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LiDAR and VFH: A Synergistic Approach to Quadcopter Obstacle Avoidance

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ABSTRACT: This report represents the Development and Implementation of a LiDAR Based Obstacle Avoidance Algorithm for an Unmanned Aerial Vehicle (UAV) - A Quadcopter in our case, utilizing the Vector Field Histogram (VFH) Algorithm, specifically focusing on Static Obstacles in comparison with the given example in the MAT LAB integrated with our Plant Model. The algorithm is designed to enhance the UAV's autonomous navigation capabilities by enabling it to detect and avoid static obstacles in real-time. The development process is carried out using MATLAB and Simulink, leveraging their robust simulation and modelling environments. The VFH method is chosen for its computational efficiency and effectiveness in handling static environments. The algorithm processes LiDAR data to construct a polar histogram of the surrounding obstacles, calculates potential collision-free paths and guides the UAV through a safe trajectory. The integration of the algorithm within MATLAB and Simulink allows for comprehensive simulation, enabling the testing and validation of the UAV's performance in various static scenarios. Simulation results demonstrate the algorithm's capability to navigate complex environments with static obstacles, effectively avoiding collisions while maintaining an optimal path. The report also discusses the tuning of VFH parameters to optimize the balance between obstacle avoidance and path smoothness. This development provides a significant step towards the deployment of autonomous UAV systems in controlled environments, ensuring enhanced safety and reliability. The findings and methodologies detailed in this report are expected to contribute to the advancement of UAV autonomy, with potential applications in areas such as surveillance, aerial photography, industrial inspection, agriculture, and infrastructure monitoring. Future work will focus on the field testing and further refinement of the algorithm to address additional real-world challenges.

KEYWORDS: Obstacle Avoidance, Vector Field Histogram, Static Obstacle, Propulsion System, PID Controllers, LiDAR Point Cloud Data

I. INTRODUCTION

The proliferation of unmanned aerial vehicles (UAVs), particularly quadcopters, has revolutionized various fields such as surveillance, delivery, and agricultural monitoring. Among the various configurations, the “+” configuration quadcopter stands out due to its enhanced stability and manoeuvrability, making it ideal for complex navigation tasks. However, the effective operation of these quadcopters is contingent upon their ability to autonomously detect and avoid obstacles, ensuring safe and efficient flight. The VFH algorithm involves several key steps: modelling the quadcopter's dynamics, integrating LiDAR sensor data for obstacle detection, and implementing control strategies for avoidance. By simulating the quadcopter's behaviour in a controlled setting, we aim to validate the effectiveness of the algorithm in real-world scenarios. This research contributes to advancing UAV technology by providing a reliable solution for static obstacle avoidance, thereby enhancing the autonomous capabilities of quadcopters, and expanding their potential applications.

II. LITERATURE SURVEY

The propulsion system consists of the Brushless DC Motor, Propeller, Electronic Speed Controller (ESC) and Battery. We referred the "Multicopter Design and Control Practice, A Series Experiment based on MATLAB and Pixhawk" book, which was written by Quan Quan, Xunhua Dai and Shuai Wang and published by the Springer Publication in the year 2020. This book deals the mathematical approach on designing the components and therefore we used the same equations and modelled the components of the propulsion system. On the other hand, for the propeller alone, we considered the MATLAB Documentation to design it. For designing the battery of the propulsion system [6], we had a glimpse over the research paper "Modelling of Lithium-Ion Battery Using MATLAB/Simulink" [9] and designed a similar battery as per our requirement.

Next major step in designing the multirotor is to build a plant model, where we can control the system and where the propulsion system needs to be onboard [3]. This plant model was designed using a project thesis by Nicholas Ferry [10]. We used the equations that were given in this project thesis and modelled a similar multirotor plant model as per the requirements of our desired drone parameters the "Elios 3 by Flyability". Furthermore, we used the same paper in order to convert the position coordinates into the Motor Signals, namely, U1, U2, U3 and U4 respectively [7]

We used the Vector Field Histogram (VFH) Algorithm for obstacle detection and avoidance. To conclude on which algorithm to be used, we had a wide range of discussion on all possible different types of algorithms for obstacle detection and avoidance, as well as for path planning and trajectory control. Since, we are confined with LiDAR sensor, we must choose an appropriate algorithm that will be able to satisfy the LiDAR data as well [2]. And so, we referred the MATLAB Documentation for the same as well as the research paper "Vector Field Histogram Star Obstacle Avoidance System for Multicopters" by Ruan Jacobus van Breda.

Finally, the main objective of the report is the Obstacle Avoidance block set. We referred the paper "Obstacle Avoidance-Based Autonomous Navigation of a Quadrotor System" [8] and keeping this paper as the basis, we built the UAV 3D Animation block set that is needed to process the LiDAR Point Cloud data along with the UAV Motion data [5]. We referred the same paper to make the navigational controller along with the PID Controller that is needed to make our quadcopter fly stable.

III. THE PROPULSION SYSTEM

The propulsion system is the heart of the entire quadcopter. Without the propulsion system, the quadcopter will not be able to fly. As mentioned above in the literature survey, our quadcopter's propulsion system is purely a mathematical system which was modelled using the pre-defined mathematical equations given in the textbooks and other sources like MATLAB Documentations. The propulsion system consists of the following components: Battery, Electronic Speed Controller, BLDC Motor and Propeller.

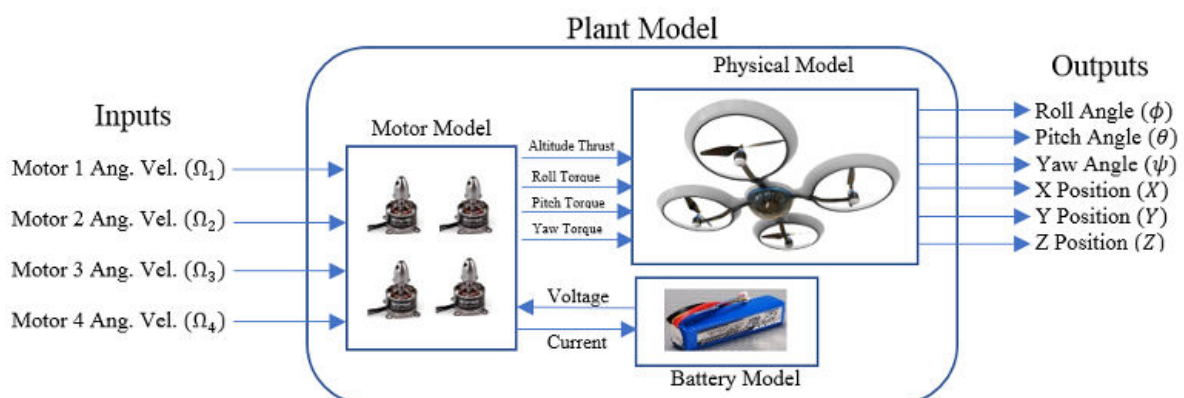


Fig. 1. Propulsion system along with the plant model

Table 1. Mathematical equations along with their respective components

Mathematical Equations	Component
$V_t = V_{oc} - I_{load} \cdot R_{batt}$ $I_{load} = \frac{P_{sys}}{V_t}$ $V_t = \frac{1}{2} \cdot (V_{oc} + \sqrt{V_{oc}^2 - 4 \cdot P_{sys} \cdot R_{batt}})$ $E_{batt} = N_{batt.pack} \cdot N_{batt.cell} \cdot (3.7V \cdot e_{batt.cell})$ $V_{oc} = 1.7 \cdot SoC^3 - 2.1 \cdot SoC^2 + 1.2 \cdot SoC + 3.4$ $R_{batt.cell} = 21 \cdot (e_{batt.cell})^{-0.8056}$	(For Battery)
$U_m = \left(\frac{MK_{V0}U_{m0}}{9.55(U_{m0} - I_{m0}R_m)} + I_{m0} \right) R_m + \frac{U_{m0} - I_{m0}R_m}{K_{V0}U_{m0}} N$ $I_m = \frac{MK_{V0}U_{m0}}{9.55(U_{m0} - I_{m0}R_m)} + I_{m0}$	(For BLDC Motor)
$\sigma = \frac{U_m + I_m R_e}{U_b}$ $I_e = \sigma I_m$ $U_e = U_b - I_b R_e$	(For ESC)
$J = \frac{V_\alpha \epsilon n}{D(n^2 - n_{thr}^2)} \quad C_T^* = \frac{T}{\frac{1}{8} \rho V_R^2 \pi D^2} \quad n = \frac{Power_{out}}{Power_{in}} = \frac{TV_A}{2\pi n Q}$ $C_Q^* = \frac{Q}{\frac{1}{8} \rho V_R^2 \pi D^3} \quad \beta = \arctan\left(\frac{V_\alpha}{0.7\pi \epsilon n D}\right)$ $\hat{C}_T = 0.02791 - 0.06543J + 0.11867\beta + 0.27334\beta^2 - 0.28852\beta^3 - 0.23504J^2 + 0.02104J^3 + 0.18677\beta J^2$	(For Propeller)

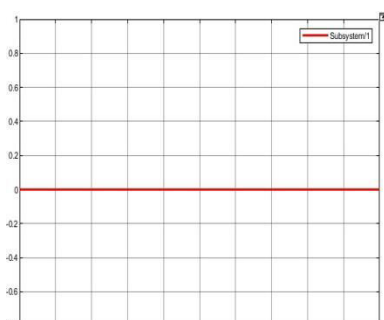
IV. THE QUADROTOR MODEL

This model mainly consists of the Motor Control Block, Attitude Control Block, and the Altitude Control Block. These blocks ensure the smooth flight control of the multicopter by giving the necessary inputs that is being gathered from the surrounding.

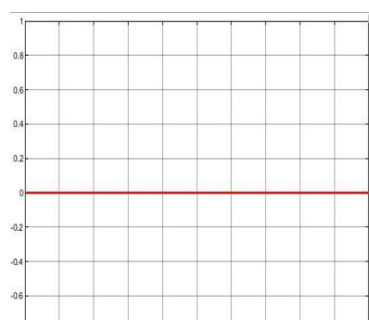
Table 2. Mathematical equations along with their respective parameters

Plant Model Equations	Parameter
$U1_+ = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2)$	(General Thrust)
$U2_+ = b(-\Omega_2^2 + \Omega_4^2)$	(Roll Thrust)
$U3_+ = b(\Omega_1^2 - \Omega_3^2)$	(Pitch Thrust)
$U4_+ = d(\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2)$	(Yaw Thrust)
$\Omega_r = \Omega_1 - \Omega_2 + \Omega_3 - \Omega_4$	(Net Angular Velocity)
Moment Equations	Parameter
$I_{xx}\ddot{\phi} = \dot{\theta}\dot{\psi}(I_{yy} - I_{zz}) + J_r\dot{\theta}\Omega_r + l(U2)$	(Rolling Torque)
$I_{yy}\ddot{\theta} = \dot{\phi}\dot{\psi}(I_{zz} - I_{xx}) - J_r\dot{\phi}\Omega_r + l(U3)$	(Pitching Torque)
$I_{zz}\ddot{\psi} = \dot{\theta}\dot{\phi}(I_{xx} - I_{yy}) + (U4)$	(Yawing Torque)
Force Equations	Parameter
$m\ddot{x} = (\sin\psi\sin\phi - \cos\psi\sin\theta\cos\phi)U1 - A_x\dot{x}$	(X - Force)
$m\ddot{y} = (\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi)U1 - A_y\dot{y}$	(Y - Force)
$m\ddot{z} = mg - (\cos\theta\cos\phi)U1 - A_z\dot{z}$	(Z - Force)

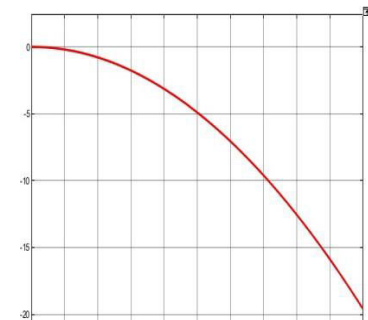
Using the above equations, the controllers were designed and given input of 20 meters in z – direction.



(a)



(b)



(c)

2. Displacement along different axes (a)

Displacement in x - direction (b)

Displacement in y – axis (c) Displacement in z – axis

V. OBSTACLE DETECTION AND OBSTACLE AVOIDANCE

A PID controller aids a quadcopter in obstacle avoidance by continuously adjusting the drone’s flight parameters to maintain stability and execute precise manoeuvres in response to real-time sensor data. When integrated with obstacle

detection algorithms, such as those using LiDAR sensors and the Vector Field Histogram (VFH) algorithm, the PID controller processes the error between the desired and actual positions or orientations. By calculating proportional, integral, and derivative actions, it generates control signals to adjust the speeds of the individual motors, thereby controlling roll, pitch, yaw, and throttle. For the fine tuning of the designed PID controller, the following constant values were used:

Table 3. Representing the constant values used to design the PID controller

Serial Number	Parameter	Kp	Ki	Kd
1	Altitude	1.5	0.2	0.001
2	Roll	0.1471	0.6391	0.1787
3	Pitch	0	0.6606	0
4	Yaw	0.1	0.7943	-0.13

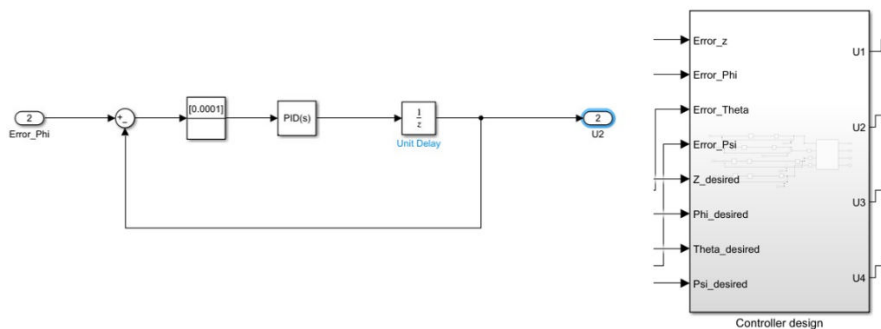


Fig. 3. Propulsion system along with the plant model

The following results were yielded using the designed PID controller.

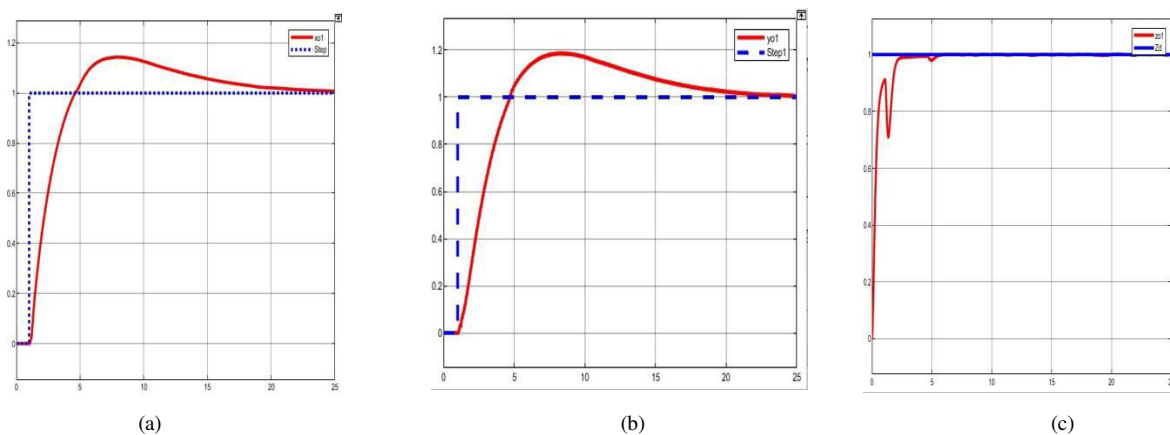


Fig. 4. PID controller settling values for different directions (a) Settling in x - direction (b) Settling in y – axis (c) Settling in z – axis

VI. TRAJECTORY, NAVIGATION AND UAV ANIMATION

The trajectory, navigation and the UAV animation blocks are very essential for the quadcopter, to assess its current orientation and act accordingly to the changes in the environment and detect the static obstacles, if any are present. The UAV animation block ensures to collect the data of the environment using the LiDAR sensor and convert these data into point clouds, so that the system will be able to assess.

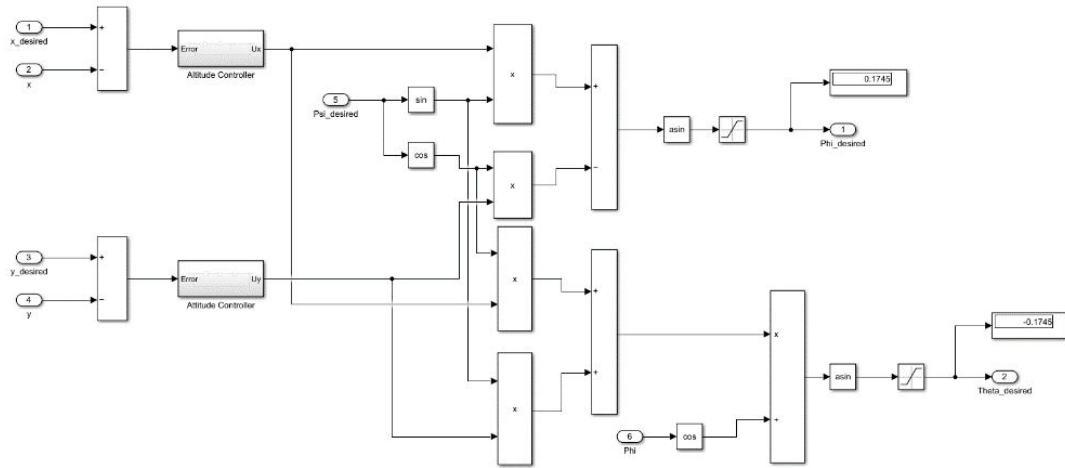


Fig. 5. Designed trajectory controller in Simulink

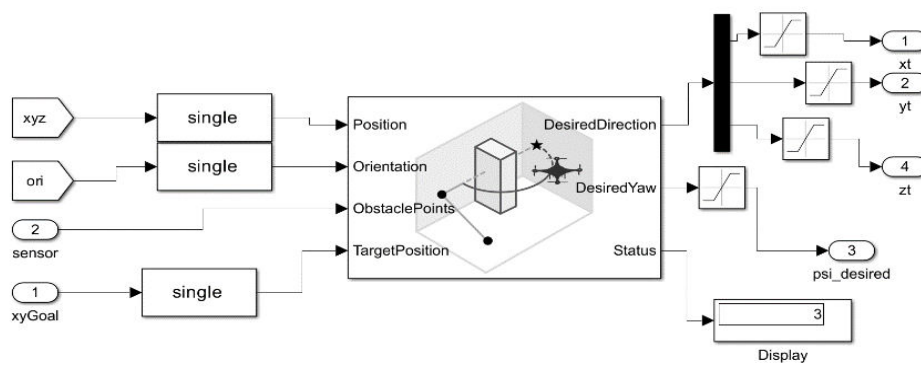


Fig. 6. Navigational controller using Simulink Obstacle Avoidance Block

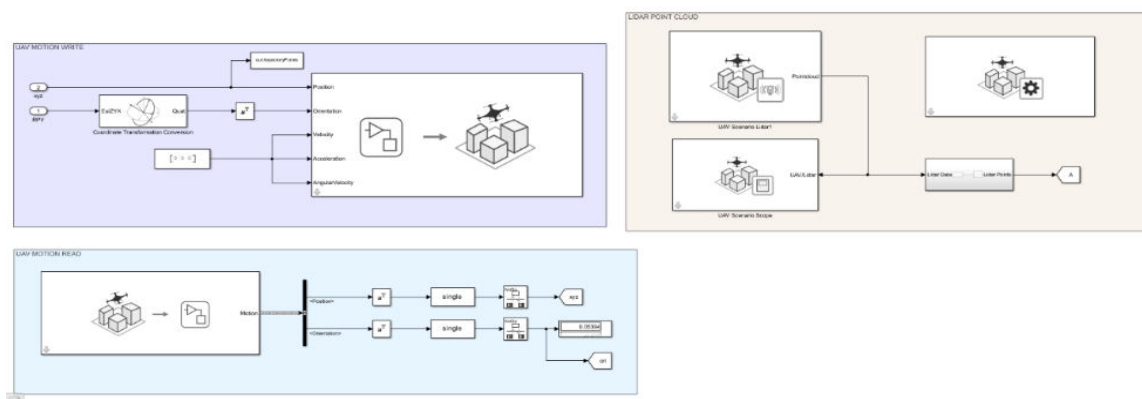


Fig. 7. Designed UAV animation block in Simulink

VII. RESULT

The visualization of the result that we got is shown below in the figure, the quadcopter can detect the obstacle and then avoid it subsequently. Since, this was the main motive of the project, we can say that the results are satisfactory and is what we expected.

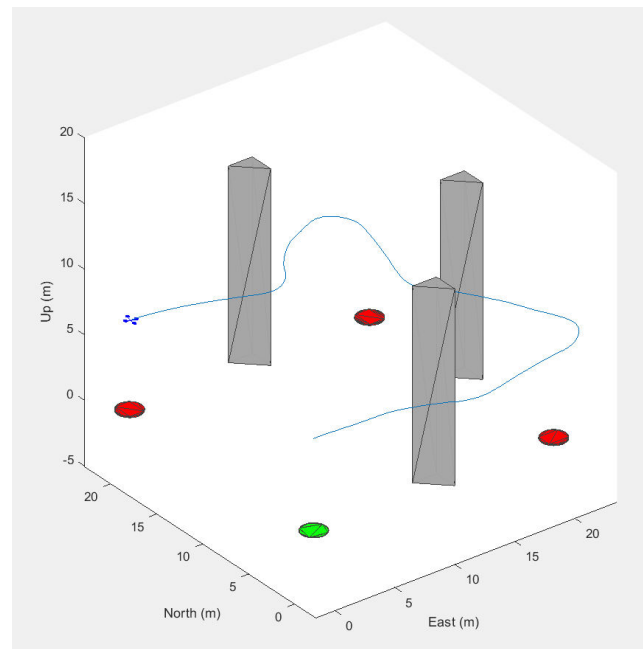


Fig. 8. Representation of the quadcopter being able to detect and avoid obstacles

VIII. CONCLUSION

The comprehensive quadcopter model designed and implemented in Simulink has proven to be highly effective in detecting and avoiding dynamic obstacles, showcasing the robustness of the integrated control algorithms and sensor systems.

Utilizing the UAV Animation block set, we established a detailed simulation environment where the UAV Scenario Configuration block enabled precise setup of the terrain and obstacles, creating a realistic testbed. The UAV Scenario Motion Write and Read blocks facilitated the recording and analysis of the quadcopter's flight trajectories, while the UAV Scenario Scope provided real-time visualization of the UAV's movements and sensor outputs. Central to the obstacle avoidance capability was the UAV Scenario LiDAR1 block, which simulated LiDAR sensor data to detect and map obstacles accurately.

The Vector Field Histogram (VFH) algorithm processed this data to generate safe navigation paths. The quadcopter's trajectory and navigational controllers dynamically adjusted the flight path based on sensor inputs, ensuring smooth and stable avoidance maneuvers.

Throughout extensive simulations encompassing various complex environments and scenarios, the quadcopter consistently maintained optimal performance, avoiding obstacles, and adapting to environmental changes. This successful implementation underscores the reliability and effectiveness of the developed model and control strategies, providing a solid framework for future advancements and real-world applications in UAV obstacle detection and avoidance.

IX. FUTURE SCOPE

In future endeavors, the integration of Reinforcement Learning (RL) [1] methodologies offer a promising avenue to further enhance the quadcopter's obstacle avoidance capabilities, particularly in environments with dynamic obstacles. RL algorithms, such as Deep Q-Networks (DQN) or Proximal Policy Optimization (PPO), enable the quadcopter to learn optimal policies through trial and error, gradually improving its decision-making process based on interactions with the environment. This approach allows the quadcopter to adapt its navigation strategy dynamically in response to changing conditions, such as the sudden appearance of moving obstacles or alterations in the terrain. By training the

quadcopter in simulation environments that accurately mimic real-world scenarios, it can learn to navigate safely and efficiently in complex environments while avoiding collisions with both stationary and dynamic obstacles.

Additionally, RL enables the quadcopter to learn from past experiences, allowing it to anticipate potential collision scenarios and proactively adjust its trajectory to prevent accidents. Furthermore, RL-based approaches can facilitate the development of hierarchical control policies, where the quadcopter learns to navigate at different levels of abstraction, from high-level mission planning to low-level obstacle avoidance maneuvers [4].

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REFERENCES

- [1] Ahmad Taher Azar, Anis Koubaa, Nada Ali Mohamed, Habiba A. Ibrahim, Zahra Fathy Ibrahim, Muhamad Kazim, Adel Ammar, Bilel Benjdira, Alaa M. Khamis, Ibrahim A. Hameed, and Gabriella Casalino. Drone deep reinforcement learning: A review. *Electronics*, 10(9), 2021. **Journal Paper**
- [2] Francisco Gomes, Tiago Hormigo, and Rodrigo Ventura. Vision based real-time obstacle avoidance for drones using a time-to-collision estimation approach. In 2020 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), pages 90–95, 2020. **Conference Proceedings**
- [3] Amudhini P. Kalidas, Christy Jackson Joshua, Abdul Quadir Md, Shakila Basheer, Senthilkumar Mohan, and Sapiyah Sakri. Deep reinforcement learning for vision-based navigation of uavs in avoiding stationary and mobile obstacles. *Drones*, 7(4), 2023. **Journal Paper**
- [4] Rafael M. S. Santos, Caio L. G. de S. Alves, Euler C. T. Macedo, Juan M. M. Villanueva, and Lucas V. Hartmann. Estimation of lithium-ion battery model parameters using experimental data. In 2017 2nd International Symposium on Instrumentation Systems, Circuits and Transducers (INSCIT), pages 1–6, 2017. **Conference Proceedings**
- [5] Jaspreet Singh, Marwan Dhuheir, Ahmed Refaey, Aiman Erbad, Amr Mohamed, and Mohsen Guizani. Navigation and obstacle avoidance system in unknown environment. In 2020 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), pages 1–4, 2020. **Conference Proceedings**
- [6] Yuefan Xu, Minling Zhu, Yue Xu, and Mingjie Liu. Design and implementation of uav obstacle avoidance system. In 2019 2nd International Conference on Safety Produce Informatization (IICSPI), pages 275–278, 2019. **Conference Proceedings**
- [7] Low Wen Yao, J. A. Aziz, Pui Yee Kong, and N. R. N. Idris. Modelling of lithium-ion battery using matlab/simulink. In IECON 2013- 39th Annual Conference of the IEEE Industrial Electronics Society, pages 1729–1734, 2013. **Conference Proceedings**
- [8] Nicholas Ferry. Quadcopter Plant Model and Control System Development With MATLAB/Simulink Implementation. Department of Electrical and Microelectronic Engineering, Kate Gleason College of Engineering, Rochester Institute of Technology, Rochester, New York- December 2017. **Dissertation**
- [9] Quan Quan. Introduction to Multicopter Design and Control. Springer- 2017. **Book**



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