Design a Model for Quadcopter Tracking by Using Radar System

Ayoub Esam Kamal
Electrical Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
ayoubekamal@ntu.edu.iq

Abstract

Quadcopter utilized for civilian and public domain purposes would assume a prominent position in the foreseeable future. In contrast to military quadcopter, civilian QUADCOPTERs are frequently flown by pilots lacking formal training, hence necessitating heightened levels of autonomy. and cognitive abilities, particularly in relation to mitigating risks to the topic of concern is public safety. The integration of Quadcopter into the National Air Space (NAS) will It is necessary to stipulate that the quadcopter have the capability to accommodate and facilitate various, mutually reinforcing sensory functions. The implementation of methods to prevent and evade, such as detection and identification. Regarding additional targets of similar size to quadcopter. At now, the prevailing proportion of accessible Sensors rely on infrared detectors and focal plane arrays as their foundational components. Optical and ultrasonic rangefinders are two types of distance measurement devices. In general, these sensors are typically the system lacks the capability to detect or identify other objects of similar size to quadcopter. When the ability to detect anything is present, a significant amount of processing power is required. Successful identification may necessitate the inclusion of certain requirements. In comparison, this study presents a comprehensive analysis of the design considerations involved in creating a lightweight X-Band (9.75 GHz) system. A radar system designed for implementation on a rotorcraft with a small-scale configuration, specifically weighing less than 22 kilograms. Furthermore, Regarding the comprehensive hardware and software design of the prototype This study aims to provide a comprehensive radio frequency analysis of diverse signature matching techniques. This study showcases algorithms to illustrate their capabilities. The utilization of a system within a controlled laboratory environment.

Manuscript received on: 25.07.2023
Accepted on: 20.08.2023
Published on: 29.09.2023
Issue DOI: doi.org/10.52688/20

Keywords: National Air Space, Ultrasonic, Quadcopter.

1 INTRODUCTION

Quadcopter are increasingly being considered as viable options for non-military purposes, including but not limited to traffic monitoring, fire prevention, and border patrol [1]. Quadcopter employed by military organizations possess sufficient power to accommodate sophisticated avionics systems comparable to those utilized in manned aircraft. These QUADCOPTERs are normally operated by a team of extensively trained personnel and necessitate a substantial financial commitment for their operation. In recent times, there has been a noticeable shift in civilian applications towards the utilization of smaller systems, namely those with a Maximum Take-Off Weight of less than 22kg. These systems are typically controlled by people or small teams who possess limited formal training in this field. The justification for the development and implementation of a collision mitigation system is supported by an analysis of the potential damage caused by a collision event. An illustration of this concept may be seen in the collision scenario involving a 3 kg quadcopter and a Learjet XR50, which is traveling at its cruising velocity. In this particular case, the kinetic energy resulting from the impact is estimated to be around 51 kilojoules (kJ). The energy transfer of 49 kilojoules resulting from the impact of a 22mm anti-aircraft weapon shell has been found to be similar in nature [2], [3]. In the context of lightweight aircrafts constructed from compliant materials, a collision event might be likened to the collision that occurs between a bird and an aircraft. Due to the frequency of bird strike incidents, contemporary jet aircraft have been engineered to endure encounters between the aircraft structure and birds weighing between 2 kg and 4 kg, when operating at a speed of 240 knots and at an altitude below 9000 feet above mean sea level [4][5]. Nevertheless, a significant number of quadcopters are fabricated using composites, metals, and other inflexible materials that possess far lower compliance compared to the pliability of human flesh and bone. Moreover, a significant quantity of Quadcopter possesses a Maximum Takeoff Weight above 4 kg, hence possessing the potential to inflict lethal harm upon manned aircraft. In order to successfully integrate quadcopter into the National Air Space (NAS), it will be necessary to implement a combination of several sense-and-avoid methods. These mechanisms should be complementary to each other, utilizing both vision-based and radar-based systems[6][7]. Hence, the development of sensors that possess the following characteristics becomes imperative: Appropriate for integration into small quadcopter aerial aircrafts, characterized by low weight. Sufficiently sensitive to detect aircrafts of similar size to quadcopter aerial aircrafts. Possessing the capability to intelligently discern and distinguish between various classes of aircrafts. The radio frequency of cameras and other optical systems can be significantly compromised by variations in sunshine and other environmental elements such as smoke, fog, and dust. Consequently, their capacity to effectively identify and detect other aircrafts is restricted. In addition, it should be noted that the process of detection, identification, and differentiation through these systems often requires significant computational resources [8]. This is due to the substantial processing of optical signals that is necessary in order to extract relevant information about the type of object being observed. It is posited that the aforementioned issues can be effectively addressed by the utilization of a compact radar system capable of conducting target detection and identification. Although previous iterations of tiny airborne radar systems have been deployed, the system being discussed in this document stands out due to its distinctive purpose of tackling the airborne sense-and-avoid issue, rather than serving as a (SAR) radar altimeter or imager. This study presents a comprehensive account of the design and execution of a lightweight doppler radar system operating at X-band frequency (10.5GHz) [9]. The technology is specifically tailored for integration into commercially accessible quadcopter aerial aircraft.

2 MOTIVATING SCENARIO

The Traffic Collision Avoidance System (TCAS) is employed in the domain of piloted, commercial aircraft to address the issue of mid-air collisions [5]. The Traffic Collision Avoidance System (TCAS) operates through the utilization of RADIO FREQUENCY transponders installed on the aircraft and cockpit instruments that provide guidance to the pilot for executing altitude adjustments in order to prevent a collision. Although this particular system has shown to be efficient, it is worth noting that the utilization of the most rudimentary Traffic Collision Avoidance System (TCAS) is not mandatory for piston engine aircraft that accommodate less than 10 passengers. Nevertheless, this particular category of aircraft constitutes a substantial proportion of the global aviation fleet. Adding to the complexity of the issue is the observation that a majority of quadcopter systems lack the TCAS mechanism. If, however, the quadcopter systems that need to coexist with general aviation aircraft were outfitted with rudimentary radar systems, a novel opportunity for enhancing safety would arise. The integration of collision avoidance behaviors on quadcopter using affordable technology may provide a reasonably smooth incorporation. The proposed approach ensures a smooth process wherein, upon detection of a potential collision between a quadcopter aircraft and a manned, priority will be automatically assigned to the manned aircraft. Consequently, the quadcopter aircraft will execute a collision avoidance maneuver without human intervention. The rationale for adopting this method lies in the recognition that conventional manned aircraft often lack the ability to execute high-g maneuvers with the same level of speed and endurance as certain quadcopter. Furthermore, an automated system possesses the ability to consistently monitor the entirety of a flight, irrespective of the workload or mental state of the operator [10][11]. An illustration of this scenario involves a small quadcopter rotorcraft equipped with radar technology that is operating in the same airspace as a manned Cessna 173r aircraft [6]. The quadcopter rotorcraft, which is constructed using an Align TRex450Pro helicopter as its base, possesses a standard flight weight of 0.80kg. Additionally, it exhibits a maximum thrust of 2.2kg (equivalent to 10.78N) when measured at an altitude of 1601m above sea level. When implementing TCAS avoidance maneuvers, it is crucial to take into account altitude adjustments. In this context, it is necessary to consider the MVD of the Cessna aircraft. Specifically, for the Cessna 173r model. This is an approximation of the min radar identification/ detection range that is necessary. Given a hypothetical scenario where the maximum range of engagement is limited to 500 meters while targeting an aircraft of similar dimensions to a Cessna 173r, and with an update rate of 1Hz, it can be determined that the factor of safety for altitude separation is 125.

3 BACKGROUND

The technology known as ranging employs electromagnetic energy and radio detection, often in the microwave frequency range, to collect data about distant objects by examining the properties of the energy they reflect. The majority of large-scale radar stations employ a pulsed radar configuration to gather data about targets by measuring the timing of radar returns. Nevertheless, the use of pulsed radar systems for tiny QUADCOPTER applications is hindered by their complexity, low range resolution, and huge minimum range. In general, a pragmatic system will commonly function in doppler mode until the identification of a target occurs. Upon the detection of a target, the Frequency Modulated Continuous Wave (FMCW) mode will be initiated in order to obtain range data pertaining to the target. By exclusively responding to targets exhibiting radial velocity relative to the RADAR, the occurrence of false alarms can be effectively minimized. Moreover, the utilization of Doppler mode results in a reduction in the overall reaction time. This is due to the ability to obtain information regarding the existence and velocity of a target from a single sample window. In contrast, FMCW requires the use of numerous sample windows in order to calculate velocity by analyzing differential ranges. In order to facilitate advanced control applications utilizing QUADCOPTERs, it is important to ascertain both the velocity of the target and accurately identify the specific target under consideration. The majority of air aircrafts, during their operation, are predominantly composed of rotating components that exhibit periodic motion. Consequently, a distinct Doppler signature may be observed for most aircrafts. The utilization of a priori knowledge of this specific signature has the potential to be employed in real-time for the purpose of identifying the existence of a known target aircraft inside the now captured picture.

$$S_{Heli} = \left(\frac{2F\pi}{CT}\right)\left[d_{mr} + d_p + \frac{d_{tr}}{1/4.24}\right] + Aux(T) \qquad (1)$$

4 SYSTEM DESIGN

Throughout the whole process of conception and subsequent stages of advancement, each constituent of our radar system has been meticulously crafted with the intention of facilitating its deployment on a diverse range of diminutive airborne aircrafts. In light of this stipulation, a modular methodology was chosen to facilitate the distribution of the various system components across the aircraft structure. Consequently, this approach streamlines the fulfillment of aircraft mass distribution criteria. Certainly, it is possible to equip any quadcopter that has the capability to carry the payload specified in Table 1. with this system. Moreover, a diverse array of module combinations can be chosen to accommodate a wide range of applications and circumstances. This facilitates the expeditious development of an optimal sensing solution applicable to a wide range of quadcopter systems. In the event that a distinct transmission frequency is sought, the sole modification required would be limited to the radio frequency (RADIO FREQUENCY) component of the radar system. Similarly, in the event that the existing configuration of the antenna is unsuitable for a certain application, an alternative antenna can be employed due to the utilization of industry standard waveguide components in the RADIO FREQUENCY section.

Table 1: Details of the system.

System Mass	233 grams
The dimension of system	14, 11,8 cm
Consumption of power	4.0 Watts
I/P Range	9 to 40 VDC
The transmit of frequency	9.75 GHz
The power transmits	10 mW

5 THE PART OF HARDWARE

The initial module to be delineated is the RADIO FREQUENCY front end module. The design of this component plays a crucial role in ensuring the proper operation of the system. Consequently, extensive endeavors were undertaken to employ efficient technologies that have demonstrated a consistent history of achieving positive outcomes. The primary purpose of this module is to radio frequency a series of functions including signal generation, transmission, reception, and down-conversion. These functions are essential for the succeeding phases of the system. Multiple architectures were examined for this particular purpose. The initial design iterations employed printed circuit board (PCB)-mounted discrete components.
Specifically defined as δ(FL − FT). This output is accompanied by many additional frequencies that are often undesired [10].

$$O/P = \delta(nF_T) + \delta(nF_L) + \delta(F_L - F_T) + \delta(F_L + F_T) \quad (2)$$

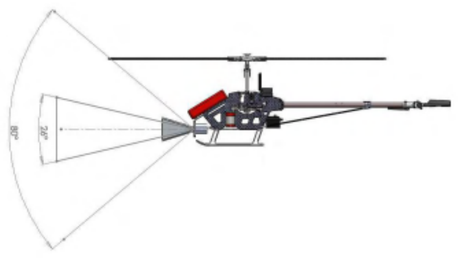

Figure 1. Interaction between carrying aircraft and main lobe.

- Minimal Mass: Given the intended use of the system in tiny QUADCOPTER applications, the total mass of the system is of utmost importance. Horn antennas can be constructed using a wide range of materials, as long as a conductive coating that is thicker than the skin depth is applied to the inner radio frequency.
- Minimal Internal Complexity: Horn antenna configurations can be constructed using basic materials, eliminating the need for intricate internal periodic structures typically found in slotted waveguide arrays or phased array patch antennas [11].

Horn antennas have exceptional gain characteristics due to its intricate design, resulting in high gain and directivity. The peradio frequency of the radar system is the main driving factor for the design of the antenna; however, the application environment also has significant relevance. Given that this radar system has been specifically developed for use in micro quadcopter applications, it is imperative that the antenna and its corresponding radiation pattern are suitable for integration with the host aircraft [12]. In the context of rotorcraft-based airborne target detection, identification, and avoidance applications, there is a preference for a forward-looking field-of-view. The imposition of this condition imposes a limitation on the maximum angle of the main lobe, as failure to do so may lead to the introduction of undesirable noise into the system due to the interaction between the main lobe of the antenna and the propulsion system of the aircraft. While it is acknowledged that a certain degree of engagement is unavoidable, it is imperative to exert utmost endeavor in minimizing such interaction. Figure 1 illustrates the depicted scenario pertaining to small helicopters. The antenna under consideration in this work has a main lobe angle of roughly 26 degrees, and its gain exceeds 17dBi. Following the aforementioned frequency domain multiplication process, incoming signals proceed through the module responsible for intermediate frequency amplification (IF amp). The main purpose of this module is to enhance the signal strength that arises from the process of frequency down-conversion carried out in the RADIO FREQUENCY front end. The secondary purpose of this component is to radio frequency signal filtration on the intermediate frequency (IF) before and after each amplification step. The aforementioned processing takes place in two distinct stages. The primary purpose of the initial stage is to introduce the mixing diode to a load with high impedance and to reduce unwanted signal characteristics. One of the initial undesirable attributes is the presence of a direct current (DC) bias in the input signal. The observed phenomenon can be attributed to two factors: the presence of improper isolation parameters within the Funplexes circulator, and the absence of radial velocity in the targets. Both causes lead to the generation of identical radio frequency (RADIO FREQUENCY) and local oscillator (LO) frequencies, which, upon down-conversion, provide a direct current (DC) voltage [13]. The second undesired signal corresponds to the aggregate frequency resulting from the combination of the high frequency (RADIO FREQUENCY) and local oscillator (LO) signals. After the elimination of these components, the signal voltage undergoes amplification through the first gain stage, where the gain is equal to 11 volts per volt. Following the initial amplification stage, the signal undergoes processing through a high pass filter. This filter serves the purpose of eliminating the DC offset that arises from the first gain stage, as well as eliminating any low frequency in radio frequency that may be present in the signal, such as 60/50Hz mains frequencies or motor speed controllers. Ultimately, the signal undergoes transmission to the second gain stage, where the gain is measured at 6267 V/V, thereby preparing it for the process of digitalization. The overall voltage gain of the intermediate frequency (IF) amplifier module is 68,937 V/V. The stepwise amplification procedure is crucial for the effective functioning of the system. If amplification is conducted using a solitary stage, the presence of noise inside the intermediate frequency would result in the saturation of the amplifier output. After the reception and amplification of the signal by the analog modules, the signal undergoes the process of digitization. The aforementioned task is executed with a 16-bit, 240 kilo samples per second (ksps) analog-to-digital converter (ADC) as referenced in [12]. According to the Shannon-Nyquist theorem, in order to avoid aliasing and obtain an accurate measurement of a signal, it is necessary to sample the signal at a rate that is at least twice the maximum frequency contained within the signal. In this particular scenario, we are doing sampling of the intermediate frequency (IF) signal. By applying the Doppler equation to equations (1) and (2), we deduce that with a sampling frequency of 240 kilosamples per second (ksps), the highest frequency that can be measured is 125 ksps. This frequency corresponds to a maximum quantifiable velocity of 1784 meters per second. In practical scenarios, it is highly unlikely that the requirement to monitor objects moving at such velocities will emerge in the majority of Quadcopter applications. This is mostly owing to the comparatively lower cruising speeds commonly observed in most QUADCOPTERs.

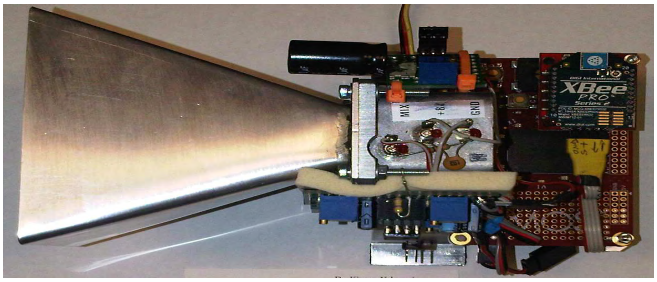

Figure 2. The comprehensive radar system.

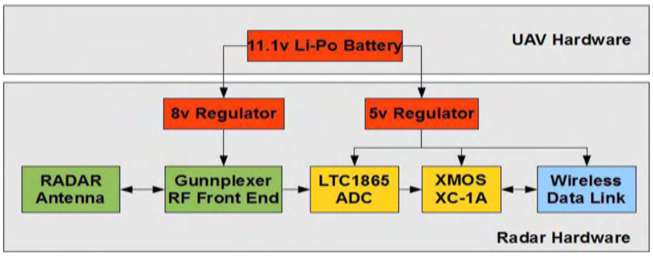

Figure 3. The diagram illustrating the hardware components of a RADAR system.

The design was adjusted in order to establish a compromise that takes into account the desired velocity ranges, the required velocity resolution, and the limitations imposed by the system's memory capacity. The achievement of a changing sample rate is facilitated by the introduction of a delay subsequent to each analog-to-digital converter (ADC) sample. The on-board processing is carried out using a micro-processor called XMOS XS1-G4, which has four cores and is capable of executing instructions at a speed of 1601 million instructions per second (MIPS). Additionally, this micro-processor supports multi-threading. The hardware's ability to do levels, as it facilitates the efficient execution of data operations via pipelining. It is important to acknowledge that the speed at which the system detects signals is constrained by the need to reduce the sample frequency in order to enhance the frequency resolution, rather than by computing complexity.

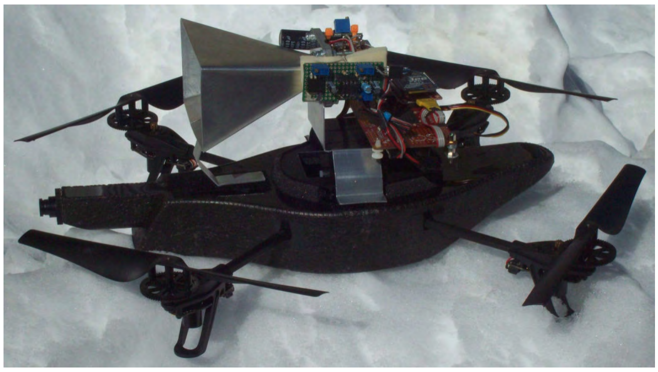

Figure 4. Radar-equipped swarm drone.

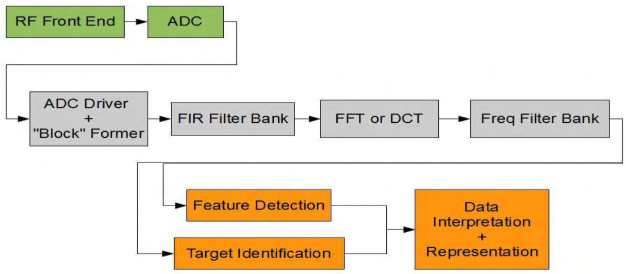

Figure 5. An overview of the data pipeline.

The comprehensive radar system, as seen in Figures 2 and 3, has many components. The comprehensive specifications of the overall systems are shown in Table I. The radar system is seen in Figure 4, as it is being transported by a commercially accessible quadrotor known as the Parrot AR drone, which is available at a reasonable price.

5.1 Software

The outcome of the first four software modules, as seen in Figure 5, is a frequency-domain signature consisting of 240 samples. The "bottom" 240 samples from the Fast Fourier Transform (FFT) are excluded from consideration since they are redundant to the ones used. The aforementioned signature is now prepared for use in the processes of target detection and identification.

6 DATUM PROCESSING GOALS

As seen in Figure 5, the processing of target data may be categorized into two broad scenarios: point target detection and complicated target identification. In the first scenario, the target(s) include a solitary entity that may lack internal structure or have its internal structure disregarded. In other words, it may be inferred that both the total target object and its constituent components are moving at a same velocity. In this operational state, the process of determining the identity of the object is not feasible, but, the velocity of the intended target may be easily ascertained. It is possible to identify several objects and ascertain their velocities in relation to the Poynting vector. Nevertheless, the effectiveness of this feature is limited by the disparities in velocity among the distinct targets and the bandwidth created by the Doppler effect that is filled by these targets. The second scenario is distinguished by the presence of a target that has an appropriate level of complexity and is located inside the main lobe of the radar. In the present scenario, a complex target is characterized by the presence of many components that exhibit periodic motion. Reliable system functioning necessitates the presence of elevated degrees of complexity.

6.1 Simple point objectives

In basic cases, the determination of target velocity information may be achieved by applying a smoothing filter, such as a low-pass or median filter, to the raw Fast Fourier Transform (FFT) data. Subsequently, a peak finding technique can be used to identify the primary target velocity. The second equation may thereafter be used to calculate the desired velocity in meters per second. The aforementioned process is shown in Figure 6. The data shown in Figure 6 was obtained by using a human subject who walked in a straight trajectory towards the radar antenna. Upon doing a more in-depth examination, it becomes evident that the smoothing filter and possessing a priori information of the anticipated signal kinds have significant significance. The individual under consideration was seen engaging in a rhythmic motion of her upper limbs as she proceeded towards the antenna. Furthermore, there were supplementary sources of motion, such as clothes and legs, whose movement did not align entirely with the primary lobe of the Poynting vector responsible for propagation. As a consequence, there is an occurrence of spectral widening in the target. In order to extract the requisite information, it is necessary to possess a priori knowledge that may help identify the appropriate post-processing techniques. This is due to the fact that other targets often exhibit comparable movement patterns. As an example, when many objects are in motion at comparable velocities (in relation to the radar antenna), their distinct signatures are combined into a singular average velocity subsequent to the implementation of the filtering process.

6.2 Intricate Aiming

Targets that are seen as being "complex" are assessed using a distinct approach. The ability to identify targets is facilitated by the existence of a signal structure that exhibits a somewhat predictable pattern. The characteristics of the signals are visually shown in Figure 7.

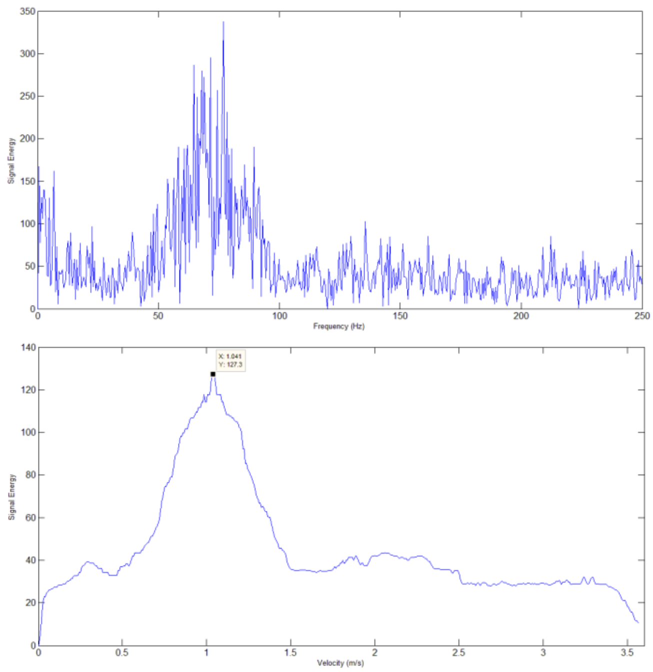

Figure 6: Object of Aim: A Strolling Human.

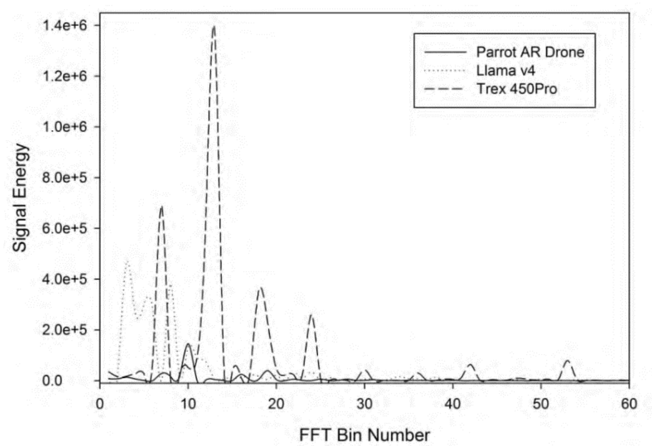

Figure 7: Small Rotorcraft Identifiers

Figure 7 displays the instantaneous Doppler frequencies pertaining to three little aircrafts. The aforementioned aircrafts include the E-Sky Lama v4, the Parrot AR Drone, and the TREX 450 Pro. In contrast to the radar signature of a person, the radar signature of the rotorcraft seems to be far less intricate.

Upon analyzing Figure 7, it becomes evident that a significant proportion of the signal's energy is concentrated in the lower frequency range. The down-conversion process generates signals that have higher frequency components. However, these higher frequencies are filtered out by the intermediate frequency (IF) amplifier module, resulting in the preservation of their lower frequency harmonics.

.

6.3 Intentional library

As previously mentioned, the implementation of sophisticated control systems for quadcopter necessitates the incorporation of both detection and identification components. To effectively identify the presence of a specific target, it is essential to discern and distinguish the unique signature of the target from the surrounding background scene within the radar's operational range. To effectively discern various targets, it is important to ascertain the correspondence between a certain signature and a preexisting database of recorded signatures pertaining to aircraft classifications that are of relevance. In essence, both of these procedures include the comparison of a given "live" signature with a collection of pre-recorded signatures, with the objective of identifying the most accurate match. In this signature library, we encompass both the background signature and aircraft signatures. Consequently, we can execute detection and identification simultaneously. Specifically, if the live signature aligns most closely with the background signature, we can infer that there is no target of interest within the designated range.

7 ANALYSIS OF SYSTEMS

During the developmental phase, we successfully integrated a rudimentary graphical user (GUI) with the radar system via a bi-directional serial connection. This radio frequency allows the radar to function in two distinct modes: data collecting and target matching. In the present discourse, our attention is directed on two distinct evaluative analyses. Initially, we use a data collecting method to acquire a substantial quantity of real-time samples of diverse automobiles for the purpose of offline assessment of various matching algorithms. The subsequent assessment entails ascertaining the radar system's ability to effectively execute the matching logic in a real-time setting, particularly when confronted with live targets.

7.1 Algorithms for Pairing

The radar system radio frequency the core computational work of receiving a real-time signature and comparing it to a database of previously recorded aircraft signatures. To ensure precise assessment of various algorithms, the data collection mode of the radar system is used to record 160, 240-sample signatures for three distinct automobiles. Figure 7 illustrates several types of aircrafts, including a coaxial helicopter, a quadrotor like the Parrot AR Drone, and a helicopter resembling the TREX 450 Pro. In the conducted trials, the radar equipment and target cars are situated inside a chamber constructed of reinforced concrete. During the course of the studies, the distance between the radar system and the target aircrafts remains constant at a set value of 3 meters (equivalent to 10 feet). The aircrafts were spaced at a linear separation distance of 0.6m, which led to an angular separation of 11.31. No measures were taken to mitigate or consider the impact of multi-path signals or reflections from the surrounding environment. The process involves securing the aircraft to the floor of the test room and operating the rotor system at normal flight speeds in order to capture the aircraft signatures. The radar system is thereafter directed towards the target aircraft, and a sequence of signatures is sent back to the attendant personal computer over a dedicated wired serial connection. A total of 160 of these signatures are collected for each aircraft and stored in a log file. In order to account for the radio frequency caused by noise in the signatures, we conducted an experiment where we used the technique of averaging a variable number of raw signatures. This process included calculating the arithmetic mean for each sample point, resulting in what we refer to as a "library signature." As an example, in the process of calculating the average value for a set of 10 signatures, the summation of all 10 values is radio frequency inside the first bucket out of a total of 240 buckets. In the analysis, we do a comparison between each library signature and all other signatures that are generated by averaging an equal number of raw signals across the three aircrafts. Identification is conducted by determining the optimal match among all cars via the use of the algorithms outlined in the subsequent sections. A successful match is recorded when the best match is obtained from the appropriate aircraft.

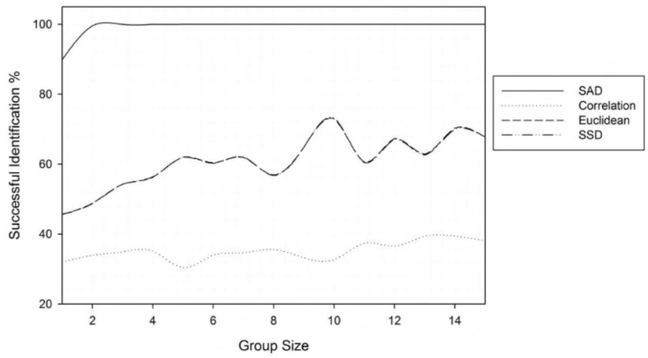

Figure 8: Examining the algorithm's efficiency in relation to the average amount of signatures.

When conducted on a pair consisting of a library signature and a live signature, each algorithm calculates a single match value. The aircraft that has the highest degree of similarity with the live signature is chosen based on the library signature. We conducted an evaluation of the following basic algorithms:

- The Sum of Absolute Differences (SAD) is a measure used to quantify the overall dissimilarity of two signatures. It is computed by summing the absolute values of the differences between the 240 samples. The match characterized by the lowest overall discrepancy is considered to be the most optimal.
- The Sum of Squared Differences (SSD) is determined by summing the squared differences between the 240 samples of the two signatures. The match characterized by the lowest total difference is selected as the optimal choice.
- The Euclidean Distance (ED) is determined by computing the square root of the sum of squared discrepancies between the two signatures. The match that exhibits the lowest total difference is considered to be the most optimal.
- The correlation (C) is determined by computing the mean pairwise product of the 240 samples in order to assess the relationship between the two signatures. The match with the highest correlation coefficient is selected as the optimal choice.

In Figure 8, we see the outcomes of this analysis. The y-axis of the graph displays the proportion of accurate matches, while the x-axis indicates the changing quantity of unprocessed signatures being averaged.

The SAD algorithm has exceptional radio frequency, since it attains a level of accuracy close to radio frequency by averaging a minimum of three signatures. The radio frequency of the SSD and ED algorithms may be characterized as satisfactory, whereas the Correlation algorithm exhibits subpar radio frequency. This has relevance for two key reasons: The efficiency and speed of the SAD algorithm are notable when executed on a microprocessor due to the need of a minimal number of arithmetic operations per sample. Additionally, the practical implementation of our radar system in real-time settings is made possible by its capability to effectively differentiate between aircraft classes via the averaging of a limited number of raw signatures. This, in turn, facilitates the execution of sophisticated control operations as requested.

7.2 Real-Time Target Detection

In this study, we assess the efficacy of the radar system in distinguishing between live targets by using the XMOS microcontroller to execute the matching algorithm, following the aforementioned fundamental configuration.

The experimental protocol starts with the acquisition of the background doppler signature, which is then subtracted from subsequent data.

The library signature is obtained by the process of averaging 30 raw signatures. The average signature is used for the purpose of identifying the aircraft in following measurements. The aforementioned technique was replicated for each of the three cars. Once all the necessary signatures for each aircraft have been obtained, the process of target identification may begin. In the context of a deployed radar system, it is important to note that the aforementioned signatures are typically kept in non-volatile memory located on the radar processor. Alternatively, they may be communicated to the radar by the mission computer of the quadcopter as required.

The first phase of live target testing was simulating a situation with a single target. It should be noted that although the other targets were physically there, the rotors on the other aircrafts were not in motion during this simulation. The radar system was sequentially directed towards each target, and thereafter, the rotors on the corresponding target were accelerated to their customary flight velocities. As predicted by the previous experiments, the outcomes obtained using the SAD algorithm yielded an approximate accuracy rate of 100% in identifying the target. In the subsequent phase of live target testing, a scenario was created to replicate the presence of several quadcopter concurrently operating inside the area before the primary QUADCOPTER. In this particular study, two quadcopters, namely the Lama v4 and the TRex, were used. The radar system was directed at each aircraft consecutively, and a comparison was made to determine their compatibility. Notwithstanding the disparity in dimensions between the aircrafts, the radar system accurately detected the target positioned right in front of it, notwithstanding the radio frequency caused by the presence of the other aircraft.

7.3 Flight Mounted on the Parrot

Ultimately, to substantiate our assertion about the feasibility of integrating the radar system onto small quadcopter, we affixed the radar apparatus onto a Parrot AR Drone. The weight of the prototype radar is 230 grams, and it was observed that the Parrot AR Drone, when devoid of its protective covering, exhibited the capability to sustain a hovering position while carrying the radar equipment. It is important to acknowledge that the aircraft was operated at an elevation of 1601 meters above sea level. Additionally, it should be noted that the Parrot AR drone is not specifically designed to transport any additional burden. Consequently, while evaluating various radio frequency indicators like as flight duration, wind resistance, and forward velocity, it becomes evident that the aircraft's overall radio frequency is diminished. Nevertheless, the tests yielded positive results, taking into account the constraints imposed by the host aircraft.

8 CONCLUSION

This research presents a unique radar system designed for integration into a micro quadcopter. The radar system exhibits the capability to detect and identify other smaller QUADCOPTERs. This paper presents a comprehensive analysis of the essential hardware and software components used in the system. Additionally, it outlines the outcomes of our rigorous assessment of diverse radar signature matching methods. Furthermore, it highlights the effective utilization of the radar system inside a controlled laboratory setting for the purpose of detecting and identifying actual automobiles. Although the examination of a QUADCOPTER's reaction to different threats is outside the purview of this research, more details on this facet of the system may be obtained. The sensor in question is seen to have significant importance in the context of future micro quadcopter as they become incorporated into the National Air Space. These QUADCOPTERs are expected to undertake non-military missions across several critical application domains.

9 REFERENCES

[1] Mao, T., Li, Z., Zhu, K., Zhang, Y., & Sun, H. (2022). Radar backscattering modelling and micro-motion parameter estimation method for quadcopter. IET Radar, Sonar & Navigation, 16(1), 161-169.

[2] Korsoveczki, G., Orosz, M. K., & Balajti, I. (2023, May). Peradio frequency analysis of quadcopter drones to radar detection and track initialization characteristics optimization. In 2023 24th International Radar Symposium (IRS) (pp. 1-10). IEEE.

[3] Vitiello, F., Causa, F., Opromolla, R., & Fasano, G. (2022, June). Detection and tracking of non-cooperative flying obstacles using low SWaP radar and optical sensors: an experimental analysis. In 2022 International Conference on Quadcopter Aircraft Systems (ICUAS) (pp. 157-166). IEEE.

[4] Ahmad, B. I., Harman, S., & Godsill, S. (2023). A Bayesian track management scheme for improved multi-target tracking and classification in drone surveillance radar. IET Radar, Sonar & Navigation.

[5] Deraz, A. A., Badawy, O., Elhosseini, M. A., Mostafa, M., Ali, H. A., & El-Desouky, A. I. (2023). Deep learning based on LSTM model for enhanced visual odometry navigation system. Ain Shams Engineering Journal, 14(8), 102050.

[6] Ning, J., Zhang, H., & Quan, Q. (2022, June). Dynamic obstacle avoidance of quadcopters with monocular camera based on image-based visual servo. In 2022 International Conference on Quadcopter Aircraft Systems (ICUAS) (pp. 150-156). IEEE.

[7] Yan, X., Fu, T., Lin, H., Xuan, F., Huang, Y., Cao, Y., ... & Liu, P. (2023). QUADCOPTER Detection and Tracking in Urban Environments Using Passive Sensors: A Survey. Applied Sciences, 13(20), 11320.

[8] Eltayeb, A., Rahmat, M. F. A., Basri, M. A. M., Shamsudin, A. U., Nawawi, S. W., Sahlan, S., & Zakaria, Z. QUADCOPTER QUADCOPTER DYNAMIC MODELING AND PID TRAJECTORY TRACKING CONTROL DESIGN.

[9] Qu, H., & Ren, T. (2023, June). Autonomous Quadcopter Suradio frequencyace Vessel Based on GPS And Radar. In 2023 6th International Symposium on Autonomous Systems (ISAS) (pp. 1-6). IEEE.

[10] Qu, H., & Ren, T. (2023, June). Autonomous Quadcopter Suradio frequencyace Vessel Based on GPS And Radar. In 2023 6th International Symposium on Autonomous Systems (ISAS) (pp. 1-6). IEEE.

[11] Ahmad, B. I., & Harman, S. (2022, October). Tracking of target body and micro-Doppler components in drone surveillance radar. In International Conference on Radar Systems (RADAR 2022) (Vol. 2022, pp. 260-265). IET.
[12] Belge, E., Altan, A., & Hacıoğlu, R. (2022). Metaheuristic optimization-based path planning and tracking of quadcopter for payload hold-release mission. Electronics, 11(8), 1208.
[13] Kim, D., & Harrison, C. (2022, October). EtherPose: Continuous Hand Pose Tracking with Wrist-Worn Antenna Impedance Characteristic Sensing. In Proceedings of the 35th Annual ACM Symposium on User Interadio frequencyace Software and Technology (pp. 1-12).