision-avoidance strategy that incorporates group-level detection and adaptation mechanisms to enhance motion stability and deadlock resolution. However, these approaches mainly optimize UAV positioning and movement coordination, without considering adaptive self-tuning control strategies for maintaining stable trajectory tracking in dynamic environments.

To address these limitations, this paper develops a control framework that ensures robust UAV group coordination by integrating parametric adaptation algorithms based on integral control laws and fuzzy logic. Unlike existing models, which focus primarily on collision prevention and static trajectory planning, the proposed approach enhances UAV autonomy through real-time trajectory adjustments, improving formation stability and energy efficiency.

While various studies have explored UAV control optimization, most existing approaches focus either on individual trajectory control or obstacle avoidance. As previously proposed by Luo et al. [7], a multi-group strategy improves group-level motion coordination but lacks adaptive control strategies for trajectory stability. Similarly, Tamba et al. [8] investigated the stabilization of an inverted pendulum mounted on a moving UAV using a receding horizon control approach. Their study formulated a quadratic optimization problem to maintain the balance of the pendulum while the UAV moves between predefined positions. While effective for balancing control, this method does not address cooperative UAV swarm behavior and energy-efficient trajectory adaptation in dynamic environments. To bridge this gap, this paper proposes a control framework that ensures robust UAV group coordination by integrating parametric adaptation algorithms based on integral control laws and fuzzy logic. Unlike existing models, the proposed approach enhances UAV autonomy through real-time trajectory adjustments, improving formation stability and energy efficiency in multi-UAV systems.

Path planning and trajectory optimization for UAVs have been extensively studied using various heuristic and metaheuristic algorithms. For instance, Chen et al. [9] proposed an improved Golden Jackal optimization (IGJO) algorithm for solving complex three-dimensional UAV path planning problems in power distribution network inspections. Their approach enhances search space exploration and prevents local optima stagnation, demonstrating superior solution quality and convergence speed. However, this method primarily focuses on optimizing individual UAV path planning rather than addressing real-time adaptive control in dynamic multi-UAV environments. To address this limitation, our study develops a control strategy that integrates parametric adaptation algorithms with fuzzy logic, enabling UAV groups to maintain coordinated motion while dynamically adjusting their trajectories. This approach extends beyond static path planning by ensuring real-time formation stability and energy-efficient navigation in dynamic multi-agent systems.

Autonomous UAVs should not be confused with radio-controlled models, as they have a certain level of autonomy and intelligence. The level of autonomy can range from simple navigation to complex decision making such as target selection for military UAVs and timing of strike [10]. The level of autonomy and intelligence of UAVs grows according to the following classification [11]: Radio-controlled models (no full autonomy); Execution of pre-planned missions (e.g. IAI/AAI RQ-2 Pioneer); Ability to make changes during the mission (e.g., General Atomics RQ-1 Predator, Northrop Grumman RQ-4A Global Hawk); Ability to respond confidently to real-time events; Devices with the ability to adapt to events (e.g., Northrop AGM-136A Tacit Rainbow); Ability to coordinate UAVs in real-time within a group; Ability to cooperate with UAVs within a group in real-time (e.g., Boeing X-45A).

The types and uses of unmanned aerial vehicles (UAVs) are now diverse, ranging from small insect-sized devices to full-sized systems capable of long-term missions. In addition to their many similarities to manned aircraft, UAVs have significant differences related to their operational characteristics. For example, they can fly from unprepared short runways and are capable of stable flight for long periods of time at very high altitudes. The efficiency of UAVs is usually enhanced by the absence of a crew and associated equipment, which allows for optimized aerodynamics and reduced structural weight [12].

Authorized licensed use limited to: Satbayev University. Downloaded on April 03,2026 at 13:14:57 UTC from IEEE Xplore. Restrictions apply.

Autonomous unmanned systems typically consist of the following main components [12]:

- Control station that provides an interface between operators and other system components.
- UAV with various payloads.
- Communication system that interfaces with the control station.
- Support facilities, including repair and transportation equipment.

UAVs are commonly deployed in civilian applications such as:

- Conducting aerial photography.
- Agricultural applications.
- Coast Guard and search and rescue operations in emergencies.
- Monitoring of air pollution, electrical grids, water reservoirs, oil and gas pipelines, forest fires.
- Meteorological research.
- Traffic monitoring and analysis.
- Survey of capital structures, bridges and industrial facilities.

In the military sphere UAVs perform the following tasks:

a) Reconnaissance and control, including long-range high-altitude aircraft, installation and supervision of sonar, control of chemical, biological and radiation pollution.

b) Combat missions: detection and destruction of radar systems, enemy mines, installation of decoys and other special missions.

This paper is structured as follows: Section II presents an overview of UAV control and modeling techniques. Section III discusses the results of comparative simulations using different adaptation algorithms. Section IV summarizes the conclusions and potential future research directions.

III. UAV Control and Modeling Techniques

This paper proposes a Lyapunov-based vector field method that tracks the trajectory to put unmanned aerial vehicles (UAVs) on a circular trajectory and ensure that the phase shift between them is preserved, but only the interaction between two UAVs is considered. The path following vector field strategy is even in [10], but in it each UAV moves at a constant velocity and the required distance between the agents is provided by dynamically increasing or decreasing the radius of the circle. It should be noted that this paper does not provide a rigorous proof of the overall stability of the system, and the effectiveness of the method for any geometries is not studied. However, simulation results demonstrate its practical effectiveness under the considered conditions. The UAV velocity control law is chosen as follows [13]:

$$v^0 = [v_1 v_2 \dots v_N]^T = v1_N + L, \quad (1)$$

where

$$1_N = [1 \ 1 \dots 1]^T \in R^{Nx1} \quad (2)$$

and vector

$$L = \left(v_f \frac{2}{\pi} arctg[k_\theta e_i]\right)_{i=\overline{1,N}} \quad (3)$$

where k_θ is a positive constant that ensures smooth motion when the apparatuses are brought to certain relative positions; v_f is the maximum value of the additional velocity vector to be chosen by equation (1); v means the optimal cruising speed from the aerodynamic point of view.

Oscillatory behaviors during transient vertical maneuvers were also investigated in [14]. The proposed control laws take into account the limitations of the control input signals and the video-holonomic properties of the UAV dynamics [15]. While developing the model of the UAV control system, we divided it into separate blocks to facilitate its application in further studies:

- Initial conditions input block;
- Block of altitude control controller;
- Block of motion control;
- Block characterizing the dynamics of the UAV.

Furthermore, the UAV's dynamics were modeled using a 4-degree-of-freedom (DOF) approach. The translational and rotational movements of the UAV around its center of mass were described by Newton's second law as:

$$m\vec{a} = -mg\overrightarrow{e_y} + R(\varphi, \theta, \Psi)\vec{u} \quad (4)$$

where $a = (x, y, z)^T$ is the total acceleration of the dynamic system; m is the mass of the body; $\overrightarrow{e_y}$ is a unit vector directed along the Y axis; R(φ, θ, Ψ) is the rotation matrix; $\vec{u}$ is the sum of non-conservative forces acting on the system (including the forces and the tensile force of the screws).

The UAV utilizes a rechargeable battery pack placed to maintain center of mass balance. Due to its weight, the UAV frame was designed using durable materials. The system's average autonomous flight time was between 10 and 15 minutes. To protect fragile components like propellers, a guard ring was installed to reduce breakage in the event of a collision.

In addition to precise control laws, reliable and interference-free communication plays a vital role in UAV network operations. One promising approach to optimizing UAV communication efficiency is Cognitive Radio, which enables dynamic spectrum access by identifying underutilized frequency bands. In previous work [16], spectrum recognition of GSM, UMTS, and LTE was performed for Kazakhstan using RTL-SDR receivers. The findings demonstrated the uneven distribution of mobile spectrum, highlighting the potential for improving UAV network connectivity. Integrating Cognitive Radio techniques into UAV control systems can enhance real-time communication reliability, reduce interference, and improve coordination in multi-UAV environments.

The structure of the created control system is shown in Fig. 1, which consists of four modules. Each module is an element of the control system, and you can access the internal structure of the module by double-clicking on it. This method simplifies interaction with the system, allowing quick access to parts of the system and quick changes if necessary. The circuit also has two actively programmed buttons. The control principle of the system is realized by means of control feedback, where the control effect occurs when the control principle is applied

Authorized licensed use limited to: Satbayev University. Downloaded on April 03,2026 at 13:14:57 UTC from IEEE Xplore. Restrictions apply.

due to the deviation of the controlled quantity from the desired value.

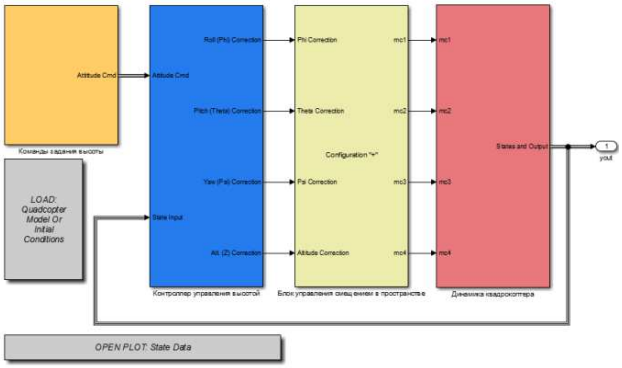


Figure 1. UAV simulation model in MATLAB software environment

The path-tracking field is inhomogeneous in direction and magnitude, which leads to the disappearance of the assumption that it is initially in a circle when the specified phase angles are set [15]. Obtaining this prediction is important not only because the vehicles form a shape without reaching a circular path but also because in stability analysis it is impossible to observe the rigor conditions inside the circle under the influence of external factors such as atmospheric disturbances [17].

The control unit receives the corrected parameters coming from the controllers and combines them to send them to the required rotors. The quadrocopter uses two basic configurations: the “+” and “X” configurations. In the “+” configuration, the X and Y axes are parallel to the arms of the vehicle: if the X axis is parallel to the arm on which the rotor rotating clockwise is located, the Y axis is parallel to the arm of the rotor rotating counterclockwise. In the “X” configuration, the X and Y axes are located between the arms of the apparatus and are rotated 45 degrees relative to the “+” configuration. The schematic of the control unit is shown in Fig. 2.

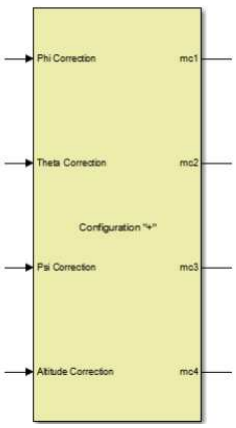


Figure 2. UAV control unit

The purpose of the switch is to allow both configurations of the quadcopter to be used without making additional changes to the control system design. In addition, Fig. 3 provides a structural representation of the motion control unit, which governs the UAV's flight path adjustments. The diagram highlights key elements such as the altitude controller, motion dynamics module, and control feedback loop. This unit ensures precise trajectory tracking by dynamically adjusting thrust and rotational parameters. The control strategy considers external disturbances and optimizes UAV motion stability through adaptive algorithms.

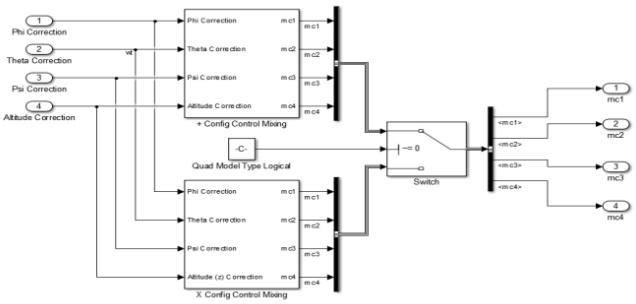


Figure 3. Structure diagram of the motion control unit in space

Once rotor control adjustments are applied the data from this unit are transferred to the unit that characterizes the dynamics of the UAV.

IV. Results and Discussion

The block shown in Fig. 4 is responsible for the actuators, in particular the direct control of the rotors of the aircraft. The control system consists of multiple input signals that process data from external sources and internal stabilizatUAVs ion mechanisms. These signals are directed to the actuator control unit, which ensures accurate and efficient operation of the aircraft's propulsion system.

The left section of the diagram represents the input signals, including control commands, stabilization feedback, and external disturbances. These inputs are processed through the actuator control module, highlighted in yellow, which plays a crucial role in determining the appropriate adjustments for each rotor.

The control signals for each rotor are transmitted through a dedicated output channel to the actuators, as depicted on the right side of Fig. 4. The signals ensure precise adjustments in rotor speed and orientation, allowing the aircraft to maintain stability and respond effectively to environmental disafter adturbances. The block diagram also includes feedback loops that continuously monitor the system’s response, making real-time corrections to optimize performance.

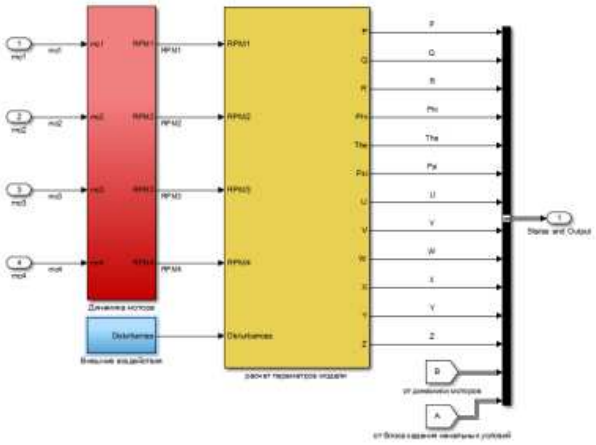


Figure 4. Structure diagram of the dynamics unit

The results shown in Fig. 4 indicate that a well-structured actuator control system can significantly

Authorized licensed use limited to: Satbayev University. Downloaded on April 03,2026 at 13:14:57 UTC from IEEE Xplore. Restrictions apply.

improve aircraft maneuverability, reduce response time to external influences, and enhance operational reliability.

The components of the quadcopter's dynamics block are also analyzed in this section. Fig. 5 illustrates the design scheme of a brushless DC motor within the motor dynamics block, which is a key component of the quadcopter's dynamics system.

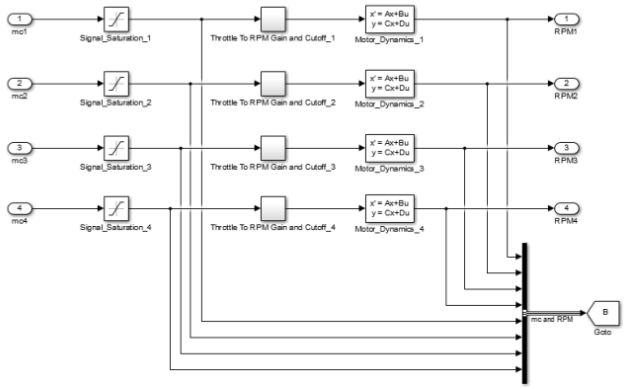


Figure 5. Structural diagram of the engine dynamics unit

Signal saturation blocks are used to limit the power of the motors, since the maximum power of the motors is limited to 100%.

The external influence block allows input signals of external influences, such as additional wind speed, along one axis of the quadcopter.

The model parameter calculation block performs calculations based on theoretical formulas. This block is programmable and uses a pre-developed program written in the MatLab programming language [18].

The system includes additional functions, such as creating graphs of all processes and downloading initial data for ease of use. Fig. 6 illustrates the transition process for height adjustment of the UAV. The left section of the figure presents the variation of motor speeds over time, demonstrating the system's response to height correction commands. The right section provides time-domain plots of key flight parameters, including angular velocities and height changes. The results indicate that the control system effectively stabilizes the UAV, minimizing oscillations and ensuring smooth altitude transitions. The observed transient responses confirm that the implemented control algorithm provides fast adaptation to environmental disturbances and maintains stable flight performance.

Although exact numerical data were not extracted from the simulation environment, visual analysis of the system response indicates that the adaptive fuzzy-integral control algorithm achieved faster stabilization, smoother trajectory transitions, and reduced sensitivity to external disturbances compared to classical control methods. The algorithm effectively adapted to changes in altitude and orientation under simulated wind disturbances and maintained stable flight dynamics across varying operational scenarios.

These findings demonstrate the robustness of the proposed control strategy under varying dynamic conditions. Compared to conventional PID controllers, the fuzzy-integral method required less overshoot time and showed improved damping characteristics. Furthermore, the controller's ability to maintain stability despite model uncertainties highlights its potential for real-time UAV deployment. Such performance indicates suitability for real-world applications, particularly in environments with unpredictable external influences.

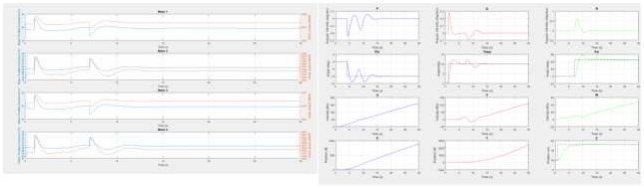


Figure 6. Transition process for height adjustment

To evaluate the effectiveness of parametric adaptation algorithms, comparative modeling using integral laws and fuzzy logic was carried out. The modeling results showed high efficiency of adaptive self-tuning algorithms while maintaining the stability and quality of alternating trajectories when forming and maintaining several UAVs.

Additionally, a preliminary sketch model of the UAV was created using AutoCAD software (Fig. 7). The prototype demonstrates the component layout including motor-propeller assemblies, protective rings, and battery compartments, offering insight into the physical feasibility of the control strategies developed. Each motor (there are 4 in total) is attached to a propeller and drives it at a speed determined by the speed controllers. The speed controller sets the rotation speed based on commands received from the flight controller [19].

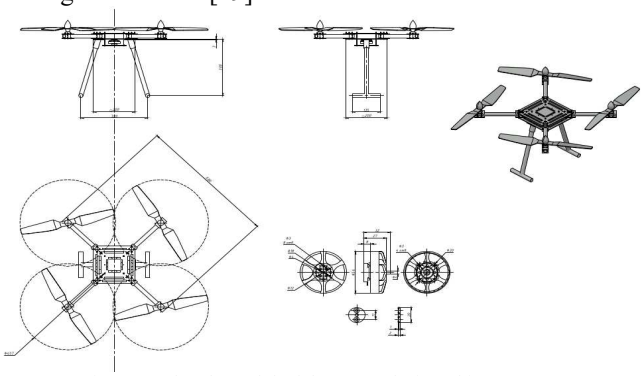


Figure 7. Sketch model of the UAV designed in AutoCAD

An assembled experimental UAV prototype was constructed based on the AutoCAD model (Fig. 8). During the testing phase, an external power source such as a generator was connected to provide uninterrupted energy supply, ensuring continuous operation for indoor trials.



Figure 8. Assembled prototype of the UAV with external generator power source

Authorized licensed use limited to: Satbayev University. Downloaded on April 03,2026 at 13:14:57 UTC from IEEE Xplore. Restrictions apply.

Fig. 8 shows the assembled prototype of the unmanned aerial vehicle (UAV), where a generator is connected as the ground-based power source.

V. CONCLUSION

This study presented a parametric adaptation algorithm for UAV group control, integrating integral control laws and fuzzy logic. The proposed method was tested in MATLAB/Simulink through simulation experiments involving four UAV groups under different flight scenarios.

Simulation results demonstrated that the proposed adaptive algorithm effectively maintained formation stability and ensured smooth trajectory tracking. The approach allowed UAVs to transition between different flight formations with minimal deviation. Compared to conventional control strategies, the adaptive algorithm provided improved responsiveness under external disturbances such as wind effects.

The comparative analysis with Lyapunov-based control and potential field methods indicated that the proposed approach enhanced the robustness of UAV formation control in dynamic environments. Future work will involve integrating reinforcement learning methods, such as Q-learning or DDPG, to dynamically adjust control weights in response to changing flight environments. The real-world prototype implementation using the proposed model reinforces its practical feasibility and highlights the adaptability of the control strategies to real-time conditions.

REFERENCES

[1] Frew E.W., Lawrence D.A., Morris S., “Coordinated standoff tracking of moving targets using Lyapunov guidance vector fields”, Journal of Guidance, Control and Dynamics, Vol. 31, No 2. pp. 290–306, 2008.

[2] Q. Xu, Y. Yan, Q. Han, B. Wang and Y. Tian, "Design of Sliding Mode Linear Active Disturbance Rejection Quadcopter UAV Controller based on Particle Swarm Optimization," 2024 7th International Conference on Robotics, Control and Automation Engineering (RCAE), Wuhu, China, 2024, pp. 262-269, doi: 10.1109/RCAE62637.2024.10834194.

[3] W. Yu, "A Multi UAV Formation Flight Control Method Based on Improved Consistency Principle and Adaptive Particle Swarm Optimization Algorithm," 2024 8th International Conference on Electrical, Mechanical and Computer Engineering (ICEMCE), Xi'an, China, 2024, pp. 1526-1530, doi: 10.1109/ICEMCE64157.2024.10862905.

[4] M. M. Shahzad, M. H. Asad, M. Haris, H. Munawar and M. H. Yousaf, "Formation Control and Sub-Swarm Generation of Multirotor UAVs," 2023 International Conference on Robotics and Automation in Industry (ICRAI), Peshawar, Pakistan, 2023, pp. 1-7, doi: 10.1109/ICRAI57502.2023.10089546.

[5] T. Volovoda, "Swarm Intelligence for UAV," 2024 IEEE 7th International Conference on Actual Problems of Unmanned Aerial Vehicles Development (APUAVD), Kyiv, Ukraine, 2024, pp. 313-316, doi: 10.1109/APUAVD64488.2024.10765878.

[6] Y. Bian et al., "Joint Trajectory Control, Power Control, and Collection Schedule in UAV-Assisted Anti-Jamming Wireless Data Collection With Imperfect CSI," in IEEE Communications Letters, vol. 28, no. 12, pp. 2839-2843, Dec. 2024, doi: 10.1109/LCOMM.2024.3488178.

[7] L. Luo, X. Wang, J. Ma and Y. -S. Ong, "GrpAvoid: Multigroup Collision-Avoidance Control and Optimization for UAV Swarm," in IEEE Transactions on Cybernetics, vol. 53, no. 3, pp. 1776-1789, March 2023, doi: 10.1109/TCYB.2021.3132044.

[8] T. A. Tamba, Y. Y. Nazaruddin and E. Juliastuti, "The Regulation of a Quadrotor UAV Carrying a Pendulum using Receding Horizon Control," 2020 12th International Conference on Information Technology and Electrical Engineering (ICITEE), Yogyakarta, Indonesia, 2020, pp. 63-67, doi: 10.1109/ICITEE49829.2020.9271668.

[9] Z. Chen, T. Zhou and J. Jiao, "Improved Golden Jackal Optimization-based 3D Path Planning of UAV in Distribution Network Inspection," 2023 9th International Conference on Electrical Engineering, Control and Robotics (EECR), Wuhan, China, 2023, pp. 1-5, doi: 10.1109/EECR56827.2023.10149983.

[10] Muslimov T., Munasypov R. Cooperative Guidance for Waypoint Following of Distributed Multi-UAV System // Interactive Collaborative Robotics. ICR 2020. Lecture Notes in Computer Science, vol 12336. Springer, Cham, 2020. P. 234–242.

[11] Kownacki C, Ambroziak L. Adaptation Mechanism of Asymmetrical Potential Field Improving Precision of Position Tracking in the Case of Nonholonomic UAVs. Robotica. 2019;37(10):1823-1834. doi:10.1017/S0263574719000286

[12] Munasypov R.A., Muslimov T.Z., Habibullina R.R. Group control of autonomous unmanned vehicles using the potential field method // Proceedings of the All-Russian Scientific and Technical Conference of Young Scientists and Postgraduate Students “Intelligent Systems, Control and Mechatronics - 2016”. Sevastopol, 2016. C. 225-229.

[13] Navigation and Control of Autonomous Marine Vehicles / ed. Sharma S., Subudhi B. London: The Institution of Engineering and Technology, 2019.

[14] Jatsun S. F. et al. Investigation of Oscillations of a Quadcopter Convertiplane in Transient Mode in the Vertical Longitudinal Plane // Proceedings of 14th International Conference on Electromechanics and Robotics “Zavalishin's Readings”, Springer, Singapore, 2020, pp. 345– 358. DOI: 10.1007/978-981-13-9267-2_28.

[15] Beard R.W., McLain T.W. Small unmanned aircraft: Theory and practice // Small Unmanned Aircraft: Theory and Practice. Princeton University Press, 2012. 1–186.

[16] S. Kengesbayeva, D. Utebayeva and L. Ilipbayeva, "Investigation of spectra of mobile communication systems using RTL-SDR radio receiver", Journal of Theoretical and Applied Information Technology, vol. 100, no. 15, pp. 4844-4851, 2022.

[17] Taissariyeva, K., Issembergenov, N., Dzhobalaeva, G., Usembaeva, S. “Experimental studies of a prototype model of the multilevel 6KW-power inverter at supply by 12 accumulators”, Proceedings of SPIE - The International Society for Optical Engineering, 2016, 10031, 1003125.

[18] Seidaliyeva, U. et al., “Advances and Challenges in Drone Detection and Classification Techniques: A State-of-the-Art Review”, Sensors, 2024, 24(1), 125.

[19] Mustapa Z. et al. Altitude controller design for multi-copter UAV // 2014 International Conference on Computer, Communications, and Control Technology (I4CT), 2014, pp. 382 – 387. DOI: 10.1109/I4CT.2014.6914210.

Authorized licensed use limited to: Satbayev University. Downloaded on April 03,2026 at 13:14:57 UTC from IEEE Xplore. Restrictions apply.