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Automatic Drones Detection using Micro Doppler Analysis, a Preliminary Modelling

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1. Abstract

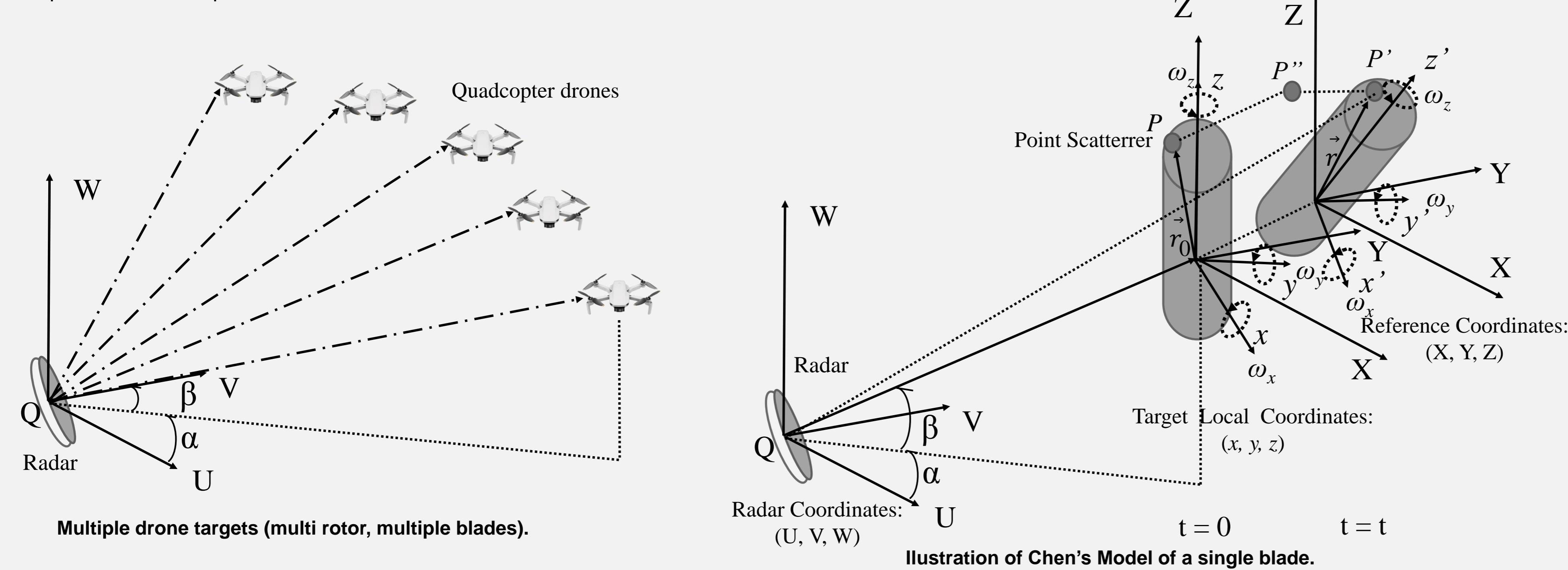
The study described herein focuses on the automatic detection of drones utilizing micro Doppler effects. Drones are often employed for both military and commercial applications. As a result of their small size, reasonable flight speed, and low flying altitude, they are difficult to spot. Because of the increasing density of drone deployment in the near future, a comprehensive detection and monitoring system is essential for safety. Preliminary analytical study has been conducted in this regard to examine the micro Doppler signature of drones caused by their rotating blades. Following that, such micro Doppler effects were investigated for possible target detection. In this context, rotational blades are presumed to have flat, rectangular point scatter reflections. The relevant signal model was then created by integrating geometrical and analytical functions. In fact, Chen's model was used as the basis and was updated for multi-rotor, multi-target scenarios. Finally, for target detection, a detection algorithm based on the Doppler filter has been constructed. As a result, the findings can be seen below.

2. Introduction

A drone's blade rotation produces a micro-Doppler signature (m-DS), which is a viable means of detecting and detecting quadcopter drones. The increased popularity of such drones in recent years is due to their improved flight capabilities, low cost, and ease of use. Drones are often employed for both military and commercial purposes. As a result of their small size, moderate flight speed, and low flying height, they are difficult to detect. These qualities, whether used in the military or public sectors, will represent a severe security risk. As a result, there is an increasing demand for reliable drone monitoring systems. One of the potential features for identifying drones using the micro-Doppler signal produced by its rotor blades. The radar cross-sections (RCS) and micro-doppler profiles of two-blade drones are modelled, and the m-DS of rotating blades employing electromagnetic scattering from two blades is investigated in [1,2]. The scientists used physical optics to simulate how these reflections altered as a function of frequency, azimuth, elevation angle, and object velocity [1,2]. The Chen model [2] is used for target and signal modelling in this study using a single carrier continuous wave doppler radar, and it is extended to allow for multi-rotor and multi-drone scenarios. The goal is to see if a multi-drone environment can be monitored to distinguish between Doppler targets and micro-doppler targets. Meanwhile, a simple Doppler filter [3] (high pass filter) based detection envelope has been utilized to identify drones based on their micro-doppler signature. As a result, employing micro-doppler features, this scenario may assist to not only identify, but also discriminating drones from other micro-doppler targets in noisy environments such as urban areas.

5. Signal Modelling

- Chen's model [1,2] incorporates observation angles, single carrier radar frequency, blade rotational speed and angles, object and blade starting coordinates, and blade dimensions to estimate the scattered RCS of blades. In addition, the flat rectangular blade and point scatter (physical optics) were included as hypothesis.
- Equation (7) and (8) illustrate the received based band phase signal and RCS calculations respectively. The detail of blade's Rotation matrix \vec{R}_0 is not presented in this poster.



$$s(t) = \rho(x, y, z) \exp \left\{ j2\pi f \frac{2r(t)}{c} \right\} \quad (7)$$

$$\sigma_{fp} = 4\pi \frac{L^2 H^2}{\lambda^2} \sin^2 \theta \left(\frac{\sin n(2\pi L/\lambda) \cos \theta}{(2\pi L/\lambda) \cos \theta} \right)^2 \quad (8)$$

$s(t)$ received base band signal of a single point
 $\rho(x, y, z)$ reflectivity function
 $r(t)$ scatter point coordinates
 \vec{R}_0 initial target coordinates
 \vec{V} velocity vector of target
 \mathfrak{R}_t rotational matrix of the target and local structures
 \vec{r}_0 initial coordinates matrix of the rotational points

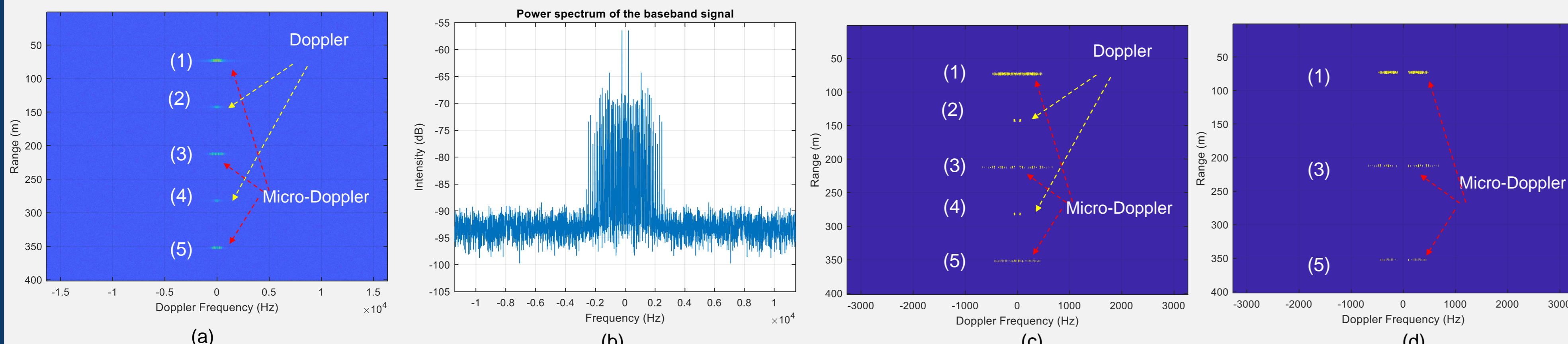
Note : The figures were drawn with the contribution of Mr. Thomas ALBERT (student's SOIA - ENSTA Bretagne)

8. Results

Chen's model was modified for multi-rotor, multi-blade, and multi-target scenarios, and white gaussian noise was included. The results shown below were obtained using $f = 10$ GHz of Single-carrier Continuous Wave Radar (SCWR), and the drones have four rotors with two rectangular blades (30cm x 10cm) each. The received signals were then subjected to baseband phase signal analysis (Figure (b)) before being treated to range-doppler analysis (Figure (a)). A power threshold has also been used to distinguish objects from noise. Figure (c) depicts a binary visual of range-doppler analysis following the power threshold filter. As a result, the binary image confirms all five targets. Following that, assuming that the maximum clutter micro-doppler frequency is 200Hz, a high pass filter of 200Hz was used to distinguish micro-doppler targets from Doppler targets. Because the Doppler frequency of micro-doppler targets is substantially higher than 200Hz. Figure (d) depicts micro-doppler targets extracted from all Doppler targets.

- Doppler targets : Drones with linear velocity and no rotational structures.
- Micro-doppler targets : Drones with linear velocity and rotating blades are (4 rotors with 2 blades per rotor).

- Figure (a) : Doppler-range profile of Multi targets with doppler (2 & 4) and micro-doppler effects (1,3 & 5)
- Figure (b) : Cumulative baseband of the reflected signal for a given time window
- Figure (c) : Doppler-range profile of Multi targets with doppler (2 & 4) and micro-doppler effects (1,3 & 5) after power threshold filter
- Figure (d) : Filtered micro-doppler targets (1,3 & 5) after bandpass filtering



9. Conclusion

The work presented here was carried out to evaluate the possible applicability of micro-doppler effects for automatically detecting multiple drones. Chen's micro doppler modelling was utilized as the basis for this scenario, which was then modified to produce multi-target scenarios. The analytical signal and detection results were also shown. The constructed analytical model, along with the proposed signal processing and detection methods, presents a promising route for further study in this area. Furthermore, modifications to micro-doppler targets with the inclusion of the main body of the drones, as well as noise addition SNR < 0, will be explored in future in order to validate the model's resilience. The authors then recommend numerical and field validation of the proposed model for further investigation.

3. Objectives

This work has been accomplished with the following objectives:

- Modelling of micro-doppler targets represent drones.
- Estimation of RCS and received signals for a given radar source.
- Add white Gaussian noise to the reflected signals.
- Perform 1D and 2D signal analysis.
- Create a detection scenario.
- Extend the model for a multi rotor, multi target scenario.
- Perform 1D and 2D signal analysis of multi-targets to validate detection

4. Doppler Principles

The Doppler effect is the apparent shift in frequency of a signal generated by a relative motion of the source or observer. The phase difference between the transmitted and received signals are calculated by the continuous wave radar. As indicated in Equation (1), the size of this phase difference is the ratio of the wavelength of the signal to the distance travelled. Furthermore, if the distance to the reflector is not constant the phase difference varies as a function of time, as shown by Equation (2). Moreover, provided that the Doppler frequency (f_D) is consistent with Equation (3).

$$\varphi = -2\pi \frac{2r}{\lambda} \quad (1) \quad \text{where } \varphi = \text{Phase difference}$$

$$\varphi(t) = -4\pi \frac{r(t)}{\lambda} \quad (2) \quad \begin{matrix} r = \text{Distance of the reflector to the antenna} \\ \lambda = \text{Wavelength of the transmitted signal} \\ v = \text{Velocity of the target / structure} \\ f_D = \text{Doppler frequency} \end{matrix}$$

$$f_D = \frac{2 \cdot v}{\lambda} \quad (3)$$

Hence, the relative motion of a blades in the moving drones produce micro-Doppler effect that can be defined by Equations (4), (5) and (6).

$$r(t) = \|\vec{R}_0 + \vec{V}t + \mathfrak{R}_t \vec{r}_0\| \quad (4)$$

$$f_D = \frac{2f}{c} [\vec{V} + \vec{\omega} \times \vec{r}] \quad (5)$$

$$f_{md} = \frac{2f}{c} [\vec{\omega} \times \vec{r}] \quad (6)$$

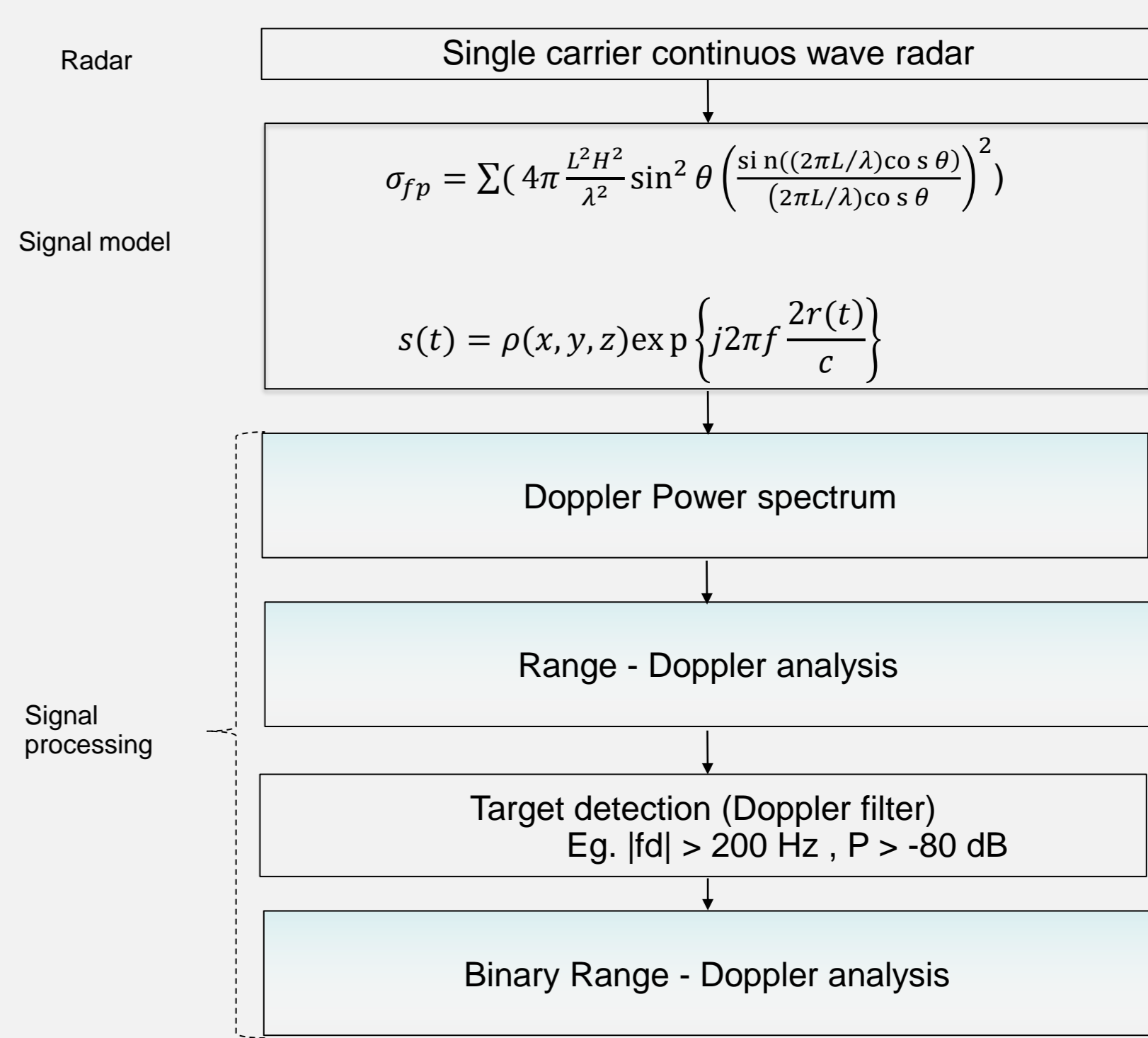
6. Model Hypothesis

In this respect, several hypotheses had been made at this stage, as follows.

- The rotor blades are flat and rectangular
- Reflection occurs in the physical optics range (point scatter)
- The Radar is single carrier continuous wave
- Noise and clutter adhere to white Gaussian
- Received signal SNR > 0 dB
- m-D frequency of Sea / Ground clutter: < 200Hz [4]

7. Analytical Detection Model

The suggested detection model was developed by following the steps shown in the diagram below. The steps, on the other hand, include a radar source, a modified Chen's model, and signal processing including Doppler cumulative power spectrum and range-doppler analysis. Then, to filter micro-doppler targets, target detection techniques such as power threshold and micro-doppler high pass filter (Doppler filter) were used. Finally, binary range-doppler signal images were used to display the detected targets.



10. References

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