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Master student: **Nicat Gasimzada**

Scientific adviser: **Ph.D. Farida Tatardar**

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MÖVZU: Smartfonla İdarə olunan Vasitənin Dizaynı və Modelləşdirilməsi.

Magistrant: **Nicat Qasımzadə**

Elmi rəhbər: **Ph.D. Fəridə Tatardar**

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KHAZAR UNIVERSITY
Faculty of Graduate School of Science, Art and Technology
Author: Nijat Gasimzade
Topic of the Master's Thesis: Design and Modeling of Smartphone Controlled Vehicle
Instructor: Farida Tatardar
Degree: Master of Science in Electronics and Automation

ABSTRACT

While many have worked on the transition phases of more popular hybrid aerial vehicle configurations, In this paper, we explore a novel multi-mode hybrid Unmanned Aerial Vehicle (UAV). Due to its expanded flying range and adaptability, hybrid aerial vehicles—which integrates two or more operating configurations—have become more and more widespread. The stages of transition between these modes are reasonably important whether there are two or more flight forms present. Whereas numerous have worked on the early stages of more widely used hybrid aerial vehicle types, in this paper a brand-new multi-mode hybrid UAV will be investigated. In order to fully exploit the vehicle's propulsion equipment and aerodynamic surfaces in both a horizontal cruising configuration and a vertical hovering configuration, we combine a tailless fixed-wing with a four-wing monocopter. By increasing construction integrity over the whole operational range, this lowers drag and wasteful mass when the aircraft is in motion in both modes. The transformation between the two flight states can be carried out in midair with just its current flying actuators and sensors. Through a ground controller, this vehicle may be operated by an Android device.

Keywords: quadcopter; hybrid aerial robots; system design, monocopter

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Təbiət Elmləri və Mühəndislik
Müəllif: Nicat Qasımzadə
Magistr Tezisinin Mövzusu: Smartfonla İdarə Olunan Vasitənin Layihələndirilməsi və Modelləşdirilməsi
Rəhbər: Farida Tatardar

XÜLASƏ

Hibrid hava vasitəsi konfiqurasiyaları olduqca populyardır və bir çoxları keçid mərhələləri üzərində işləyir. Bu yazıda biz yeni çox rejimli hibrid Pilotsuz Uçuş Vasitəsini (PUA) araşdırırıq. Genişlənmiş uçuş məsafəsi və uyğunlaşma qabiliyyəti sayəsində iki və ya daha çox əməliyyat konfiqurasiyasını birləşdirən hibrid hava vasitələri getdikcə daha geniş yayılmışdır. İki və ya daha çox uçuş formasının mövcud olub-olmamasından asılı olmayaraq, bu rejimlər arasında keçid mərhələləri kifayət qədər vacibdir. Bir çoxları daha geniş istifadə olunan hibrid hava vasitəsi növlərinin ilkin mərhələləri üzərində işlədiyi halda, bu məqalədə tamamilə yeni çox rejimli hibrid PUA araşdırılacaqdır. Həm üfüqi kruiz konfiqurasiyasında, həm də şaquli uçan konfiqurasiyada vasitənin hərəkət avadanlığından və aerodinamik səthlərdən tam istifadə etmək üçün biz quyruqsuz sabit qanadı (Tailles Fixed-wing) dörd qanadlı monokopterlə birləşdiririk. Bütün əməliyyat diapazonunda konstruktiv bütövlüyünü artırmaqla, bu, vasitə hər iki rejimdə hərəkətdə olarkən sürtünmə və israfçı kütləni azaldır. İki uçuş vəziyyəti arasında transformasiya yalnız cari uçan aktuatorlar və sensorlar ilə havada həyata keçirilir. Yer nəzarətçisi (Ground Controller) vasitəsilə bu vasitə Android cihaz ilə idarə olunur.

Açarsözlər: quakopter; hibrid hava robotları; sistem dizaynı, monokopter

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ABBREVIATIONS

BET: Blade Element Theory

BLDC: Brushless Direct Current Motors

BVLOS: Beyond Visual Line of Sight

DL: Deep Learning

DRL: Deep Reinforcement Learning

ESC: Electronic Speed Controller

FAA: Federal Aviation Administration

FLC: Fuzzy Logic Controller

GNSS: Global Navigation Satellite Technologies

GPS: Global Position Systems

HAV: Hybrid Aerial Vehicles

ICAO: the International Civil Aviation Organization

IMU: Inertial Measurement Units

LIDAR: Light Detection and Ranging

ML: Machine Learning

MPC: Model Predictive Control

MSE: Mean Squared Error

PDB: power Distribution Board

PID: Proportional-Integral-Derivative

RRT: Random Trees

UAS: Unmanned Aircraft Systems

UAV: Unmanned Aerial Vehicle

VTOL: Vertical Take-Off and Landing

Introduction

Relevance of the topic. Unmanned aerial vehicle (UAV) system has advanced to the point that there are currently four main categories of configurations: fixed-wing, rotor-wing, flapping-wing, and aerostat. Long-range rapid responses can be provided by fixed-wing arrangements. In crowded situations, rotor-wings are handy. In tiny scale applications (micro-UAVs) (Mueller T. J., 2001), restricted or undeveloped flapping wings reach impressive levels of flight efficiency and aerostats have potentially unlimited airborne time. Hybrid UAVs exist somewhere between these, and its main goal is to combine two or more designs in a compatible form. A UAV configuration that has both a gliding and a hovering flight state is advantageous for a variety of UAV applications. While the latter offers flexibility and mobility to travel through restricted and limited surroundings, the earlier enables faster velocities and a greater reach. For instance, in emergency situations, the UAV would have to be available to float at any stage during the operation and have a quick reaction duration across wide range. For the extraction or transport of supplies or individuals, it may be necessary to fly across mountains, jungles or rivers and lakes.

A further instance would be in the delivery industry, where service providers may utilize the greater reach to both cut back on the amount of aerodromes required to handle an area and enable mentioned areas to encompass crowded metropolitan areas where conventional airfield are not available. The combination of a gliding state and a floating state on a individual structure presents a number of substantial construction issues, as attractive as these features may sound. The most fundamental of these is that the propulsion systems and aerodynamic surfaces are not completely exploited in both flight regimes, making present approaches highly functionally inefficient. This happens because floating and gliding have inherently diverse functioning concepts; effective floating relies more on rotating airflow than cruising does, which is why optimal flying is focused on longitudinal airflow. This frequently results in a large amount of single phase exclusive elements that reduce flight efficiency by adding unnecessary weight or by acting as an unnecessary cause of drag. Worse than that, the system's weight and structural intricacy may increase if extra elements are required to carry out the shift between the two states. In order to increase the constructional effectiveness of mixed aircraft, initiatives to minimize single-mode exclusive elements have largely been successful. The V-22 Osprey, utilizes the exact thruster components for both flying and floating flight, is a manned case of it. The concept is a powerful example of a hybrid aircraft even if many of its wing surfaces are still single-mode solely and it needs supplementary systems for its conversion phase. CH-46 Sea Knight acquires nearly three times the engagement radius and double the cruising speed relative to the, its only rotor-winged forerunner, yet maintaining comparable hovering characteristics (Norton, 2004). The lack of an on operator minimizes the necessity to adhere to precise configurations in forward flight and permits a wider mass expenditure for additional elements, which leads to a broader diversity of alternatives to improve constructional efficiency in the context of UAVs. A few instances in comparison to the V-22 Osprey can be seen in Figure 1. Structural efficiency can be defined as a characteristic as of a multi-mode aircraft, and can be mathematically represented as:

$$\frac{A_u}{A_{Tot}} \times 100\%$$

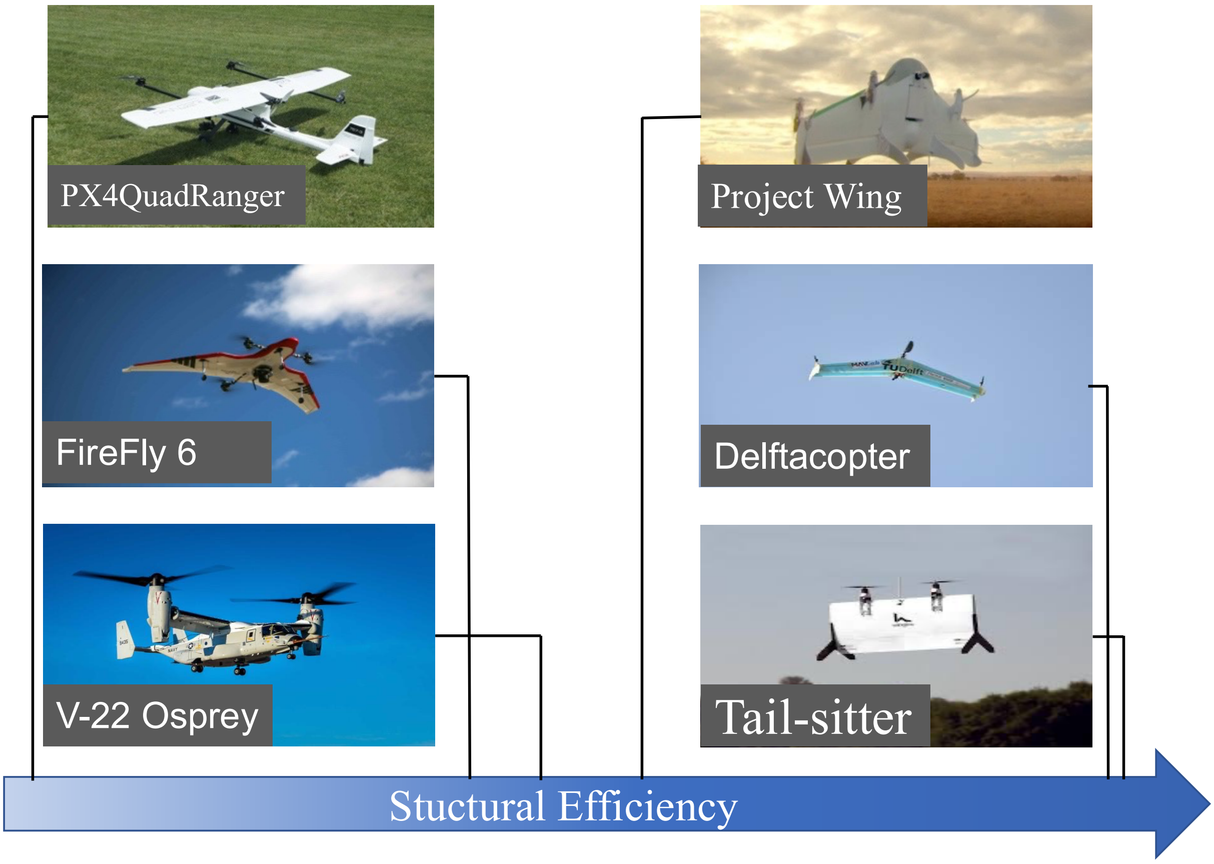
In which A_u is the overall aerodynamically responsive area of the aircraft used in all configurations (including propellers, wings, flaps, etc.) and A_{Tot} is the aerodynamically usable region. A vehicle with a distributed structure utilized in all forms would produce a structural efficiency of 100% compared to a craft with entirely individual mechanisms for each configuration have 0%. In this paper, we investigate configurations that give users rapid, long range functionality in even the most impedimental situations by combining the scope of fixed wings with the flexibility of rotor wings.The QuadRanger by PX4 (Volantex Ranger-Ex QuadPlane VTOL (Pixhawk), 2023) is one instance of a configuration that fuses the two forms of construction onto a single chassis. Such mixtures have separate thrusters and control mechanisms for each of their flight configurations. Some layouts employ a supplemental actuator to reposition some of the thrusters or control mechanisms throughout a transformation phase, increasing construction efficiency. A prime instance of this is the BirdEyeView FireFly6, which uses fewer redundant elements in both flight mode. Even more extreme hybrids such as Google's Project Wing (Transforming the way goods are transported, 2023) use their own thrusters and monitoring model to shift between and function in both flight configuration.

There are designs that achieve even higher compositional performance by using the same operating surfaces and thruster systems for all flight configurations, such as TU Delft's distinctive Delftacopter (De Wagter, et al., 2018), which was inspired by biplanes, and ETH Zurich's more straightforward Tail-sitter UAV (Bapst, Ritz, Meier, & Pollefeys, 2015). Even so, the majority of modern hybrid vehicles still use their wing space just for fixed-wing flight.

Therefore, to enhance the system performance of the hybrid and maintain full wing area utilization in both flight configurations, we suggest the fusion of a fixed layout with the monocopter rotor-wing, a craft that rotates its whole fusealage to reach greatly productive flight, (Houghton & Hoburg, 2008), and (Fregen & Bolden, 2010) contains a list of significant

Figure 1.

Structural efficiency comparison of various multi-mode aircraft designs

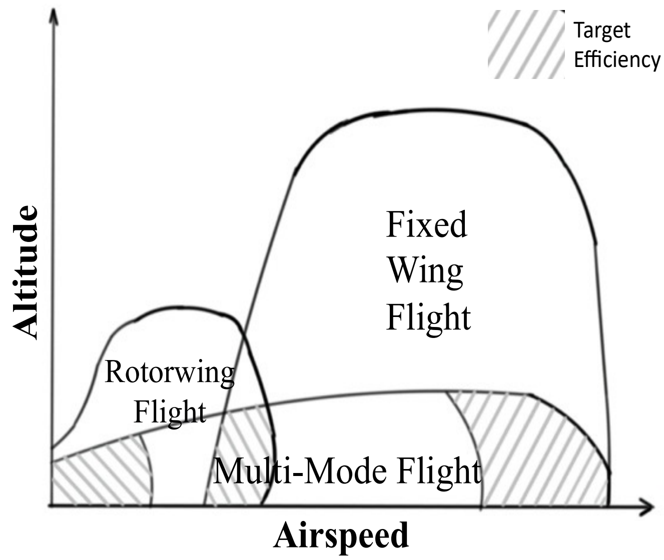


publications on the subject. Because of its demanding handling necessities and entirely spinning structure, the monocopter has originally declined behind other rotor-wing designs. This framework, however, has seen a revival as focus in manned flight has changed to unmanned flight and accurate microelectronic and actuator devices have shrunk in size. It is implemented by hybrid aircraft like Dzyne's ROTORwing (Page, McCueRobert, & Godlasky, 2015) for its Vertical Take-Off and Landing (VTOL) phase of flight. But in this design, the despin motor is only used during shift, and the tail arrangement is just involved throughout forward flight.

In order to create a hybrid UAV that is systemically proficient, we initiate the Multimode Hovering Vehicle in this paper as well as its three flight styles, Quadcopter Mode, Fixed Wing Mode, and Monocopter Mode. We define the operational fundamentals and essential concept criteria of such a setup in Section 3, leading to a dynamic model that is described in Section 4. We think that dual-wing monocopters have an exceptionally solid argument within the domain of hybrid UAVs due to their fundamental resemblance to a tailless fixed-wing. We postulate that such a model can have two sections of flying performance inside its operational range as opposed to the single zone of typical hybrid models like the tailsitters because they are able to maintain the wings entirely engaged in both monocopter arrangement and tailless fixed-wing arrangement (see Figure 2).

Figure 2

Target efficiency regions of flight of a multi-mode UAV as compared to other multi-mode designs.



Note. Area in the figure shows different types of aerial vehicle structures' efficient regions and crossed area is suggested vehicle target efficiency region.

The purpose of the thesis. The main goal of this dissertation work is increasing construction integrity and structural efficiency of UAV over the whole operational range, decreasing drag and wasteful mass when the aircraft is in motion.

The research object of the thesis. The inquiry at the heart of this research project is the complex processes linked to the difficulties experienced when operating transformable UAVs. The main goal of this research is to develop structural transforming mechanisms and natural control systems that will improve the operational effectiveness and flexibility of transformable UAVs in a range of operations . By exploring this area, the research hopes to offer light on the possibility of improving the flight dynamics and mission adaptability of these UAVs, opening the door for developments in aerial robotics and their use in a variety of industries.

Scientific innovations of the research thesis. Currently, one of the most active areas of research is the design, construction for a future control system development, of a quad rotor, 4 propellered platform capable of moving in different types of flying modes with multiple degrees of freedom increasing efficiency in complicated scenarios. A genetic algorithm of machine learning with the linear regression was used to create an optimum vehicle stabilization for the vehicle's hovering scenario. All the necessary variables for a rapid prototyping process of areal model were determined as well as the rotor's propulsion system.

The use of an ARM architecture based microcontroller in the project will contribute to low power consumption and high processing speed. A major advantage of the system is that it provides real time gesture recognition and visual data leading to an effective and natural way of controlling vehicle.

The structure of the work. The investigations made in the simulation and laboratory, along with the gathered theoretical data, were used to generate the dissertation that is being submitted. The dissertation consists of an introduction, literature review, methodology and three chapters, a conclusion, and a bibliography.

The dissertation consists of 89 pages and 29 figures and 8 data tables. The list of used literature includes 149 titles of literature.

CHAPTER 1

1. HYBRID AERIAL VEHICLES

1.1. LITERATURE REVIEW

By adding responsive processes to multirotors' standard architecture, several convertible multirotor designs have been put out in published works. These components may have an impact on the length, number, and rotation of the arms, as well as the direction in which the propellers or rotors are oriented. One setting change can be made consecutively by maintaining a constant elevation, changing, and then resuming the flight, or concurrently while the task is being carried out.

With the advantages of both fixed-wing and multirotor forms, hybrid aerial vehicles (HAVs) have become a potential development in the field of unmanned aerial vehicles (UAVs). HAVs have more cargo capacity, operating versatility, and traveling longevity than their single-configuration equivalents. The present level of investigation and advancement in the field of HAVs is thoroughly analyzed in this review of the literature, with an emphasis on design factors, control systems, applications, regulatory factors, and potential future developments.
Monocopters are not a brand-new idea. The samara seed, an achene with wings which uses its whole body to produce lift, is a living instance of how nature has long advocated this theory. The results of research like (Kellas, 2007) (Lentink , Dickson, van Leeuwen, & Dickinson, 2009)have demonstrated that these seeds have outstanding, passive lift producing characteristics (autorotation), are extremely steady, and can be operated. Because of these desirable qualities, human-made variants included flaps for directional management and propulsion structures to facilitate consistent flight. The Gyroptre, a massive, manned project created by Alphonse Papin and Didier Rouilly (Papin & Rouilly, 1915) in the 1910s, serves as an initial illustration of these. Although this prototype didn't take off (both literally and abstractly), it served as the starting point for scientists' efforts to create an aircraft with an effective structural design that can hover. The concept presented in Mueller and Bucki’s work (Mueller & Bucki, 2019) this relates to the development of an innovative retractable shifting quadrotor, where the connections between the drone arms and the primary structure are substituted by formed pivots, and based on the contributors, this concept enables the arms to retract downward in the event of inadequate propels generated by the four the rotors. In order to increase impact robustness, an innovative concept for a small quadrotor was put out in (Dilaveroglu & Ozcan, 2020). A quadrotor constructed around bendable scissor-shaped components was created in (Zhao, Luo, Hongbin , & Yantao, 2017) . An angulated piece that

creates a changeable bending is the foundation of the planned construction. Additionally, it makes it simple to change the UAV's capacity to accommodate various obstructions.

In the research given in (Tuna, Ovur, Gokbel, & Kumbasar, 2018), a self-folding quadcopter was shown, in which the four arms are simultaneously rotated laterally by an individual servomotor. Riviere et al. suggested a quadrotor in (Riviere, Augustin , & Stéphane , 2018) that is capable of folding the frame through an opening that is slanted or upright. However, when the device retracts, the positioning of the four rotors results in a reduction of roll stability.

The issue of maximizing the electrical power used by a novel quadrotor with spinning arms was addressed by Xiong et al (Xiong, Jin, & Diao, 2019). Falanga et al. use the identical theory in an effort to use the least amount of electricity possible for the work at hand (Falanga D. , Kleber , Mintchev, & Floreano , 2018). Mintchev et al. investigated another quadrotor with folding arms in which the construction of the robot centered on an origami method employing multi-layer substance (Mintchev, Daler, L'Eplattenier , Saint-Raymond, & Floreano, 2015). Bai et al. (Bai & Gururajan, 2019) and Desbiez's (Desbiez, Expert, Boyron, Diperi, & Vi, 2017) researches are regarded a brand-new retractable UAV concept that allows the arms' angles to be adjusted while the aircraft is in flight. The low weight of such constructions is a drawback. The amount of cargo is insufficient, and the four arms' rotations do not independently revolve.

Folding-wing UAVs possess the unique ability to swivel their wings, like birds which enables them to shrink in dimension in contrast to fixed-wing UAVs (Matloff, et al., 2020). Due to the reduced contact drag created by the tilting procedure, the drone moves faster and can keep a steady surface speed even in comparatively greater headwinds (Ma, Song, Pei, & Chen, 2020). However, it can be challenging to operate these kinds of UAVs in overall, especially when there is turbulence. Additionally, there are effects on price, weight, and architectural intricacy. Through the development of a multidisciplinary folding-wing drone, Daler et al. (Daler, Mintchev, Stefanini , & Floreano , 2015) were able to change the geometry of the drone from an airborne to a subterranean form. Additionally, its expanded wings enhance elevate while flying while its folding wings increase the robot's performance on the ground. Morton et al. used a similar notion (Morton & Papanikolopoulos, 2017). This hovering machine can operate as a standard quadrotor but additionally has the ability to fold up and transform into an agile unicycle robot when it has to navigate a tight space. This structure's drawback is that it is limited to passing through a tiny opening when the machine is mounted on an aircraft. The operational efficiency of solar-powered fixed-wing drones in addition to their morphing during

aerial action have been improved by realizing a transformable solar UAV with four wing components (D'Sa, Design of a Transformable Unmanned Aerial Vehicle, 2020).
A different kind of convertible quadrotor is a multi-link multirotor. They include multiple servomotors and rotors, which allow the aerial robot to change in the trip in order to do the needed duties.

Zhao et al. created a convertible multirotor UAV made up of several multifaceted linkages (Zhao , et al., 2017). Items may be moved by this machine by being grabbed, picked up, transported, and dropped at various locations. The following structure's drawback is the fact that it's unable to fold up while in motion; instead, it needs to be kept at a constant height. Yet additional multi-link multirotor was suggested by Zhao et al. (Zhao , et al., 2018). This construction was motivated by a snake's capability to pass through a narrow opening by altering its form. But since there are so many rotors and servomotors, folding is a very slow, laborious, and intricate operation. The project concept is for a customizable multi-linked mini air vehicles that can move things, navigate through tight spaces, and choose the optimum path for preventing hitting barriers.

One of the most popular techniques among current aeronautical technology is the bio-inspired convertible UAV (Han , Hui , Tian, & Chen , 2020). Furthermore, a few studies (Mintchev, Shintake, & Floreano, Bioinspired dual-stiffness origami, 2018) (Fuller, 2019) have been motivated by the abilities observed in birds and insects to create drones that are suited to traversing in crowded and restricted areas and bending or deteriorating in the case of encounters with various obstacles to avoid damages. This is because the structure of conventional quadrotors is constrained. Since it has solved various UAV-related issues, including graphical modification, this novel method has lately grown significant.

The lateral area of the quadrotor may be kept while the proportions of multirotor UAVs having extensible limbs can be reduced. Servomotors and a gear arrangement are typically used to reduce the limb span. Kamil et al. in their study (Kamil, Hazry, Wan, Razlan, & Shahriman, 2017) took into account an architecture for a convertible quadrotor. Compared to the traditional quadrotor, its construction is primarily centered on varying the span of the four limbs to achieve a yaw motion. With the goal to provide steady navigation with three spinners in the case of a rotor breakdown, the developers of an innovative concept for a transforming quadrotor took into account the enlargement and revolution of the quadrotor extremities (Avant , Lee, Katona , & Morgansen, 2018). In this work, just concept and simulation were covered. A unique unmanned aerial vehicle (UAV) capable of lengthen and withdraw its four limbs was created and detailed in as a result of the shipment uavs' unprotected rotors (Kornatowski, Feroskhan , Stewart , & Floreano , 2020).

An additional type of convertible unmanned aerial vehicles (UAVs) that has been suggested in multiple studies is the tilt-rotor UAV (Invernizz, Giurato, Gattazzo, & Lovera, 2020) (Kumar, , Sridhar, Cazaurang, Cohen, & Kumar, 2018). Tilt-body UAVs were also introduced in this study, and they have a number of benefits over tilt-rotor UAVs, including increased flexibility and accuracy, excessive resilience, significant mobility, the capacity to modify the thrust obligation through reimbursement in the case of a failure, horizontal and vertical relocation, a lack of the over-actuation issue, and a greater velocity (Bai Y. , 2017). Tilting rotors' low hover efficiency, which is brought on due to their tiny rotor dimensions and long rotor mast, is, nevertheless, their principal drawback. Furthermore, since the uplift rates are impacted by the rotor tilt, floating could fail to remain sustainable at high rotor inclinations.

Because they are made up of several components that are coupled to one another, flexible UAVs, like those presented in, represent an innovative category of convertible UAVs (Mu & Chirarattananon, 2020). Those UAVs are made more adaptable by their detachable structure, which promotes their employment in transportation, parachute use, and pursuit and recovery operations.

When many suggested layouts are combined, it is clear that the majority of them are complicated, have sluggish conversion processes, and are expensive. The primary objective of the present layout is to enhance the efficiency of our convertible quadrotor's structural construction and these models.

The concept and trials for a transformable VTOL UAV are shown in D'sa's article (D’Sa & Papanikolopoulos, Design and Experiments for MultI-Section-Transformable (MIST)-UAV, 2019). Based on the theoretical concepts shown in (D’Sa, Jenson, & Papanikolopoulos, SUAV:Q - A Hybrid Approach To Solar-Powered Flight, 2016) and (D'Sa, et al., 2016), coupled with physical prototype and element evaluations from (D'Sa, et al., 2017) illustrates morphing transition. To describe the MIST-UAV's simulated movement, a deterministic framework is provided. The device's practical findings show for the first time how well multirotor, tail-sitter, and fixed-wing action may be converted to inair operation. Through the effective assessment of several consecutive modifications, investigations also confirmed the recurrence of conversions.

Opportunities to utilize information collecting, processing, and exchange in several domains have emerged as a result of the convergence of UAVs with IoTs. A network of interconnected UAVs, detectors, and IoT equipment may gather, procedure, and exchange data instantaneously. In order to allow the smooth incorporation and compatibility between Aircraft and various IoT components including detectors and data centers, current studies (Goyal, Sharma , Rana, & Tripathi, 2022) (Israr, Abro, Sadiq Ali Khan, Farhan, & Bin Mohd Zulkifli, 2021) on IoT-enabled UAVs has concentrated on building effective and sustainable connectivity procedures, system structures (Aldeen & Abdulhadi, 2021) and material analysis methods. UAVs with IoT capabilities have several advantages, including enhancing the performance and productivity of different operations (Sun, et al., 2022) and emergency administration. In order to make judgments about watering and fertilization, UAVs fitted with detectors, for instance, are able to gather information on the condition of crops, the water content of the the ground, and the temperature. UAVs may also be utilized to track environmental catastrophes and evaluate harm, allowing for a quicker and more precise reaction. IoT-enabled UAVs have enormous promise, but there are also big problems that have to be solved. IoT-enabled UAV confidentiality and protection must be guaranteed, and efficient techniques for data handling and evaluation must be developed. An intriguing subject of study, nevertheless, which has the possibility to transform many industries and open up significant opportunities is the combination of UAVs with IoT.

UAVs must have the vision and detection ability to acquire, analyze, and evaluate data from their environment. These features are necessary for UAVs to carry out a range of operations, including routing, visualization, examination, and monitoring. These fields of study, however, are intricate and difficult, necessitating the fusion of several innovations, such as detectors, computer vision, and artificial intelligence. The supreme objective is to create UAVs that can sense and comprehend their surroundings and center their judgments on that knowledge. The incorporation of numerous detectors, including cameras, LiDAR, and radar, is one of the essential elements of vision and detecting (Corradi & Fioranelli, 2022). Such detectors give UAVs data about their surroundings, such as the positioning of barriers, the topography, and various structures. The creation of computer vision techniques which can analyze and interpreting the data gathered by detectors is a further vital aspect of vision and detecting. This entails acknowledging patterns, following motion, and distinguishing things. Scientists are also looking at integrating AI methods like ML and DL (Osco, et al., 2021) to help UAVs gain insight into errors and develop enhanced vision and detecting skills gradually. The development of machines which are capable of precisely detect and comprehend their surroundings and select choices according to that knowledge is the primary objective of vision and detection in UAVs. It has the capability to transform several sectors, namely farming (Sun, et al., 2021), building, civil applications (Guan, Zhu, & Wang, 2022), naval usages (Yang, et al., 2022), extraction (Ren, Zhao, & Xiao, 2019), military activities, and pursuit and recovery tasks, such as surveillance for wildfires (Bailon-Ruiz & Lacroix, 2020). In order to improve operational features, scientists are now looking at the possibility of simultaneous sensing employing numerous UAVs (Merino, Caballero, Ferruz, Wiklund , & Forssén, 2007).

A key aspect of UAV development involves energy-efficient flying, which aims to create UAVs capable of fly for long durations of time while using little power. The functionality and capacities of UAVs, comprising flying duration, cargo limit, and spectrum, must be improved via energy conservation. Numerous strategies are being investigated by scientists (Chodnicki, Siemiatkowska, Stecz, & Stepien, 2022), including solar power insertion (Boukoberine, Zhou, & Benbouzid, 2019), lighter substances, and aerodynamic structure improvement. One of the main obstacles to attaining cost-effective navigation is the mass of UAVs. In order to overcome this issue, scientists are looking at novel production processes and the usage of compact components like polymers to lighten UAVs. Additionally, improving the propulsion mechanism (Amici, et al., 2021) is essential for attaining power conservation. This includes using more effective engines and creating new propulsion systems. Investigation is also being done on combining hybrid and electric propulsion structures, which are more energy efficient than conventional inner combustion motors. The incorporation of alternative energy sources, like solar power, is a different field of study (Betancourth, Villamarin, Rios, Bravo-Mosquera, & Cerón-Muñoz, 2016). This entails creating new photovoltaic cells that are portable as well as power preservation devices that can supply electricity for a long time. Energy-efficient flying has the promise to greatly enhance the efficiency and features of UAVs, opening up novel possibilities and usages. Enormous data flow throughout transmission and monitoring, however, can cause latency and use a lot of energy. Because of this, deep reinforcement learning (DRL) alongside various AI techniques were applied in such situation (Nemer, Sheltami, Belhaiza, & Mahmoud, 2022).

1.2. Design Challenges

Developing HAVs entails combining fixed-wing and multirotor technologies into a single structure to provide both optimal forward flight and VTOL operations. To improve HAV efficiency, the investigators have looked into a variety of design factors. Enhancing the lift-to-drag ratio and minimizing energy expenditure throughout various flight stages are both made possible by aerodynamic construction. To increase aerodynamic effectiveness and flying features, researchers have looked at sophisticated airfoil forms such laminar flow airfoils and high-lift components involving flaps and slats (Garcia, Torres-Pomales , & Diaz, 2019). Studies have also concentrated on lightweight components and cutting-edge production processes to lighten HAV frames without sacrificing fundamental strength. In order to reduce mass while preserving toughness and longevity, additive manufacturing processes such as 3D printing, and carbon fiber composites have been investigated.

The monocopter idea was revived at the beginning of the twenty-first century. Hoburg and Houghton created a design in 2008 that demonstrated its practicability for usages in enclosed areas by being able to repeatedly fly along a 70 m by 3 m corridor accompanied by a 1.5 m doorway (Houghton & Hobrug, 2008). Additionally, Hoburg and Houghton made two major breakthroughs. The first was the discovery that a propulsion system and flap equipped monocopter can still accomplish passive consistency in hover, returning it to its samara seed predecessors, with the appropriate choice of construction variables. The second involved connecting this naturally influenced configuration to the dynamics and control of helicopters, such as the benefits of employing a fixed angular speed for the rotor and cyclic motion to achieve forward flight. The monocopter has disadvantages in addition to its incredible systemic efficiency. Specific common and practical payloads, like video cameras, are affected by the continuously revolving fuselage because they are prone to orientation sensitivity. For this kind of payloads, software or supplemental pneumatic parts would be needed to maintain the sensor's direction (Youngren, Jameson, & Satterfield, 2009) (Hockley & Butka, 2010). The last is heavily reliant on ambient luminance and on-board nutation, while the first results in increased weight and structural difficulty. More importantly, the greater the hover angular speed, the more accurate the detector and regulation would need to be, making both operated and non-actuated workarounds correspondingly more difficult to execute (Consequently, downsizing the configuration presents an increased task). Nevertheless, these flaws shouldn't be used as an excuse to ignore the concept. There are several payloads that are not vulnerable to revolution, including first aid packages, gas sensors, Global Position Systems (GPS), fertilizers and pesticides, wireless signal relays, to mention a few. In addition, there are devices as spinning Light Detection and Ranging (LIDAR) sensors and event-based cameras that might gain from a regulated rotational movement.

For HAVs to operate safely and reliably, robust control systems must be developed. To assure accurate and steady flying, investigators have investigated a variety of control systems and techniques. For trajectory tracking, stability, and response effectiveness, model predictive control (MPC), adaptive control, and proportional-integral-derivative (PID) control approaches have all been examined (Orsag, Christopher , Bogdan, & Yu Oh, 2014).

Additionally, study has been concentrated on HAV autonomy with the goal of enabling autonomous navigation and decision-making skills. In order to offer precise location estimates and barrier identification, HAVs are equipped with cutting-edge navigation technologies such Global Navigation Satellite technologies (GNSS), Inertial Measurement Units (IMUs), and LiDAR sensors (Kwon, et al., 2020). To create collision-free and cost-effective flying pathways, route developing techniques such as rapidly exploring random trees (RRT) and potential field approaches have been used (Tullu , Endale , Wondosen , & Hwang, 2021).

Using sophisticated management techniques and guidance structures, unattended aviation relates to the capability of UAVs to function without the need to person involvement (Zhang, Zhang , & Yu, 2018). UAVs may fly, locate, and carry out operations independently. In the realm of UAVs, independent flying is a complicated and difficult area of study that calls for the fusion of several innovations, including detectors, computer vision (Xin, Tang, Gai, & Liu, 2022), and AI (Choi & Cha, 2019). The goal is to create unmanned aerial vehicles (UAVs) which carry out difficult jobs safely and effectively, such precise landings (Xin, Tang, Gai, & Liu, 2022), eliminating the need for personal involvement. Creating drones which are able to maneuver while avoiding obstructions instantaneously while retaining steadiness and coordination constitutes one of the key difficulties in driverless operation. For this, sophisticated management techniques (Zulu & John, 2016) and detectors (Shen, Mulgaonkar, Michael, & Kumar, 2014) that can precisely identify and react to environmental alterations must be created. Assuring the assurance and dependability of drones, especially in situations with little person participation or in dangerous places, is a key problem for driverless flying (Li, Chen, & Liu, 2016). Scientists are creating novel methods for observing, regulating, and analyzing aircrafts to solve these problems, notably the incorporation of safeguards, emergency processes, and continuous surveillance technologies. The development of UAVs competent of carrying out a variety of activities securely, effectively, and consistently without the assistance of humans is the aim of self-sufficient flying. Numerous sectors, such agricultural, transportation, warfare processes, investigate and recovery activities, and structural purposes, might be completely changed by that.

A growing area of study called "human-UAV engagement" looks into how people engage with unmanned aerial vehicles in a variety of settings, including studies, recreation, and instruction. It possesses an opportunity to completely transform a number of sectors. It entails creating novel innovations and layouts that make it possible for people to engage with UAVs in inventive and natural methods. Such innovations cover actions (Kassab, Ahmed, Maher, & Zhang, 2020), augmented and simulated reality, and other types of human-machine communication. The development of Drones capable of react to user instruction in instantaneously while preserving steadiness and management constitutes one of the key problems in human-UAV interface. In order to accomplish this, it is necessary to integrate sophisticated management methods, detectors, and easy to use human-machine interfaces. Assuring the integrity and dependability of drones, especially in situations when there is little room for human involvement, is a difficulty in establishing a relationship between humans and drones. Conversational speech, hand actions, and bodily motions were suggested as methods for commanding aircraft. Technologies for cognitive human-UAV interface have been created, using ML and DL to identify motions and allow effective drone management (Kassab, Ahmed, Maher, & Zhang, 2020).

In addition, a few study articles have put forth unique designs that let people pilot UAVs using their own motions (Rajappa, Towards Human-UAV Physical Interaction and Fully Actuated Aerial Vehicles, 2017). Numerous research has explored human aspects and UAV use difficulties, that include user interfaces, learning, and task load, in addition to technological alternatives (Nisser & Westin, 2006). Studying how humans make choices when operating drones, especially for search and rescue purposes is an important topic for studies in the human-UAV interface (Hart, Steane, Bullock, & Noyes, 2022). This emphasizes the significance of creating human-UAV interface systems that are simple to use and effective across a range of applications and areas. A summary report that identified fields like recreation, logistics, and public assurance is one example of an exploratory paper that reviewed the state-of-the-art in human-UAV interaction. A different questionnaire that provided a snapshot of different command layouts, motion comprehension approaches, and self-sufficient execution methodologies is a different one (Tezza & Andujar, 2019). Additionally, scientific research has looked into the personal components and difficulties that come with utilizing UAVs, particularly problems with user layouts, instruction, and job duties. Studies continues in order to comprehend how people make decisions when operating unmanned aerial vehicles, especially for use in seek and recovery operations (Hart, Steane, Bullock, & Noyes, 2022). It emphasizes the value of creating user-friendly and effective human-UAV interface technologies that may be applied across a variety of areas and activities.

HAVs have shown their adaptability and prospective impact in a number of industries. HAVs offer high-resolution photography and 3D mapping features for aerial reconnaissance and mapping. They are used for infrastructure evaluations, environmental surveillance, and topographic imaging. HAVs are appropriate for inspecting bridges, electricity lines, and other

infrastructure components that are difficult to access using conventional methods because to their capacity to hover and navigate in constrained places (Nex & Remondino , 2013)
HAVs outfitted with remote monitoring technology, such as multispectral and infrared cameras, make it possible to monitor crop health, nutrient deficiency, and irrigation needs effectively in precise farming. They aid in enhanced agricultural yields and better handling of resources (Sarabia , Aquino, Ponce, López, & Andújar, 2020)

HAVs are essential for managing disasters and responding to emergencies. They aid in search and rescue operations, quickly analyze the situation, and evaluate the damage in impacted regions. HAVs are fitted with cutting-edge sensors that enable them to identify dangerous chemicals, keep an eye on fires, and assist in catastrophe restoration (Luo, et al., 2019).

Regulatory Structures and Challenges: Regulations and airspace cooperation are obstacles to the broad implementation of HAV systems. Key factors to take into account include confidentiality and security issues, air traffic control, and the incorporation of HAVs with current manned aviation systems. HAV activities are governed by policies and laws that have been adopted by regulatory organizations including the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO). These consist of criteria for aviator education, licensing demands, and airspace limitations. To maintain sustainable and safe HAV activities, adherence to these laws is crucial.

Furthermore, for the secure cohabitation of HAVs with other airspace individuals, airspace management and traffic integration are essential. Various approaches to managing airspace have been put forth by investigators, including dynamic geofencing, traffic flow optimization algorithms, and secure communication protocols. These initiatives seek to make it possible for HAVs to seamlessly integrate into the current airspace infrastructures (Aissaoui, Deneuville, & Pirovano, 2022).

UAM, a relatively fresh discipline, has a lot of potential for the transportation industry (Bauranov & Rakas, 2021) (Garrow, German, & Leonard, 2021). By providing a quick, effective, and sustainable substitute to conventional ground-based structures, UAVs possess the promise to transform metropolitan transit (Bauranov & Rakas, 2021). Nevertheless, major technical developments in routing, unsupervised flying, and security technologies are required in order to fully realize this promise. Furthermore, for the secure and sustainable deployment of UAVs in highly inhabited regions, the establishment of customized air traffic administration technologies intended to solve the particular problems of urban surroundings is essential (Shrestha, Oh, & Kim, 2021). UAVs are positioned to play a key role in the development of possible metropolitan commuting infrastructures as this industry continues to expand and receive funding.

The reduction of size is an increasingly common development in the UAV business which concentrates on creating smaller, more portable drones that may be used for a variety of purposes (DiGiovanni, et al., 2021). Such uses include shipping, monitoring, and rescue operations, among others. However, achieving miniaturization requires significant technical developments, such as the creation of lightweight and robust components in addition to small and effective propellant mechanisms. As a result, downsizing has become an essential sector for UAV industry exploration and improvement, opening up fresh opportunities for drone use in a variety of industries.

Technology that enables UAVs to function outside of the pilot's range of vision is known as beyond visual line of sight (BVLOS) missions (Matalonga, White, Hartmann, & Riordan, 2022). Improved sense-and-avoid technologies that can recognize obstructions and prevent crashes must be developed in order to achieve BVLOS potential (Skowron, Chmielowiec, Glowacka, Krupa, & Srebro, 2019). To maintain secure and effective operations, dependable transmission and management mechanisms are also required. To guarantee adherence to precautionary requirements and reduce possible dangers, administrative structures must be developed in order to facilitate the common implementation of BVLOS activities (Hartley, Henderson, & Jackson, 2022).

The improvement of long-distance and high-altitude missions is additional field of progress in the UAV sector. This calls for giving UAVs the capacity to operate for longer durations of time and at higher elevations. In order to do this, more cost-effective propulsion mechanisms that can support lengthy missions must be developed (Gray, 2018). In order to boost the durability and spectrum, UAV models are being investigated for the incorporation of sustainable power sources, such as solar panels (Chen, 2022).

1.3. Upcoming Prospects.

As a result of continued study and developments in technology, the area of HAVs tends to develop quickly. New improvements in HAV innovation are anticipated to concentrate on raising cargo capacity, maximizing power economy, and operating reliability.

The lifespan of HAVs may be increased because to developments in power preservation technologies like fuel cells and lighter batteries. To boost energy density and decrease weight, investigators are investigating innovative battery chemistries including lithium-sulfur and solid-state batteries (Li et al., 2021). The efficiency and sustainability of HAV operations will also be improved by continuous research into innovative propulsion systems, such as electric propulsion and hybrid powertrains (Lieh, Spahr , Behbahani , & Hoying, 2011).

A fascinating new area is the incorporation of HAVs into urban aerial mobility (UAM) infrastructures. With the possibility to change transportation systems and reduce traffic jams, UAM sees the employment of HAVs for passenger transportation and freight transportation in metropolitan regions. For the broad deployment of HAVs in UAM uses, studies are concentrated on building facilities overcoming air traffic control difficulties and assuring public acceptability (Cohen & Shaheen, 2021).

Hybrid aerial vehicles (HAVs) provide substantial benefits in terms of cargo capacity, operating mobility, and flying durability. The goal of ongoing investigation and production is to advance the potential of HAVs for urban air mobility by improving HAV design, strengthening control systems and autonomy, investigating a variety of uses, resolving administrative constraints, and addressing these issues. HAVs have the possibility to transform many sectors and open up new opportunities for airborne operations with additional technological improvements, integration with current airspace systems, and proper legal frameworks.

Even though such investigations have significantly advanced the area, more study is still required to examine how machine learning algorithms and fuzzy control systems may be used in the framework of a four-motored monocopter. Particularly, the integration of sensor data, control inputs, and motion assumptions in this particular context has not been well addressed. Therefore, the purpose of this work is to fill in these deficiencies and explore if stabilizing and controlling a four-motored monocopter using machine learning and fuzzy control approaches is feasible.

In order to produce freely accessible systems, instruments, and norms for UAV architecture, expansion, and functioning, the open innovation axis for UAVs entails establishing a cooperative environment where creators, academics, and operators may collaborate. With this strategy, the UAV sector is more open to creativity and adaptability (Fan, Li, Zhang, & Fu, 2020), and AI and ML techniques may be integrated to improve autonomous flying and decision-making skills (Rezwan & Choi, 2022). The subsequent concerns are capable of being developed on in more detail to discuss additional problems and potential areas for study.

UAV operation is being revolutionized by AI technologies. Such algorithms enable UAVs to have enhanced independent flying and governance skills, which can lead to less hazardous and highly effective activities (Rezwan & Choi, 2022). Improved sensor modules are one method that AI and ML algorithms may be employed for UAVs. For instance, LIDAR and computer vision may be linked into UAVs to give the AI platform immediate input (Ferraz, et al., 2021). It enables the UAV to form judgments according to its surroundings and respond to alterations quickly. The UAV can distinguish individuals and things in its surroundings thanks to computer vision, which may be utilized to increase security and stop crashes. LIDAR, on the other hand, may give the UAV particular details about its setting, such as the dimensions, location, and velocity of the items, that may be utilized to maneuver challenging terrain further skillfully. Using AI to optimize flight routes is a different method that UAVs may leverage the technology. UAVs may refine their itineraries and acquire from previous missions to use less resource and operate more effectively by applying ML techniques. This may be accomplished by examining information regarding the surroundings variables such as weather, the breeze acceleration and others (Li, et al., 2022)..

A prospective use of such cutting-edge innovation is the use of UAVs for ecosystem observation and preservation (Ventura, Bonifazi, Gravina, & Ardizzone, 2017). These unmanned aerial vehicles have enormous promise for a variety of tasks, such as observing wildlife groupings (Kabir & Lee, 2021), following ecological alterations (Tiwary, Rimal, Himeur, & Amira, 2021), and spotting ecological risks (Himeur, Rimal, Tiwary, & Amira, 2022). They are outfitted with superior quality cameras and other innovative equipment. We may considerably improve our ability to gather accurate and trustworthy statistics and hence obtain greater understanding into the general wellness and welfare of the earth by utilizing the features of UAVs in such fields (Serna, Vanegas, Gonzalez, & Flannery, 2020).. This priceless knowledge enables us to create and put into practice efficient conserving plans, guaranteeing the maintenance and protection of the natural world for generations to come (Himeur, et al., 2022).

Investigations have shown an increase in the usage of drones in environmental and glaciological study in places like Antarctica (Fudala & Bialik, 2022). Unmanned aerial vehicles simplify accurate observation of vegetation across large regions, thorough geomorphological visualization, and evaluations of wellness indicators. They enable the non-invasive enumeration and morphometrics of many animal varieties, revolutionizing faunal investigations and improving the determination and evaluation of cryospheric characteristics, covering subterranean implications. UAV atmospheric assessments provide quick and flexible information gathering, involving the collecting of aerosol measurement. For such operations to be successful, systems have to be designed and developed specifically for the severe Antarctic climate. Existing UAVs may gather material specimens from inconvenient or distant locations, and additional improvements in autonomy and resilience will increase their usefulness for exploration in the Antarctic (Pina & Vieira, 2022). Both the interests of the earth and of humans are served by the use of UAVs for environmental observation and preservation.

UAV attachment cargo is the term used to describe the design and improvement of suspension mechanisms for UAVs that can transport a variety of cargo, involving heavy objects like nourishment, healthcare equipment, and additional necessities. In order to safeguard the cargo and delicate apparatus on board, the suspension mechanism is essential for guaranteeing a steady flight during operations that include cargo lowering. It serves to reduce disturbances while offering impact mitigation (Hadi, Varianto, Trilaksono, & Budiyono, 2014).

The primary objective of current developments in stabilization loading innovation for aircraft has been on enhancing the functionality and effectiveness of damper devices in addition to combining these into other aircraft parts. Utilizing cutting-edge components and production processes, creating engaged suspension structures which can instantly adapt to shifting motion circumstances, and integrating suspension mechanisms with movement, management, and cargo mechanisms to guarantee effortless execution and optimal performance are several instances of such innovations.

Additionally, latest developments in operating quadrotors with hanging weights have concentrated on creating innovative methods and command techniques that can manage the added complication and difficulties brought on by the attached cargo (Mohammadi, 2021). Several research have suggested techniques to increase the precision and balance of quadrotors with attached deliveries, such the application of flexible learning algorithms and anticipatory management systems (Santos, Rego, Raffo, & Ferramosca, 2017) (Mohammadi, 2021). Such advancements in aircraft suspension cargo systems will increase shipment and mobility features and broaden the uses of drones in a variety of industries.

Unmanned aerial vehicles can alter their structure or arrangement while in air thanks to a novel innovation called transformability or conversion (Derrouaoui, Bouzid, Guiatni, & Dib, 2022). By enabling UAVs to adjust to various operating settings and tasks, this development has an opportunity to increase their adaptability and performance. Transformability in UAVs may be attained in a number of ways, such as:

Utilizing shifting wings is one significant aspect of transformability which shall be studied. This novel strategy includes creating wings that can change form while in air to improve performance and agility (Moosavian, Xi, & Hashemi, 2013). Drones that use shifting wings technique may change their wing shapes in response to changes in elevation, velocity, and wind flow. Drones' span, resilience, and steadiness may all be increased thanks to the flexible wings' enhanced aerodynamic capability and general effectiveness (Ajanic, Feroskhan, Mintchev, Noca, & Floreano, 2020). Structural memory compounds, intelligent substances, and physical structures are just a few of the techniques used to create shifting wings.

With the use of these systems, drones may modify the airfoil's curve, modify the wing's form entirely, and vary the wing's tilt. The "RoboSwift" was created by the Delft University of Technology in the Netherlands as a non-table instance of the changing wings concept. This tiny drone, which resembles a quick bird in nature, has the capacity to change the shape of its wings while in ascending, enhancing effectiveness and lowering noise. Due to the RoboSwift's ground-breaking transforming wings innovation and its prospective uses in a variety of industries, including tracking, environmental inspection, and wildlife studies, it has attracted a great deal of attention from academic circles. Several research studies have emphasized its amazing qualities (Jiakun, Zhe, Fangbao, & Gang, 2021) (Kilian, Shahid, Zhao, & Nayeri, 2022). The "FlexFoil" created by FlexSys Inc., Ann Arbor, MI, USA, is a different noteworthy illustration.

A special "morphing trailing edge" technique used by the FlexFoil allows the back part of the wing to stretch and curl in reaction to variations in the airflow (Miller, et al., 2015). The aforementioned design element improves the drone's aerodynamic efficiency and its capability to adjust to various operating circumstances, leading to increased effectiveness. Drones can change flight by obtaining higher responsiveness, spectrum, and steadiness by utilizing the potential of changing wings technology. Exciting opportunities for a variety of sectors, from observation and tracking to study and discovery, are made possible by the emergence of such revolutionary competences.

Exploring the idea of folding UAVs with detachable arms or wings is an interesting prospect (Frigioescu, Condruz, Badea, & Paraschiv, 2023). Due to this layout element, the drones' total size is reduced, improving mobility and allowing for more organized packing and transit. Given its versatility and simplicity, such bendable drones, featuring variants such as the Mavic Pro, DJI Mavic Air 2, Parrot Anafi, PowerVision PowerEgg X, and Robotics EVO, have significantly increased in demand (Gökbel, Güllü, & Ersoy, 2023). Such drones are versatile since they can simply retract their arms or wings, which enables operators to carry them in tiny containers or packs. This innovation increases the mobility of the drones while also enhancing their toughness and safety during transit. As a result, the potential harm is reduced, resulting in the drones being secure and prepared for use in a range of settings and circumstances (DeFrangesco & DeFrangesco, 2022).

The next area of change for UAVs is represented by adaptable airframes. Drones with customizable airframes may modify their structure or form while in air to accommodate various objectives or operating settings. This adaptability can be achieved by altering the arrangement of their wings, including or excluding cargo, or by shifting the center of weight. Drones with customizable airframes tend to be more versatile and affordable than drones with static designs because they can accommodate a broader spectrum of task needs. Although the ability for changeable airframes in UAVs continues to be in its infancy, there are at least a few notable instances of businesses and groups who are working on these kinds of aircraft right now (Falanga D. , Kleber, Mintchev, Floreano, & Scaramuzza, 2018). In this regard, engineers from the University of Zurich and EPFL have created flexible quadrotors that can change their form between "X" and "O" structure while in flight (Falanga D. , Kleber , Mintchev, & Floreano , 2018). These cutting-edge models exhibit the versatility and responsiveness of adaptable airframe drones in a variety of movement circumstances.

The introduction of pitch-shifting rotors is another important advancement in UAV innovation (Podsędkowski, Konopiński, Obidowski, & Koter, 2020). Such propellers have blades that may change in tilt or angle while in motion. Flexible pitch propellers, sometimes referred to as customizable or customizable pitch propellers, offer the drone's flying efficiency and greater precision, especially in difficult or unpredictable circumstances. The drone can precisely control its power and lifting by adjusting the angle of its propeller blades, which enables it to sustain a steady flight regardless in a variety of wind situations, elevations, or flying phases. The drone's mobility, effectiveness, and entire effectiveness are significantly improved thanks to this feature across a variety of usages, such as aerial monitoring, visualization, and examination. In sophisticated or niche UAVs, such as commercial or military drones, which accurate handling and optimum effectiveness are essential, flexible pitch propellers are frequently encountered (Wu, 2018). Nevertheless, these are also ending up available in commercial drones, giving amateurs and aficionados a way to take advantage of their advantages and experience more adaptability and flexibility in their aviation efforts. The incorporation of convertible rotors is a crucial development in UAV innovation (Misra, et al., 2022). Adaptive rotors allow UAVs to change the rotor arrangement while in movement, allowing aircraft to adjust to different flying circumstances or operation needs. It also involves having the capacity to alter the rotors' count or direction. Unmanned aerial vehicle technology has a great deal of opportunity to change with the growth of adaptable UAVs. It enables UAVs to carry out a wider variety of tasks more successfully and efficiently. The VA-X4, having four rotors that may lean onward and switch between vertical takeoff and landing (VTOL) configuration to frontal flying setting, serves as an impressive instance. Due to its improved speed—up to 200 mph—the UAV is now able to further effectively traverse greater ranges (Misra, et al., 2022). The Voliro Hexcopter created by the ETH Zurich team is a different famous adaptable rotor UAV (Voliro Hexcopter, , 2023). This hexacopter makes use of several rotors that may provide propulsion in a variety of directives, enabling the aircraft to move independently and operate in challenging settings. Another impressive convertible rotor UAV is NASA's Greased Lightning GL-10 (GL-10, 2023). It can fluidly switch between a fixed-wing configuration and a VTOL configuration to maximize performance while moving ahead. With 10 electric motors driving ten rotors, Aircraft is able to go at great velocities while maintaining outstanding agility. The instances show the flexible rotor UAVs' tremendous scope for enhancing the flexibility and capability of drones and opening the door to highly effective and versatile aerial operations in a variety of sectors. In general, convertible UAVs offer an opportunity to significantly increase the adaptability and productivity of UAVs, allowing aircraft to be used in a variety of functional settings and objectives. These UAVs may maximize their efficiency for various flying circumstances and task objectives by changing their design or structure while in movement, resulting in a priceless instrument for a variety of purposes.

Aerospace engineering's crucial field of aviation mechanics regulation addresses the steadiness and management of a vehicle while it is in motion (Campion , Prakash, & Faruque , 2018). The primary goal of aerodynamic management is to maintain the vehicle's stability, controllability, and safety throughout the entirety of its operating domain (Kangunde, Jamisola, & Theophilus, 2021). Flight dynamics management designs supervision structures that regulate and stabilize an UAV's actions while it is performing a variety of the air, such as route pursuing (Rubí, Pérez, & Morcego, 2020), transforming skills (Schiano, Kornatowski, Cencetti, & Floreano, 2022), routing and monitoring, swarm flights (Campion , Prakash, & Faruque , 2018), self-sufficient driving (Zhang, Zhang , & Yu, 2018), visualization, and sprayer activities (Sonugur, 2022). Such methods and procedures make use of the algebraic representations of aerodynamics and control theory (Idrissi, Salami, & Annaz, 2022) to provide command instructions that alter the actions of the aircraft in order to meet predetermined operational goals.

The ultimate objective is to provide effective, stable, and safe flight operations. The kind of drones being commanded, the command goals, and the numerical approaches used may all be used to categorize UAV management strategies in various manners (López, Garcia-Fernandez, Alvarez-Narciandi, & Andrés, 2022). There are a few control theory categories that are typical: Comparisons between feedback and feedforward command; linear and nonlinear control (Farid, Hongwei, Ali, & Liwei, 2017); continuous-time and discrete-time control; predictable and stochastic control; model-based control and model-free; fixed (Derrouaoui, Bouzid, Guiatni, & Dib, 2022) and adaptive control (Cao & Yu, 2022); concentrated and distributed control, optimal and suboptimal control, and time-invariant and time-varying control are made. The many methodologies and techniques utilized in aerodynamics management are represented by these categories.

To handle the complexity of flight dynamics control, four basic groups are generally acknowledged: classical control, contemporary management, smart control, and reactive control. All of these classifications present a variety of approaches and strategies.

Conventional regulation theory centered around algebraic representations of linear systems is referred to as "classical control" (Dolega, Kopecki, Kordos, & Rogalski, 2017). The proportional, integral, and derivative (PID) control methods are used often in this method for managing aircraft dynamics. The advantages of classical control include its ease of use and solid conceptual underpinnings. Yet it is limited in how it handles nonlinear systems and disruptions that affect the operation of the vehicle.

Designing regulation structures that can handle irregularities and disruptions involves using cutting-edge control theory, such as state-space and optimized management. This method, which offers greater precision regulation and can handle complicated structures, is widely used in aircraft dynamics regulation. Current administration has the benefit of being able to deal with nonlinear processes and uncertainty (Joukhadar, Alchehabi, & Jejeh, 2019). Instantaneous deployment is complicated by the need for increased computer capacity and complex methods. For the best command of linear models, the linear quadratic regulator (LQR) is a well-liked control technique that is frequently employed in aviation regulation.

A subfield of control theory called smart management (Azar, et al., 2021) uses artificial intelligence (AI) tools including neural networks, fuzzy logic, and genetic algorithms to create management methods. Due to its substantial degree of resilience and ability to adjust to fluctuating situations, this technique is widely used in aircraft regulation. The benefit of smart administration comes from its capacity to manage intricate, nonlinear structures as well as from its adaptability. Nevertheless, it may be difficult to evaluate and troubleshoot, and it needs a lot of processing power. In aircraft supervision, neural networks are often used, especially for management and problem diagnostics. Autopilots, aviation regulation frameworks, and engine regulation technologies have all developed employment for them.

According to the actions of the vehicle and the surrounding situations, reactive management is a family of management algorithms that can actively alter control settings in instantaneously (Cao & Yu, 2022). As it successfully manages inconsistencies and disruptions, this method is frequently used in aviation regulation because it is adaptable for a range of working circumstances. The benefit of reactive management is that it can tolerate ambiguous processes and adjust to shifting circumstances. Still, learning the actions of the framework necessitates a large quantity of information, which might be difficult to acquire in some circumstances. A common reactive management technique in aviation dynamics governance, model reference adaptive control (MRAC) finds utility in a variety of aviation management systems, involving autopilots, flying executives, and aviation management units (Nguen, Putov, & Nguen, 2017).

In conclusion, techniques and methods for aerodynamic regulation are essential for assuring the secure and productive functioning of UAVs. The selection of a certain strategy is based on the unique needs of the management challenge, as each type of management method has its own advantages and drawbacks. New strategies and methods are anticipated to be developed as scientists and engineers strive to create and improve airplane management technologies. Aerial motion oversight, as stated before, is a crucial area of aeronautical design that guarantees the equilibrium and management of an UAV while it's in motion. The three main categories of aerodynamics regulation are fixed steadiness management, flexible steadiness management, and agility management.

Chapter 2.

2. Methodology

Control Application Development

The control application was developed using MIT App Inventor, a visual programming environment for creating mobile applications. The application provided an intuitive user interface with options for joysticks, buttons, and hand gestures. The graphical components in MIT App Inventor were utilized to design the interface and map user inputs to control commands. The application was deployed on a smartphone or tablet, allowing users to interact with the four-motored monocopter remotely.

Analysis of Human Motion Assumptions

To capture and analyze human motion assumptions, a LSM6DO gyroscope and acceleration sensor was employed. The sensor was securely attached to the remote control device, such as a smartphone or tablet, to measure the device's motion. Participants were instructed to perform various motions, including tilting, rotating, and moving the device, while the sensor recorded the corresponding gyroscope and acceleration values. This data was collected for multiple participants to capture a range of human motion assumptions.

Data Processing and Feature Extraction

The gyroscope and acceleration data collected from the sensor underwent processing and feature extraction to identify patterns and characteristics of human motion assumptions. Signal processing techniques, such as filtering and noise reduction algorithms, were applied to enhance the quality of the raw data. Relevant features, such as angular velocity, acceleration magnitude, and orientation, were extracted from the processed data to represent the motion assumptions.

Generation of Fuzzy Input Sets

Based on the processed data and extracted features, fuzzy input sets were generated to represent different motion assumptions. Fuzzy logic techniques were applied to map the continuous sensor values to linguistic terms using membership functions. The membership functions defined the degrees of membership for each linguistic term based on the extracted features. Triangular or trapezoidal membership functions were commonly used to represent the uncertainty and variability of human motion assumptions.

Formulation of Fuzzy Control Rules

To govern the behavior of the four-motored monocopter based on the fuzzy inputs, fuzzy control rules were formulated. These rules were developed based on expert knowledge and domain expertise in the field of aerial vehicle control. The rules defined the relationship between the fuzzy inputs (gyroscope and acceleration values) and the corresponding control actions (thrust, pitch, roll, yaw). The rules captured the decision-making process within the fuzzy control system, enabling the interpretation of sensor data to generate appropriate control signals.

Fuzzy Inference System and Control

The fuzzy control system was implemented using MATLAB software. A fuzzy inference system was developed using the fuzzy logic toolbox in MATLAB. The membership functions, fuzzy input sets, and control rules were integrated into the inference system. The system took the gyroscope and acceleration values as inputs and applied fuzzy logic inference to determine the appropriate control actions for the four-motored monocopter. The output of the fuzzy inference system provided the control signals for the motors, including thrust adjustments and angular movements.

Evaluation of the Fuzzy Control System

The performance of the fuzzy control system was evaluated by conducting various experiments and flight tests. The stability, responsiveness, and accuracy of the four-motored monocopter's movements were assessed based on the control actions generated by the fuzzy inference system. Parameters such as settling time, overshoot, and steady-state error were considered to measure the performance of the control system. Comparison with conventional control methods or alternative approaches could also be performed to evaluate the effectiveness and advantages of the fuzzy control system.

Overall, this methodology incorporated the development of a control application using MIT App Inventor, analysis of human motion assumptions using the gyroscope and acceleration sensor, generation of fuzzy input sets based on extracted features, formulation of fuzzy control rules, implementation of a fuzzy inference system in MATLAB software, and evaluation of the fuzzy control system's performance. These steps enabled the utilization of human motion assumptions and fuzzy logic techniques for controlling the four-motored monocopter, providing a flexible and adaptive control mechanism.

CHAPTER 3.

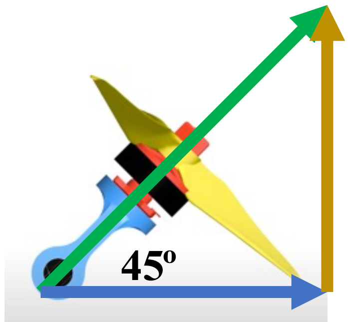
3. OPERATIONAL PRINCIPLES AND DESIGN

3.1 Kinematics of aerial vehicle

The main purpose of the given hybrid build is when fitted with wings on the arms with sufficiently tilted angle it requires substantially less power to hover than if the 4 motors were just oriented vertically like a regular quadcopter drone. This may look counter-intuitive, if we tilt the motors to enable the spinning, a substantial fraction of the motors upwards thrust force is lost. For example, if the motor is tilted to 45º, that will be half of the total thrust pushing in horizontal axis instead of full thrust force. This means drone will fall if the throttle is not increased. By using intuition of a regular drone without additional airfoils fixed to it, this would mean that to hover with motors at this angle, it would need twice of the regular power required to match the vertical thrust component with downward weight of the vehicle enabling a steady state hover.

Figure 3

Vertical and horizontal components of thrust of motors tilted 45º.



$$F_x = F \times \sin\frac{\pi}{4} = 0.5F \qquad F_y = F \times \sin\frac{\pi}{4} = 0.5F$$

When the wings are added to the arms of quadcopter and it is spinned by tilting motors, power required to hover decreases significantly. In order to get stable, comparable data flight altitude is fixed by PID controller (Appendix 1). The relationship between angular velocity and required power for this velocity is shown on Figure 4. The take-off happens 83 W without spinning, as the speed increases, power increase as expected from intuition about the thrust vector components. After certain point, power increment slows relatively, as the propeller becoming more efficient at generating thrust. Propeller efficiency changes as a function of incoming airspeed or inflow. For fixed pitch propeller the efficiency will increase with inflow until a certain point where it drops off dramatically. This drop-off in efficiency is caused by incoming air being too fast for propeller to keep a positive angle of attack while it spins.

Figure 4

Relationship between angular velocity and required power

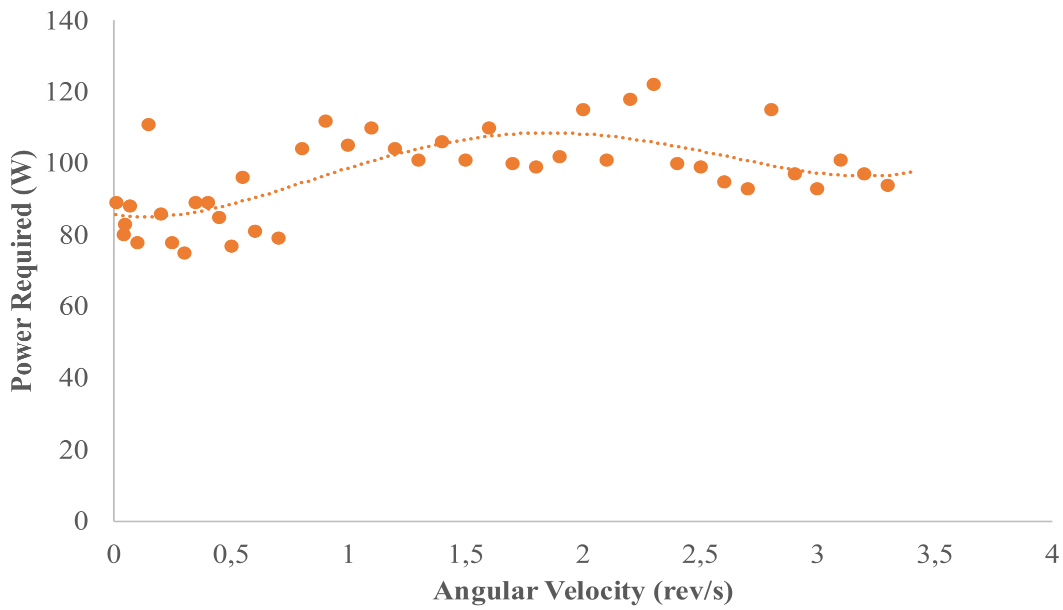


Figure 5

Dependency of propeller efficiency from air inflow

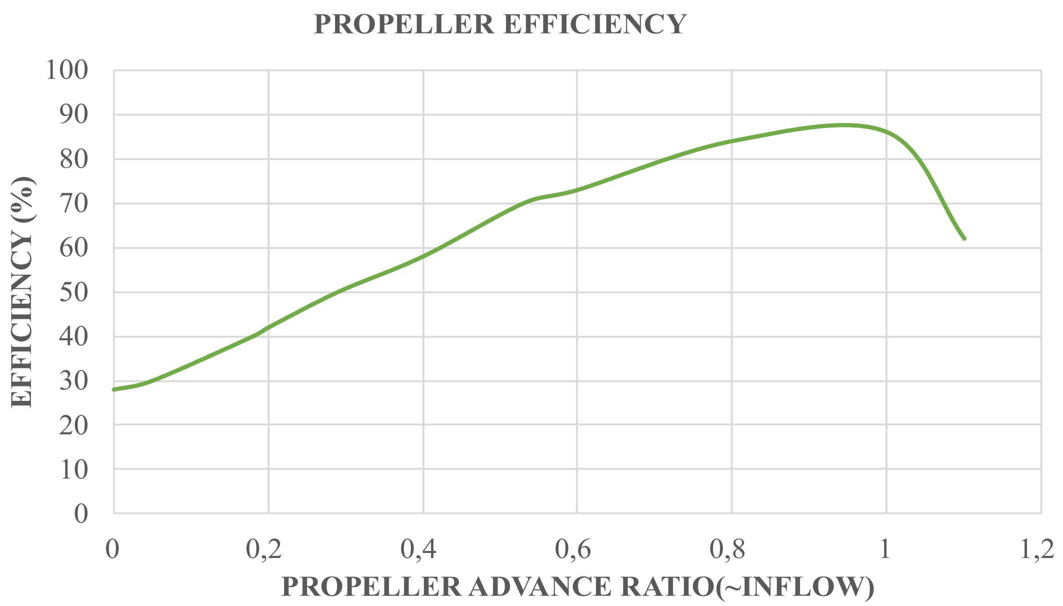
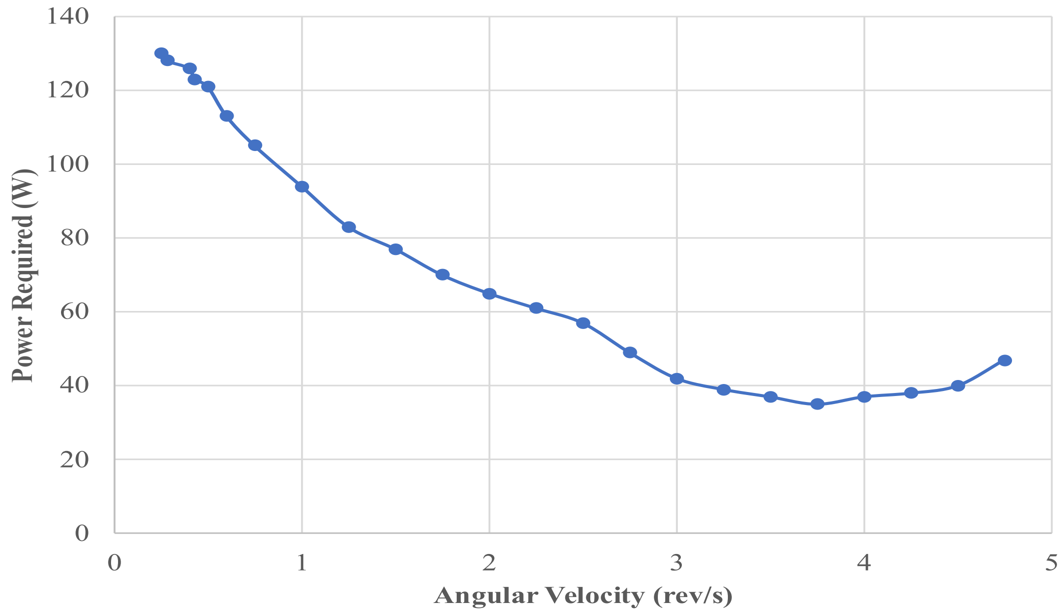


Figure 6

Relationship between angular velocity and required power with wings



In the context of flying, the utilization of multiple smaller and potentially less efficient motors instead of a single larger motor has been found to offer certain advantages. This approach, known as distributed propulsion, has gained attention in the field of aviation due to its potential to enhance performance, efficiency, and overall flight characteristics of aircraft. This response will explore the academic rationale behind the preference for smaller inefficient motors spinning as opposed to one big motor spinning.

One key advantage of using smaller motors in a distributed propulsion system is the increased level of redundancy and fault tolerance it provides. By employing multiple motors, each responsible for generating a portion of the required thrust, the failure of one motor does not lead to a complete loss of propulsion. This inherent redundancy can significantly enhance the safety and reliability of the aircraft during flight, reducing the risk of catastrophic failure.

Additionally, the use of smaller motors allows for more precise and agile control of the aircraft. By independently controlling the speed and thrust output of each motor, the flight dynamics can be finely tuned, enabling greater maneuverability and responsiveness. This capability is particularly important for applications such as aerial drones, where precise control and stability are vital for various tasks, including aerial photography, surveillance, or package delivery.

Furthermore, distributed propulsion systems can enhance the overall efficiency of the aircraft. While smaller motors may individually be less efficient than a larger motor, their collective operation can result in improved energy efficiency. By distributing the load across multiple motors, each motor can operate closer to its optimal operating point, maximizing its efficiency. This can lead to reduced energy consumption and extended flight endurance, critical factors in applications where prolonged flight time is desired.

The distributed propulsion concept also offers benefits in terms of noise reduction. By distributing the propulsive forces over multiple smaller motors, the acoustic signature of the aircraft can be reduced. This can be especially advantageous in urban environments or other noise-sensitive areas, where minimizing noise pollution is essential for regulatory compliance and public acceptance.

Moreover, distributed propulsion systems provide design flexibility. The arrangement of multiple smaller motors can be more easily integrated into various aircraft configurations, including unconventional and highly maneuverable platforms. This flexibility allows for innovative aircraft designs that can cater to specific mission requirements, such as vertical takeoff and landing capabilities or efficient hovering.

In summary, the preference for smaller, potentially less efficient motors spinning in a distributed propulsion system over a single larger motor stems from the benefits it offers in terms of redundancy, maneuverability, efficiency, noise reduction, and design flexibility. These advantages make distributed propulsion systems an attractive choice for a range of aerial applications, including drones, unmanned aerial vehicles (UAVs), and other types of aircraft.

The efficiency from spinning is related to energy and momentum of vehicle. Propeller thrust is proportional to change in momentum of the airflow through the propeller and drag on the propeller is directly proportional to kinetic energy of the air, more drag requires more power to be used. Power is proportional to v^2, while the momentum is proportional to only v. If there are 2 propellers, one twice as big as the other, from this relationship shows that smaller one would need to move the air twice as fast to generate the same thrust of the bigger one. Spinning faster to move air faster substantially increases the power required, so slower spinning large propeller is more efficient.

$$Drag \sim E = \frac{1}{2} m \times v^2$$

$$Thrust \sim P = m \times v$$

In suggested design, small inefficient propellers are doing the spinning, while larger efficient propeller does the heavy lifting. Putting propellers at the edges of frame, increases moment arm, decreasing the thrust required to overcome lesser drag of large propeller.

The aircraft has 3 operational modes: Quadcopter Mode which has difference from traditional multicopter design by having wings on the arms, Fixed Wing Mode similar to tail-sitter aircrafts, using multiple motors to move forward but main lift comes from wings enables traveling long distances with relatively low power requirement, Monocopter Mode which is more efficient in take-off and hovering in a specific coordinate. The transition and control process are done by rotating main gear in base of aircraft which arms' gears are in link and rotates wings giving desired angle of attack to aircraft for Monocopter Mode. Wings also contribute to Quadcopter Mode to the lift, making less power usage in motors.

Figure 7

Internal structure of aircraft

The monocopter mode, M-MOD, is an efficient hovering flight mode that spins the entire frame to achieve lift. Aircraft is also capable of transiting to F-MOD, or the fixed wing mode, which is a fixed-wing mode which excels at long endurance and long-distance flights. Staying true to the concept of structural efficiency, aircraft has virtually no redundant surfaces and as all control surfaces and propulsion systems are used in all flight modes. The forward transition phase where aircraft goes from M-MOD to T-MOD would be known as MT-Transition, and the back transition from T-MOD to M-MOD known as TM-Transition. Another motivation for having a particular hovering mode as described above is that due to the rotating nature of UAV to achieve lift, it also has the potential to be capable of entering autorotation in the event of power loss to the propulsion system or merely a way to conserve energy during descent. However, due to this rotating nature of aircraft during F-MOD, the transition phases are more challenging to handle compared to other hybrid UAVs with a more straightforward flight path.

3.2. SPECIFICATIONS OF THE ROBOT

The chassis is constructed from TPU, arms are made from 8x6x330 carbon fiber tubes. The airborne vehicle's core is positioned in the center, where all of the mechanic and electronics elements are either attached to or positioned. The avionics—electronic parts required for the management of the vehicle—are the most crucial parts of the core section. These are the crucial elements:

- The power preservation mechanism includes a battery;
- four Electronic Speed Control (ESC) to regulate the angular velocity of every motor;
- a choice system, in this instance a micro-controller where the management software would be;
- a set of detectors (magnetometer, accelerometer, and gyroscopes); interaction equipment, shown as a wireless connection to a computer but which could be replaced by a radio controller receiver;
- A power Distribution Board (PDB), which is plugged into the battery and provides electricity to each of the remaining electrical parts.

Flight controller is Teensy 4.1 (see Figure 8). The finest Arduino compliant microcontroller currently on the market is the Teensy 4.1. Centered on an overclockable 600MHz ARM Cortex-M7 processor from NXP called the i.MX RT1062. This is set up in a 'teensy' circuit design style for quick integration into applications or use with solderless breadboards. The fact that it is compliant to the well-known Arduino IDE development platform and a lot of the current Arduino libraries may be its strongest feature. This makes it, in contrast with numerous other powerful microcontrollers on the market, quite simple to set up and begin using. electronic speed controllers are contained in container in the middle of vehicle.

FEATURES OF TEENSY 4.1:

- i.MX RT1062 ARM Cortex-M7 running at 600MHz. Can be overclocked
- 1MB (1024K) RAM (512K tightly coupled)
- 8MB FLASH (64K reserved for recovery & EEPROM emulation)
- 2 QSPI chip locations to add up to 16MB PSRAM or 8MB PSRAM and 16MB FLASH
- 10/100 Mbit DP83825 PHY Ethernet header (Non-NE version only)

- USB host pins
- Micro SD Socket
- 2 USB ports, both 480 Mbit/sec, can be any device type
- 3 CAN Bus (1 with CAN FD)
- 1 SDIO (4-bit) native SD
- 3 SPI, all with 16 word FIFO
- 3 I2C, all with 4 byte FIFO
- 8 serial ports, all with 4 byte FIFO
- 32 general purpose DMA channels
- 35 PWM capable pins
- 55 digital I/O, all interrupt capable
- 42 breadboard friendly I/O pins
- 18 analog input pins with 2 12-bit ADCs on-chip
- True 64-bit floating point via FPU hardware
- Peripheral cross-triggering
- Compatible with Arduino IDE and many libraries
- Works with Windows, Mac OS X and Linux
- Small size is perfect for embedding or use with solderless breadboards
- 3.3V operation and I/O compatibility

Figure 8

Teensy 4.1

3.2.1 MOTOR SELECTION

Each quadrotor has rotors, which are one of the most important parts because they transmit the energy from the motor to the air and produce force within the aircraft to either counterbalance its mass or propel it into airspace. The rotors in our situation are attached to the motors and do not require any additional degrees of freedom in that regard; instead, they only need to generate an upward action in the orientation of the motor. There are many different rotor alternatives for use as a vehicle's propeller on the marketplace, however they are often limited for right-hand spinning. The name differs for historical motives, with a blade being exclusively in charge of producing horizontal drive and a rotor being in charge of elevating helicopters, but tiltrotors allowed rotors to be modified to move with the blade. Because of the requirement for torque termination, right-hand (pusher) and left-hand (puller) propellers are required in every quadrotor. However, the industry fails to offer a broad selection of puller alternatives, so the development of an ideal rotor for the vehicle is an intriguing and difficult solution. Selecting the ideal aerofoil for the circumstances at the moment, selecting a rotor theory to predict the behavior of the rotor, and ultimately assembling the inherited method to figure out the highest of the performs derived from the chosen rotor theory are a few factors that are crucial for the development of an ideal rotor.

Most important component for vehicle is motor of it, supplier of thrust required for motion. For lifting and controlling with good responsivity, 4 motors are supposed to have 3 times more than the weight of vehicle, making for one motor to have thrust between 790g and 860g. From the market search, 4 alternatives are chosen, shown in table 1.

The Thrust-to-Power ratio, whose greatest number indicates the motor that can cause the rotor to create the maximum thrust with the least amount of power, is picked as the key choice factor. The motor with the most favorable results is the Racestar model, which, while being bulkier than the Aelous model, can generate a greater overall thrust and, because it has a greater Thrust-to-Power ratio, is expected to have a superior longevity than the rival motors. Four Racerstar BR2205 2300KV were therefore selected. Racerstar BR2205 2300KV model is selected as this model is more efficient, being able to supply more thrust per given power shown in Figure 9. At the end of arms, a mount is designed for this model to connect motors to body of the vehicle shown in Figure 10.

Table 1.

Motor alternative and technical parameters

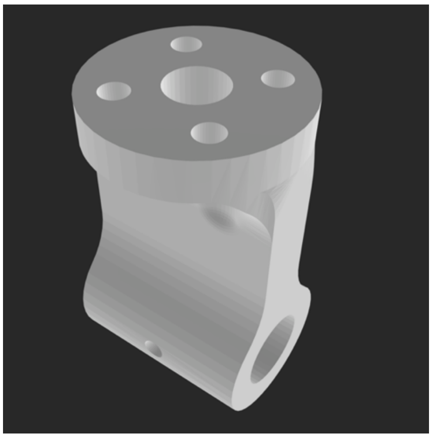
	Price	*Voltage(V)*	*Current*	*Thrust(g)*	*Power(W)*	*Efficiency(g/W)*
iFlight XING-E Pro 2207 1800KV	23$	24	33.28	1613	798.7	2.019
DIAVOLA 2207 1960KV	31.14$	22.20	40.6	1730	901.3	1.92
Racerstar BR2205 2300KV	17.99$	14.8	27.6	950	408	2.3
Aeolus 2306.5 1900KV	16.61$	16V	38.3	1388	612.8	2.27

Figure 10.

Racerstar BR2205 2300KV

Figure 9.

Motor mount 3D model



Specifications of motor:

- RPM/V: 2300KV
- Height: 31.5mm
- Width: 27.9mm
- Shaft diameter: M5
- Motor mount hole size: M3
- Weight: 28 grams
- Voltage: 2-4S
- Battery: 2-4S lipo battery
- Max.current: 27.6A
- Max.power: 408W

3.2.2. ELECTRONIC SPEED CONTROLLER

The vehicle's elevation is entirely the responsibility of the propulsion system, which is made up of a motor, a rotor, and all essential auxiliary parts. For instance, every motor in an electric brushless motor must have an Electronic Speed Control (ESC). Rotor selection was already completed. However, since the speedy development phase envisaged for the ideal rotor failed to occur, another rotor choice would be required. As a result, a four rotor set, consisting of two pullers and two pushers, should be explored as an option. The components of an electric propulsion unit must include the electronic speed controller (ESC). By directing the motor's speed depending on the commands it gets from the throttle controller, it serves as the structure's brain. The ESC's function is to serve as a controlling intermediary between the battery and the electric motor. By sending periodic electric impulses that are converted into fluctuations in speed, it regulates the motor's spin. It generates an alternating three-phase current that is transmitted to the motor using the direct current from the battery in conjunction with a switch mechanism. The motor speed is adjusted using the vehicle's throttle controller; increasing the throttle raises the output power, which changes how quickly the switches in the ESC's circuit engage and shut. Some alternatives of ESC’s are chosen from available market and features are shown in table 2. To regulate the spinning of the motor, a suitable ESC must now be chosen. Since these parts are prone to ignite, a 50% security buffer was specified to guard against any unforeseen failures or burnings. Four models were chosen as the best possibilities and are shown in table. The alternative that was selected has a peak flow of 30A, hence the ESC has to maintain no fewer than a current of 40A.

Table 2.

ESC alternative and technical parameters

	Weight(g)	Price($)	Size(mm)	Battery
SKYWALKER 40A	39	8.50	68x25x8	2-4S
AXLE 40A	30	4.50	68x25x8	2-4S
Mitoot 40A	30	15.26	68x25x8	2-4S
HTIRC Hornet 2-6S 40A	43	18.99	52x25x11	2-6S
FMS Predator 40A	59	18.99	490x22x11	2-4S

AXLE 40A ESC is chosen for cheaper price and having less weight relatively.

3.2.3. BATTERY

Battery selection is made over different criteria. First one is number of cells, a criteria which doesn't have effect on others. According to parameters of motors and ESCs, 4 celled 14.8V battery is suitable. One motor can give 950g thrust with full throttle, as we have 4 makes it 3600g and other components should have around 600g weight. Calculating as thrust being able to lift 3 times of weight of vehicle:

$$(600 + X) \times 3 = 950 \ \times \ 4$$

$$X = 600$$

We get that battery should be around 600g.

According to weight of vehicle with all components, hover time is calculated for 80% of given capacity of battery is:

$$\frac{6000mAh \times 60min \times 80\%}{11A \times 4} = 6.55min$$

$$\frac{1800mAh \times 60min \times 80\%}{11A \times 4} = 1.9min$$

$$\frac{1100mAh \times 60min \times 80\%}{11A \times 4} = 1.2min$$

$$\frac{7000mAh \times 60min \times 80\%}{11A \times 4} = 7.64min$$

$$\frac{5000mAh \times 60min \times 80\%}{11A \times 4} = 5.45min$$

Table 3.

Battery alternative and technical parameters

	Price ($)	**Weight (g)**	**Capacity(mAh)**	**Discharge rate(C)**
XF POWER 14.8V 6000mAh 60C 4S	39.99	596.2	6000	60C
URUAV GRAPHENE V2.0 14.8V 1800mAh 160C 4S	32.99	199.7	1800	160C
GNB 15.2V 1100mAh 60C 4S	23.99	88	1100	60C
ZOP Power 14.8V 7000mAh 60C 4S	42.99	598.6	7000	60C
ZOP Power 14.8V 5000mAh 60C 4S	41.99	513.1	5000	60C

Other step is to check whether battery can supply required current for 4 motors. Maximal current required for 4 motors:

$$27.6A \times 4 = 110.4A$$

Maximal current batteries can supply:

$$\frac{6000mAh \times 60C}{1000} = 360A$$

$$(\frac{1800mAh \times 160C}{1000} = 288A$$

$$\frac{1100mAh \times 60C}{1000} = 66A$$

$$\frac{7000mAh \times 60C}{1000} = 420A$$

$$\frac{5000mAh \times 60C}{1000} = 300A$$

ZOP Power 14.8V 7000mAh 60C 4S Battery is chosen for longer flight time and discharge rate.

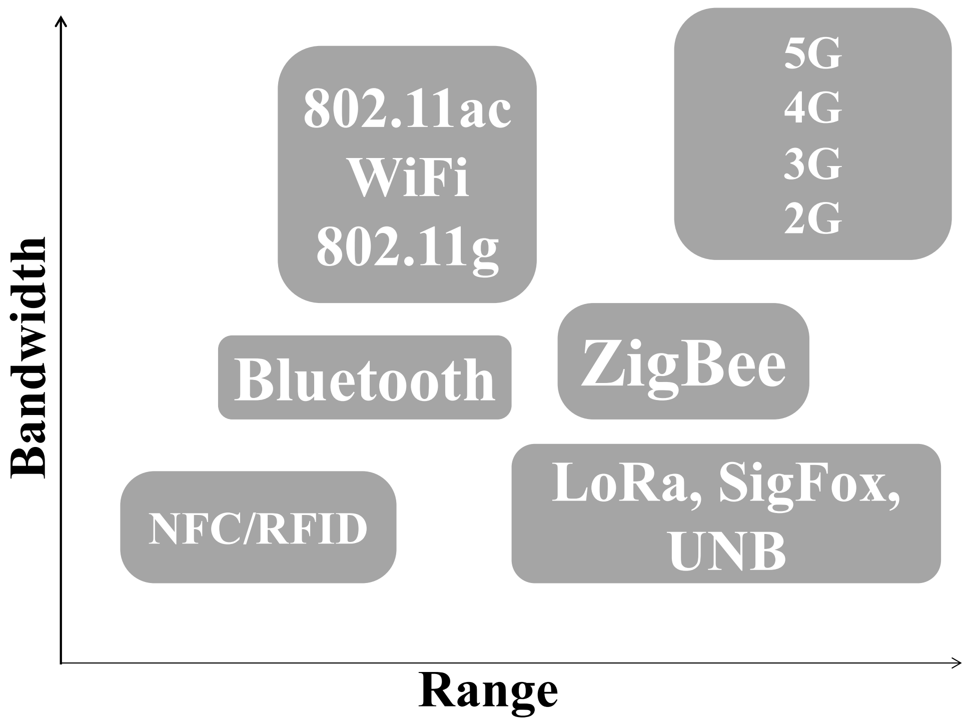
Our propulsion system consists of four identical sets of plastic propellers, brushless direct current motors (BLDC), and electronic speed controllers (ESC). The thrust force generated by the air propelled by the propellers (F_{PM}; F_{SM}) and the torque needed to maintain momentum (τ_{PM}; τ_{SM}) are the other two parts of their dynamic contributions. When simulating the monocopter's propulsion systems in Section 4, these are two intriguing elements to take into account.

3.3. Communication and Control Systems

There are multiple ways to control the vehicle with a mobile phone: GSM, WI-FI, Bluetooth, IR blaster. The quality of a wireless communication technology is determined by 3 things, distance, speed and power consumption. Only 2 of the 3 specifications can applied at a same time. The range comparison of some wireless communication technology (Susanto , Atmadja, & Anthony, 2018) is shown in Figure 11.

Figure 11

Bandwidth vs Range of wireless technology.



Each has its own drawbacks and advantages. Determine best solution for application TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) method (Hwang & Yoon, Multiple Attribute Decision Making: Methods and Applications, 1981) (Yoon, 1987) (Hwang, Lai, & Liu, A new approach for multiple objective decision making, 1993) is implemented.

Table 4.

Decision matrix

Decision Matrix	**RANGE (m)**	**IMPEMENTATION HARDNESS**	**RELIABILITY**	**USER INTERFACE**	**SPEED**
WEIGHT	0,2	0,15	0,3	0,15	0,2
GSM	35000	2	2	3	1
WIFI	45	3	4	3	4
BLUETOOTH	10	1	2	4	2
IR BLAST	5	1	1	3	4
APPLICATION+RF MODULE	152	4	5	5	4
Total	35000,3608	5,5678	7,0711	8,2462	7,2801

Next step is vector normalization the decision matrix by given formula:

$$\bar{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} X_{ij}^2}}$$

Table 5.

Vector Decision Matrix

Vector Normalized Matrix	*RANGE*	*IMPEMENTATION HARDNESS*	*RELIABILITY*	*USER INTERFACE*	*SPEED*
WEIGHT	**0,2**	**0,15**	**0,3**	**0,15**	**0,2**
GSM	0,99999	0,35921	0,28284	0,36380	0,13736
WIFI	0,00129	0,53882	0,56569	0,36380	0,54944
BLUETOOTH	0,00029	0,17961	0,28284	0,48507	0,27472
IR BLAST	0,00014	0,17961	0,14142	0,36380	0,54944
APPLICATION+ RF MODULE	0,00434	0,71842	0,70711	0,60634	0,54944

Then getting weighted values of each component by multiplying weight of each criteria to each alternatives vector normalized value.

$$t_{ij} = w_j \bar{X}_{ij}$$

Table 6.

Weighted Normalized Decision Matrix

Weighted Normalized Matrix	*RANGE*	*IMPEMENTATION HARDNESS*	*RELIABILITY*	*USER INTERFACE*	*SPEED*
GSM	0,20000	0,05388	0,08485	0,05457	0,02747
WIFI	0,00026	0,08082	0,16971	0,05457	0,10989
BLUETOOTH	0,00006	0,02694	0,08485	0,07276	0,05494
IR BLAST	0,00003	0,02694	0,04243	0,05457	0,10989
APPLICATION + RF MODULE	0,00087	0,10776	0,21213	0,09095	0,10989

In order to find best (A^*) and worst alternative(A^-), maximum value and minimum value is chosen accordingly for beneficial criteria. For cost criteria minimum value is chosen for A^* and maximum value for A^-:

$$A^- = \{< \min(t_{ij} \mid i = 1,2,\dots,m) \mid j \in J^{\rightarrow}, < \max(t_{ij})\, i = 1,2,\dots,m) | j \in J^+\}$$
$$\equiv \{t_{bj} | j = 1,2,\dots,m\}$$

$$A^* = \{< \max(t_{ij} \mid i = 1,2,\dots,m) \mid j \in J^{\rightarrow}, < \min(t_{ij})\, i = 1,2,\dots,m) | j \in J^+\}$$
$$\equiv \{t_{wj} | j = 1,2,\dots,m\}$$

Next step is finding distance between the target alternative t_{ij} and the worst condition A^-:

$$S^- = \sqrt{\sum_{j=1}^{n} \left(t_{ij} - t_{wj}\right)^2}$$

and distance between the target alternative t_{ij} and the best condition A^+:

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(t_{ij} - t_{bj}\right)^2}$$

Then calculating the similarity to the worst condition:

$$C = \frac{S^-}{[\![(S]\!]^+ + S^-)}$$

Alternatives are ranked according to values of these similarities:

For the speed and range needs of the project, controlling from an application with Bluetooth connection to Ground Control/ Remote Controller is seemed more suitable as it will be able to switch the device even when the vehicle is on the air. Communication scheme is given below:

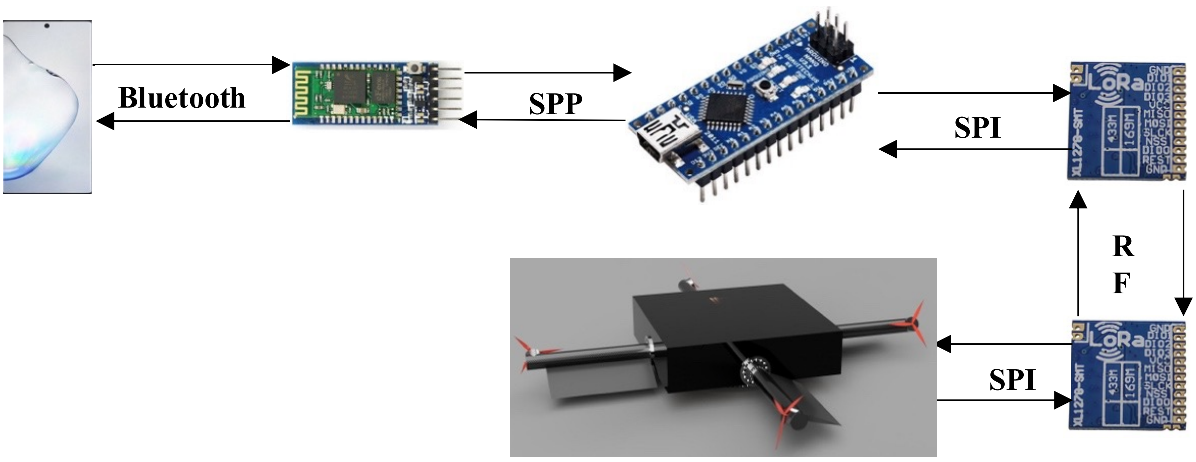
Table 7.

Ranked Decision Matrix

Weighted Normalized Matrix	*RANGE*	*IMPEMENTATION HARDNESS*	*RELIABILITY*	*USER INTERFACE*	*SPEED*	*S+*	*S-*	*C*	*RANK*
GSM	0,20000	0,05388	0,08485	0,05457	0,02747	0,16498	0,20619	5,00387	2
WIFI	0,00026	0,08082	0,16971	0,05457	0,10989	0,20915	0,16092	-3,33632	5
BLUETOOTH	0,00006	0,02694	0,08485	0,07276	0,05494	0,25702	0,05372	-0,26423	3
IR BLAST	0,00003	0,02694	0,04243	0,05457	0,10989	0,27685	0,08242	-0,42389	4
APPLICATION+RF MODULE	0,00087	0,10776	0,21213	0,09095	0,10989	0,19913	0,20844	22,37790	1
*A**	0,20000	0,10776	0,21213	0,09095	0,10989				
A-	0,00003	0,02694	0,04243	0,05457	0,02747				

Figure 12

Communication diagram of model

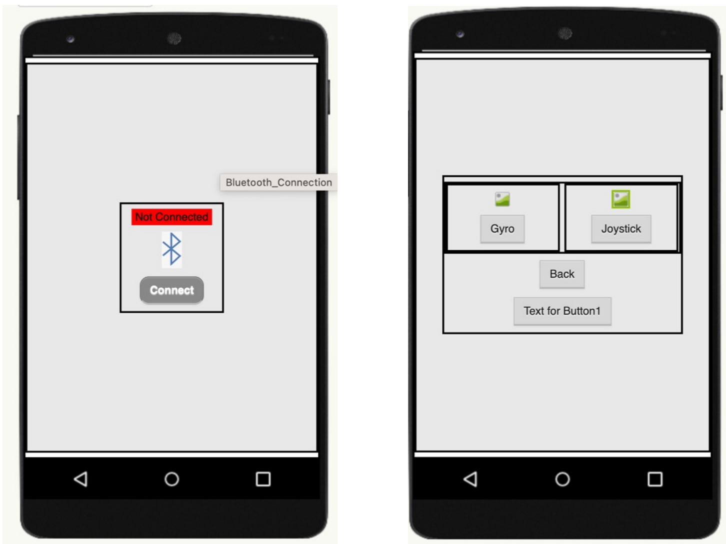


3.3.1. CONTROLLER APPLICATION

For controller part an android application is designed. In the main page of application, connection to controller over Bluetooth is implemented. After connection is secured, controller selection page is opening where user can choose to control either traditional method "Joystick Mode" or "Gyro Mode". On "Joystick Mode" there are 2 controller joysticks can be used in all configurations, left one for throttle and yaw motions, right one for pitch and roll motions.

Figure 13

Application's interface



3.3.2. FUZZY LOGIC IN CONTROLLING

Humans are capable of tremendously adaptable regulation but do not require accurate, quantifiable sensory intake to produce decisions. The astonishing skill of individuals to do a broad range of physiological and cognitive actions without any specific assessments or calculations is a tremendous accomplishment. Instances of commonplace activities include cooking, tuning musical instrument, playing football, parking or adjusting AC. Humans employ their senses of space, time, velocity, shape, temperature and other characteristics of tangible and intangible entities to carry out such routine activities (Pham, Afify, & Koc, 2007). Lofti Zadeh developed fuzzy set theory in the middle of the 1960s. In a paper that was published in 1965, Lotfi Zadeh proposed the fuzzy set theory (Zadeh , 1965). From control theory to artificial intelligence, fuzzy logic has been applied to a variety of domains. From compact, simple integrated systems to massive, interconnected workstation-based information collection and regulation structures, fuzzy logic provides an approach for problem-solving operational configurations that adapts itself to execution. The astonishing capacity of humans to use and make sense of information using sensation serves as basis for the concept of fuzzy logic. A systematic framework for rationalization and judgment with ambiguous and imperfect data is offered by rule-based fuzzy logic. It may be put into practice using in software level, hardware level, or a blending of the two. The use of fuzzy logic to solve operational issues simulates human decision-making. The capacity to draw intuitive principles from individual experience and avoid the requirement for a scientific framework of the procedure are the primary upsides of a fuzzy navigation technique (Yang , Li , Meng , & Liu , 2004,) (Seraji & Howard , 2002).

The capacity to make decisions like a human being and to avoid both organized and unorganized obstacles in a complicated situation is a feature of fuzzy logic. The Fuzzy Logic Controller (FLC) is a problem-solving control system that handles deployment in a variety of structures, from small, basic embedded microcontrollers to big, networked, multi-channel PC or workstation-based data collection and control systems .A scientific framework for evaluating and deciding choices with ambiguous and incomplete data is offered by rule-based fuzzy logic. It may be put into practice using either hardware, software, or a mix of the two. The use of fuzzy logic to solve control issues simulates human decision-making. Another benefit of fuzzy guidance is that it eliminates the requirement for an analytical model of the process by extracting heuristic principles from the perspective of humans. An input phase, an analysis period, and an output stage make up fuzzy controllers. The entry phase converts inputs from switches, thumbwheels, sensors, and other devices into the proper membership functions and truth values. Each suitable rule is invoked throughout the processing step, producing a result for each one before the results are combined. The output step then transforms the combined result once again into a particular control return signal. The IF-THEN expressions that make up the analysis phase are composed of a set of logic guidelines, with the IF portion serving as the "antecedent" and the THEN half serving as the "consequent."

The fuzzy controller is a powerful control methodology that operates through a series of well-defined steps: input, processing, and output. Each step plays a crucial role in transforming raw sensor data into meaningful control actions.

In the input step, the fuzzy controller receives inputs from various sensors, including gyro sensors, switches, light detectors, hall sensors, and other devices. These sensors provide data about the system's state, such as orientation, environmental conditions, or user commands. To make sense of this data, it undergoes a transformation process known as fuzzification. During fuzzification, the raw sensor data is converted into linguistic variables, which are expressed in terms of fuzzy sets and membership functions. These linguistic variables enable the fuzzy controller to reason and make decisions based on human-like understanding.

Moving to the processing step, the transformed inputs are subjected to a set of fuzzy logic rules. These rules capture the expert knowledge and define the relationship between the inputs and the desired control outputs. Each rule follows an IF-THEN expression, where the IF part represents the conditions or precursors, and the THEN part represents the resultant or action to be taken. By evaluating the degree of match between the inputs and the antecedent (IF) portion of each rule, the fuzzy controller assigns an activation value or degree of truth to each rule. This activation value reflects the strength or relevance of the rule given the current inputs.

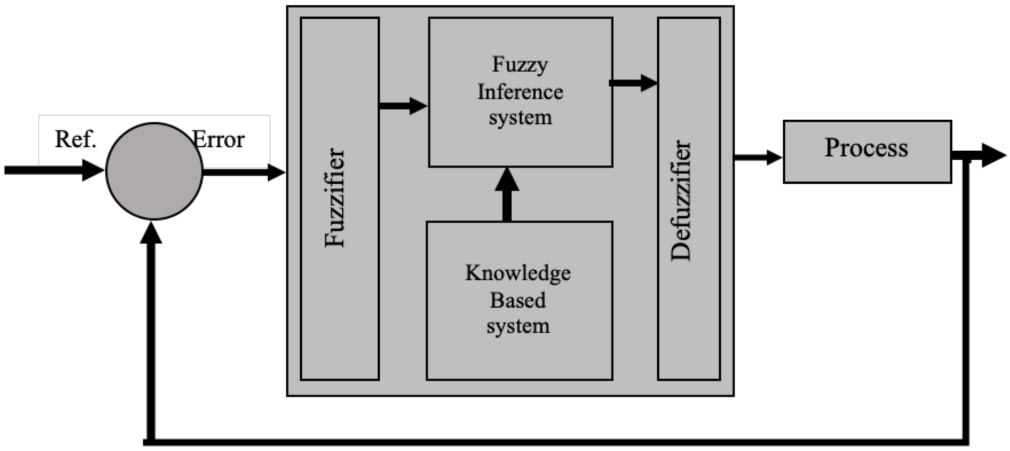
As the processing step progresses, the outcomes produced by each rule are aggregated to obtain a collective decision. Aggregation methods, such as maximum, minimum, average, or weighted average, are applied to combine the rule outcomes. The goal is to incorporate all relevant information from the rules and obtain a comprehensive view of the system's behavior. The aggregation process ensures that the fuzzy controller considers the overall influence of the rules in the decision-making process.

In the output step, the aggregated outcome is transformed into a specific control output value. This transformation process involves mapping the aggregated outcome, which represents a fuzzy or linguistic description, to a crisp control signal that can be applied to the system. This mapping is achieved through a process called defuzzification, which selects a representative value from the aggregated outcome. Different defuzzification methods, such as centroid, maximum membership, or weighted average, can be employed depending on the desired behavior of the system. Within the processing step, the fuzzy controller relies on fuzzy operators to handle the combination of multiple precursors in the fuzzy rule sets. These operators include AND, OR, and NOT. The AND operator computes the minimum value of the precursors, indicating the minimum degree of membership between the inputs and the rules' antecedents. The OR operator calculates the maximum value, representing the maximum degree of membership between the inputs and the rules' antecedents. The NOT operator deducts a membership function from 1, providing a means to express the complement or negation of a fuzzy set.

By employing fuzzy logic and rule-based reasoning, fuzzy controllers offer a robust and adaptive control approach for systems with uncertain or imprecise information. The combination of linguistic variables, membership functions, fuzzy rules, and fuzzy operators allows the fuzzy controller to handle complex control tasks while accommodating the inherent uncertainties in the system. This makes fuzzy controllers well-suited for applications that involve non-linear dynamics, imprecise data, and human-like decision-making processes. The IF-THEN expressions that make up the processing step are composed of a set of logic rules, with the IF portion serving as the "precursor" and the THEN portion serving as the "resultant". Fuzzy operators like AND, OR, and NOT are used to merge the multiple precursors in fuzzy rule sets. AND utilizes the precursors' lowest possible value, OR uses their peak value, and to provide the "complementary" function NOT deducts a membership function from 1 (Bishop, 1995). Figure 14 illustrates how fuzzy logic is applied to an issue in its entirety. Here, the problem's real-world inputs are represented by the crisp space variables

Figure 14

Fuzzy Controller with fuzzy inference system

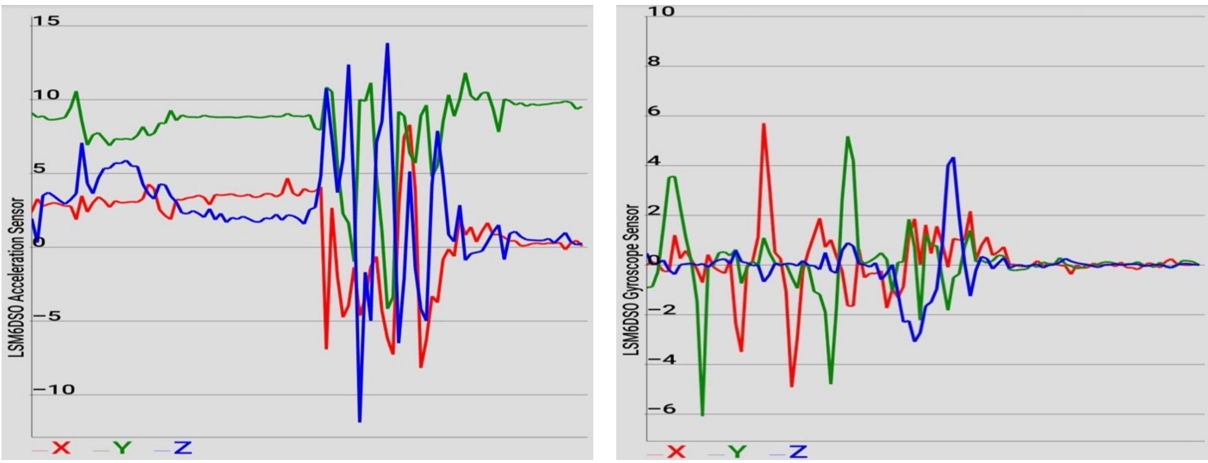


A fuzzy set's membership function is an extension of the characteristic function in conventional sets. The level of validity is represented in fuzzy logic as an supplement of evaluation. Although degrees of truth and probabilities are sometimes conflated, they are fundamentally different, because fuzzy truth refers to membership in inadequately defined sets rather than the possibility of an occurrence or state. A extension of the sign value in conventional groups is the membership function of a fuzzy set. The degree of truth is represented in fuzzy logic as a form of assessment. While theoretically separate, degrees of truth and possibilities are sometimes conflated because fuzzy truth refers to membership in unclear sets rather than the potential of an occurrence or situation. According to the kinds of changes in the input and output, the membership function can take on a variety of forms. For instance, if we require a sharp value, we use a triangular participation function, and when we need an unchanging value, we use a trapezoidal function. Based on the kinds of changes in the input and output, the membership function may take a wide range of forms. For instance, when defining a acute, crispy value, we use a triangular membership function and when we need a value stays same for some values of variables, a constant value, we use a trapezoidal function, for more complicated relationships gaussian curve can be used. Any function from the given set X to the real unit interval [0, 1] is referred to as a membership function on X. Fuzzy subsets of X are represented by membership functions on X. μA is often used to indicate the membership function that describes a fuzzy set $\bar{A}$. For an element x of X, the membership degree of x in the fuzzy set $\bar{A}$ is the value μA (x). The grade of membership of the element x to the fuzzy set $\bar{A}$ is characterized by the membership degree μA (x). If x doesn't have a membership in fuzzy set membership value is 0; if x is fully a member of the fuzzy set, membership value is 1; if x is fragmentary included in the set, membership value range between 0 and 1.

With the input values collected from LSM6DSO sensor shown in Figure 15 and maximal working range of motors, input and output fuzzy sets are generated:

Figure 15

LSM6DSO accelerometer and gyroscope



Fuzzy control systems, a branch of artificial intelligence, are designed to emulate human decision-making processes by formulating rules based on human perception and expertise. The core component of a fuzzy control system is the fuzzy rule base, which comprises a collection of linguistic rules in the form of "if a set of conditions are satisfied, then a set of consequences are inferred." These rules serve as the fundamental guidelines for the control system to make intelligent decisions and generate appropriate control actions.

Figure 16

Input Fuzzy Sets

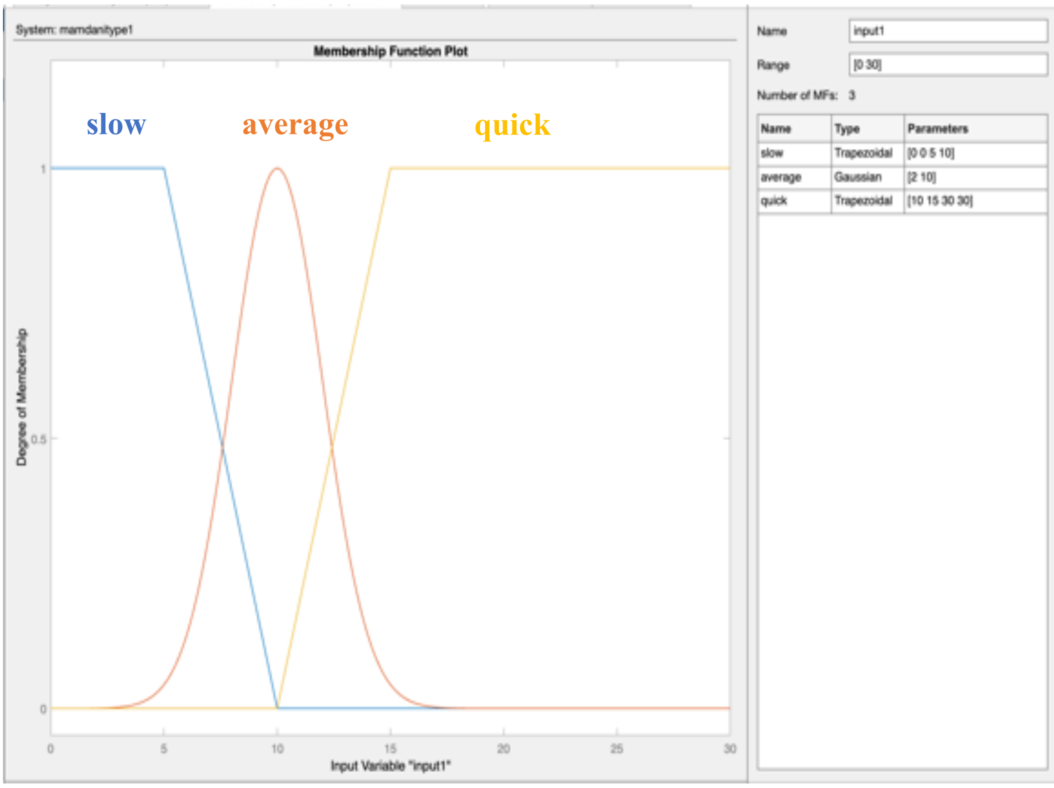
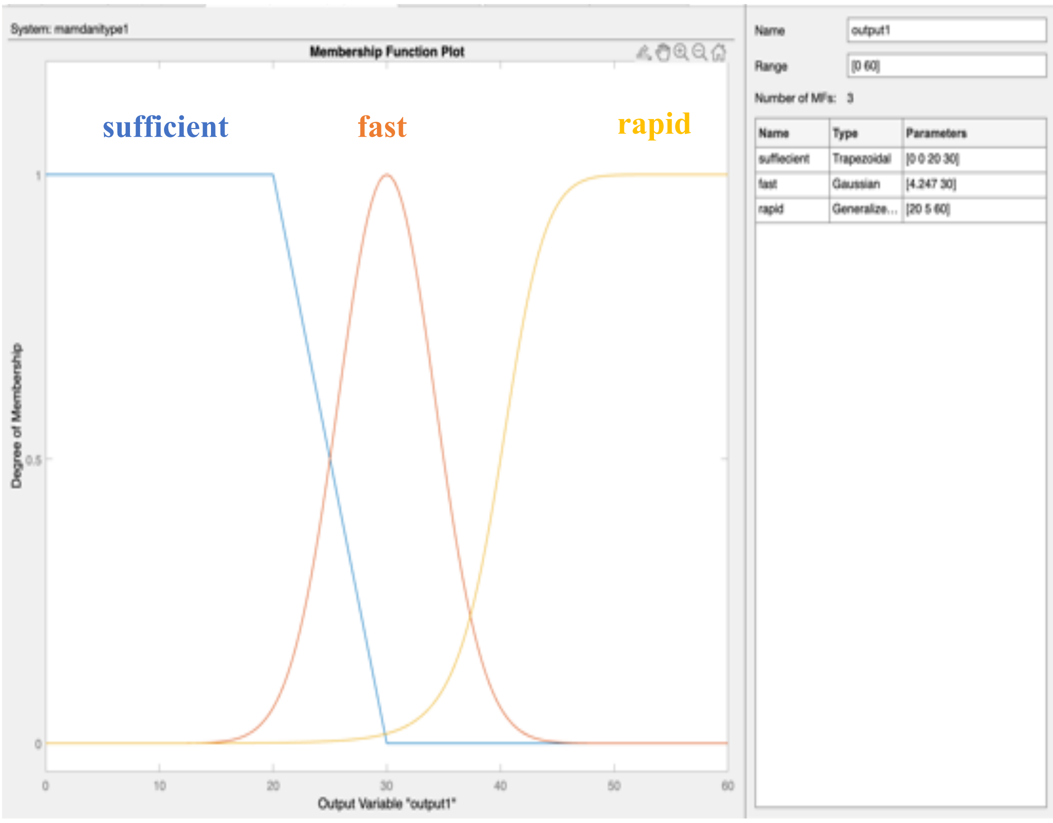


Figure 17

Output Fuzzy Sets



In the context of a three-input and three-output fuzzy system, the fuzzy control rules are devised to accommodate the specific variables and outputs of interest. The inputs to the system, such as sensor data or environmental parameters, undergo a transformation process to convert them into fuzzy subsets using linguistic terms. These fuzzy subsets represent the varying degrees of membership or relevance of each input to specific linguistic labels or categories.

Once the fuzzy subsets are established for the inputs, the fuzzy control rules are defined based on these linguistic labels and their interrelationships. Each rule within the rule base corresponds to a distinct combination of input conditions and the associated output consequences. These rules encapsulate the knowledge and expertise of human operators or domain experts who possess a profound understanding of the system dynamics and desired control behaviors.

The formulation of a fuzzy control rule typically follows a general structure comprising an antecedent (IF part) and a consequent (THEN part). The antecedent specifies the conditions that must be satisfied for the rule to be applied, while the consequent dictates the actions or outputs to be inferred once the conditions are met. The antecedent frequently involves the use of fuzzy sets and fuzzy operators that combine the membership values of different linguistic terms, such as AND, OR, and NOT operators, to represent intricate conditions. On the other hand, the consequent assigns appropriate linguistic labels or values to the outputs based on the desired control actions.

By defining these fuzzy control rules, the system can effectively handle uncertainty, imprecision, and vagueness inherent in real-world applications. The fuzzy control system leverages these rules to make decisions by considering the degree of membership of each input in the corresponding linguistic terms and inferring the suitable control actions based on the defined consequences.

It is important to note that the specific linguistic terms, fuzzy sets, and control rules are established based on the expertise and knowledge of the system designers. These rules are refined through rigorous experimentation, validation, and fine-tuning to achieve the desired control performance and behavior. Fuzzy control systems employ fuzzy rule bases formulated from human perception and expertise. The rules are articulated in the "if a set of conditions are satisfied, then a set of consequences are inferred" format, capturing the intricate relationships between inputs and outputs. By employing linguistic terms, fuzzy sets, and fuzzy operators, the system adeptly manages uncertainty and imprecision, facilitating intelligent control actions in complex and dynamic environments. Based on the above fuzzy subsets, the fuzzy control rules are defined in a general form for three inputs and three outputs fuzzy system shown in Table 8.

Table 8.

Fuzzy Control Rules

	Rule	Weight	Name
1	**If <u>input1</u> is** *slow* **then <u>output1</u> is** *sufficient*	1	Rule 1
2	**If <u>input1</u> is** average **then <u>output1</u> is** *fast*	1	Rule 2
3	**If <u>input1</u> is** *quick* **then <u>output1</u> is** *rapid*	1	Rule 3

With given values and rules a model is generated on MATLAB software (see Figure 18). Depending on input values, output values are calculated by given rule sets, result of these calculations of some examples are shown in Figure 19, 20.

Figure 18

Fuzzy Inference System

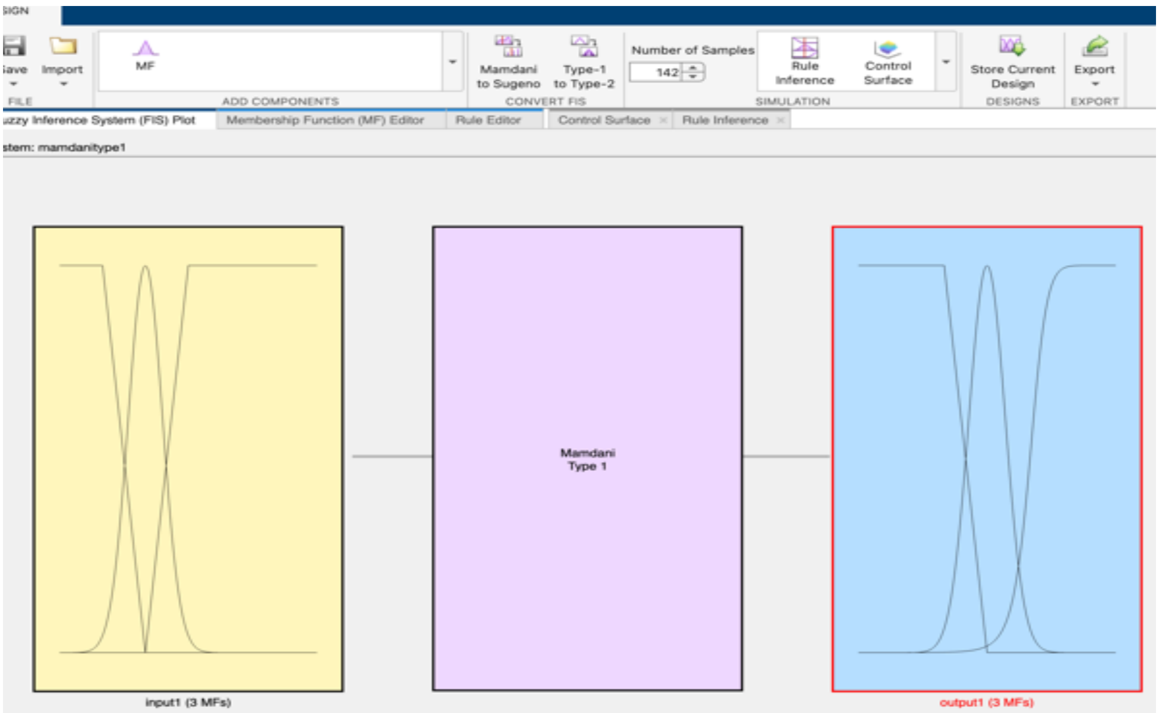


Figure 19

Result of selected random point

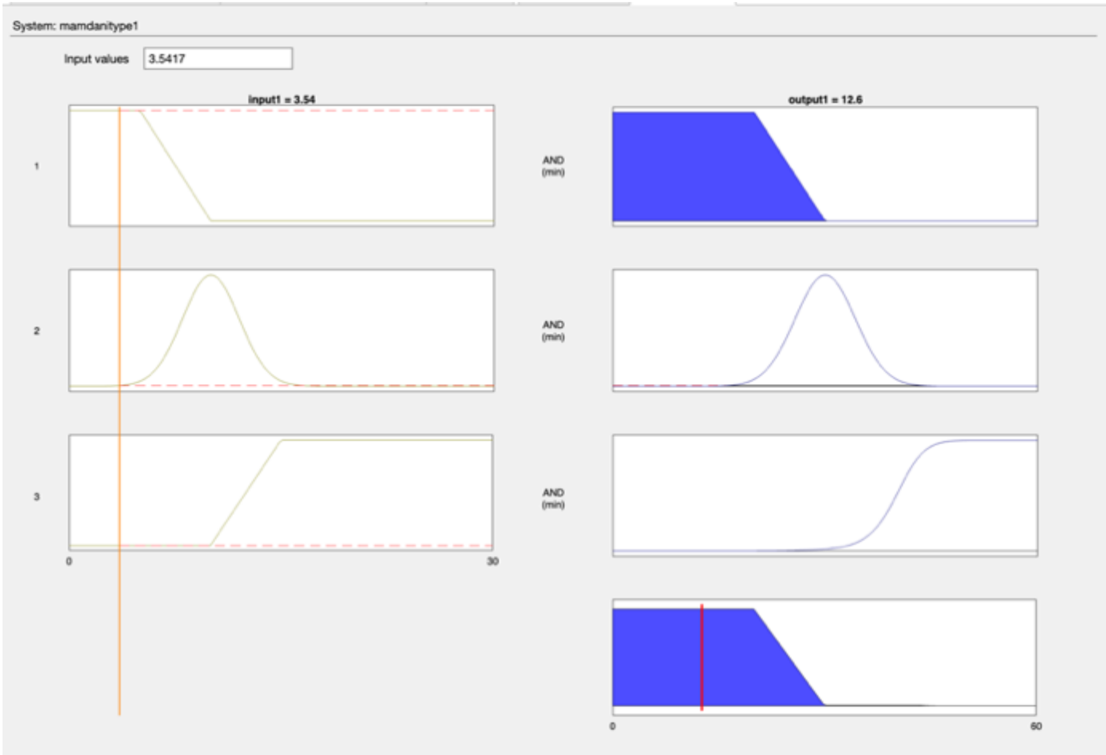
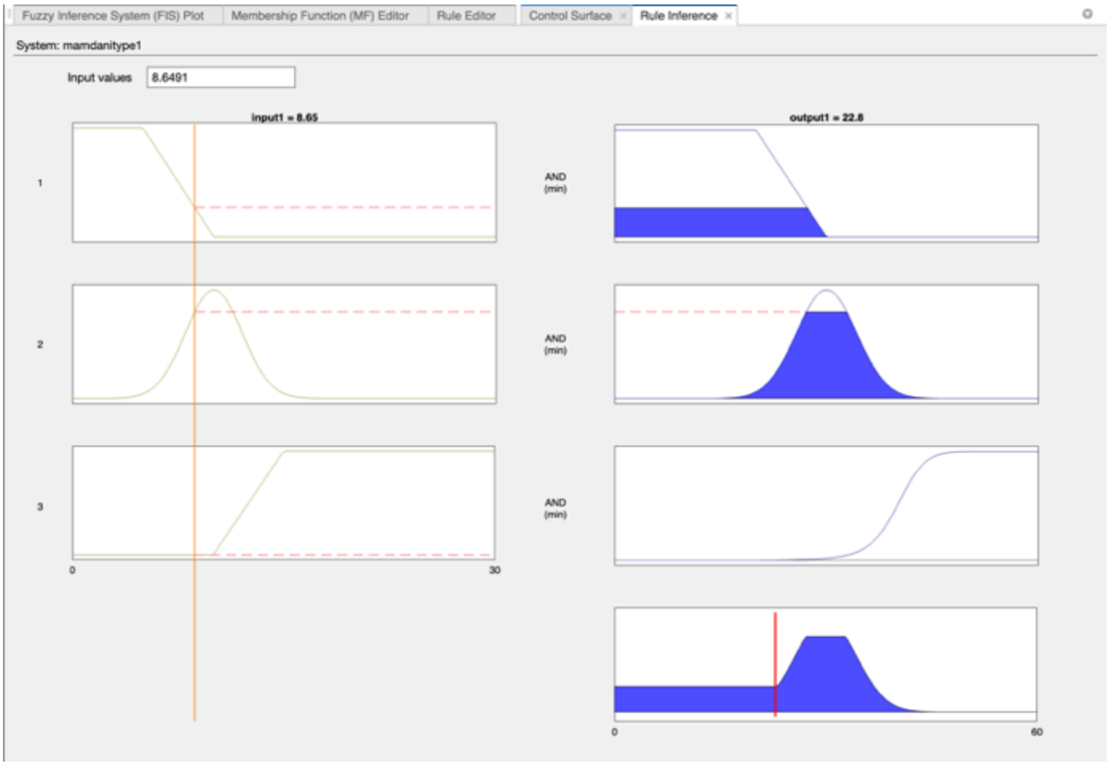


Figure 20

Result of selected random point



CHAPTER 4

4.DYNAMIC MODELS

In recent years, quadcopters have gained significant popularity due to their agility, versatility, and potential for various applications. These unmanned aerial vehicles (UAVs) exhibit remarkable maneuverability and stability, making them ideal platforms for aerial photography, surveillance, delivery systems, and more. To effectively control and optimize the performance of quadcopters, it is crucial to understand the dynamic models and principles that govern their movement.

4.1 Dynamic Models of Quadcopters

Dynamic modeling is a fundamental aspect of quadcopter analysis and control. By formulating mathematical models that describe the quadcopter's dynamics, we can gain valuable insights into its behavior in different flight conditions. Dynamic models capture the complex interactions between the quadcopter's components, such as the rigid body dynamics, propeller forces, and torques. These models enable us to predict the quadcopter's motion and stability, facilitating the development of effective control strategies.

In this section, we will explore various dynamic models of quadcopters. We will begin by examining the basic rigid body dynamics, which consider the quadcopter as a single rigid body subjected to external forces and torques. Next, we will delve into the propeller forces and torques generated by the individual motors. These forces are influenced by factors such as the rotational speed of the propellers, the pitch angles, and the aerodynamic effects. Additionally, we will consider external factors that affect the quadcopter's dynamics, such as wind disturbances and aerodynamic interactions. We will discuss both simplified models for initial analysis and more complex models that incorporate additional factors to improve accuracy.

4.2. Principles of Quadcopter Movement

To understand how quadcopters achieve controlled movement, it is essential to grasp the underlying principles governing their flight dynamics. Quadcopters utilize the principle of multi-rotor flight, which involves adjusting the thrust and torque generated by each propeller to control their motion in various directions.

In this section, we will explore the principles of lift, thrust, drag, and weight distribution in quadcopters. Lift is the upward force generated by the propellers, counteracting the weight of the quadcopter. Thrust is the forward force that propels the quadcopter in the desired direction, while drag acts in the opposite direction, resisting the quadcopter's motion through the air. By adjusting the rotational speed of each propeller, quadcopters can achieve controlled movement in different directions, including forward, backward, upward, downward, and rotational motions.

Stability and control are crucial aspects of quadcopter flight. We will delve into the principles of stability, which involve maintaining the quadcopter's desired orientation and preventing unwanted oscillations. Control mechanisms, including sensors and feedback systems, play a vital role in achieving stability by continuously monitoring the quadcopter's position, orientation, and other relevant parameters. These systems provide inputs to control algorithms that make real-time adjustments to the quadcopter's motor speeds, ensuring stable and controlled flight.

4.3 Significance and Scope

By gaining a comprehensive understanding of the dynamic models and principles of quadcopter movement, we can design effective control strategies and optimize their performance. This knowledge is essential for enhancing stability, maneuverability, and safety in various applications. The subsequent chapters of this thesis will build upon this foundation, focusing on the development and optimization of control algorithms for quadcopters.

In conclusion, this chapter has provided an introduction to the dynamic models and principles of quadcopter movement. We have explored the dynamic models that describe the quadcopter's behavior in different flight conditions, as well as the principles governing its movement, including lift, thrust, drag, and stability. By comprehending these concepts, we can develop advanced control strategies that enable precise and efficient control of quadcopters in a wide range of applications.

The route tuning should be carried out using a dynamic model, which must be generated. The inertial frame XYZ and the corpus frame xyz are both used to establish the source frames.

The body frame xyz is attached to the UAV’s center of mass with the z-axis coinciding with the yaw axis of M-MOD, and the y-axis coinciding with the yaw axis of F-MOD, with the z axis pointing to M-MOD forward. The frames are illustrated in Figure 21. A free body diagram of aircraft in both F-MOD and MF-Transition are presented in Figures 23 and 24. The orientation of the motors on the wing is characterized to be r_{1m}, r_{2m}, r_{3m}, r_{pm} and r_{4m}, as well as the position of the point of motion of the wing to be $\bar{r}_{1w}$, $\bar{r}_{2w}$, $\bar{r}_{3w}$ and $\bar{r}_{4w}$.

Figure 21.

Reference frames

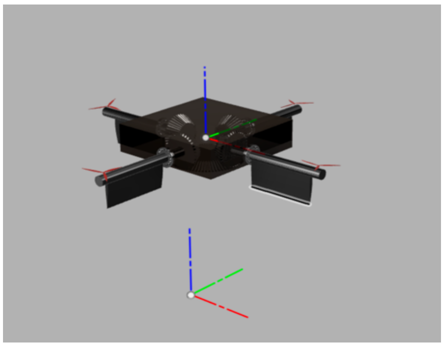


Figure 22

MF-Transition

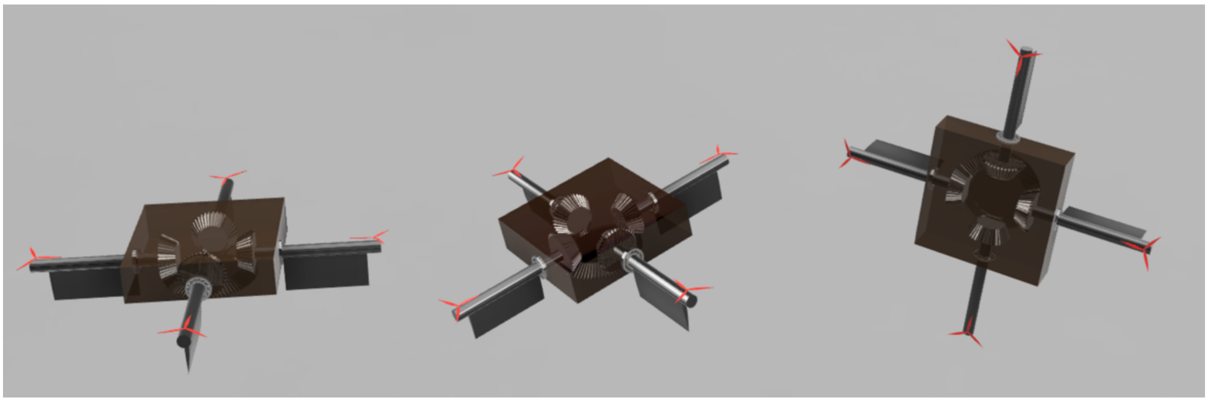


Figure 23.

Fixed Wing Mode

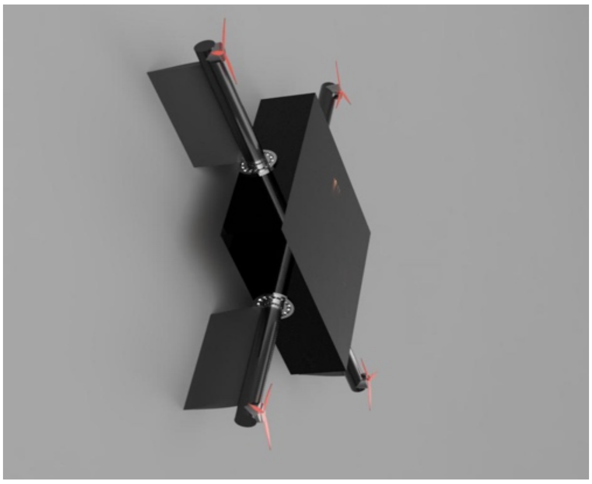
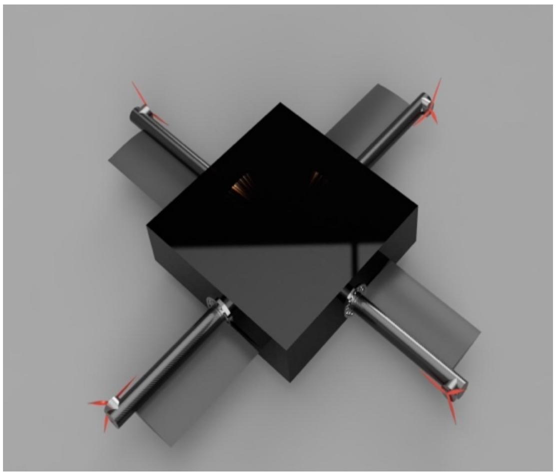


Figure 24.

Monocopter Mode



The lift and drag forces, $\overline{L_1}$, $\overline{D_1}$, $\overline{L_2}$, $\overline{D_2}$, $\overline{L_3}$, $\overline{D_3}$, $\overline{L_4}$ and $\overline{D_4}$ are also condensed into vectors $\overline{A_{1w}}$, $\overline{A_{2w}}$, $\overline{A_{3w}}$ and $\overline{A_{4w}}$ for each wing as such: $\overline{A_{1w}} = \overline{L_1} + \overline{D_1}$, $\overline{A_{2w}} = \overline{L_2} + \overline{D_2}$, $\overline{A_{3w}} = \overline{L_3} + \overline{D_3}$ and $\overline{A_{4w}} = \overline{L_4} + \overline{D_4}$. The definition of the aerodynamic forces is further elaborated on in Section III-A. W refers to the weight force. The total forces and moments acting on the craft, ∑F and ∑M are formulated as such:

$$\sum \bar{F} = \overline{F_1} + \overline{F_2} + \overline{F_3} + \overline{F_4} + \overline{A_{1w}} + \overline{A_{2w}} + \overline{A_{3w}} + \overline{A_{4w}} + \bar{W}$$

$$\sum \bar{M} = \overline{M_1} + \overline{M_2} + \overline{M_3} + \overline{M_4} + \overline{M_{1w}} + \overline{M_{2w}} + \overline{M_{3w}} + \overline{M_{4w}} + \overline{F_1} \times (\bar{r}_{1w}) + \overline{F_2} \times (\bar{r}_{2w}) + \overline{F_3} \times (\bar{r}_{3w}) + \overline{F_4} \times (\bar{r}_{4w}) + \bar{A} \times (\bar{r}_{1w}) + \overline{A_2} \times (\bar{r}_{2w}) + \overline{A_3} \times (\bar{r}_{3w}) + \overline{A_4} \times (\bar{r}_{4w})$$

The aerial vehicle stays level to the surface during all adjusting movements (including all adaptations and rotations in z). Any quadrotor may hover, which is the easiest leveled action possible since each rotor must produce the same amount of force and, thus, torque. Due to their similarity, all the motors provide an identical amount of power. The preceding equations enable the overall thrust to correspond with the mass of the aerial vehicle in a hovering situation:

$$\sum F_z = 0 \Rightarrow 0 = -(T_1 + T_2 + T_3 + T_4) + \mathrm{mg}|_{T_1 = T_2 = T_3 = T_4}$$

$$\sum M_z = 0 \Rightarrow 0 = Q_1 + Q_2 + Q_3 + Q_4|_{Q_1 = -Q_2 = -Q_3 = Q_4}$$

The easiest potential action for the vehicle is ascent, which comes following hovering. The equilibrium of the vehicle, flight remains intact by raising the torque of each engine equally, and when the raised thrust is more than the drag force, a vertical acceleration occurs. The thrust increment (T) will determine the ascent velocity, and the subsequent formulations explain all the following elements:

$$\sum F_z = ma_z \Rightarrow -ma_z = -4\left(\overline{\mathrm{T}} + \Delta\mathrm{T}\right) + \mathrm{mg} + D_z|_{T_1 = T_2 = T_3 = T_4}$$

$$\sum M_z = 0 \Rightarrow 0 = Q_1 + Q_2 + Q_3 + Q_4|_{Q_1 = -Q_2 = -Q_3 = Q_4}$$

4.4. Aerodynamic Forces and Moments.

Glauert (Glauert, 1935) introduced the BEM approach as a useful tool for rotor blade analysis and development. Blade Element Momentum (BEM) theory is a widely used aerodynamic theory that provides a detailed analysis of the forces and moments acting on the rotor blades of a rotating wing, such as those found in helicopters or wind turbines. It is based on the principle that the rotor disc can be divided into multiple annular sections, or blade elements, each experiencing different aerodynamic conditions.

The BEM theory considers the aerodynamic characteristics of each blade element individually, taking into account factors such as the local airspeed, angle of attack, and airfoil properties. By analyzing these parameters, the theory calculates the distribution of forces and moments along the length of the rotor blades, providing valuable insights into the overall performance of the rotor system.

The BEM theory assumes that the flow around each blade element can be treated as an independent and steady-state flow, neglecting any unsteady or dynamic effects. It also assumes that the inflow velocity is uniform and unaffected by the presence of the rotor itself, known as the axial induction factor. The theory takes into account the lift and drag forces acting on each blade element, as well as the induced velocity resulting from the rotor's rotation.

To calculate the forces and moments on the rotor blades, the BEM theory integrates the aerodynamic properties of each blade element along the entire span of the rotor. This integration process considers the varying blade geometry, including the twist angle and chord length distribution, and the resulting variations in local angle of attack and airspeed. By summing up the contributions from all blade elements, the theory provides an estimation of the overall thrust, power, and efficiency of the rotor system.

The BEM theory has proven to be a valuable tool in the design, analysis, and optimization of rotor systems. It allows engineers to predict the performance characteristics of rotating wings, assess the impact of different design parameters, and optimize the rotor geometry for improved efficiency and performance. It is particularly useful in the field of helicopter and wind turbine design, where accurate predictions of forces and moments are essential for safe and efficient operation.

In summary, Blade Element Momentum (BEM) theory is an aerodynamic theory that analyzes the forces and moments acting on the rotor blades of rotating wings. It provides a detailed understanding of the aerodynamic behavior of the rotor system, enabling engineers to design and optimize efficient and high-performing rotor systems for various applications.

In the BEM theory, the force applied is calculated using two separate approaches, integrating a regional blade-element analysis with the one-dimensional momentum theorem and graphical two-dimensional airfoil data. Take into account the straightforward scenario of a wind flow that is always operating at perpendicular to the rotor plane. The unrestricted air velocity, the blade azimuthal velocity,Ωr, and the generated velocity brought on by the pressure area of the blade circulation make up the comparative stream as it is tracked by the rotor blade (see Figure 25).

This allows us to calculate the local angle of attack,, which is the angle between the ψ comparable speed and the chord line of the airfoil. The dimensionless airfoil characteristics, i.e., the lift and drag parameters, are effectively determined from graphical airfoil information provided by the regional angle of attack, airfoil type, and Reynolds number. It's achievable to get values of the loading across the rotor blade from the airfoil properties, and when paired with statements from momentum theory, one may eventually derive a complete set of calculations to estimate the generated speeds. The controlling set of solutions will be developed in the paragraphs that follow.

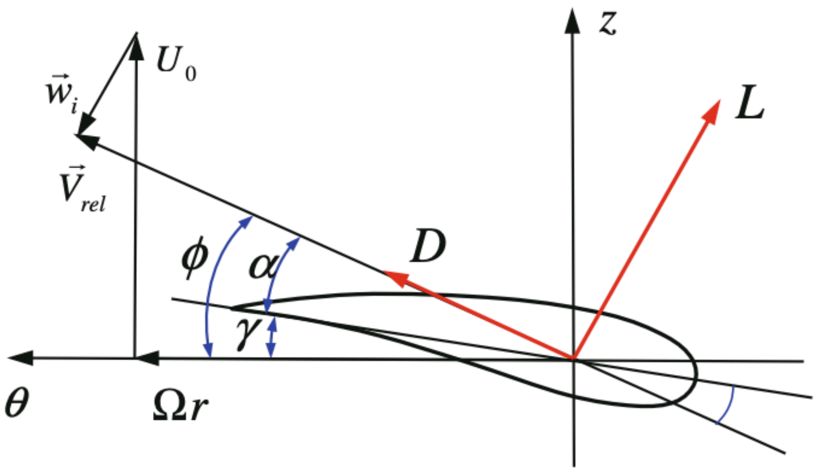
Initially using the blade-element theory, the axial load and torque are expressed as:

$$\frac{dT}{dR} = N_b F_n = \frac{1}{2}\rho c N_b {V_{rel}}^2 C_n$$

$$\frac{dQ}{dR} = N_b r F_t = \frac{1}{2}\rho c N_b r {V_{rel}}^2 C_t$$

Figure 25

Cross-sectional airfoil element



where c is the blade chord, Nb is the number of blades, Vrel is the relative velocity, Fn and Ft is the loading on each blade in axial and tangential direction, Cn and Ct are the corresponding two-dimensional force coefficients, defined as

$$C_n = \frac{F_n}{\frac{1}{2}\rho c V_{rel}{}^2}$$

$$C_t = \frac{F_t}{\frac{1}{2}\rho c V_{rel}{}^2}$$

The lift and drag constants are projected to create the force factors.

$$C_n = C_l \cos\phi + C_d \sin\phi$$

$$C_t = C_l \cos\phi - C_d \sin\phi$$

ϕ is the flow angle. The rotor blade is often twisted to create ideal performance characteristics throughout the majority of the blade span. Using Blade Element Theory (BET) (Leishman, 2006.), the overall lift and drag forces for every wing are computed BET. Each element's aerodynamic forces are represented:

$$\mathrm{dL} = \mathrm{c}\big(\alpha_e(\alpha, \delta)\big)\nu_\infty^2$$

$$\mathrm{dD} = \mathrm{d}\big(\alpha_e(\alpha, \delta)\big)\nu_\infty^2$$

where α is incident angle, flap deflection is δ, α_e is the effective angle of attack, which is a function of previous two, v_∞ is the freestream velocity.

CHAPTER 5

5. MACHINE LEARNING IN STABILIZATION

For flying and stabilizing in certain position the vehicle a lot of calculations are needed to be done. Instead of calculating all the outputs depended on multiple variables machine learning can be used. Machine learning is the science of algorithms that can adapt from practice, consisting of 3 main parts: Input Layer, Hidden Layer and Output Layer (see Figure 26). Firstly, data collection is necessary to gather a comprehensive dataset. This dataset should include the relevant input data from the IMU sensor, such as orientation, acceleration, and angular velocity. Additionally, it should include the desired motor and servo control values corresponding to the input data. This dataset will be utilized for both training and validating the neural network.

Once the dataset is collected, it needs to be preprocessed. This involves performing necessary preprocessing steps, such as normalizing the input and output values to a suitable range and handling any missing data. It is also important to split the dataset into training and validation subsets to ensure proper evaluation of the trained network.

The next step is to define the architecture of the neural network. In this case, the network should consist of an input layer with nine neurons to accommodate the IMU sensor data. The hidden layers can have any number of nodes, but for this specific scenario, let's consider a configuration with seven hidden layer nodes. Lastly, the output layer should consist of five neurons to control the four BLDC motors and the servo motor.

With the architecture defined, the neural network can be trained using the gradient descent algorithm. The goal of training is to minimize a cost function using linear regression. The network adjusts its weights and biases iteratively to reduce the error between the predicted motor and servo values and the desired output values. This process allows the network to learn the relationship between the IMU sensor data and the corresponding motor and servo control values.

After training, the performance of the network needs to be evaluated using the validation subset of the dataset. Metrics such as mean squared error (MSE) can be calculated to assess how well the network generalizes to new, unseen data. This evaluation process helps determine the effectiveness and reliability of the trained network.

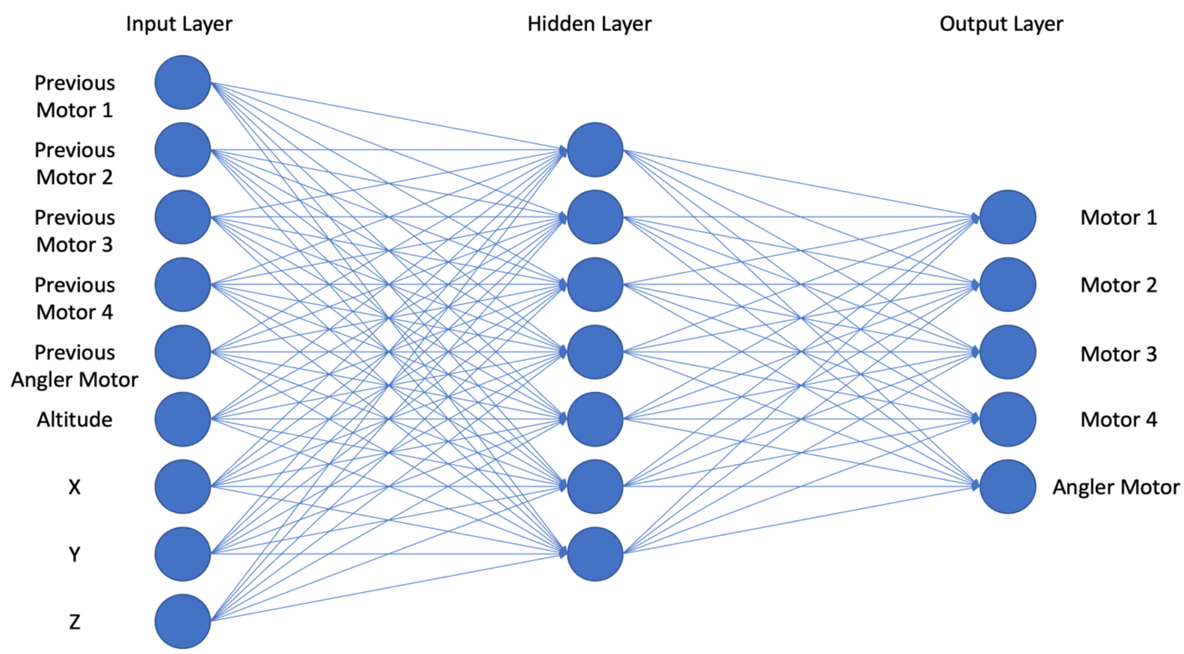
Once the network has been evaluated and its performance deemed satisfactory, it can be tested on new data. This testing phase ensures that the network can generate appropriate control signals for the four BLDC motors and the servo motor based on input from the IMU sensor. Through this testing, the stability and accuracy of the network can be verified.

Finally, when the network has been validated and tested, it can be deployed in the four-motored monocopter system. In real-time operation, the network takes input from the IMU sensor and processes it through the network layers (including the 9 input nodes, 7 hidden layer nodes, and 5 output nodes). It then generates control signals for the motors and servo, enabling the stabilization of the monocopter in the air.

Effectiveness increases as a machine learning system gains more expertise, often in the type of interpretative material or encounters with the surrounding. Every method has a model at its core that explains how features may be converted into an estimation of the objective. A weighted sum of the attributes may be used to indicate the expected value of the goal (motor speed and angle) under the expectation of linearity.

Figure 26

Diagram of Neural Network for Stabilization



5.1. LINEAR REGRESSION

Linear regression is a fundamental statistical technique that plays a pivotal role in the realm of machine learning and data analysis. It offers a robust and flexible approach to model the association between variables and generate predictions based on observed data. The main objective of linear regression is to identify the optimal-fitting line or hyperplane that effectively captures the relationship between the independent variables (also referred to as predictor variables or features) and the dependent variable (the target variable or outcome). This technique operates under the assumption that this relationship can be effectively described through a linear equation.

In its simplest form, linear regression assumes a linear connection between the independent variables and the dependent variable. By estimating the slope and intercept of a straight line that minimizes the overall discrepancy between predicted values and actual observed values, linear regression effectively models this relationship. To accomplish this, a cost function, typically the sum of squared differences (also known as the residual sum of squares), is minimized through the application of optimization algorithms, such as gradient descent.

Linear regression finds application in a wide range of scenarios. It is widely employed in regression tasks for predicting numerical values. For instance, it can be effectively utilized to forecast housing prices based on features such as square footage, number of bedrooms, and location. Additionally, linear regression can be adapted for classification tasks by estimating the probabilities of class membership, although certain adjustments, such as logistic regression, are necessary.

One of the notable advantages of linear regression lies in its interpretability. The coefficients in the linear equation provide insights into the influence of each independent variable on the dependent variable. These coefficients enable the quantification of the strength and direction of relationships, thereby offering valuable insights into the underlying factors that influence the outcome. Moreover, statistical tests can be employed to evaluate the significance of these relationships and draw inferences about the broader population. While linear regression assumes linearity, it can be extended to encompass more intricate relationships through the process of feature engineering. Polynomial regression, for instance, involves transforming the original features into polynomial terms to capture nonlinear effects. Similarly, interaction terms can be incorporated to account for interactions between variables. These techniques expand the capabilities of linear regression, enabling it to handle a broader spectrum of relationships and enhance predictive accuracy.

Nonetheless, linear regression is subject to certain limitations. It assumes linearity in the relationship between variables and assumes that errors follow a normal distribution with consistent variance (homoscedasticity). Furthermore, linear regression is sensitive to outliers and influential observations, which may disproportionately impact the model's performance. In cases where the relationship between variables is highly nonlinear, linear regression may yield suboptimal results, necessitating the application of alternative modeling techniques, such as nonlinear regression or machine learning algorithms.

In conclusion, linear regression stands as a versatile and extensively utilized method for modeling variable relationships and generating predictions. Its simplicity and interpretability render it an invaluable tool for data analysis and inference. However, it is crucial to acknowledge the assumptions and limitations of linear regression and consider alternative approaches when dealing with nonlinear relationships or addressing outliers and heteroscedasticity.

Linear Regression is implemented by plotting a straight line approximately fits best to given data set. Input values are used to get output value with given formula:

$$M_1 = PM_1 \times \omega_{PM1} + PM_2 \times \omega_{PM2} + PM_3 \times \omega_{PM3} + PM_4 \times \omega_{PM4} + PA \times \omega_A + D_A \times \omega_A + D_X \times \omega_X + D_Y \times \omega_Y + D_Z \times \omega_Z + b$$

$$M_2 = PM_1 \times \omega_{PM1} + PM_2 \times \omega_{PM2} + PM_3 \times \omega_{PM3} + PM_4 \times \omega_{PM4} + PA \times \omega_A + D_A \times \omega_A + D_X \times \omega_X + D_Y \times \omega_Y + D_Z \times \omega_Z + b$$

$$M_3 = PM_1 \times \omega_{PM1} + PM_2 \times \omega_{PM2} + PM_3 \times \omega_{PM3} + PM_4 \times \omega_{PM4} + PA \times \omega_A + D_A \times \omega_A + D_X \times \omega_X + D_Y \times \omega_Y + D_Z \times \omega_Z + b$$

$$M_4 = PM_1 \times \omega_{PM1} + PM_2 \times \omega_{PM2} + PM_3 \times \omega_{PM3} + PM_4 \times \omega_{PM4} + PA \times \omega_A + D_A \times \omega_A + D_X \times \omega_X + D_Y \times \omega_Y + D_Z \times \omega_Z + b$$

$$A = PM_1 \times \omega_{PM1} + PM_2 \times \omega_{PM2} + PM_3 \times \omega_{PM3} + PM_4 \times \omega_{PM4} + PA \times \omega_A + A \times \omega_A + D_X \times \omega_X + D_Y \times \omega_Y + D_Z \times \omega_Z + b$$

5.2. Cost Function

In machine learning, the concepts of error and cost function play crucial roles in assessing the performance and optimizing models. Understanding these concepts is essential for evaluating model accuracy and guiding the learning process.

Error refers to the discrepancy between the predicted values generated by a machine learning model and the actual observed values. It quantifies the extent to which the model's predictions deviate from the ground truth. By examining the errors, we gain insights into the model's ability to capture the underlying patterns and make accurate predictions. The goal of machine learning is to minimize these errors and improve the overall predictive performance of the model.

To measure and quantify the errors in a machine learning model, various metrics and measures are utilized, depending on the nature of the problem and the type of data. Common error metrics include mean squared error (MSE), mean absolute error (MAE), root mean squared error (RMSE), and accuracy (for classification tasks). These metrics provide a numerical representation of the magnitude and direction of the errors, allowing for the comparison and evaluation of different models.

The cost function, also known as the loss function or objective function, serves as a mathematical representation of the errors within a machine learning model. It calculates the overall error or discrepancy between the predicted values and the true values across the entire dataset. The choice of the cost function depends on the specific learning task and the nature of the data.

The role of the cost function is two fold: evaluation and optimization. Firstly, it serves as an evaluation metric by providing a measure of how well the model is performing. Lower values of the cost function indicate better model performance, as they imply reduced errors and improved alignment between predicted and actual values. This allows for the comparison of different models and the selection of the one with the lowest cost.

Secondly, the cost function plays a crucial role in model optimization. The goal is to find the optimal set of parameters or weights that minimize the cost function, thereby reducing the errors in the model. This process is often achieved through optimization algorithms, such as gradient descent, which iteratively adjusts the parameters to minimize the cost function.

Different machine learning algorithms and models may employ different cost functions based on the specific problem and objectives. For example, in linear regression, the cost function is typically the sum of squared errors (SSE), while in logistic regression, it is the log loss or cross-entropy loss. Convolutional neural networks (CNNs) commonly use the categorical cross-entropy loss for classification tasks.

The choice of an appropriate cost function is crucial, as it directly impacts the model's ability to learn and make accurate predictions. It is important to select a cost function that aligns with the specific problem and effectively captures the desired behavior of the model. Additionally, the choice of cost function may also consider factors such as computational efficiency and mathematical properties that aid in the optimization process.

In summary, error and cost functions are fundamental concepts in machine learning that enable the evaluation and optimization of models. By quantifying the errors and defining a cost function, we can assess model performance, compare different models, and guide the learning process to minimize errors and improve predictive accuracy.

Adjusting the weights is essential part of the system. It is done by cost function which represents error between actual value and predicted value. In other words, it determines how well model is predicting for the given dataset, value of cost function is inversely proportional with accuracy of model.

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(y_i - \hat{y}_i)^2$$

$J(\theta)$ is cost, m is number of examples, y is output values of system, $\hat{y}$ is predicted values of outputs by model (M_1, M_2, M_3, M_4, A). The objective of linear regression is to minimize the cost function. Reducing the error by updating the parameters (θ) in the direction that incrementally lowers the loss function. One of the popular algorithms used is gradient descent. Gradient descent is a fundamental optimization algorithm widely used in machine learning for training models and finding the optimal set of parameters. It is particularly effective in minimizing the cost function and improving the performance of the model.

The main objective of machine learning is to learn from data and make accurate predictions or estimations. This learning process involves finding the optimal values of parameters that best fit the observed data. Gradient descent is employed to iteratively update these parameters in a way that minimizes the cost function, leading to improved model performance.

The algorithm is based on the idea of taking steps in the direction of steepest descent in the multidimensional parameter space. It calculates the gradient of the cost function with respect to each parameter, representing the slope or rate of change of the cost function. By iteratively adjusting the parameters in the opposite direction of the gradient, the algorithm aims to reach the minimum point of the cost function.

The gradient descent algorithm can be classified into two main types: batch gradient descent and stochastic gradient descent. In batch gradient descent, the entire dataset is used to compute the gradient, and the parameters are updated based on the average gradient across all data points. This method ensures a more accurate estimation of the gradient but can be computationally expensive for large datasets.

On the other hand, stochastic gradient descent updates the parameters for each individual data point, making it more computationally efficient but potentially less accurate. It randomly selects a single data point or a small batch of data points to compute the gradient and update the parameters. Stochastic gradient descent is especially useful when dealing with large datasets or online learning scenarios where data arrives in a sequential manner.

The gradient descent algorithm iteratively adjusts the parameters by multiplying the gradient with a learning rate, which determines the step size for each iteration. Choosing an appropriate learning rate is crucial, as a small learning rate may result in slow convergence, while a large learning rate can cause the algorithm to overshoot the minimum or fail to converge.

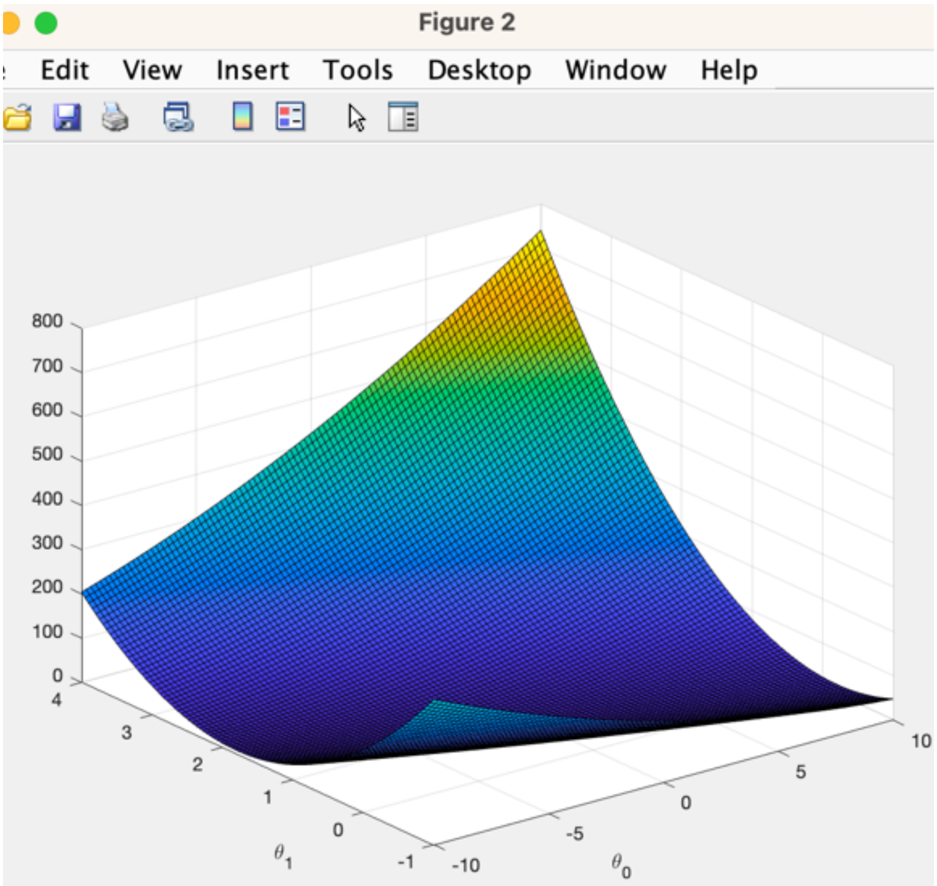
One challenge in using gradient descent is the possibility of getting stuck in local minima, where the algorithm converges to a suboptimal solution. To overcome this, variants of gradient descent, such as momentum-based techniques and adaptive learning rate methods (e.g., Adam, RMSprop), have been developed to improve convergence and prevent getting trapped in local minima.

In summary, gradient descent is a widely used optimization algorithm in machine learning. It iteratively updates model parameters by computing the gradient of the cost function and adjusting the parameters in the direction of steepest descent. By minimizing the cost function, gradient descent helps improve model performance and find the optimal set of parameters for accurate predictions.

$$\theta \coloneqq \theta - \alpha \frac{\partial J}{\partial \theta}$$

Figure 27

J(θ) dependance from θ0 and θ1 in MATLAB



CONCLUSION

In this paper, we offer a hybrid aircraft prototype system that uses the same aerodynamic surfaces and thruster components for quadcopter, fixed-wing, and rotor-wing flying in order to achieve optimum operational performance. We provide a model that enables the coexistence and complementarity of these structures within the same platform without the installation of any extra or specific mode-only components. Our method takes advantage of mechanical construction factors to both compensate for the specific flying circumstances of the vehicle and to reduce the stability issue of both flight phases. We think the method provides compelling rationale for creating new evaluation and operating techniques that would be useful for applications other than this specific craft considering that the vehicle incorporates principles from two distinct domains of aerodynamics. Our present exploration is concentrated on a number of areas, including further confirmation and enhancements to the model of the platform's dynamics, the implementation of a more complex controller for all flight configurations and the switchover phase, the implementation of extra design parameters that enhance the craft's reaction to user instructions, modifying gyroscope-based guidance, and ultimately enhancing rotorcraft stability.

We think that these initiatives have cleared the way in a variety of disciplines going ahead. First off, we now think we have enough data to create figures of merit to accurately set side by side this system with other comparable hybrid systems. Although the decreased throttle in various flyer configurations is a positive sign, much more research is required to accurately assess the energy efficiency of this hybrid. This can include particular wing configurations according to the objectives the vehicle is meant to perform. The methods of stabilization, controls, and communication should be researched further to be enhanced and supplied with more data. Mechanical design changes are needed to compensate for the vehicle's shortcomings, such as the incapacity to install stationary sensors. This area will be subject of future research.

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