



Radar-based object detection at drones and underground facilities for enhanced environmental perception in Indian mines

Pritam Sanyal¹, Tamesh Halder^{2*}, Anindya Ghosh³, Arindam Basak⁴, Rintu Kumar Gayen⁵, Debashish Chakravarty²

¹Department of Civil Engineering, Indian Institute of Technology Delhi, India

²Department of Mining Engineering, Indian Institute of Technology, Kharagpur, India

³ATDC, Indian Institute of Technology, Kharagpur, India

⁴KIIT, Odisha, India

⁵IEM, Kolkata, India.

*Corresponding Author

Tamesh Halder

Department of Mining Engineering, Indian Institute of Technology, Kharagpur, India

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Abstract: This research paper presents an innovative approach to object detection in drones utilizing the HB100 radar module. The primary objective of this study was to develop a system capable of capturing both stationary and moving objects, regardless of the visibility conditions in the surrounding environment. By integrating the HB100 radar module into the drone's architecture, real-time object detection and tracking capabilities were achieved, significantly enhancing the drone's perception abilities. The experimental setup involved integrating the HB100 radar module for a quad-copter drone external platform linked to the base station; enabling the collection of radar signals and subsequent processing for object detection. Various stationary and moving objects were employed to evaluate the effectiveness of the system under different environmental conditions, including scenarios with limited visibility, such as fog or darkness and power-bandwidth. The HB100 radar module operates based on the principle of Doppler radar. It emits continuous wave (CW) signals and detects the Doppler shift in the reflected signals to 1(zero crossing). This article motivates on the RGB Charged Coupled Device or night vision camera and Synthetic Aperture Radar (SAR) integration at UAV or drone platform. The on board Arduino micro-controller trigger the external circuit of the airborne transceiver. The modular change of the COFFE CAN radar digital signal processing (DSP) and HB100 radar infer the omni-direction antenna piece out with the directional DSP. As a result, the wide sense stationary (WSS) signal forms image of inner-wall and outer wall but clinging on syphoned based diffractive medium caused on deliverable environmental conditions. The changing to standing wave in a reflecting wall distance or determine the presence and movement of objects. The safety and mine hazard conditions the flooding and double differentiating checks it accelerating values on positive and negative sides forming colored pattern of moving directional object movement. The phase patterns of these images are the region of convergence using Z transform on those images changing values to spirals. Lastly, the issues of whole setup is tested with load balancing on both on weight and electric circuits DC due to not operating shunting based on electron discharge phenomenon in any environmental conditions.

Keywords: HB100 radar module; object detection; drone; environmental perception; real-time tracking; visibility constraints.

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1. Introduction

The development and application of drone technology have revolutionized numerous industries, including surveillance, mapping, and delivery services. Among the critical components that enable drones to operate effectively is the integration of radar systems, such as the HB100 radar. This research paper aims to explore the utilization of HB100 radar in drones, investigating its functionality, advantages, and limitations. By examining the capabilities of this radar system and its impact on drone operations, this study seeks to provide valuable insights for researchers, engineers, and industry professionals in enhancing the performance and safety of drone-based applications. HB100 radar is commonly used in drones for various applications due to its compact size, low power consumption, and cost-effectiveness. Here are a few reasons why the HB100 radar module is utilized in drones.

Obstacle Avoidance: The HB100 radar module can be used to detect and avoid obstacles in the flight path of a drone. By emitting radio waves and analyzing their reflections, the radar can determine the presence of objects in the vicinity of the drone, enabling it to adjust its course and avoid collisions (Dill *et al.* 2019).

Altitude Measurement: Drones equipped with an HB100 radar module can accurately measure their altitude above the ground. The radar sends out signals and measures the time it takes for the echoes to return, allowing the drone to calculate the distance to the ground. This information is crucial for maintaining a stable flight and executing altitude-based maneuvers (Aldowesh, *et al.* 2019, Kumari, *et al.* 2020).

Navigation and Positioning: The HB100 radar module can assist in drone navigation and positioning. By analyzing the reflected signals from the ground or other objects, the radar can provide information about the drone's relative position and movement. This data can be combined with other sensors to enhance the drone's overall navigational capabilities <https://www.limpkin.fr/public/HB100/>.

Target Tracking: The HB100 radar module can track moving targets in real-time. This feature is particularly useful in applications such as surveillance, search and rescue, or monitoring wildlife. By detecting and tracking the position of targets, the drone can autonomously follow or monitor them while maintaining a safe distance.

Weather Conditions: Radar technology can help drones gather data on weather conditions, such as rainfall intensity or wind patterns. By analyzing the radar returns from precipitation or atmospheric disturbances, drones can provide valuable meteorological information or make informed decisions about flight routes in adverse weather conditions.

Overall, the HB100 radar module offers drones a reliable and cost-effective solution for obstacle avoidance, altitude measurement, navigation, target tracking, and weather sensing, enhancing their autonomy and safety during operations (Sipos, *et al.* 2017).

The section 2 describe the research methodology of the article and micro-controller code whereas, section 3 depicts the results and discussions. Section 4 concludes the article.

2. Methodology

Here are some specifications of the HB100 radar module:

Transmitter: The HB100 radar module consists of a transmitter section that generates and emits continuous wave signals at a frequency of 10.525 GHz (X-band). These signals are typically produced using a voltage-controlled oscillator (VCO) or a frequency synthesizer.

Antenna: The module has an integrated antenna that transmits the emitted radar signals into the surrounding space. The antenna also receives the reflected signals from objects in the vicinity.

Mixer: The module includes a mixer that combines the transmitted signal with the received signal. The mixer's purpose is to extract the Doppler-shifted frequencies resulting from the movement of objects.

Intermediate Frequency (IF) Amplifier: The mixed signals are passed through an IF Amplifier. The amplifier amplifies the signals and filters out unwanted noise and interference. According to Woodward theorem, the RF signal to IF signals conversion with minimum loss of various signal parameters, *i.e.*, time, frequency, bandwidth, shape, time-bandwidth product, shaping or edge filtering etc.

Demodulator: The demodulator section demodulates the amplified signals to extract the Doppler frequency information. It converts the frequency variations caused by object movement into corresponding voltage variations.

Signal Processing: The demodulated voltage variations are further processed to determine the presence and movement of objects. This processing involves filtering, amplification, and possibly digital signal processing (DSP) techniques.

Output: The processed signals or data are made available at the OUT pin of the HB100 radar module. This output can be connected to a microcontroller, processor, or other circuitry for further analysis, interpretation, and integration into the drone's control system.

Frequency: The HB100 radar module operates at a frequency of 10.525 GHz, which falls within the X-band of the electromagnetic spectrum.

Operating Voltage: The recommended operating voltage for the HB100 radar module is typically around 5V DC.

Power Consumption: The power consumption of the HB100 radar module is relatively low, typically ranging from 20mA to 40mA.

Detection Range: The detection range of the HB100 radar module is approximately 7 meters to 9 meters, although this can vary depending on the environmental conditions and the size of the detected objects.

Output Signal: The HB100 radar module provides a continuous wave (CW) output signal, which means that it continuously emits and receives radar waves without any modulation.

Antenna Beam width: The antenna of the HB100 radar module has a relatively wide beam width, typically around 30 degrees. This wide beam allows for a broader coverage area but

sacrifices some resolution. Here patch antenna is used.

Doppler Shift: The HB100 radar module can detect Doppler shifts in the radar signal caused by the movement of objects. This information can be used to determine the relative velocity of detected targets.

Interface: The HB100 radar module typically has a simple interface, consisting of a few pins for power supply, signal output, and control.

Size and Form Factor: The HB100 radar module is compact and has a small form factor, making it suitable for integration into drones and other small devices. The module's dimensions are usually around 38mm x 45mm.

The HB100 radar module typically has three main pins: VCC, GND, and OUT. Here is a typical pin diagram for the HB100 radar module:

VCC: This pin is used to provide the power supply voltage to the HB100 radar module. It is typically connected to the positive terminal of the power source (e.g., +5V DC).

OUT: This pin is the output pin of the HB100 radar module. It provides the radar signal information, which can be used to detect and analyze the presence of objects or measure their Doppler shift. The OUT pin is connected to the input pin of a microcontroller or other processing circuitry for further analysis and processing of the

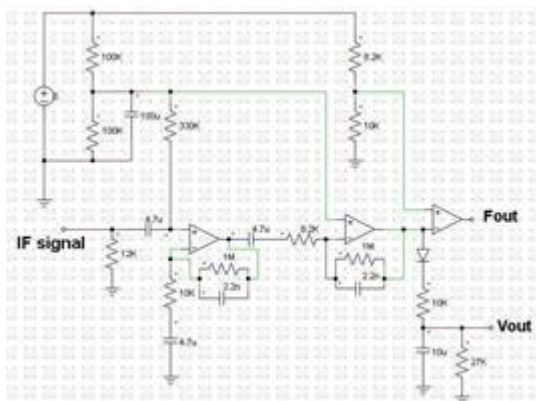


Figure 2: The additional band-pass circuit of HB100 module and its experimental setup

2.1 Code used in Arduino UNO

```

#define cbi(sfr, bit) (SFR_BYTE(sfr)&=~BV(bit))

#define sbi(sfr, bit) (SFR_BYTE(sfr) |= BV(bit))

const byte hb100foutpin = 2;

// interrupt capable pin (2 or 3 for Nano)

const byte hb100voutpininputpin = A0;

//y analog onst unsigned long analysis ever
=500; //ms

const float periodto frequenc = 70.235; // Hz/m/sconst b
y

yte levelminimum =120;

// minimum signal level for analysis

```

radar data.

GND: This pin is connected to the ground or 0V reference of the power supply. It provides the common ground connection between the HB100 radar module and the rest of the circuit.

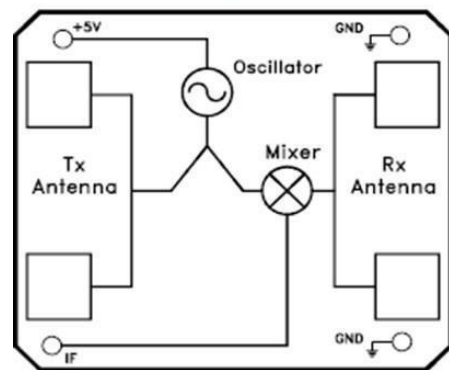
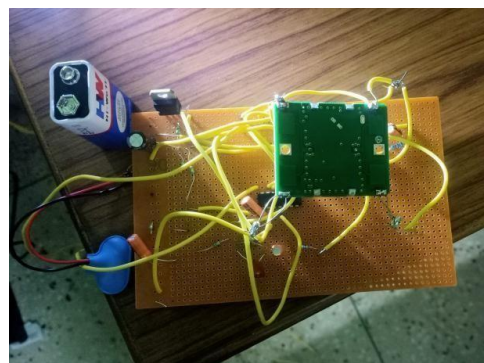


Figure 1: HB100 pinout diagram

Received frequency and attenuated oscillator frequency these two signals are multiplied at the mixer to get the IF signal. IF signal is passed through second order active bandpass filter and to record the data we have used Arduino UNO and to show the data we have used MATLAB. LM7805 is used to get 5v signal from 9v battery.



```

const float frequencylower = 4.0; //Hz const float frequencyupper = 70.0; //Hz
const byte averagepulses = 4; // min 1
volatile unsigned long pulsetimes[256]; volatile byte pulselevels[256];

volatile byte pulselast;
// last pulse written in pulsetimes ring buffer
void setup()

{
    unsigned int i;
    for (i=0; i<256; i++) // initialize pulsetimes ring buffer

    {
        pulsetimes[i]=0;
    }

    pulselast = 255; // initialize pulselast
    // Increase ADC sample rate from 10 kS/sec (100 us / S) to 1MS/ s (1 us / S) s bi
    (ADCSRA, ADPS2); cbi(ADCSRA, ADPS1); cbi(ADCSRA, ADPS0);
    Serial.begin(250000);

    pinMode(hb100foutpin, INPUT); pinMode(hb100voutpin, INPUT); attachInterrupt(digitalPinToInterrupt
    (hb100foutpin), hb100InterruptFoutPin, RISING);

    void loop()

    {
        static unsigned long analysisnext=millis();

        byte pulsecurrent;

        byte pulseprevious; unsigned long timecurrent; unsigned long timeprevious; byte
        levelcurrent;

        byte levelprevious;
        long period;

        float frequency;
        float velocity;

        if (millis()>=analysisnext)

        {
            pulse current = pulselast; // copy volatile variable pulse previous = pulse current;

```

```

pulseprevious=pulseprevious-averagepulses;time current =pulsetimes[pulsecurrent];

time previous =pulsetimes[pulseprevious];levelcurrent=pulselevels[pulsec
urrent];
levelprevious =pulselevels[pulsecurrent];
period =(timecurrent-timeprevious) /averagepulses;

if (timecurrent / 1000>millis()-analysevery&&period
>0
&&
levelcurrent >levelminimum &&levelprevious
>levelminimum )
{frequency=1000000.0 / period;

//if (frequency>frequencyupper ||
frequency<frequencylower)

//{
// frequency= 0.0;//}

velocity =frequency / periodtofrequency;}
else

{frequency =0.0;
velocity =0.0;}

/*Serial.print(frequency, 2);*/
/*Serial.print("\t");*/
Serial.print(velocity*100, 3);Serial.print("\t");
Serial.print(levelcurrent / 2, DEC);Serial.println("");analysenext=milli
s()+analysevery;}
}

void hb100InterruptFoutPin()
{pulselast++;
pulsetimes[pulselast]=micros();
pulselevels[pulselast]=analogRead(hb100voutpin) / 4;}
}

```

The DSP code is available at <https://drive.google.com/file/d/1F6ac5XOL8VsT-YFSBHYNlsZbf-iE08uH/view?usp=sharing>

3. Results and Discussion:

The range time intensity (RTI) display is a graphical representation of the returning signals in the time domain. It shows the intensity of the received signals as a function of time and range. object we move the Radar. In radar or sonar systems, a pulse of energy is transmitted and the system measures the time it takes for the pulse to bounce back after hitting an object (Figure 3). This time measurement, combined with the intensity of the returning signal, provides information about the range and characteristics of the object. Each target or object in the environment appears as a distinct "blob" or peak on the RTI display, indicating its range and strength.

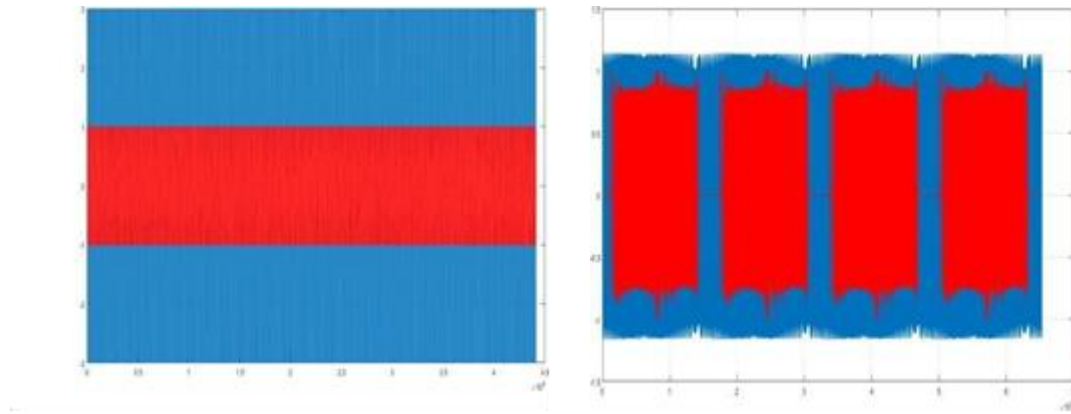


Figure 3: Still and Moving target signals acquired

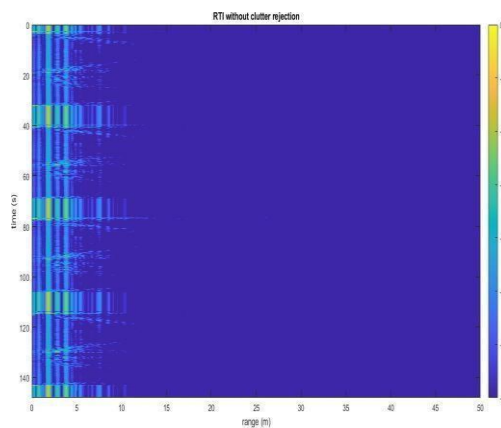


Figure 4: Range time intensity without clutter rejection [Moving target, individual targets, particularly when they are closely spaced.

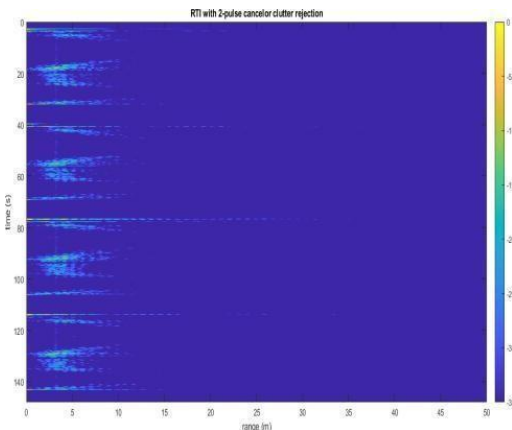


Figure 5: Range time intensity with two pulse cancel or clutter rejection [Moving target]

3.1 Range-Time Intensity without Clutter Rejection

In this case, the RTI display includes all returns detected by the radar system, including both target echoes and clutter. The clutter may appear as a spread of echoes across the range-time plot, making it challenging to distinguish actual targets from unwanted signals. This clutter can degrade the overall visibility of the desired targets, leading to reduced detection performance and increased false alarms (Figure 4).

3.2 Range-Time Intensity with Clutter Rejection

With clutter rejection techniques applied, the RTI display is improved by reducing or removing the clutter returns. These techniques utilize various algorithms and signal processing methods to distinguish between desired target echoes and clutter. By mitigating the effects of clutter, the clutter-rejected RTI display provides clearer visibility of the target returns, enhancing target detection capabilities and reducing false alarms (Figure 5).

3.3 Phase before the along-track FFT (Fast Fourier Transform)

The phase before the along-track FFT (Fast Fourier Transform) is a preprocessing step that is typically performed on data before applying the FFT algorithm in the along-track direction. The purpose of this phase is to mitigate certain effects or artifacts that may be present in the data and could adversely affect the accuracy or interpretation of the FFT results.

Here is a brief overview of the phase before the along-track FFT:

Data Acquisition: The data is first acquired from the source, which could be a sensor, instrument, or any other data collection system. The data is typically a time series representing a signaler waveform.

Preprocessing: Prior to applying the FFT, various preprocessing steps may be performed on the data to enhance its quality or remove unwanted components. These preprocessing steps can include filtering, noise reduction, baseline correction, or any other necessary adjustments depending on the specific application.

Along-Track Processing: In some applications, such as synthetic aperture radar (SAR) imaging or sonar systems, the data is acquired along a certain direction or path, known as the along-track direction. The along-track processing involves applying the FFT algorithm to the data in this direction to analyze its frequency content or perform further operations.

Phase Compensation: One common issue in along-track processing is the presence of phase errors or inconsistencies in the data. These phase errors can arise due to various factors such as sensor imperfections, platform motion, or propagation effects. To compensate for these phase errors, a phase correction or calibration step is performed before applying the along-track FFT. This step ensures that the phase information is accurately represented in the

frequency domain.

Along-Track FFT: After the phase compensation, the along-track FFT can be applied to the preprocessed data. The FFT algorithm transforms the data from the time domain to the frequency domain, providing information about the signal's spectral content and enabling various analysis and interpretation techniques (Figure 6).

By performing the phase compensation before the along-track FFT, the accuracy and reliability of the frequency analysis are improved, leading to better results in applications such as SAR imaging, sonar processing, or any other domain where along-track processing is involved.

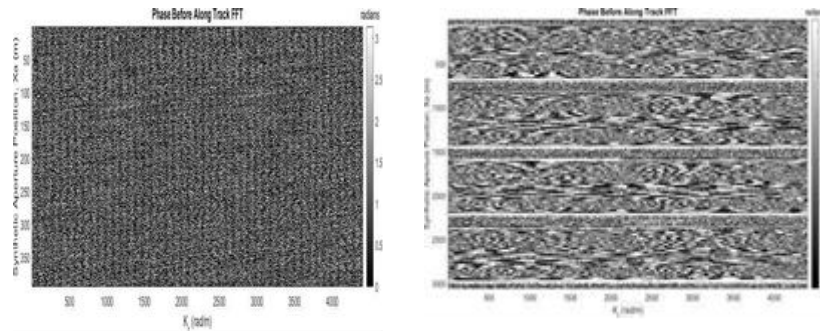


Figure 6: Phase before along track FFT [Stationary target and moving target with acceleration]

The ringing effect, or side lobes, refers to the presence of additional smaller peaks or ripples that appear around the main peak on the RTI display. These side lobes are caused by various factors, such as imperfections in the radar or sonar system's transmission and reception, interference, reflections from multiple objects, or the presence of clutter (Figure 7 and Figure 8).

In figure 4 we can see from the diagram that stationary object is a wall which is situated approximately 20m from the radar and other lines are generated due to ringing effect and multipath effect. Ringing effect is caused by modulating signal have to fluctuate more rapidly than RF signal which can be proved with band pass filtering and Woodward theorem on super heterodyne receiver.

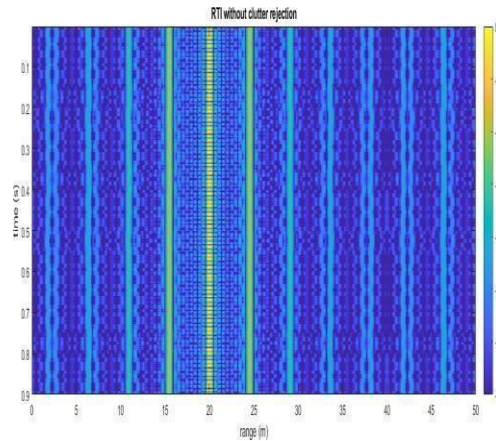


Figure 7: Range time intensity without clutter rejection [Stationary target]

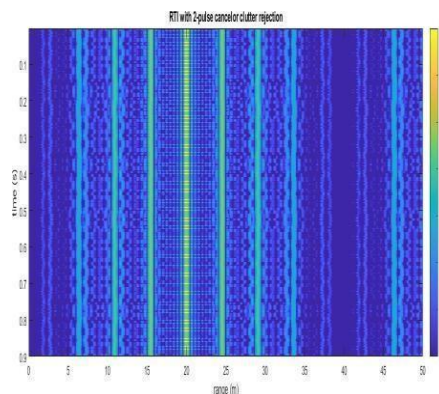


Figure 8: Range time intensity with two pulse canceler clutter rejection [Stationary target] or located in cluttered environments.

To mitigate the ringing effect and improve the quality of the RTI display, various signal processing techniques are employed. These techniques include filtering, pulse compression, clutter rejection algorithms, and adaptive beamforming.

Range-time intensity is a graphical representation used in radar systems to display the range and Doppler information of detected targets.

Clutter rejection is a technique employed in radar signal processing to mitigate the effects of unwanted returns from clutter, such as ground reflections, atmospheric interference, or other non-target objects. The difference between range- time intensity with clutter rejection and without clutter rejection lies in the quality of the displayed radar data.

The implementation of the HB100 radar in drones has shown promising potential for enhancing their capabilities in various applications. The integration of this radar system allows drones to effectively sense and detect objects in their surroundings, enabling them to navigate autonomously and avoid obstacles with greater accuracy. The HB100 radar’s compact size, low power consumption and relatively low cost make it an ideal choice for drone manufacturers looking to incorporate radar technology into their designs. However, there are certain limitations to consider. The HB100 radar has a limited detection range and may struggle to detect smaller objects or those with low radar cross- sections. Additionally, the radar’s Doppler-based sensing may be affected by environmental conditions such as wind and rain. Despite these limitations, the use of the HB100 radar in drones has shown significant progress in improving their situational awareness and obstacle avoidance capabilities. Further research and development efforts should focus on addressing these limitations and exploring advanced radar technologies to enhance the performance and reliability of radar-equipped drones in various real-world scenarios.

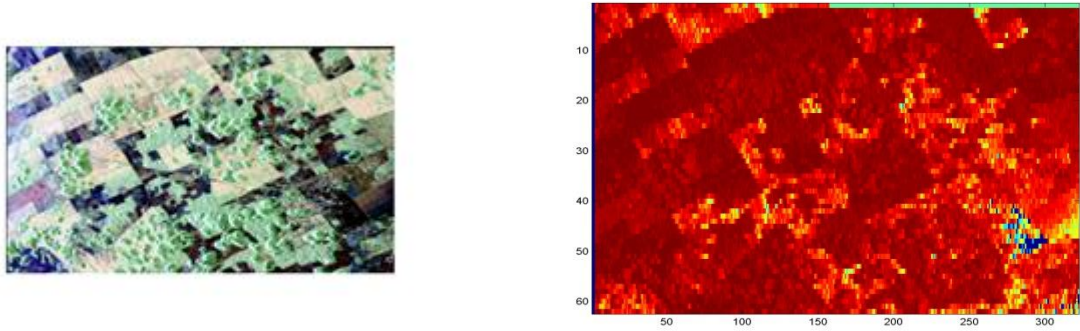


Figure 9: Polarimetric images (Pauli’s RGB and Cloude-Pottier with Shannon entropy based polarimetric decomposition) of Sierra del Lacandon National Park, Guatemala (acquired Apr 10, 2015 by UAVSAR, JPL NASA, USA)

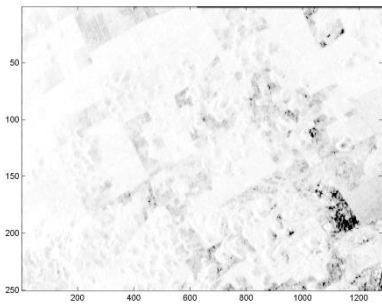


Figure 10. BW-Convolution binary image of Figure 9

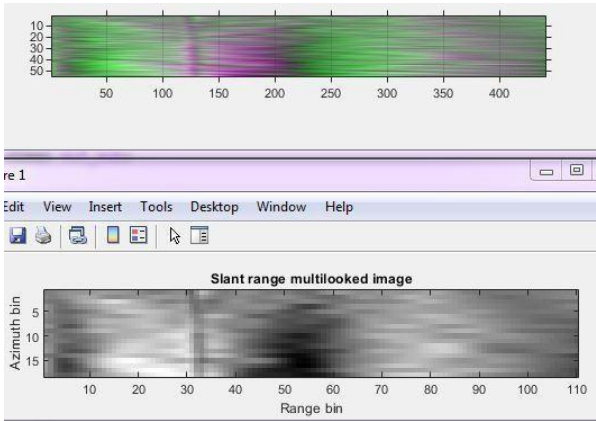


Figure 11: The multi-looking or slant to ground range

The polarimetric decomposition is described in Jones *et al.* 2011. The multi-looking or slant range to ground range might be a solution to clutter reduction. It should be noted that multi-look complex data does not hold accurate phase but phase jitter or clutter is less amount in SAR data. The range is Fermat’s no.(4n+1) of 1023; Dihedral in CIE LAB is pink and volume scattering is in green of UAVSAR of NASA, USA data is presented in figure 10 and 11. The figure 10 depicts that the surface scattering while figure 11 presents double bounce (dihedral) and volume scattering.

The mineral extraction on above ground or opencast mine and underground facilities; deposited as main product, bi-product and waste product. The GPS coordinated or ground control points

(GCP) encoded GeoTiff images from drone cameras or Satellite thermal images, are in process of digital surface model (DSM) or digital elevation model (DEM) using Agisoft software Dutta ,*et al.*,2023. The EM wave like L, S C, X bands data considered with phase unwrapping like visible RGB data. The HB100 can be worked as alarm system to the Safety and Mine planning engineer. As the HB100 has patch antenna or Omni-directional. But the movement detection with directional digital signal processor (DSP) architecture. The ground penetrating (GPR) require very high loss due to wave-front mismatch at load. The ringing effect based HB100 with accessories at X band. The ground can be done instead of shunting in underground facilities. The night vision and offside or inside wall at carcassing area limited to the officers. The GPS also provide Real time kinematics in indoor environment with loop antenna based sinks or routers but underground facilities paves the way for use of HB100 with accessories in mine safety.

4 Conclusion

The obtained results demonstrated the HB100 radar module's capability to reliably detect and track objects in real-time, even in challenging visibility conditions. The system's performance was evaluated based on metrics such as detection accuracy, range estimation, and tracking precision. Additionally, the impact of environmental factors on the radar module's performance was analyzed. The research findings indicate that the integration of the HB100 radar module into drones offers a practical and efficient solution for object detection, surpassing the limitations imposed by visibility constraints. The proposed system exhibits promising potential for applications in surveillance, search and rescue missions, and autonomous navigation, where accurate and reliable object detection is crucial

Future research directions include refining the radar-based object detection system to enhance its performance and robustness in various environments. Additionally, investigations into the integration of other sensor modalities, such as cameras or LIDAR, could be explored to achieve a more comprehensive perception system for drones. We'll try to work on sonar bass and terrible sound wave 3 phase 6 Volt system with pressure a complex system (bellow) with help by dipoli (cable jack with Gaussian noise) and

classical monopole which is magnetic interference (like fountain or umbrella which is lognormal). It is to be noted that exhaust system and longwall configuration from seam consist a very low DC signal will be utilized as Railways. Lastly the we have tried to reduce noise using multi-look which easy detect the Surface scattering (water, road etc.), double bounce scattering (Dihedral, oil pipes etc.) and volume scattering (canopies). In future we will work on Discrete Cosine Transform (DCT) for slant to ground range.

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