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Using the Doppler Effect to Improve Automatic Landing of Drones in Remote Geographical Environments

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Abstract: Drones are currently being used more and more to deliver postal goods across short, medium, and long distances. Unmanned aerial vehicles (UAVs), especially those with vertical take-off and landing (VTOL) capabilities, have the potential to be used in transportation services due to almost unrestricted access to areas without significant airspace errors. So drones are very important. Part of the process of implementing transportation services. These days, the worldwide Global Navigation Satellite System (GNSS) and Inertial Navigation System (INS) help UAVs throughout the flight phase. However, GNSS+INS's imprecision renders it irrelevant for landing with take off, entailing the assistance of human drone operators along such stages. Unfortunately, the accuracy of the navigation technologies currently in use is insufficient to locate drones. Because of this, full automation of the landing technique is Not feasible. Since the study describes the design of the autonomous system, this paper offers a solution to this issue. Automatic landing approaches are made possible by Doppler-effect-based navigation algorithms as a sophisticated accuracy evaluation. Simulation studies serve as the foundation for the vertical take off and landing (VTOL) solution. The proposed frequency hopping modulation with the Doppler effect adaptive control model has been designed and implemented to simulate the successful landing of a typical drone structure. Experimental results have shown excellent metrics for frequency hopping signal of (20-50) MHz carrier frequency and 150 hops/sec specified to UAV speed at 80 m/s having Doppler effect with N=1024 and 2024 samples. The obtained results show that the received control signals for Doppler effects match the results of the adaptive compensator, which indicates an enhancement in the take-off and landing operations of the drone model. The observed improvement was up to 98%, with an error rate of less than 0.2%, with reception power ranging from 40 to 100 dB at the operating frequencies of the path model.

Keywords: Drones, vertical take-off and landing (VTOL), Global Navigation Satellite System (GNSS), Inertial Navigation System (INS), Doppler-Effect-based Navigation Algorithms.

1.Introduction

The need to use unmanned aircraft systems has increased in recent years. Its systems and techniques for controlling its movement have developed, which has contributed to the widespread use of drones in Air vehicles in civil and military applications. In this case, it has become difficult to monitor large areas of land or sea, which has led to the need to provide advanced systems and increase the search for new technologies to be the main goal of further research. Drones are now used in most aspects of life and human endeavors, including energy science (photovoltaic and high voltage plants) and agriculture.

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Lines), environmental preservation, inequity and recovery, forest with fire disclosure, water zone authority, facility monitoring, and so forth [1-4]. Costs and human resources for drones are decreased when surveillance processes are automated. Where it causes exploitation to result in a dynamic increase in its use in applications for civil law. Drones are primarily used for monitoring. Using optical sensors, it typically takes off and lands in the same spot. Recent studies on the micro-Doppler effect [3–7] offer a fresh approach to categorizing the goals needed for UAV takeoff. Additional frequency modulation in an echo is represented by a micro-doppler. The signal for target component movement produced by acceleration, rotation, and vibration [5,6]. Using high-resolution radar and contemporary signal processing methods, precise Doppler data can be highly helpful in resolving drone takeoff and landing issues. Target classification and identification using the micro-Doppler effect have been the subject of numerous investigations. One of the most often used pieces of information in conventional signal analysis is the fast Fourier transform (FFT), which can be used to determine the amplitude spectrum of Doppler waves. However, the signal's phase information is lost. Noise significantly affects the spectrum. Because of its exceptional noise resistance capabilities and low cost, a higher order spectrum, represented by the bispectrum, is better suited in this situation [7-10]. One of the fundamental factors for identifying and categorizing the majority of airborne objects is the m-Doppler signature. The primary silhouette is created by altering the additional frequency of the reflected wave that is produced by various body sections of the target. Vibrations or a combination of multiple-point scatters can cause micromotions. Figure 1 shows schematic diagram of common UAV navigation [11,12].

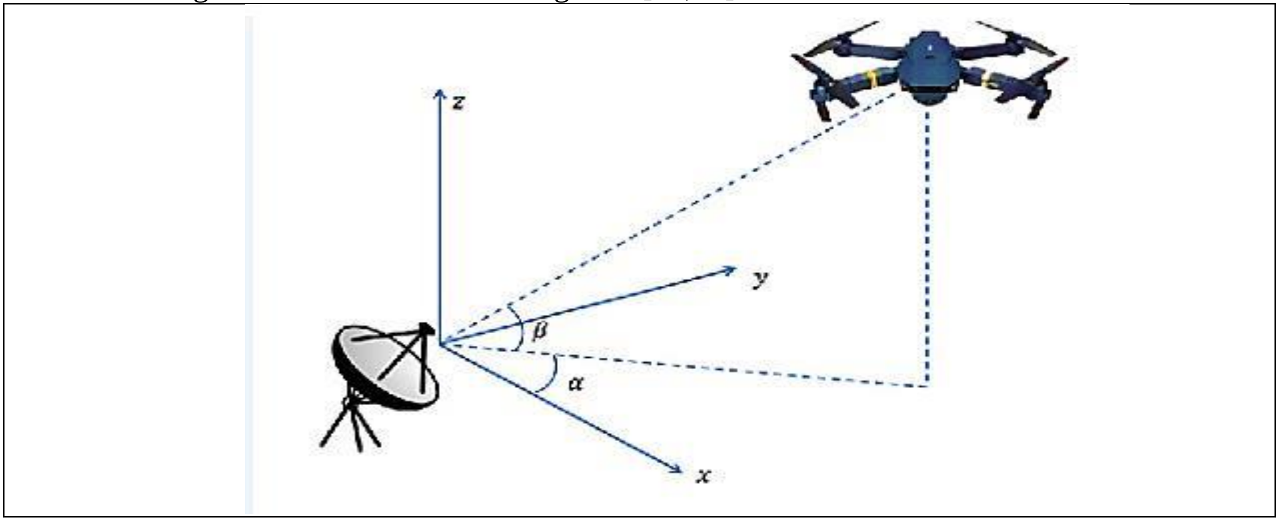

Figure 1: Schematic diagram of common UAV navigation [11,12].

There may be more risks worldwide that need for drone detection. This includes surveillance, aircraft crashes, terrorist attacks, radio frequency (RF) jamming, and unlawful filmmaking, including illegal filming in restricted regions and without permission. All of this is a result of commercial drones' affordability and operational flexibility. Additionally, in desert, mountain, and urban settings, the impact of Doppler signals caused by relative motion between the UAV and the ground station was examined. Time and frequency dispersion characteristics have been analyzed using an advanced platform and methodology. Scientific research has also employed the short-time Fourier transform (STFT) to examine Doppler signals [10-12].

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1.1 Landing system structure

To the best of our knowledge, very little research has been done on the micro-Doppler effect. There aren't many specialized research in the literature currently available on rotary-wing UAVs. Propeller length, motor revolution, and radio frequency center have all been examined in relation to the partial Doppler effect caused by propeller rotation. By setting up drones [13,14].

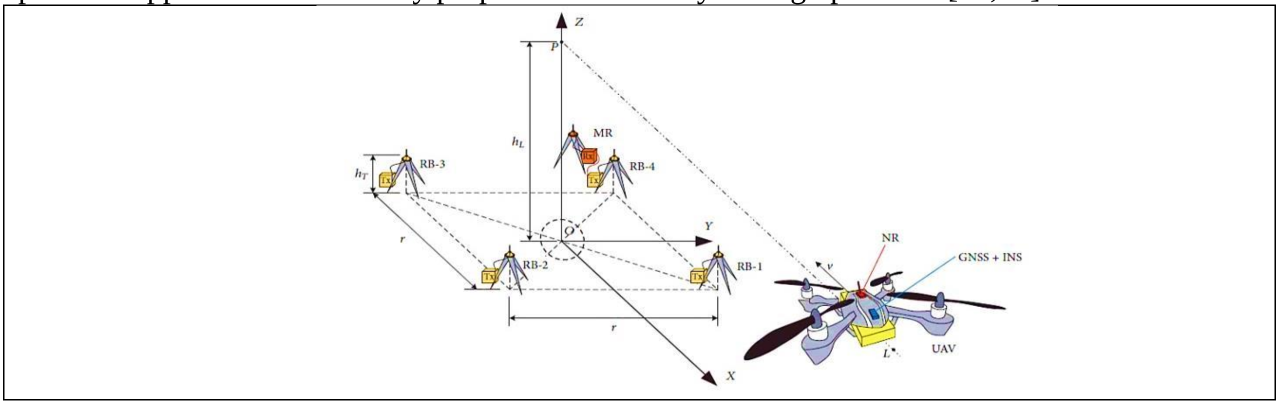

Figure 2: The automatic landing system construction [13,14].

Long-range navigation and landing are the two fundamental steps in the drone navigation process. Since exact coordinates cannot be obtained during this flight period, the long-range navigation system makes use of the integrated GNSS+ INS. But the falling phase need a rising with precise placement. Because a typical GNSS receiver is unable to provide this level of accuracy, a navigation phase is necessary. Make use of unique solutions. Figure 3 illustrates a generalized technique for pinpointing the precise position of UAVs during the landing phase [15].

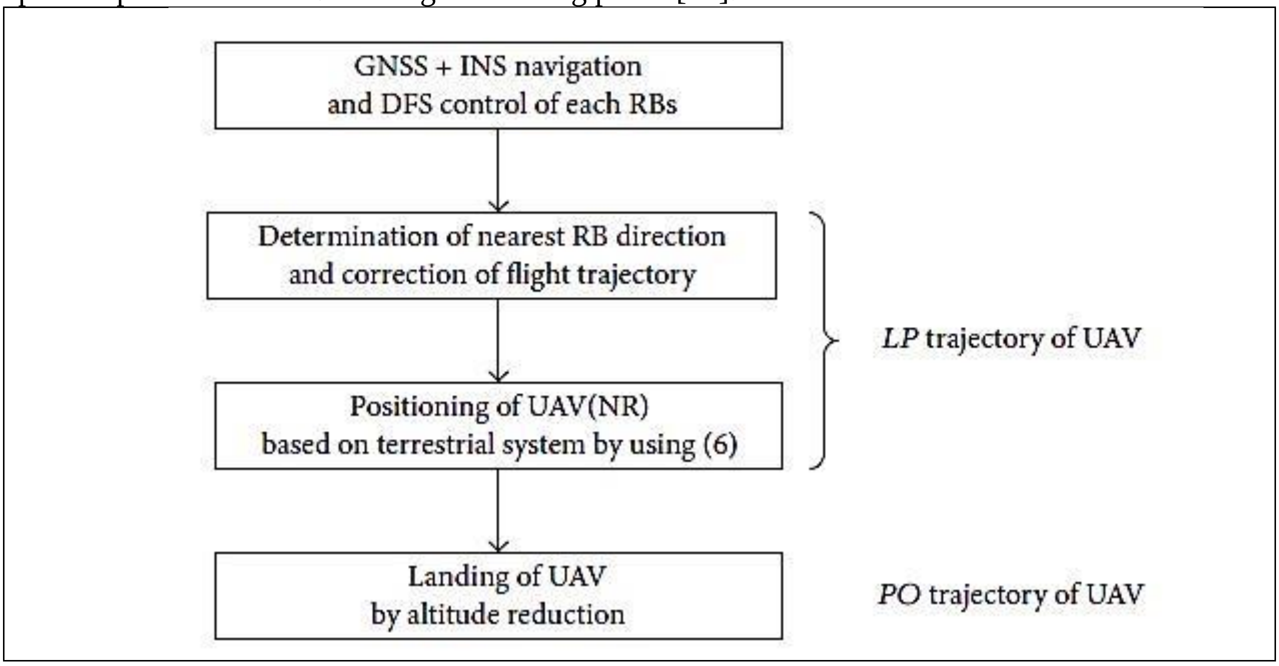

Figure 3: The design of the generalized algorithm for accurate UAV positioning during the landing phase [15].

The use of UAVs for air transportation is restricted by the high level of precision needed to determine the object's current position with the resilience needed concerning landing sites. Thus, the

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development of this transportation sector depends on the discovery of an accurate and straightforward positioning technique that would allow the user options in terms of landing places and conditions. In this study, a solution utilizing the Doppler effect's spatially unique properties is proposed. The neumerical relation that characterizes the Doppler frequency shift as a function of the Doppler frequency signal (DFS) that forms the basis of the navigation process that is being discussed [12-15].

1.2 Doppler effect analysis

Supposing that the receiving unit (i.e. the drone) is moving stably The velocity, v, relationship between Doppler frequency signals (DFSs), f_D, and the signal The source coordinates (x, y, z) are expressed by [11-15]:

$$f_D(x,y,z) \cong f_{Dmax}\frac{x-vt}{\sqrt{(x-vt)^2+y^2+z^2}} \quad (1)$$

where f_0 is the signal carrier frequency that is emitted, c which denotes the light speed, and $f_{D\max} = f_0 v/c$ is the maximum DFS. According to (1), DFS measurement provides the ability to ascertain the coordinates of two potential receiver positions for known (x, y, z), guidance, with amounts of v. We remove the uncertainty from the outcome by employing a model of two resource supplies which are situated at a length r. The error of estimation for the object's position coordinates is decreased by averaging the findings from multiple reference sources. The requirement for transforming the drone navigation scheme to the landing phase is well-defined the Doppler frequency signals (DFSs) that take place close to specific regional locations. At a considerable length along the landing station, the azimuth angle, φ, dominates f_D, such that:

$$\theta = \varphi, so\ f_D \cong f_{Lmax}.cos\varphi \quad (2)$$

Such that, θ is the angle formed between the direction of the signal source and the receiver's (UAV) velocity vector. The standard of this improvement is synchronous maximum of DFSs for every receiver base (RBs' waves since the UAV is traveling in the guidance of the signal origins. The elevation angle starts to have a big effect when it gets close. When the smallest DFSs drop to a predetermined threshold, like $0.8f_{D\max}$, the UAV alters its flight path by θ and starts moving in the direction of the closest RB. As shown in Figure 2, the RBs' coordinates are calculated in NR during movement for the model in which O is the origin and whose x-axis aligns with the new trajectory's direction. The signal Doppler frequency (SDF) technique is used to define formulas that characterize the coordinates of the RBs. Using the SDF technique, the formulas specifying the coordinates of regional points are established as below:

$$\tilde{x}_{UAV_k} = x_k + (\tilde{x}_k \cos\tilde{\alpha} + \tilde{y}_k\, sin\tilde{\alpha})cos\tilde{\beta} + \tilde{z}_k sin\tilde{\beta}, \quad \forall_{k=1,\dots,K} \quad (3)$$

$$\tilde{y}_{UAV_k} = y_k + \tilde{x}_k \sin\tilde{\alpha} + \tilde{y}_k\, cos\tilde{\alpha}, \quad \forall_{k=1,\dots,K} \quad (3.a)$$

$$\tilde{z}_{UAV_k} = z_k + (\tilde{x}_k \cos\tilde{\alpha} +$$

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$$\tilde{y}_k\, sin\tilde{\alpha})sin\tilde{\beta} + \tilde{z}_k cos\tilde{\beta},\quad \forall_{k=1,\dots,K} \tag{3.b}$$

The above equations denote the converting of the coordinates of the RBs with the system coordinates obtains from the UAV's aviation path, the coordinates of navigational of the UAV are established. Also, $\tilde{\alpha}$ and $\tilde{\beta}$ are the predicted guidelines of the UAV aviation in the azimuth (OXY) as well as altitude (OXZ) drones resolved related to the target landing station by utilizing (3), and $(\tilde{xk}, \tilde{yk}, \tilde{zk})$ are the real coordinates of the kth RB contained in every info structure; that is,

$$\tilde{\alpha} = atan\left(\frac{1}{K}\sum_{k=1}^{K}\frac{\tilde{y}_k + y_k}{\tilde{x}_k + x_k}\right) \tag{4}$$

$$\tilde{\beta} = atan\left(\frac{1}{K}\sum_{k=1}^{K}\frac{\tilde{z}_k + z_k}{\tilde{x}_k + x_k}\right) \tag{4.a}$$

The SDF method's study demonstrates that the trajectory position in relation to the waveform origin significantly affects how accurately the item is positioned.When DFS converges to zero, or when α approaches to 90∘, the least positional error happens. Thus, the weighted average coordinates relative to the individual RBs are utilized to estimate the UAV coordinates in order to reduce the navigation error.

$$\left(\tilde{x}_{UAV_k}, \tilde{y}_{UAV_k}, \tilde{z}_{UAV_k}\right) = \left(\frac{1}{W}\sum_{k=1}^{K} w_k\, \tilde{y}_{UAV_k}, \sum_{k=1}^{K} w_k\, \tilde{y}_{UAV_k}, \sum_{k=1}^{K} w_k\, \tilde{y}_{UAV_k},\right) \tag{5}$$

$$w_k = 1 - |F_k(t)|\; with\; W = \sum_{k=1}^{K} w_k \tag{5.a}$$

One could place the navigation model in any area condition because to the simplicity of the RB system. Furthermore, a major benefit of the suggested approach over the current techniques is the reduction of spectrum resources.

2. Related studies

In this section, the most prominent articles and publications that discuss the problems of taking off of unmanned aerial vehicles (UAVs) will be reviewed and address the solution options, especially those related to Doppler frequencies. The contributions of researchers and specialists in this field will be presented to identify the latest technologies and methods proposed to solve these problems, while reviewing the gaps, advantages and limitations. Accordingly, drones are considered a new threat to each the civil as well as the army world (Ritchie et al., 2015). Although its uses in fields like precision agriculture (Nguyen et al., 2016), Search and rescue, aerial photography, security surveillance, aerial monitoring, and entrepreneurship (Petrides et al., 2017), drone use has become widespread due to users abusing these devices for illegal purposes like drug smuggling, transporting weapons and other contraband materials (Osamu, 2017), invasions of privacy, reserved behavior, with another dangerous operations. UAVs carrying RF jamming units could perform long-distance attacks while enabling the culprits to go undetected, while also posing a threat to GPS receivers and cell phones (Hoffmann et al., 2016). Drones are dangerous because they might get sucked into a jet engine or crash aircraft during takeoff or landing, according to Sziill et al. (2017). The harm might be same to what would result from a collision with birds. A rogue party alerted Chancellor Merkel to the potentially hazardous nature of UAVs, and numerous drones have been observed close to nuclear power reactors, presenting serious risks to those facilities (Busset et al., 2015). In less than a month, from July 30 to August 19, 2017, a UAV crashed while transporting illicit items into an Oklahoma gail, also five additional occurrences were reported. Additionally, 28 pounds of heroin were dropped into the California boundary line city of Calexico. A boundary patrol agent swooped over the border fence and saw a drone. Later an UAV decreased drugs and a mobile toward a jail yard, three persons were taken into custody (Dedrone, 2015). A observed drone over London's Gatwick airport recently generated a distressing scenario that led to incoming flight diversions and a great deal of commotion (BBC, 2018). In conclusion, the drone exponential rise emploed over the last ten years presents a security risk due to misuse, which has raised concerns and necessitated the adoption of drone detection. Despite the progress made in drone detection efforts, micro-Doppler analysis is challenging because of the target's small size, high speed, low altitude, and disturbance from its blade rotation, which causes some information to be missed (Clemente et al., 2015; Nguyen et al., 2016; Contu et al., 2017; Osamu, 2017). In order to detect and stop a drone in an airport, Sturdivant & Chong (2017) presented a guideline principle for a system of systems (SoS) results. This merely required locating the independent systems that were already present on airport property and integrating them to function as a single unit through system architecture using ilities (SAI). relied on the assessed algorithm parameters, a proposed algorithm for UAS identification in Vilimek & Burita (2017) indicated a few areas where the system might be enhanced. Since the recently created system could identify sounds from any source, it is necessary to make improvements for sound recognition from many sources. According to the claim, helicopter UAS might be identified using linear predictive coding (LPC) coefficients, which might be enhanced by linking the system database. Park et al. (2017) employed neural object detectors based on Pan-Tilt-Zoom (PTZ) cameras to detect UAV in real time. The accuracy and speed of six convolutional object detectors were tested. When a drone trace is found, a command is issued to the PTZ camera to regard the UAV and employ the computed zoom action to maintain the horizontal and vertical field of view (FoV). While solar system dynamics (SSD) using Mobile-Net is faster, the faster region-relied convolutional neural network (R-CNN) was thought to be the best in terms of accuracy of F measures but the slowest. Aker and Kalkan (2017) also presented a convolutional neural network (CNN) for UAV localization inside a video structure. The network was trained utilizing a synthetic dataset of actual UAVs with bird photos. Actually, the UAV disclosure techniques relied on audio, visual imaging, radio frequency, heat, software-relied smartphone, and other non-technical (archery with webbing) approaches were covered in detail in the previous section, which also highlighted several noteworthy accomplishments. However, there might be some unsolved issues with tracking and detecting small drones that require attention. For example, a larger noise ratio in metropolitan areas may make it difficult to detect drone-generated audio frequencies, which are typically about 40 kHz (Ganti & Yoohwan, 2016). There is no way to track the RF link because certain drones have been found to follow a predetermined GPS course (Busset et al., 2015; Osamu, 2017). An objective using a dynamic histort undergos from little representative pixels and might be hidden in the case of camera-relied uidance. Moreover, Ganti & Yoohwan (2016) analyzed that heat revelation is less efficient due to a UAVs plastic structures with minimal heat exhaust; also lastly, noise is alternative threats because of several clients of unlicensed WIFI RF bands, as described in Nuss et al. (2017). The UAVs activities need stable updating in a biblographed tables, but this has also become a difficult problem for RF-based systems (Osamu, 2017). Therefore, a radar system is seen as a viable alternative because of its proven performance in military and automotive applications as well as in dim, noisy, and hazy or misty situations (Nuss et al., 2017; BBC, 2018). Thus, we divided the detection into two categories: major Doppler and micro Doppler (drones and other aerial objects).

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3. Methodology

In this Section, the proposed Doppler effect for the automatic drone landing model will be designed and adjusted with necessary operation settings. Thus, the structure of the proposed UAV landing FH-Doppler effect model using a BPSK/QPSK random channel is shown in Figure 4.

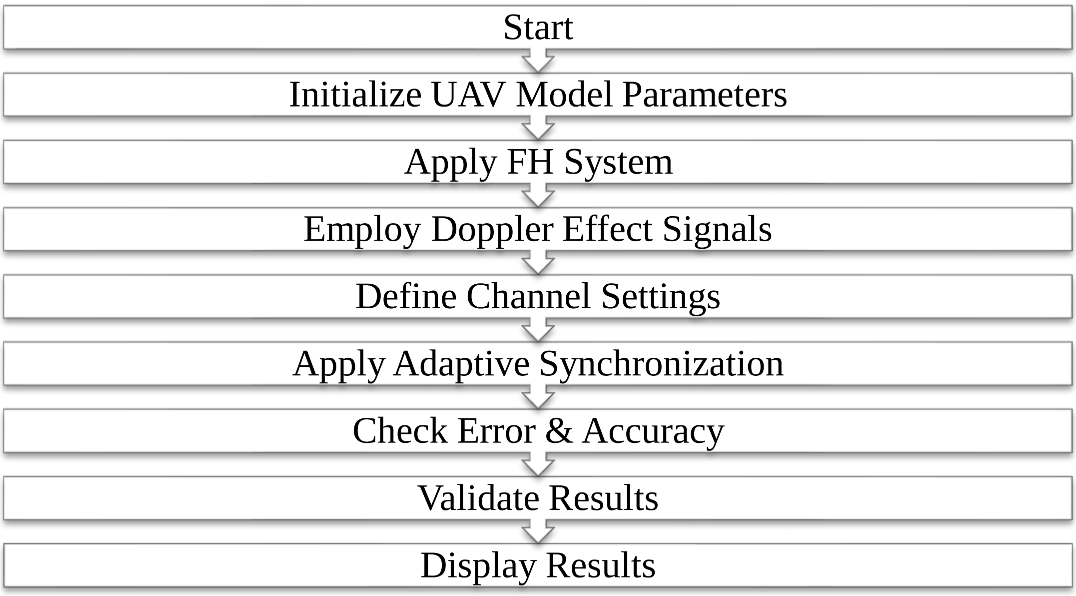

Figure 4: The flow chart structure of the proposed UAV FH-Doppler effect improved landing model using BPSK/QPSK modulation with AWGN random channel.

The proposed design model simulates drone technology by representing the frequency hopping signals of the transmitter. Also, the Doppler effects simulation system, which is used to control the take-off and landing of the drone, is represented in the best way. This is followed by the simulation of the equalizer system, which works to synchronize the work of all operating signals of the drone with the frequency hopping signals and Doppler effects signals to achieve the best simulation and improve the performance of representing the drone’s take-off and landing at the lowest rate. mistake.. Moreover, the design settings and parameters employed in the recommended model are listed in Table 1.

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Table 1: The design settings and parameters employed in the proposed UAV model.

	Sampling Frequency (f_s)	**Carrier Frequency (f_C)**	**Hopping Rate R_{Hop}**	**Maximum Doppler Shift f_{Dmax}**	**Duration τ**
Frequency Hopping Settings	10 K Samples/s	1K Hz	(10) Hops	100 Hz	1 sec
Adaptive Frequency Hopping Model	500 MHz	(20-50) MHz	(150) Hops.	1K Hz	1 sec
Doppler Detection Settings	**Relative Velocity (m/s)**	**Samples Number N**	**Frequency of the pilot tone (Hz)**	**Channel Quality**	**Modulation Type**
Parameters Values	80 m/s	1024 2024	50 K Hz	AWGN Random Interference Channel	BPSK QPSK

Also, the final block diagram of the proposed UAV enhanced landing control model is displayed in Figure 5.

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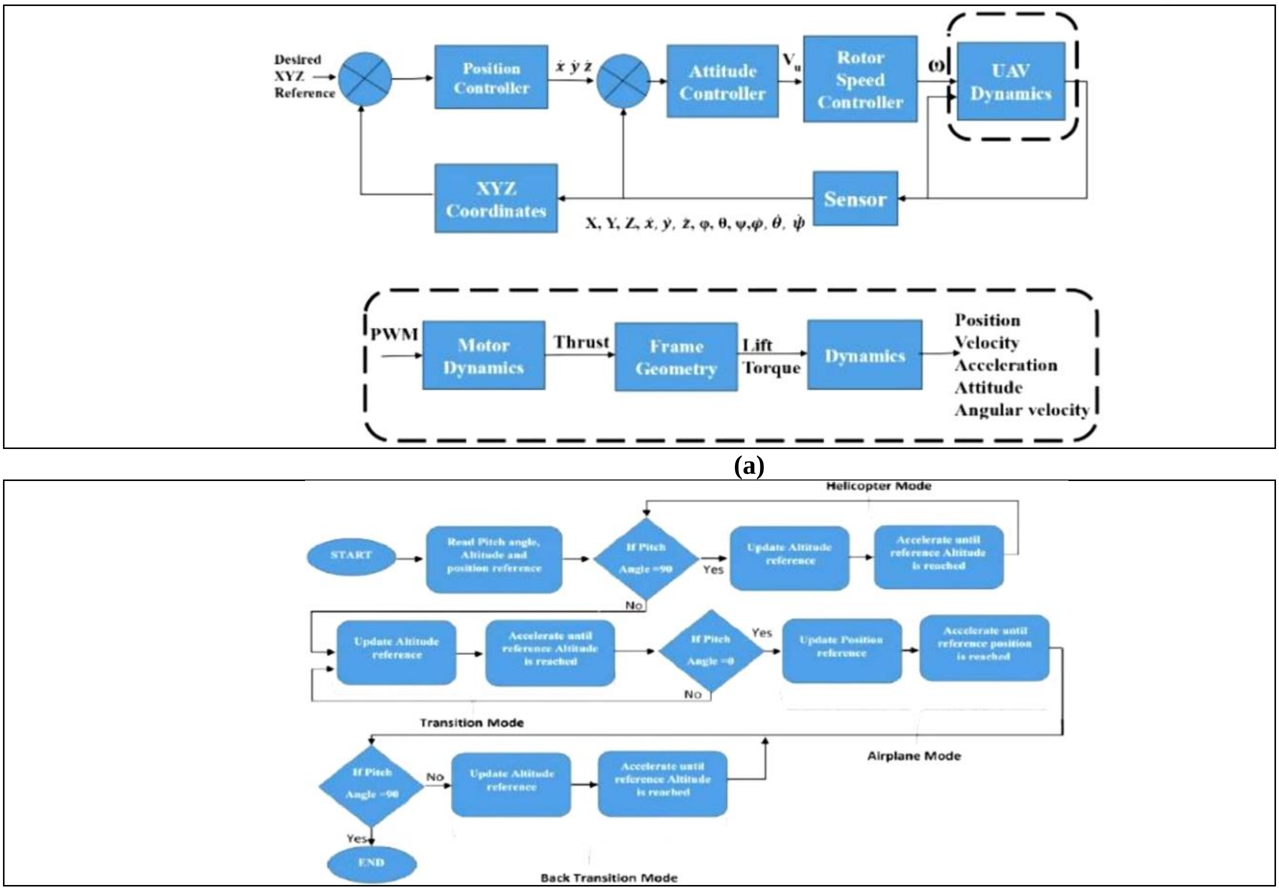

(a)

(b)

Figure 5: The final block diagram of the proposed UAV enhanced landing control model, (a) Transmitter section, (b) Receiver section.

Assuring improved system performance in the face of noise, uncertainties, disturbances, and model errors is the ultimate objective of a robust control system. When external Doppler effect turbulence acts on the system, which is especially challenging to model in the case of flight controller design, the Doppler effect control system is used to accomplish both performance and stability. With the design of control allocations for the transition period, the frequency hopping Doppler effect structure is suggested to regulate the UAV's attitude and altitude. Adding a rate feedback to the first loop of the suggested control method improves stability. By passing the attitude data to the second loop, the reference attitude commands are acquired. The linear velocity is returned to the controller via the third loop. Extensive simulations are used to confirm the stability and performance of the suggested method. Also, the adaptive controller is part of the horizontal flight control system.

4. Result and discussion

The implementation results of the proposed frequency hopping Doppler effect enhanced UAV landing control model have been implemented using MATLAB software application. This study used simulation-based experiments as a working methodology with premium MATLAB tools and libraries to perform training and testing with the design model settings. The effectiveness of the proposed technique was evaluated through the obtained metrics, including spectral efficiency, power efficiency, and bit error rate. Figure 6 shows the results of the adaptive Modulation Decisions (1 = QPSK, 0 = BPSK).

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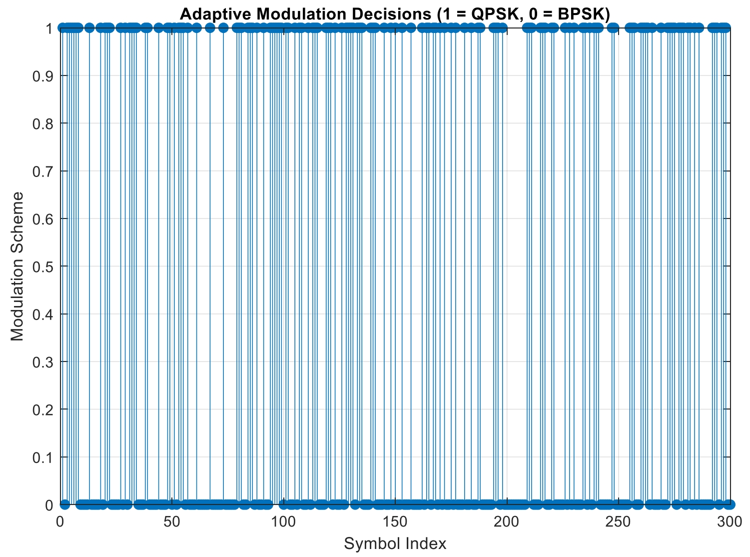

Figure 6: Adaptive Modulation Decisions (1 = QPSK, 0 = BPSK).

Also, Figure 7 displays the adaptive frequency hopping signals versus hops index.

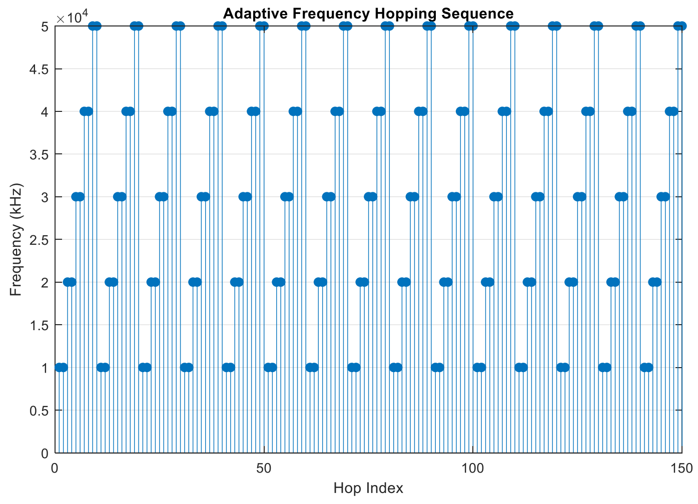

Figure 7: The adaptive frequency hopping signals versus hops index.

Also, the resulting Doppler shifted frequency hopping signal time signals have been displayed in Figure 8.

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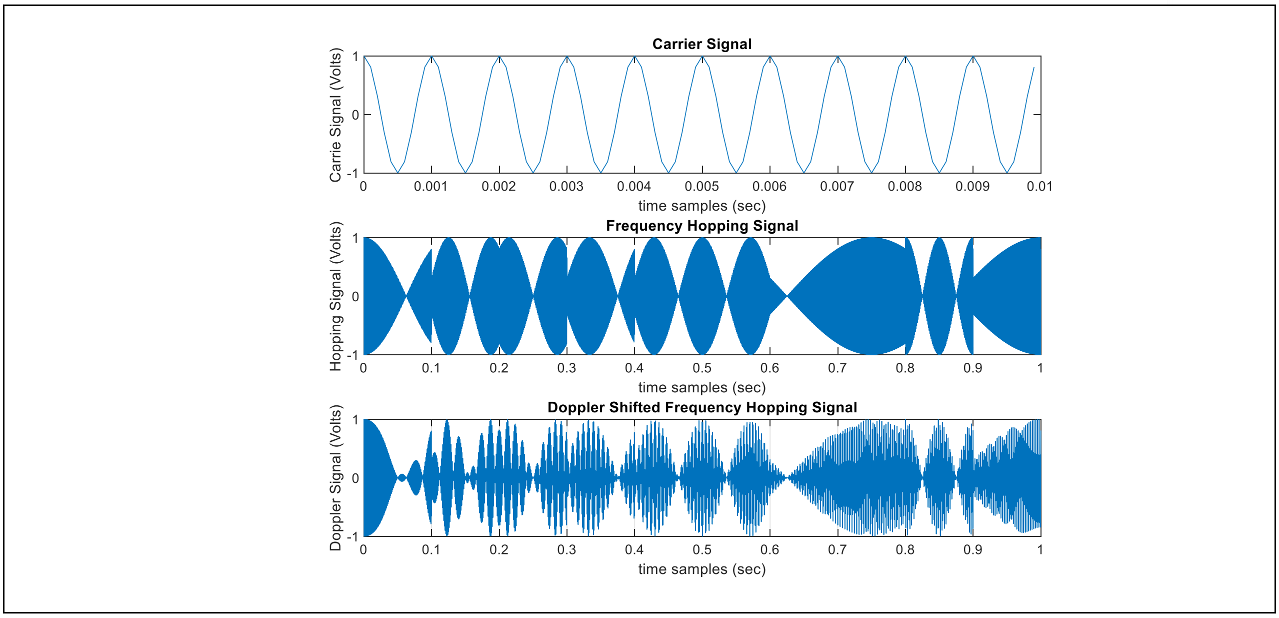

Figure 8: The Doppler shifted frequency hopping signal.

Moreover, the correlation signal between the time versus frequency synchronization is illustrated in Figure 9.

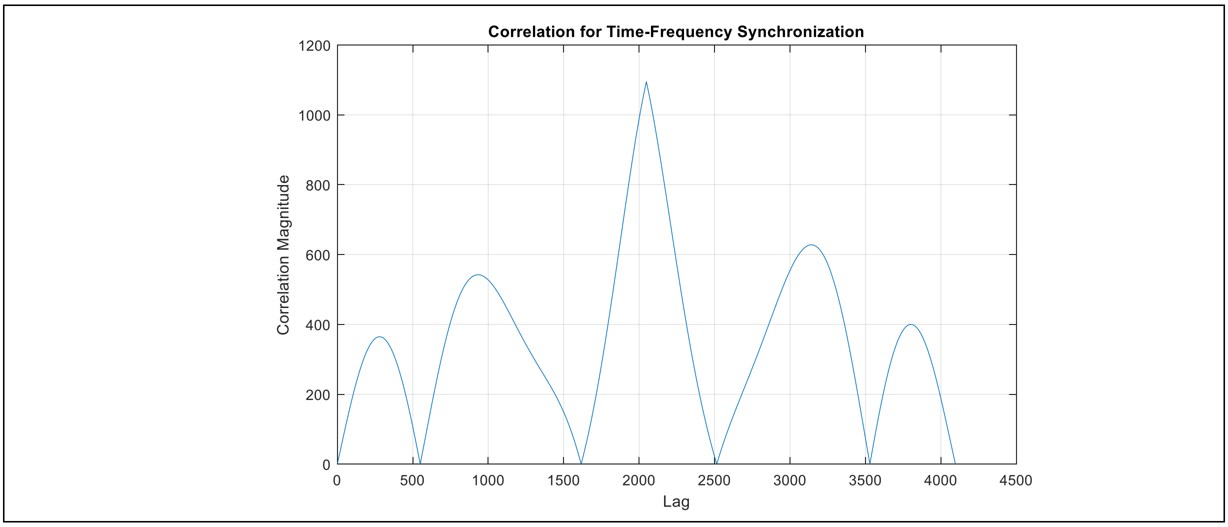

Figure 9: The correlation signal between the time versus frequency synchronization.

Next, the equalized modulated signal in time domain has been outlined in Figure 10.

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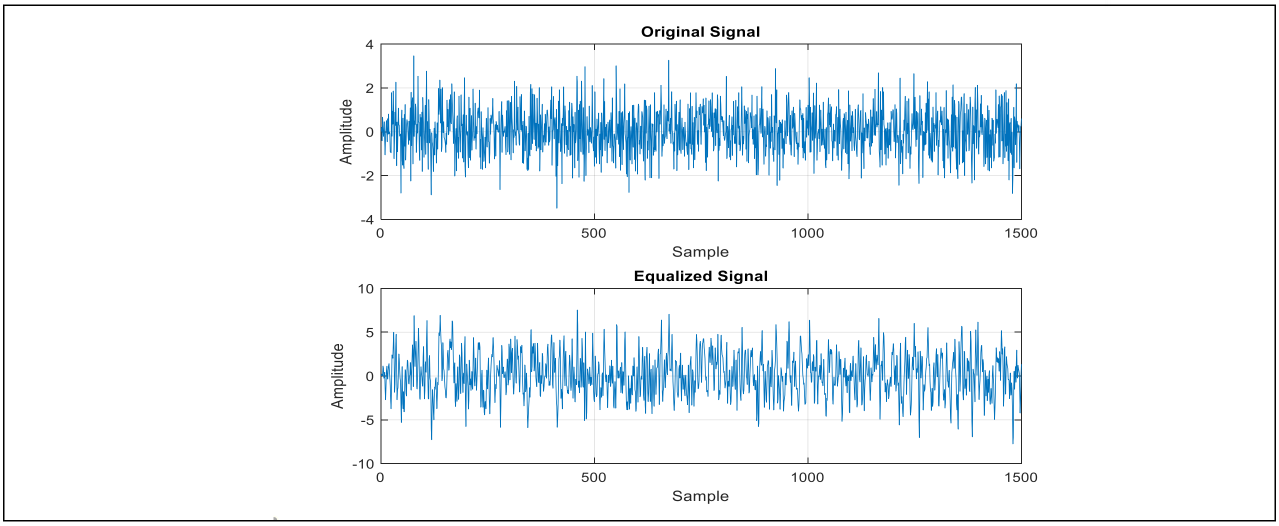

Figure 10: The equalized modulated signal in time domain.

Furthermore, the frequency diversity signals in the time domain as demonstrated in Figure 11.

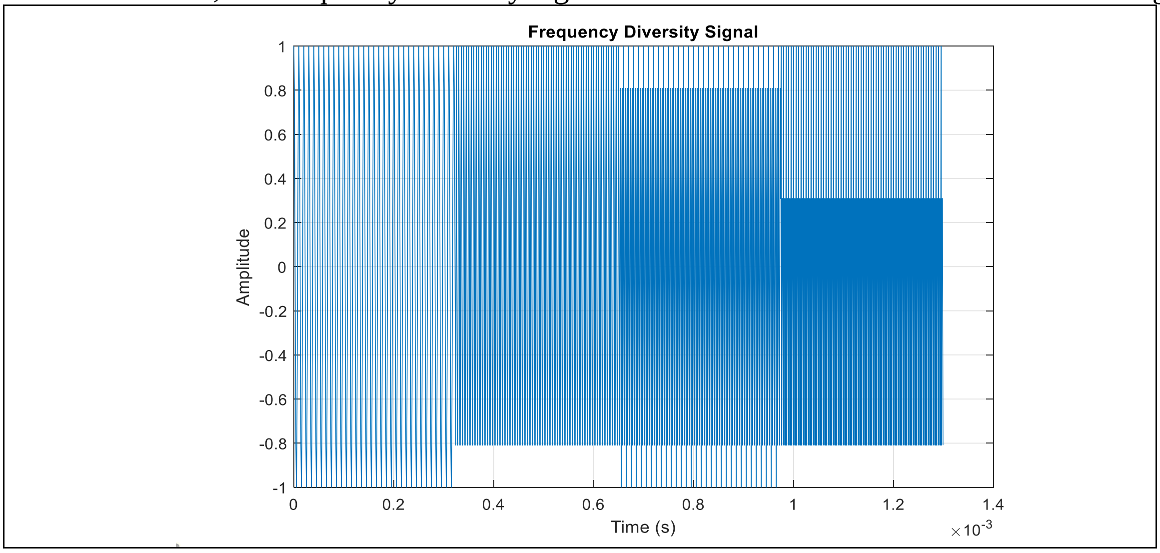

Figure 10: The frequency diversity signals in the time domain.

Moreover, Figure 11 shows the frequency hopped signal with doppler effect at N=1024 sample in time and frequency domains.

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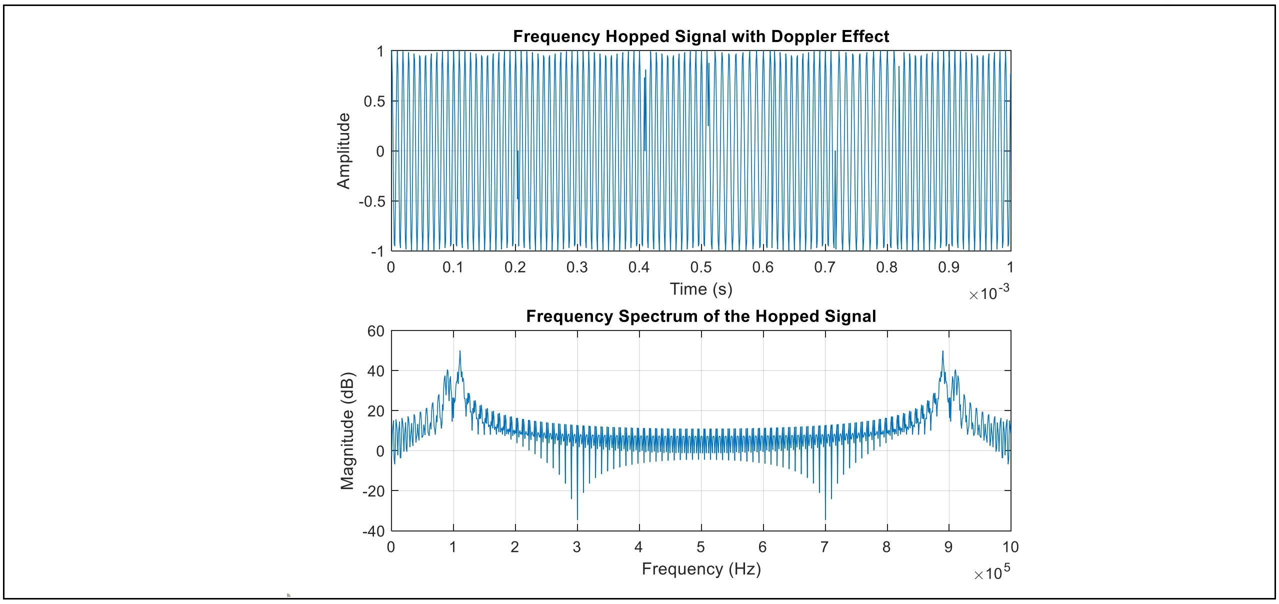

Figure 11: The resulting frequency hopped signal with Doppler effect at N=1024 sample, (a) Time domain, (b) Frequency domain.

Similarly, the results of the frequency hopped signal with doppler effect at N=2024 sample have been achieved in time and frequency domains as presented in Figure 12.

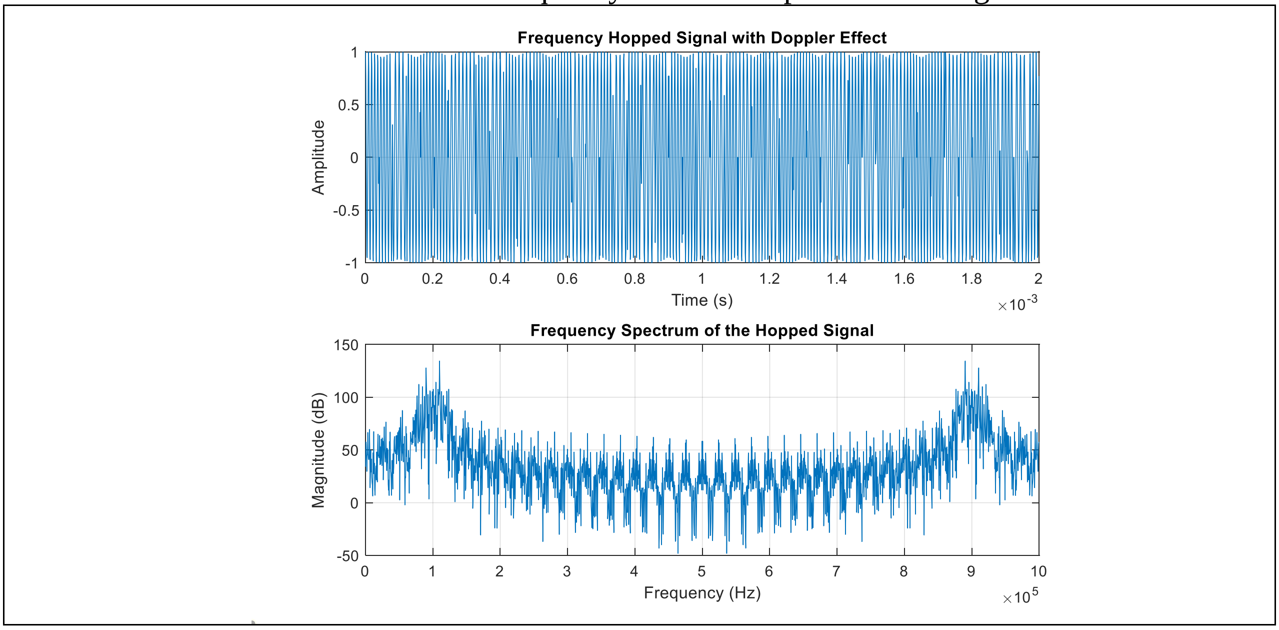

Figure 12: The resultin frequency hopped signal with Doppler effect at N=2024 sample, (a) Time domain, (b) Frequency domain.

Finally, Figure 13 displays the received signal with Doppler effect against the compensation signal.

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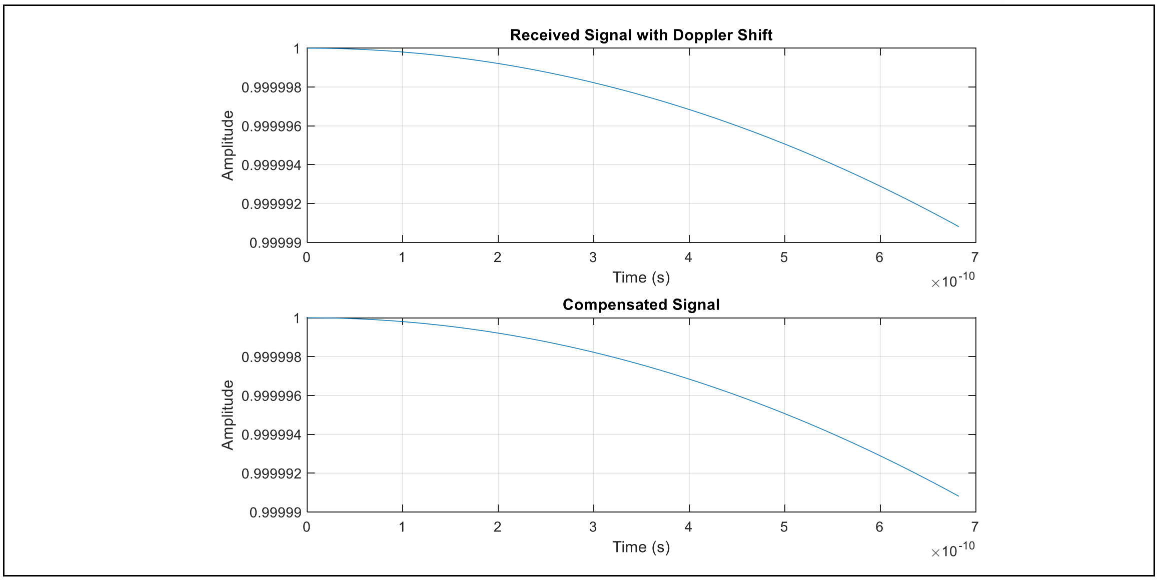

Figure 13: The received signal with Doppler effect against the compensation signal.

From the results obtained, one could notice that the results of receiving the control waves of Doppler effects match the results of the adaptive compensator, which indicates the improvement of the take-off and landing operations of the drone model. We notice an improvement of up to 98%, with an error rate of less than 0.2%, with a reception strength of 40 to 100 dB at the operating frequencies of the marching model.

5. Conclusion

In this study, the take-off and landing problems of unmanned aerial vehicles due to the inaccuracy of the GNSS+INS system, which makes them unsuitable for landing and take-off, were studied and addressed. It also addresses the inaccuracy of currently used navigation techniques that are insufficient to determine UAV positions, making full automation of landing technology infeasible. As a cutting-edge accuracy evaluation, automatic landing techniques were run via navigation algorithms based on the Doppler effect. The VTOL solution is based on simulation research. To replicate the successful landing of a conventional drone structure, an adaptive control model that combines frequency hopping modulation with the doppler effect has been developed and put into practice. With N=1024 and 2024 samples, the experimental results demonstrated outstanding metrics for the frequency hopping signal of (20–50) MHz carrier frequency and 150 hops/sec specified to UAV speed at 80 m/s with the doppler effect. It is evident from the results that the drone model's takeoff and landing operations have improved since the adaptive compensator's results match those of receiving the control waves of Doppler effects. At the marching model's operational frequencies, one could recognize an improvement of up to 98% with an error rate of less than 0.2% and a reception strength of 40 to 100 dB.

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