IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 13, Issue 1, January 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.317

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 1, January 2024||

|DOI:10.15662/IJAREEIE.2024.1301009 |

UAV Motion Controller: An Auto-Tuned PID Controller Based Approach

Himanshu Soni ,Prof. Davendra singh dohre

Research Scholar Dept. of Instrumentation & Control Engineering, MPCT, Gwalior, India

Professor, Dept. of Instrumentation & Control Engineering, MPCT, Gwalior, India

ABSTRACT: This paper presents the parameter optimisation of the flight control system of a singlerotor medium-scale Unmanned aerial vehicle (UAV). The six degrees-of-freedom (DOF) nonlinear mathematical model of the UAV is developed. This model is then used to develop proportional–integral–derivative (PID)-based controllers. Since the majority of PID controllers installed in industry are poorly tuned, this paper presents a comparison of the optimised tuning of the flight controller parameters auto-tuning algorithms. The aim is to find the best PID parameters that minimise the specified objective function. Two trim conditions are investigated, i.e., hover and 10 m/s forward flight. The proposed algorithm performed better than manual tuning of the PID controllers. It was found, through numerical simulation, that the closed loop autotuning algorithm converges the fastest and finds the best gains for the selected objective function in hover trim conditions.

KEYWORDS: Unmanned aerial vehicle, PID controller, YAW rate control, Simulink, Auto-tuning.

I. INTRODUCTION

One of the four fundamental principles of the Fourth Industrial Revolution (4IR) is the decentralisation of decisions for machines. This means increased autonomy of systems to make their own decisions in order to perform specific tasks without human intervention or supervision, especially in the presence of uncertainty and external disturbances [1]. Unmanned aerial vehicles (UAVs) have been at the forefront of autonomous systems, with specific applications already demonstrated in the military environment, such as surveillance, reconnaissance, evacuation and payload delivery, and civil applications such as filming, crop dusting, parcels and medical aid delivery [2]. These tasks require the employment of a rotorcraft UAV, because rotorcraft have the capacity for vertical takeoff and landing, hovering in place, flying backwards and side-slip. They are useful in situations where fixed-wing aircraft fail to perform, such as cluttered areas, overgrown fields and dangerous industrial areas including nuclear plants and offshore oil rigs [3].

However, a rotorcraft is a highly nonlinear, multi-input, multi-output system. It is also characterised by high coupling with a larger number of dynamics that cannot be modelled explicitly. This system is also inherently unstable, meaning that, once disturbed from equilibrium, it does not return unless an external force is introduced. This makes the achievement of the demanded autonomy a daunting challenge [4]. This performance specification for autonomy has resulted in high complexity in the rotorcraft flight control system. Significant effort has been devoted to improving the performance and reliability of flight control systems in the past two decades [1], and the increase in computational power and communication bandwidth has made possible some of the improvements that have eluded control engineers in recent years [5]. As such, a number of control strategies have been presented for the control of rotorcraft, including a proportional–integral–derivative (PID) controller and its gain scheduling counterpart [6,7]. This design methodology, also referred to as classical, requires linear approximation of the rotorcraft around a selected operating region. This is due to the fact that PID controllers are normally single-input single-output (SISO). However, these methods only work well under the simplifying assumptions of a linear system. Despite this, PID controllers have been successfully implemented in rotorcraft flight control systems. Following the advances in the development of computer systems for flight control, there was a rise in the application of "modern control" systems such as the linear quadratic regulator (LQR) [8,9] and [10]. These methods are difficult to implement practically [6]. Other methods, such as nonlinear inverse dynamics [9], including feedback linearization [11], adaptive control [12] and sliding mode controllers [13], have also been applied with moderate success.

The problem with PID has been identified as poor tuning, which means that most of the controllers currently in operation have been poorly tuned. This results in biased judgment against the PID controllers themselves. The best known method for tuning PID controllers is Ziegler–Nichols, based on empirical rules. This method does not work well

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 1, January 2024||

|DOI:10.15662/IJAREEIE.2024.1301009 |

for multi-loop systems such as rotorcraft. Significant effort has recently been invested in optimal tuning of PID controllers [14–16] and other controllers in general [17].

II. PROPOSED METHODOLOGY

In this work, we have proposed a closed loop auto tuned PID controller. The Open-Loop PID Auto-tuner block lets we tune a PID controller in real time against a physical plant. The block can tune a PID controller to achieve a specified bandwidth and phase margin without a parametric plant model or an initial controller design. If we have a code-generation product such as Simulink, we can generate code that implements the tuning algorithm on hardware, letting us tune in real time with or without using Simulink to manage the autotuning process. If we have a plant or UAV model in Simulink, we can also use the block to obtain an initial PID design. Doing so lets us preview plant response and adjust the settings for PID autotuning before tuning the controller in real time. To achieve model-free tuning, the Open-Loop PID Autotuner block:

1. Injects a test signal into the plant at the nominal operating point to collect plant input-output data and estimate frequency response in real time. The test signal is a combination of sine and step perturbation signals added on top of the nominal plant input measured when the experiment starts. If the plant is part of a feedback loop, the block opens the loop during the experiment.
2. At the end of the experiment, tunes PID controller parameters based on estimated plant frequency responses near the open-loop bandwidth.
3. Updates a PID Controller block or a custom PID controller with the tuned parameters, allowing us to validate closed-loop performance in real time.

A. Auto-tuning of PID Controller

Once we are able to fly a basic mission, we are ready to autotune the attitude and position control loops to improve the performance of the multirotor. The control system for this example contains eight PID Controllers. The system has four cascading control loops. Each loop contains two controllers, one for each axis. This diagram shows how the eight controllers are set up with the Closed-Loop PID Autotuner blocks in order to perform autotuning.

The Closed-Loop PID Autotuner blocks inject perturbation signals to the output of each of the eight existing PID Controllers. The autotuners then use the feedback signals and the output of the PID Controllers in order to perform the autotuning process. With the exception of the innermost control loops, pitch and roll rate, the two axes being controlled are decoupled from each other. For example, the x velocity and the y velocity loops are decoupled from each other. This allows we to tune these two loops simultaneously which reduces the overall time to perform autotuning. For the pitch rate and roll rate loops, tune the control loops sequentially because they are coupled. This results in the following sequence for tuning the PID Controllers:

1. Pitch Rate
2. Roll Rate
3. Pitch and Roll
4. X and Y Velocity
5. X and Y Position

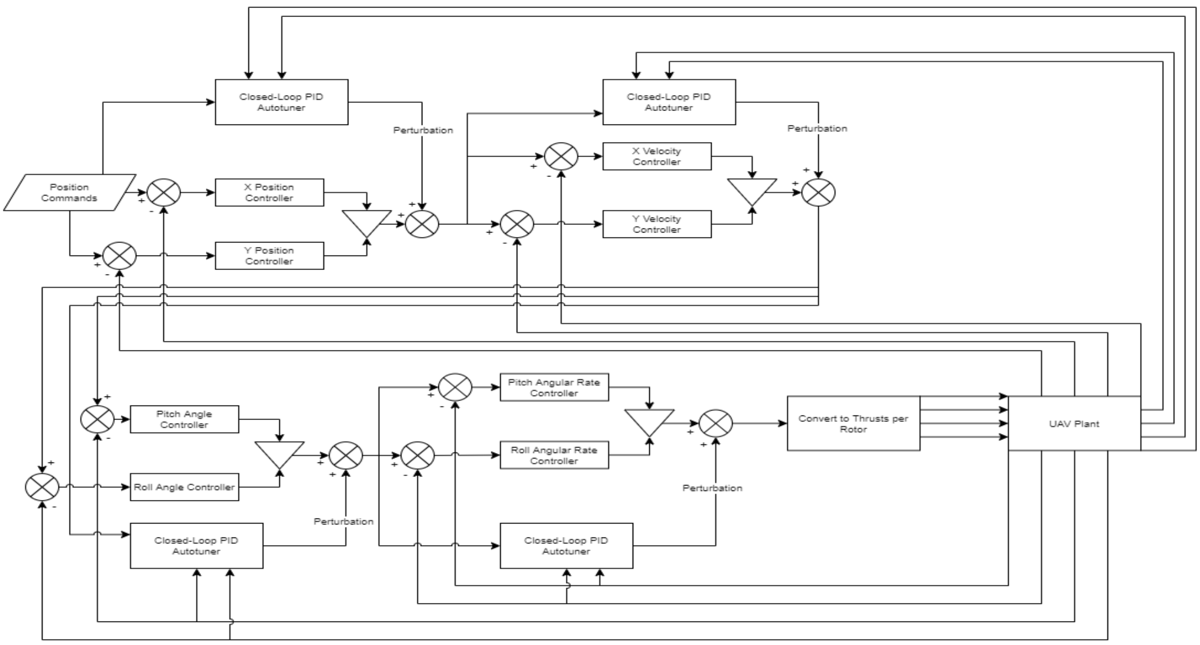


Figure 1: Block diagram of proposed closed loop auto-tuned PID controller

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 1, January 2024||

|DOI:10.15662/IJAREEIE.2024.1301009 |

To maximize performance, the bandwidth for the pitch and roll rate loops is set to 50 rad/sec. The sampling time T_S of the UAV control system is 0.005 seconds and the Closed-Loop PID Autotuner requires that the bandwidth ω must satisfy $\omega T_S \leq 0.3$, which means that bandwidth must be 60 rad/sec or less. Choose the bandwidth such that it is less than the required 60 rad/sec. The other bandwidths are set to be as large as possible while not causing stability issues with inner loops. The phase margin for each loop is set to 60 degrees as this value is typically a good compromise between performance and damping. This margin is the default setting for the Closed-Loop PID Autotuner block. The perturbation amplitudes are set such that they are less than 5% of the maximum expected output of the individual controllers. If the value for the perturbations is too high, it can cause the multirotor to become unstable during tuning. If the value for the perturbations is too low, the autotuner might not get an accurate estimate of the plant and the calculated gains might not meet the desired bandwidth or phase margin.

B. Auto-tuning Altitude and Heading/Yaw Control Loops

In this example we learned how to automatically tune the P, I, D and N gains for four separate paired control loops used for the attitude and position control. However, this example model contains two more control loops, one for altitude and one for the heading or yaw angle. Using the same methodology for autotuning presented in this example, we can add the Closed-Loop PID Autotuner to one or both of these other control loops and perform the autotuning process.

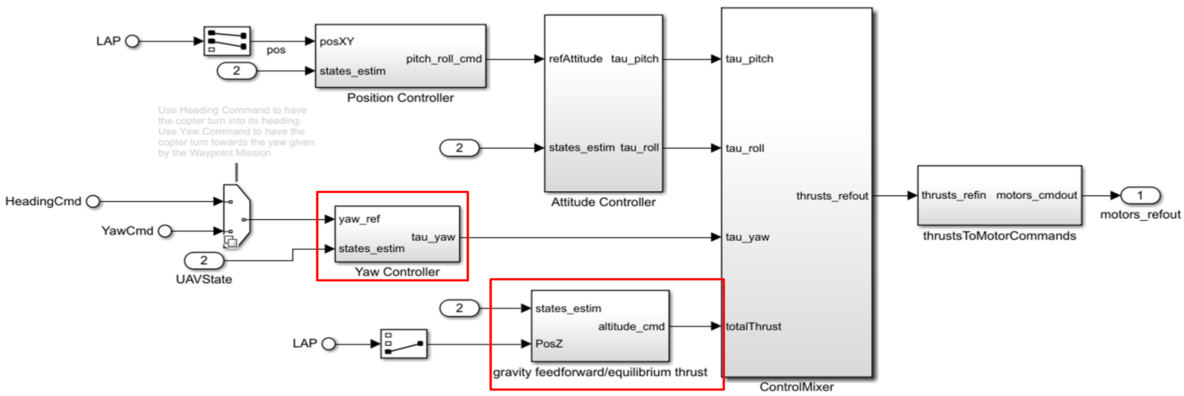


Figure 2: Block diagram representing Altitude and Heading/Yaw Control Loops

In order to tune the controllers for either of these loops, ensure that the tuning happens only when the tuning is not running for the other controllers. We can either disable tuning of the other controllers or we can tune these controllers after tuning has completed for position and attitude controllers.

III. RESULT AND DISCUSSION

The Closed-Loop PID Autotuner blocks inject perturbation signals to the output of each of the eight existing PID Controllers. The autotuners then use the feedback signals and the output of the PID Controllers in order to perform the autotuning process. With the exception of the innermost control loops, pitch and roll rate, the two axes being controlled are decoupled from each other. For example, the x velocity and the y velocity loops are decoupled from each other. This allows you to tune these two loops simultaneously which reduces the overall time to perform autotuning. For the pitch rate and roll rate loops, tune the control loops sequentially because they are coupled.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 1, January 2024||

|DOI:10.15662/IJAREEIE.2024.1301009 |

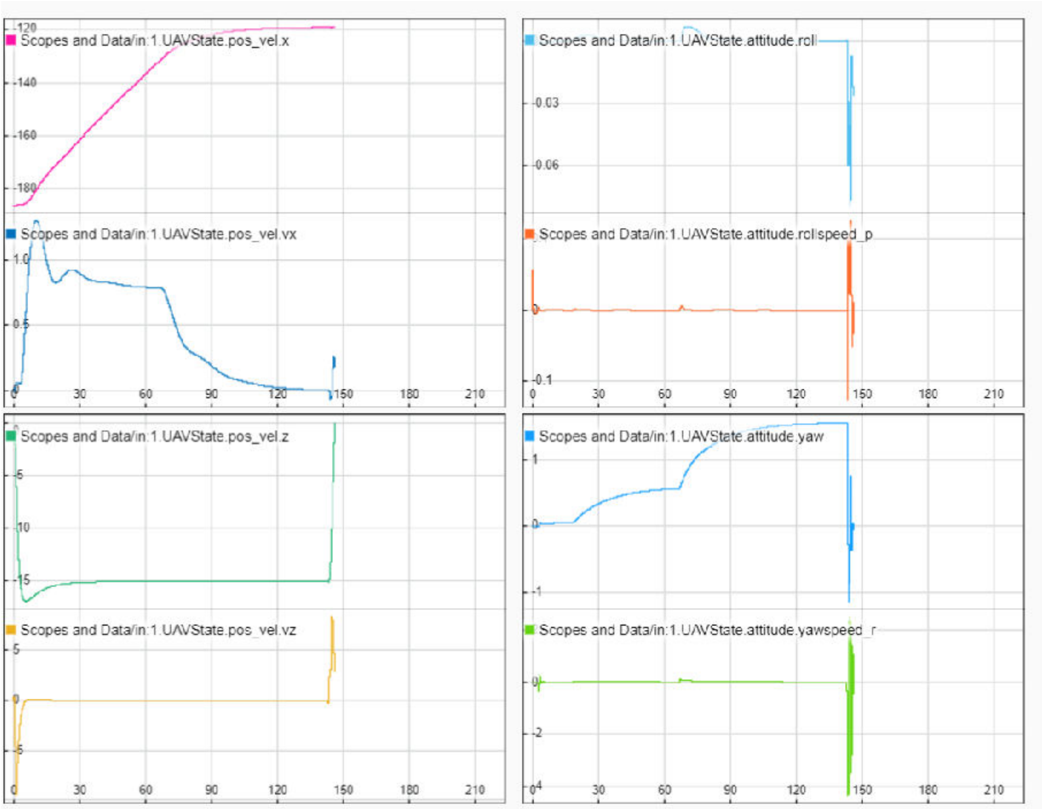


Figure 3: speed in x and z direction with roll, roll speed, yaw and yaw speed without autotuning

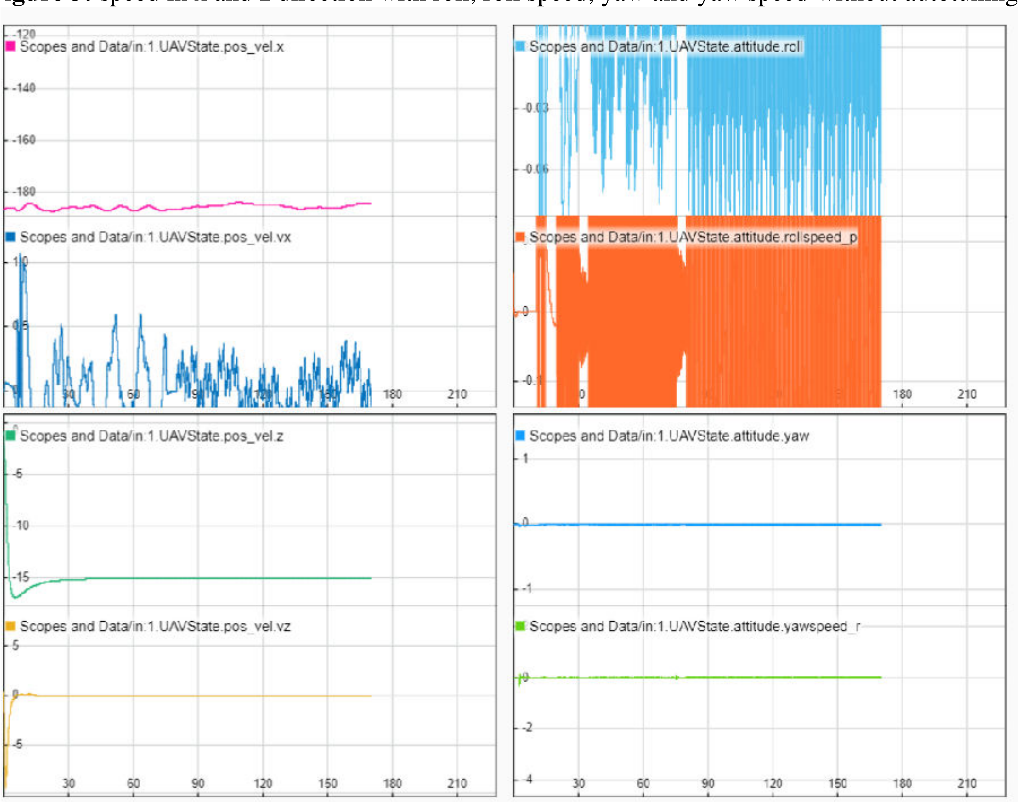


Figure 4: speed in x and z direction with roll, roll speed, yaw and yaw speed with close loop auto-tuning

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 1, January 2024||

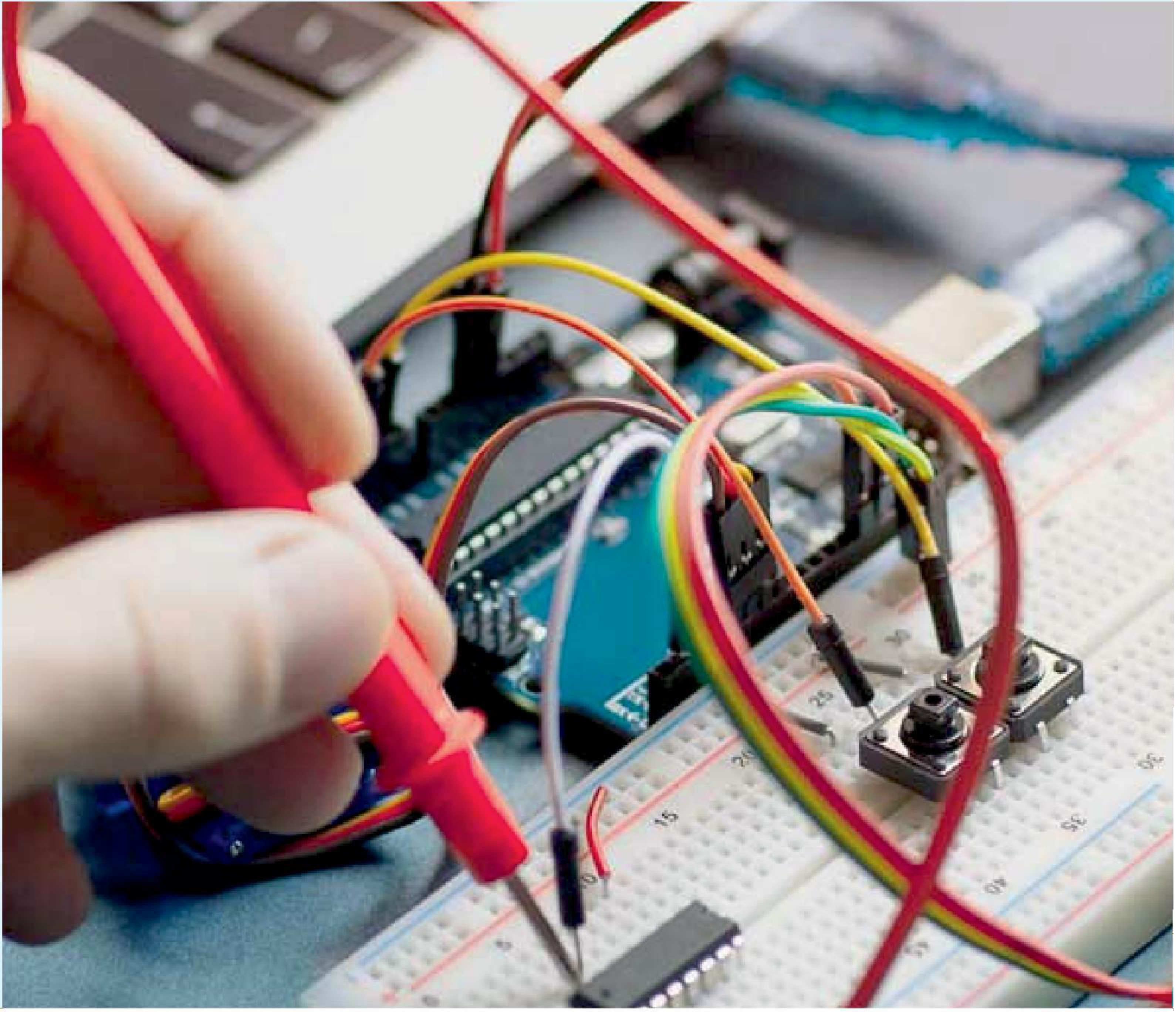
|DOI:10.15662/IJAREEIE.2024.1301009 |

IV. CONCLUSION

From the simulation results of this paper, it can be concluded that the vehicle handling and stability are improved using both of closed loop auto-tuned PID controller and a neural network control approach, which verify the effective use of the control systems. The results of this work indicated that both the controllers that were used gave good results as the yaw rate of the vehicle improved due to using of a lane change of manoeuvre steering, but simulation results show that the proposed control system with closed loop auto-tuned PID controller can improve both of vehicle yaw rate and the sideslip angle better than using of the neural network controller.

REFERENCES

1. Huang, Y.; Zhu, M.; Zheng, Z.; Feroskhan, M. Fixed-time autonomous shipboard landing control of a helicopter with external disturbances. Aerosp. Sci. Technol. **2019**, 84, 18–30.
2. Mohiuddin, A.; Tarek, T.; Zweiri, Y.; Gan, D. A survey of single and multi-UAV aerial manipulation. Unmanned Syst. **2020**, 8, 119–147.
3. Marconi, L.; Naldi, R. Aggressive control of helicopters in presence of parametric and dynamical uncertainties. Mechatronics **2008**, 18, 381–389.
4. Raptis, I.A.; Valavanis, K.P. Linear and Nonlinear Control of Small-Scale Unmanned Helicopters; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2010; Volume 45.
5. Chi, C.; Yan, X.; Chen, R.; Li, P. Analysis of low-speed height-velocity diagram of a variable-speed-rotor helicopter in one-enginefailure. Aerosp. Sci. Technol. **2019**, 91, 310–320.
6. Budiyono, A. Advances in Unmanned Aerial Vehicles Technologies. Available online: https://www.researchgate.net/profile/Agus-Budiyono2/publication/234119875_Advances_in_unmanned_aerial_vehicles_technologies/links/00b4952cea51940af2000000/Advances-in-unmanned-aerial-vehicles-technologies.pdf.
7. Mo, H.; Naigang, C. A gain scheduling controller for small-scaled unmanned helicopters. In Proceedings of the 2018 Chinese Control And Decision Conference (CCDC), Shenyang, China, 9–11 June 2018; pp. 6309–6313.
8. Budiyono, A.; Wibowo, S.S. Optimal tracking controller design for a small scale helicopter. J. Bionic Eng. **2007**, 4, 271–280.
9. Scholz, G.; Trommer, G. Model based control of a quadrotor with tiltable rotors. Gyroscopy Navig. **2016**, 7, 72–81
10. Khalesi, M.H.; Salarieh, H.; Saadat Foumani, M. System identification and robust attitude control of an unmanned helicopter using novel low-cost flight control system. Proc. Inst. Mech. Eng. Part I J. Syst. Control Eng. **2020**, 234, 634–645.
11. Nemati, A.; Kumar, M. Non-linear control of tilting-quadcopter using feedback linearization based motion Control. In Dynamic Systems and Control Conference; American Society of Mechanical Engineers: New York, NY, USA, 2014; Volume 46209, p. V003T48A005.
12. Chikasha, P.N.; Dube, C. Adaptive model predictive control of a quadrotor. IFAC-PapersOnLine **2017**, 50, 157–162.
13. Halbe, O.; Hajek, M. Robust Helicopter Sliding Mode Control for Enhanced Handling and Trajectory Following. J. Guid. Control Dyn. **2020**, 43, 1805–1821.
14. Sheng, L.; Li, W. Optimization Design by Genetic Algorithm Controller for Trajectory Control of a 3-RRR Parallel Robot. Algorithms **2018**, 11, 7.



INNO SPACE
SJIF Scientific Journal Impact Factor
Impact Factor: 8.317

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

निस्केयर NISCAIR

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

9940 572 462 6381 907 438 ijareeie@gmail.com

Scan to save the contact details

www.ijareeie.com