PROJECT ON THE DESIGN OF A PRECIPITATION PREDICTION PULSE DOPPLER RADAR

PROJECT OVERVIEW

Introduction

In this project the design of a pulse doppler radar to predict the presence as well as intensity of precipitation is carried out and implemented in the Jupyter Notebook. A number of radar parameters were used to during the design and most of the ones used are the ones that can assist in the prediction of a distributed target such as precipitation. Amongst the parameters used are the radar unambiguous range, the target reflectivity, the power received as well as the unambiguous doppler velocity factor.

Problem statement

The traditional ways of rainfall prediction are not enough to predict the rain especially its intensity as well as the rate, hence the need for the design of the pulse doppler precipitation prediction radar.

Proposed solution

In this project we will look into;

a. How the reflectivity factor determines the accuracy in the prediction of the precipitation intensity and form.

b. The impact of the unambiguous velocity factor in the prediction of whether the precipitation being observed is either moving away or towards the radar.

c. We will also use the received power calculated by the Probert-Jones equation to determine the precipitation intensity basing on the power received observed on the radar receiver as well as the maximum unambiguous range.

Objectives

a. To come up with a precipitation prediction pulse doppler radar simulation tool.

c. To predict radar target reflectivity to entail if that being observed by the radar is precipitation or not.

b. Predict the significant ambiguities inherent in trying to determine the particular rain rate and show the output in a simulated radar display.

METHODOLOGY

During the system design the parameters below and their contribution towards the prediction of the precipitation are looked into

The Reflectivity factor

The fundamental measurable property of precipitation is the radar reflectivity η which also depends on the size and concentration of the hydrometeors and their thermodynamic phase.

For a given form of precipitation from that which is hardly noticeable to extreme large hail, reflectivity factor can be calculated as;

$$z_e = \frac{\eta\lambda^4}{0.93\pi^5}, \quad (1)$$

Where Ƞ is the reflectivity of the target , λ is the wavelength and 0.93 is the dielectric factor of water.

The logarithmic reflectivity factor ZdBZ relate with the rain rate by the equation;

$$R(\frac{mm}{h}) = \left(\frac{10^{(x/10dBz)}}{200}\right)^{5/8}, \quad (2)$$

R(mm/h) is the rain rate and x is the reflectivity factor of various forms of precipitation from the hardly noticeable form to extreme hail. So, the reflectivity is the most fundamental parameter that can be used to determine whether what is being observed in the radar receiver is rain or not and which probable form.

So, from the above, reflectivity factor tends to increase with increase in the rain rate, meaning it will be higher for extreme large hail than the light rain for example.

Z(Dbz)	R (mm/h)	R(in/h)	Intensity
5	0.19	<0.01	Hardly Noticeable
10	0.31	0.01	Light mist
15	0.54	0.02	Mist
20	0.91	0.04	Very light
25	1.57	0.06	Light
30	3.34	0.13	Light to moderate
35	5.88	0.23	Moderate rain
40	11.15	0.44	Moderate rain
45	18.63	0.73	Moderate to heavy
50	34.38	1.35	Heavy
55	58.72	2.31	Very heavy/ small hail
60	141	5.57	Extreme/ moderate hail
65	287	11.31	Extreme/ large hail

Table1.0 : The table reflectivity factor and the precipitation rates per given intensity

The unambiguous Doppler velocity factor

The maximum unambiguous doppler velocity factor which is also crucial in the measurement precipitation occurrence certainty is given by,

$$v_{max} = \frac{PRF \cdot \lambda}{4}, \tag{3}$$

Where v_{max} is the maximum unambiguous doppler velocity and PRF is the pulse repetition frequency, which is also the sampling rate in the doppler phenomenology, so

$$2fd = PRF, \tag{4}$$

So, when the target (precipitation) is moving away from the radar, the wavelength of the return echo is larger than that of the emitted electromagnetic pulse. When the target is moving towards the radar, the radar return echo has a shorter wavelength than that of the emitted pulse. The wavelength / frequency shift can be used now to calculate the doppler velocity, which is the component of the movement either towards or away from the radar, also called the radial velocity,

$$V = -\frac{f\lambda}{2}, \tag{5}$$

where f is the frequency shift, V is the radial velocity and λ is the wavelength.

The received power

For a distributed target such as precipitation, which fills the radar beam, the amount of power received by a given radar is summarized by the Probert-Jones equation for meteorological radar as follows,

$$P_r = P_t \frac{G^2 \lambda^2 \theta_\phi h}{1024\pi^2 In2} \frac{\eta}{R^2} \tag{6}$$

where θ and ϕ denote the antenna beamwidth in the horizontal and vertical planes, h is the pulse length of the transmitted signal, and η is the radar reflectivity of the target.

P_r is the average echo return power. It is to be noted that the Probert- Jones equation interpret average returned power, which is calculated from more than one pulse of energy. Averaging is necessary since P_r varies greatly from pulse to pulse.

P_t is the power transmitted from the in the outgoing energy burst. The average return power varies directly with P_r.

G is the gain of the radar antenna, being a measure of the ability of an antenna to focus energy into a beam for both the transmitted and received EM waves.

R is the range to target to the target and the reflected energy reaching the antenna varies inversely with the square of the target

λ is the wavelength of the RF energy expressed in meters. The amount of power received varies directly with square of the RF energy wavelength.

The Probert-Jones equation assumes that the antenna pattern has a Gaussian shape and that the scattering volume is uniformly filled. From the equation above it can be noticed that power received from the target is directly proportional to the factor ($\frac{\eta}{R^2}$) of which is dependent on both the reflectivity of the target be it hailstorm or light rain as well as its range. However, of the two the range R can be determined by the equation,

$$R_{max} = \frac{C}{2.PRF}\,, \tag{7}$$

where R_{max} = is the maximum unambiguous range
C = 3 x 108 m s^{-1}
PRF = pulse repetition frequency [s^{-1}], i.e., number of pulses per second. So, dependant on the two elements of the factor it can be shown by equation (6) that the power received is inversely proportional to the range R calculated in equation (7). We can now tell the reflectivity η knowing the power received by the radar receiver through making it the subject of the formula in equation (6).

The practical interpretation of the variables in the Probert-Jones relates different characteristics of the radar target to the amount of returned power and therefore the indicated intensity of precipitation. The power received from a precipitation target is then highly dependant on the particle size. In fact, a drop 3mm in diameter would return 729 times as much power as a drop which is 1mm in diameter. So target reflectivity increases rapidly as the drop size grows, even though the total water content may remain essentially the same.

SUMMARY OF THE RESULTS.

From the study carried out above the reflectivity of various forms of precipitation is quite fundamental in the prediction of the intensity as well as the presence if in any case it will be there. The reflectivity factor tends to increase with increase in the rain rate, meaning it will be higher for extreme large hail than the light rain for example. Precipitation targets produce a range of the logarithmic value of precipitation, dBZ values from 0 in very light rain to in excess of 60 in extremely heavy rain and/ or hail. Without knowing the precise nature of the targets at the far end of the radar beam, the pulse doppler radar designed uses the measured average returned power to estimate the equivalent reflectivity Z_e of all the targets. During the study Z_e values have been grouped together in 13 distinct ranges as shown in table 1.0. The values of the reflectivity factor have been plotted in the fig 1 to simulate the relationship of the reflectivity fator and the rain rate as below;

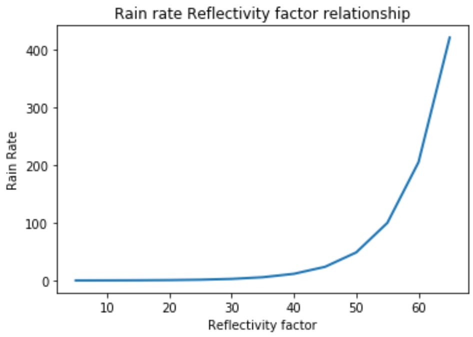

Fig 1.0 Rain rate reflectivity factor relationship

It was also demonstrated using the Probert-Jones equation that the power received from a distributed target at the radar receiver is highly dependent on the factor ($\frac{\eta}{R^2}$), which in turn is dependant the two elements in it being the reflectivity and the range of the target squared, meaning that power received is inversely proportional to the range of the target from the radar receiver. So, given power received of a particular distributed target at a given range we can make the reflectivity η subject of the Probert equation, thereby determining the type of the target in question.

We also looked into the relationship of the area of the clutter to the radar range using the equation,

$$A_C = \frac{C\tau}{2} R_C \theta_3 \text{ , where} \tag{8}$$

θ_3 is the 3Db azimuth beamwidth of the antenna
A_C is the area of the clutter cell.

C is the speed of light

Rc is the unambiguous range of the clutter

The relationship was looked into and found to be as shown in fig 2.0 below

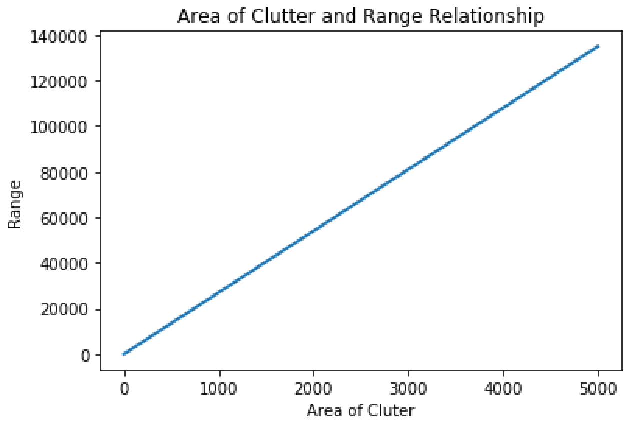

Fig 2.0: Area of Clutter and Range Relationship.