SDR as a Ground Penetrating Radar

A PROJECT REPORT

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Abstract

Surface analysis plays a pivotal role in various domains, ranging from civil infrastructure maintenance to autonomous vehicle navigation. Traditional ground-penetrating radar (GPR) systems are effective but often come with significant costs, limiting widespread adoption. This research addresses the pressing need for affordable and accessible surface analysis tools by leveraging Software Defined Radios (SDRs) equipped with Multiple Frequency Continuous Wave (MFCW) radar technology.

The project stems from the recognition of the high costs associated with GPR, which hinders routine surface assessments for road conditions, infrastructure integrity, and more. By harnessing the capabilities of SDRs and MFCW radar, our research endeavors to provide a cost-effective alternative to GPR. The adoption of a dual SDR system overcomes initial challenges, ensuring stable and reliable surface analysis.

Experiments showcase the system's remarkable precision in distance measurement, achieving sub-1 cm resolution and penetration depth assessment. Extensive frequency testing on various surfaces reveals distinctive penetration characteristics. Notably, metals exhibit minimal penetration, offering valuable insights for real-world applications.

This report details the research methodology, challenges encountered, and promising outcomes, showcasing the potential of SDR-based MFCW radar for affordable and efficient surface analysis, focusing on road condition assessments.

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Chapter 1

Introduction

1.1 Introduction

Surface analysis is integral to various applications, including civil infrastructure maintenance, environmental monitoring, and autonomous vehicle navigation. Traditional methods, particularly Ground-Penetrating Radar (GPR), offer accurate insights into subsurface structures but are often accompanied by substantial costs. The expense associated with GPR systems has limited their widespread adoption, hindering routine assessments critical for infrastructure health.

Recognizing this challenge, our research explores an alternative approach, utilizing Software-defined Radios (SDRs) equipped with multiple frequency continuous wave (MFCW) radar technology. This innovative combination aims to democratize surface analysis, making it more affordable and accessible for routine use.

GPR has been the go-to technology for subsurface investigations, but its cost implications have spurred the need for a more economical solution. The integration of SDRs, known for their versatility and cost-effectiveness, with MFCW radar provides a promising avenue. Our project focuses on overcoming the limitations of traditional GPR by introducing a dual SDR system, offering enhanced stability and accuracy for surface analysis.

In this report, we delve into the motivation behind the project, the challenges encountered, and the methodology employed. The outcomes showcase the potential of SDR-based MFCW radar in achieving high-resolution surface analysis, laying the foundation for cost-effective and efficient solutions in infrastructure management and beyond.

1.2 Motivation

The motivation behind this project stems from the critical importance of surface analysis in various domains. Infrastructure health monitoring, road condition assessment, and environmental sensing are pivotal for safety and sustainability. However, existing technologies, particularly Ground-Penetrating Radar (GPR), pose significant financial barriers, limiting their widespread adoption.

This BTP aims to explore an alternative, cost-effective solution that can democratize surface analysis, making it more accessible for routine inspections. By leveraging the versatility and affordability of Software Defined Radios (SDRs) and implementing the innovative Multiple Frequency Continuous Wave (MFCW) radar technology, we aim to create a system capable of accurate and detailed surface analysis without the financial burden associated with traditional GPR.

1.3 Problem Statement

The primary challenge addressed by this project is the high cost associated with GPR technology, hindering routine surface analysis. The financial constraints limit the frequency and scale of infrastructure inspections, potentially leading to undetected issues and delayed maintenance. Our project seeks to overcome this problem by developing a dual SDR-based MFCW radar system, providing a cost-effective alternative for precise surface analysis.

The research addresses the need for affordable yet accurate surface analysis tools, particularly in scenarios where routine inspections are critical for safety and functionality. The project aims to contribute to advancements in infrastructure management and environmental monitoring by formulating a reliable and economical solution.

Chapter 2

Literature Review

2.1 Introduction

A literature review is essential in research, providing context, identifying gaps, and guiding methodology. It ensures new research is informed and relevant and contributes meaningfully to existing knowledge in the field. We have tried to compile all the research work done so far in surface analysis and distance measured through SDR.

Surface analysis plays a crucial role in various fields, including infrastructure assessment, environmental monitoring, and security applications. Traditional methods often involve the use of Ground-Penetrating Radar (GPR), known for its effectiveness in subsurface detection. However, the high cost associated with GPR systems limits their accessibility and widespread use. This literature review examines the existing technologies, with a focus on GPR, and explores the emergence of Software Defined Radios (SDRs) as a cost-effective alternative for surface analysis.

2.1.1 Importance of Surface Analysis

Surface analysis is vital for infrastructure maintenance, road condition assessment, and environmental monitoring. The ability to non-invasively examine subsurface structures aids in identifying potential hazards and evaluating the integrity of surfaces.

2.1.2 Limitations of Ground-Penetrating Radar (GPR)

Despite its effectiveness, GPR systems are expensive, making them inaccessible for many applications. The high costs associated with GPR have led to a need for alternative technologies that offer comparable accuracy at a fraction of the expense.

2.1.3 Software-Defined Radios (SDRs) in Radar Systems

SDRs have gained prominence as versatile platforms for wireless communication systems. Their ability to reconfigure hardware through software updates makes them attractive for radar applications. The flexibility of SDRs provides a cost-effective solution for developing radar systems tailored to specific needs.

2.1.4 Multiple Frequency Continuous Wave Radar Technology

MFCW radar algorithms, operating at lower frequencies, have demonstrated promising results for distance sensing. The low bandwidth requirements and the use of multiple frequencies offer cost, power consumption, and accuracy advantages.

2.1.5 Existing Work on SDR-based Radar Systems

Prior research has explored the application of SDRs in radar systems. However, limited literature is available on the implementation of MFCW radar algorithms with SDRs for surface analysis, particularly in the context of distance measurement and penetration depth assessment.

2.1.6 Research Gap and BTP Objectives

The gap in the literature lies in the scarcity of cost-effective surface analysis solutions that maintain accuracy comparable to GPR. This project aims to bridge this gap by implementing MFCW radar technology on SDR platforms, providing a detailed exploration of its capabilities for distance sensing and penetration depth assessment.

2.2 Summary

The literature review delves into the significance of surface analysis, highlighting its crucial role in infrastructure assessment, environmental monitoring, and security applications. Ground-Penetrating Radar (GPR) has conventionally been employed for subsurface detection, but its high-cost limits accessibility. This review underscores the importance of seeking alternative technologies and introduces Software Defined Radios (SDRs) as a cost-effective solution. SDRs, known for their versatility in wireless communication systems, offer a flexible platform for radar applications.

The exploration of Multiple Frequency Continuous Wave (MFCW) radar technology emerges as a promising avenue. MFCW radar algorithms, operating at lower frequencies, demonstrate cost, power consumption, and accuracy advantages. While prior research has investigated SDRs in radar systems, limited literature exists on the implementation of MFCW radar algorithms with SDRs for surface analysis, especially in distance measurement and penetration depth assessment.

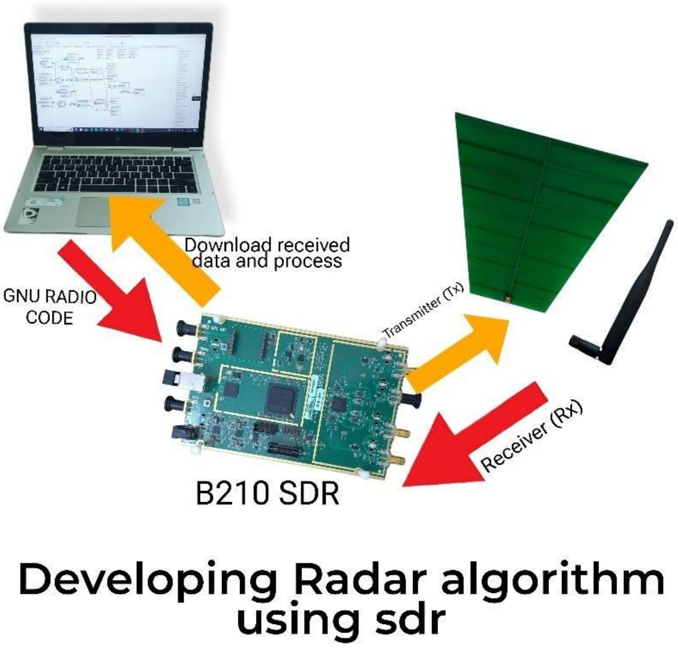
This literature review identifies the research gap and lays the foundation for the present project's objectives. The study aims to address the scarcity of cost-effective surface analysis solutions with accuracy comparable to GPR. By implementing MFCW radar technology on SDR platforms, the research seeks to comprehensively explore its capabilities for distance sensing and penetration depth assessment.

Chapter 3

SDR and Our Hypothesis

3.1 Software-Defined Radios (SDRs)

Software-Defined Radios (SDRs) are versatile communication devices that employ software-based signal processing to perform tasks traditionally carried out by hardware. They provide a flexible and programmable platform, allowing for dynamic adjustments in frequency, modulation, and signal processing. SDRs are pivotal in wireless communication, enabling a wide range of applications, from telecommunications to radar systems.



3.2 Hypothesis

In our hypothesis, we propose that a Multiple Frequency Continuous Wave (MFCW) radar implemented with a low-cost and low-power SDR unit, featuring a mere 1MHz bandwidth, can achieve a superior ~0.1m distance sensing accuracy. This hypothesis challenges the conventional notion that high bandwidth is a prerequisite for precise radar measurements. We anticipate that the adaptability and signal processing capabilities of SDRs will enable accurate distance measurements without the need for ultra-wide bandwidths.

3.2.1 Distance Measurement Formula

The fundamental formula for distance measurement in our MFCW radar setup is expressed as:

$$R = \frac{c \cdot \Delta\phi}{4\pi \cdot \Delta f}$$

The formula $R = \frac{c \cdot \Delta\phi}{4\pi \cdot \Delta f}$ can be derived as follows:

1. **Total Distance Covered:**

   $R + R = \frac{\lambda \cdot \phi}{2\pi}$

2. **Wavelength (λ):**

   $\lambda = \frac{c}{f}$

   Where c is the speed of light and f is the frequency.

3. **Substitute λ into the Total Distance Equation:**

   $R + R = \frac{c \cdot \phi}{2\pi \cdot f}$

4. **Rearrange for ϕ:**

   $\phi = \frac{4\pi \cdot f \cdot R}{c}$

5. **Phase Difference ($\Delta\phi$):**

   $\Delta\phi = 4\pi \cdot \Delta f \cdot \frac{R}{c}$

6. **Distance Formula (R):**

   $R = \frac{c \cdot \Delta\phi}{4\pi \cdot \Delta f}$

This formula, derived from MFCW radar principles, serves as the foundation for our distance measurement methodology using SDR technology.

Chapter 4

Procedure and Algorithm

4.1 Hardware Setup

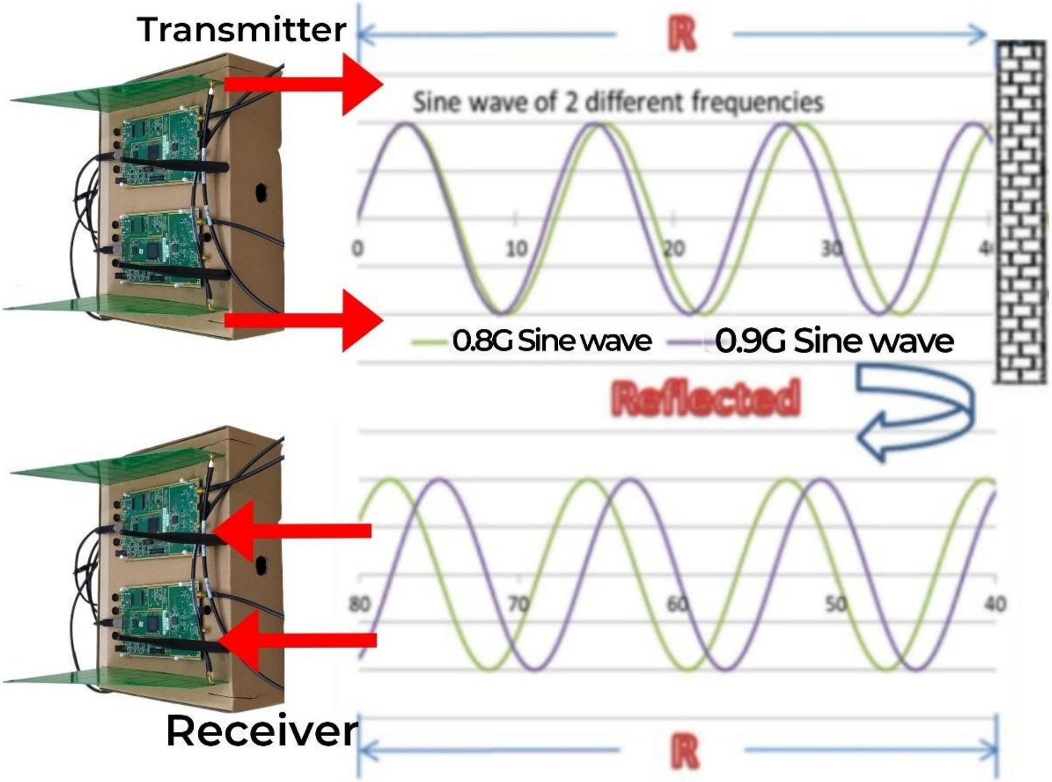
The intricate process of surface analysis using Software-Defined Radios (SDRs) required careful consideration of hardware elements. The Ettus Research B210 SDR was a pivotal choice due to its expansive frequency range from 100MHz to 6GHz. This flexibility allowed for a broad exploration of frequencies suitable for radar applications. The transmitter's choice, featuring tin can antennas, offered efficiency within the 800–900MHz band – a crucial selection to minimize interference, particularly with prevalent Wi-Fi bands.

A meticulous hardware redesign took place to address stability concerns and optimize the setup for precise readings. The introduction of cardboard and sticks resulted in a more robust and reliable structure, ensuring consistency during data collection.

4.2 MFCW Radar Design

Recognizing the inherent challenges of single SDR setups, a deliberate shift towards a dual SDR configuration was adopted. This strategic move aimed to counteract the phase shift issues encountered during frequency switching, a stumbling block in prior experiments. The designated frequency range for experimentation, 800–900MHz, was chosen for its compatibility and minimal interference with existing Wi-Fi bands.

The signal processing intricacies were navigated using the GNU Radio software. The core design involved a base signal of 2kHz, intricately multiplied with carrier signals at 800MHz and 900MHz. This modular approach allowed for adaptability and fine-tuning, crucial elements in achieving accurate and repeatable phase measurements.



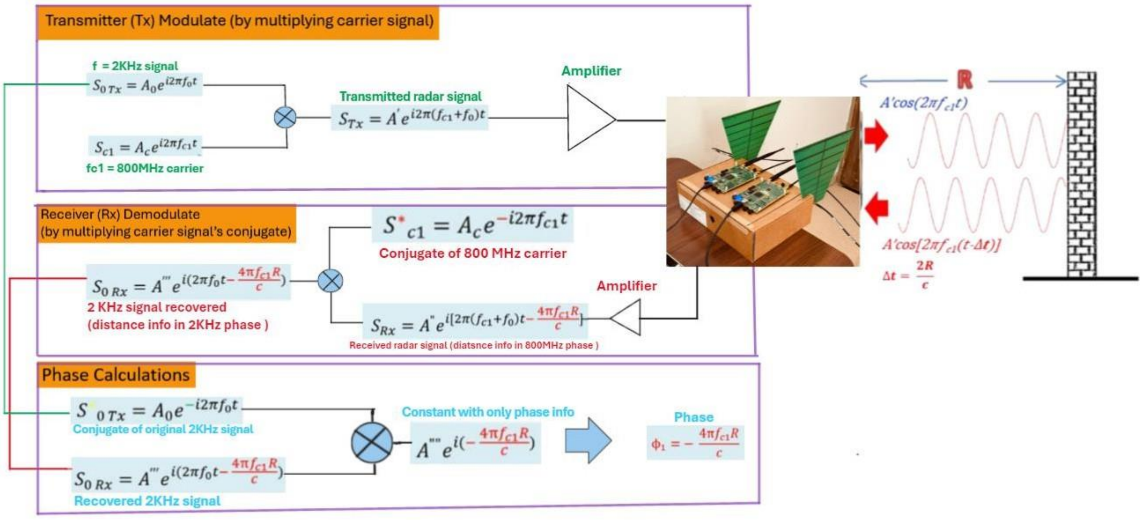
$$R = \frac{c\Delta\phi}{4\pi\Delta f}$$

$\Delta\varnothing$ is the phase difference in radians
Δf is the frequency difference in hertz.
R is distance measured

4.3 Distance Measurement Algorithm

The core of the surface analysis lies in the precise measurement of distances using the developed MFCW radar system. The receiving antenna captured the transmitted signal interacted with surfaces, and the subsequent reflections. Demodulation of the received signal paved the way for the extraction of the recovered signal, setting the stage for thorough analysis.

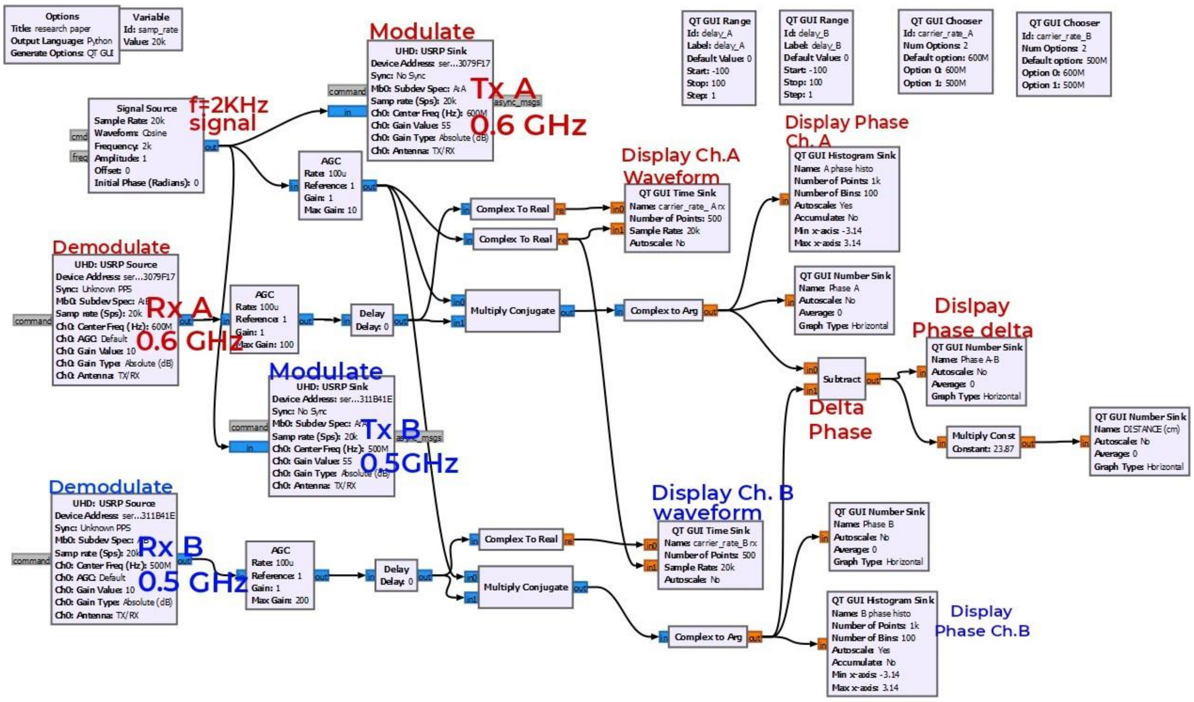
The heart of the distance measurement process resided in the calculation of the phase difference (Δϕ). This vital parameter was derived by taking the conjugate of the original and recovered signals. The foundational formula was instrumental in converting phase information into accurate distance measurements.



4.4 Testing and Data Collection

An extensive testing phase unfolded within the carefully chosen frequency band of 800–900MHz. This deliberate selection aimed to balance optimal performance with minimal interference. Stability during data collection was of paramount importance, leading to the crafting of a custom structure from cardboard and sticks – a testament to the meticulous approach taken to ensure robustness.

4.5 GNU Radio Code



The implementation of our radar system involved the development of custom GNU Radio code to efficiently handle signal processing and distance measurement. The GNU Radio code served as the backbone for our Software Defined Radio (SDR) platform, enabling the generation, transmission, reception, and processing of radio frequency signals. This bespoke code was tailored to accommodate the unique requirements of our Multiple Frequency Continuous Wave (MFCW) radar system.

Within the GNU Radio framework, we crafted real-time signal processing algorithms, including phase detection and distance calculation logic. The code was designed to handle the dual SDR setup seamlessly, ensuring synchronization between the two units and accurate subtraction of phase measurements. A graphical user interface (GUI) was also developed for debugging and demonstration purposes, providing a visual representation of intermediate calculations, waveforms, and phase movements.

Our GNU Radio code was instrumental in achieving stable and precise radar measurements, allowing for the successful differentiation of surfaces and accurate distance sensing. It played a pivotal role in realizing our research project's objectives, showcasing SDRs' capabilities in radar applications.

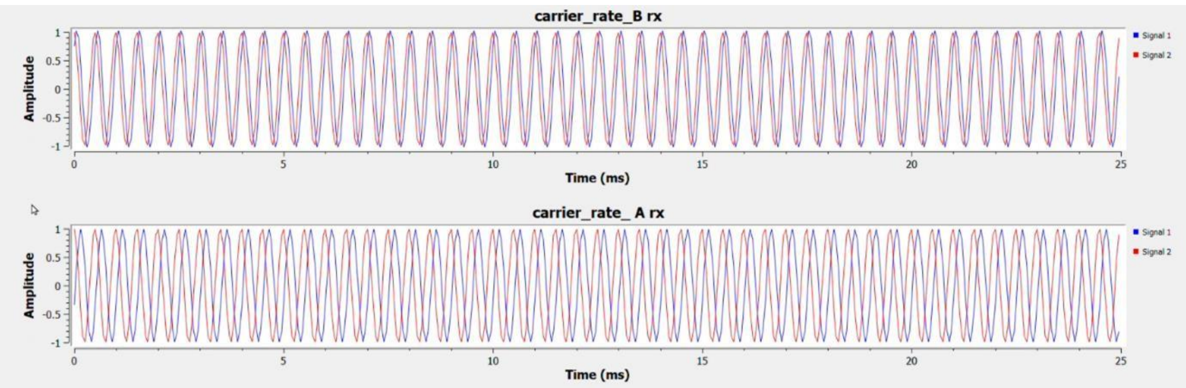
Chapter 5

Achievements

The culmination of the surface analysis project using Software-Defined Radios (SDRs) yielded significant successes, affirming the system's robustness and efficacy.

5.1 Recovered Stable 2kHz Signal from Reflection

A pivotal achievement was recovering a stable 2kHz signal from reflections. Overcoming challenges associated with signal degradation during transmission and reflection underscored the system's capability to maintain signal integrity.



5.2 Correct Phase Detection Across Distance

The precise detection of phase differences across varying distances was a notable success. This achievement is foundational for accurate distance measurements and indicates the system's ability to discern subtle signal phase variations.

5.3 Radar Distance Measurement with 1 cm Resolution

Measured vs Calculated Distances (800 MHz - 900 MHz)

Serial no.	Measured Distance	Calculated Distance	ΔΦ (Phase Difference)
1	20 cm	20.23 cm	0.13
2	22 cm	22.66 cm	0.19
3	25 cm	25.90 cm	0.21
4	27 cm	27.31 cm	0.26
5	30 cm	30.21 cm	0.32
6	35 cm	35.11 cm	0.39

A paramount success was the system's ability to measure distances accurately, achieving a resolution of less than 1 cm. This remarkable precision positions the SDR-based MFCW radar as a high-resolution tool for surface analysis.

5.4 Summary

These achievements collectively validate the effectiveness of the dual SDR setup, emphasizing its potential for real-world applications in surface analysis. The system's ability to recover stable signals, detect phase nuances, and provide accurate distance measurements underscores its success in addressing the challenges posed by traditional Ground Penetrating Radar (GPR) systems.

Chapter 6

Collecting Data: Exploring Surface Penetration Across Frequencies

The project's data collection phase focused on comprehensively understanding how varying operating frequencies impact the system's ability to penetrate surfaces and gather subsurface data. The primary objective was to ascertain the system's effectiveness in gauging the depth below road surfaces.

6.1 Experimental Design

A systematic approach was adopted to achieve this objective. Readings were taken on ten different surfaces, each assessed across seven distinct frequency bands. This meticulous approach aimed to provide a nuanced understanding of the system's performance under diverse conditions.

6.2 Surfaces Analysed

- Wood
- Road
- Cloth
- Thermocol
- Tiles
- Paper
- Wall
- Rubber
- Glass
- Metal

6.3 Frequency Pairs Investigated

- 150 - 200 MHz
- 250 - 300 MHz
- 450 - 500 MHz
- 550 - 600 MHz
- 650 - 700 MHz
- 850 - 900 MHz
- 950 - 1000 MHz

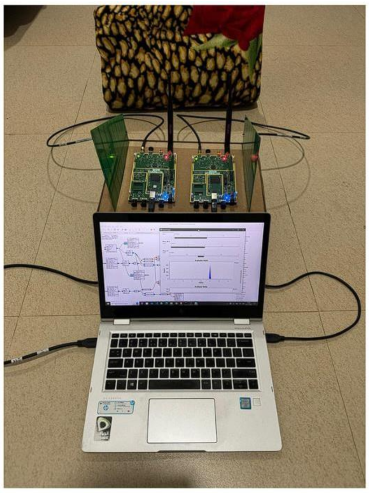
6.4 Selection of Frequency Ranges

The frequency ranges were carefully chosen to align with the capabilities of the unidirectional transmitters used in the system. Operating within the 100 - 1000 MHz range, the selected frequency pairs ensured comprehensive coverage across the entire spectrum.

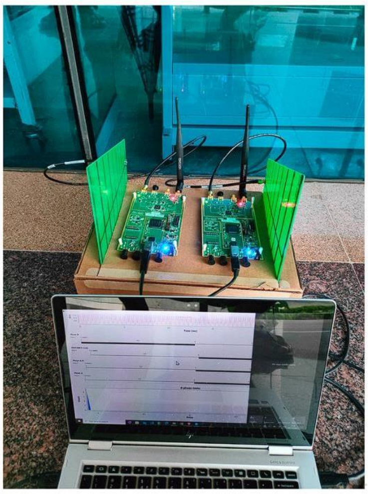
6.5 Consistent Distance Parameter

Maintaining a constant distance of 25 cm, a practical length for real-world applications, ensured uniformity in data collection. This distance choice mimics scenarios where the system might be deployed beneath a vehicle to assess road conditions.

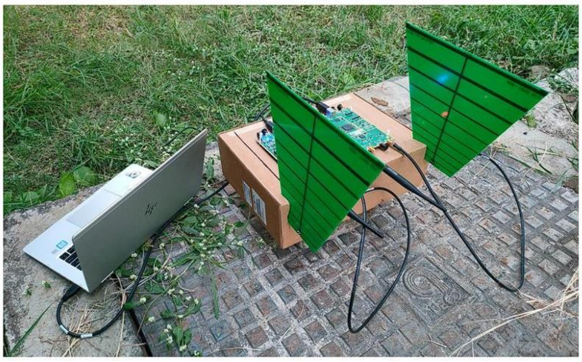
6.6 Real Time Set-up



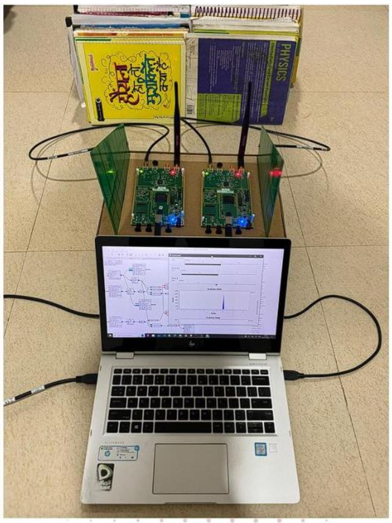
CLOTH



GLASS



METAL



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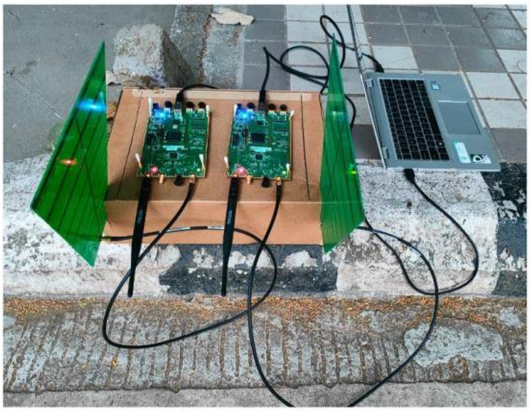
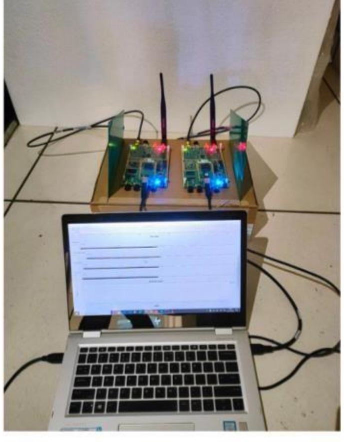


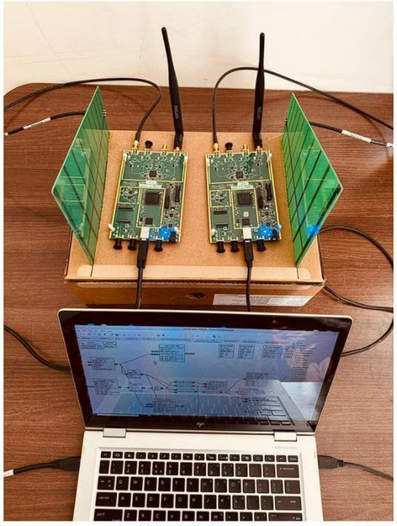
ROAD

RUBBER

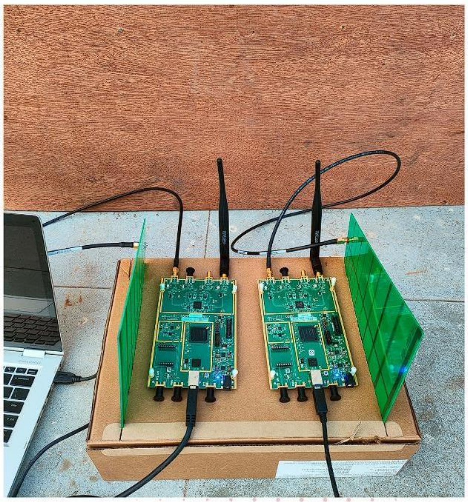


THERMOCOL

TILES



WALL



WOOD

The systematic exploration of diverse surfaces and frequencies lays the foundation for a robust analysis of the system's ability to penetrate different materials at varying depths. This extensive dataset serves as a valuable resource for understanding the nuances of subsurface analysis using Software-Defined Radios.

Chapter 7

Analysis of Data: Unravelling Surface Characteristics

The comprehensive dataset obtained through meticulous data collection is a foundation for a detailed analysis of the system's performance across different surfaces and frequency ranges.

7.1 Surface Penetration Dynamics

Upon examining the collected data, a discernible pattern emerged, revealing that each surface exhibited distinctive penetration levels. Moreover, these penetration levels demonstrated variations corresponding to changes in the operating frequency. This observation underscores the system's sensitivity to surface composition and frequency modulation.

7.2 Tabulation of Final Readings

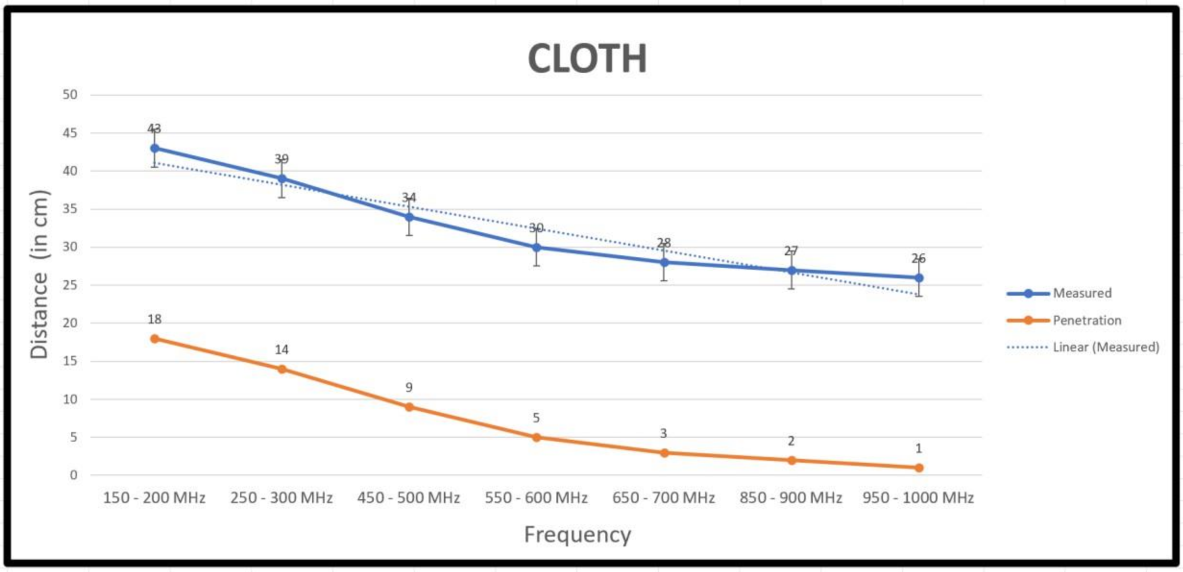
The culmination of our data analysis is encapsulated in a table comprising the final readings. This tabulated data is a reference for the subsequent graphical representation, allowing for a visual interpretation of the trends and variations across different surfaces and frequencies.

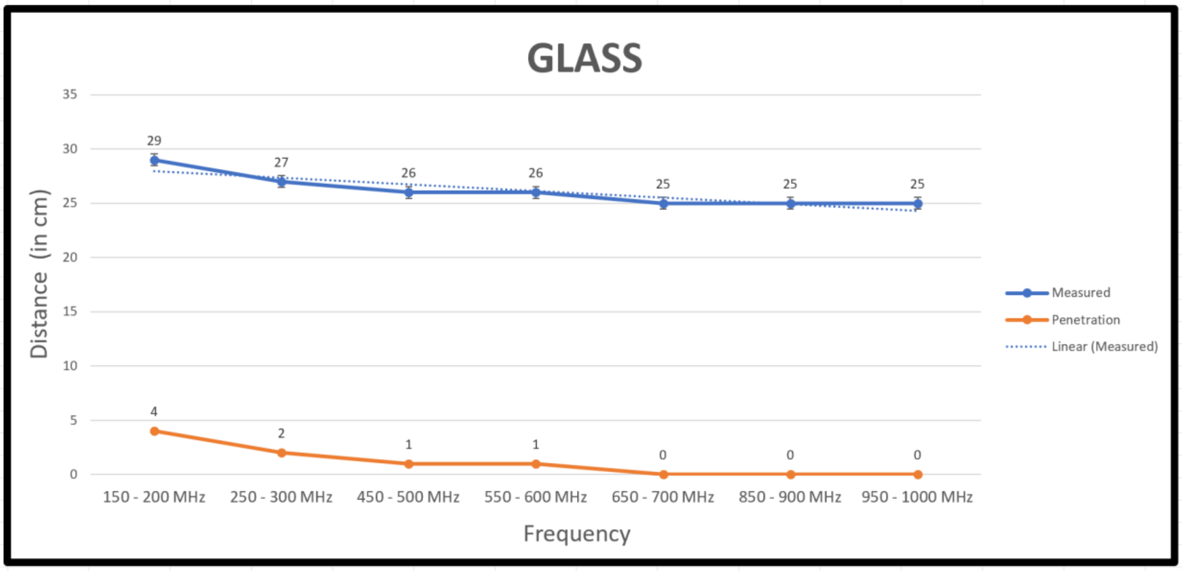
Material / Freq.	150 - 200 MHz	250 - 300 MHz	450 - 500 MHz	550 - 600 MHz	650 - 700 MHz	850 - 900 MHz	950 - 1000 MHz
Wood	46	42	36	31	29	28	26
Road	44	40	30	28	27	26	25
Cloth	43	39	34	30	28	27	26
Thermacol	40	34	32	29	27	26	25
Tiles	39	33	31	28	27	26	25
Paper	36	33	29	27	26	25	25
Wall	34	31	29	27	26	25	25
Rubber	30	28	27	26	25	25	25
Glass	29	27	26	26	25	25	25
Metal	26	25	25	25	25	25	25

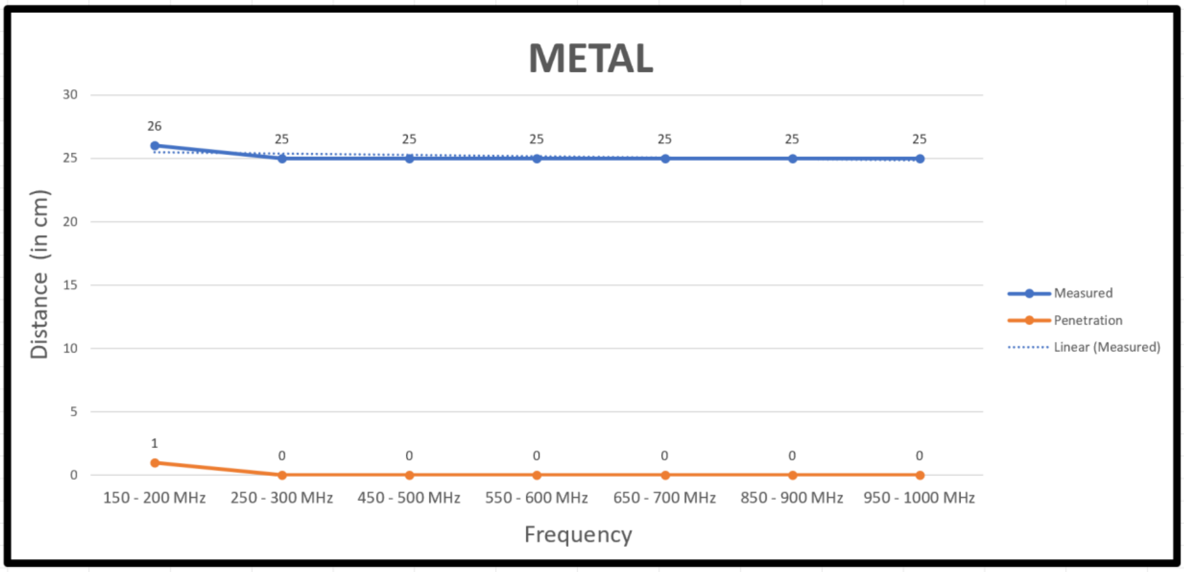
Actual Distance – 25 cm (between setup and surface)

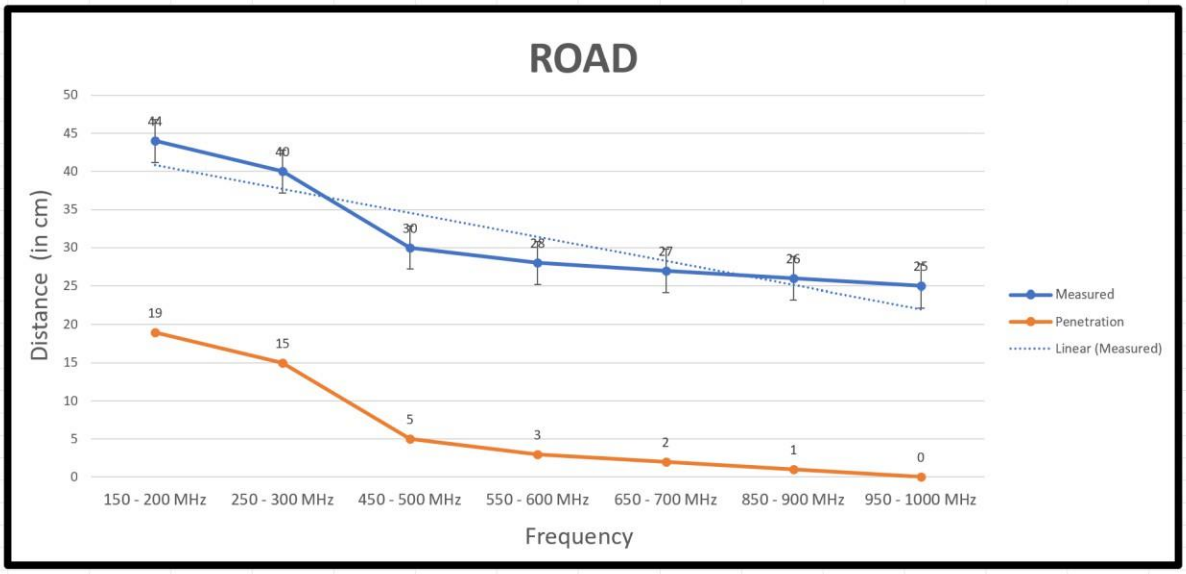
7.3 Graphical Representation

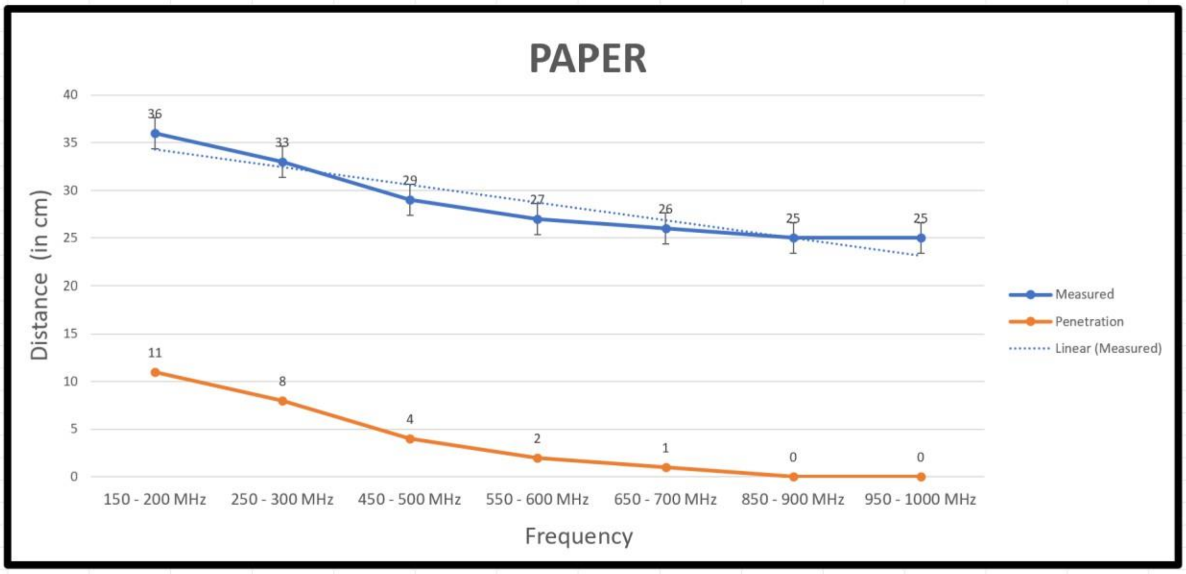
Individual graphs were generated for each surface to enhance the interpretability of the data. These graphs vividly illustrate the nuanced changes in penetration levels and distance measurements within the chosen frequency ranges. The graphical representation facilitates a more intuitive understanding of the system's interaction with diverse surfaces under different operational frequencies.

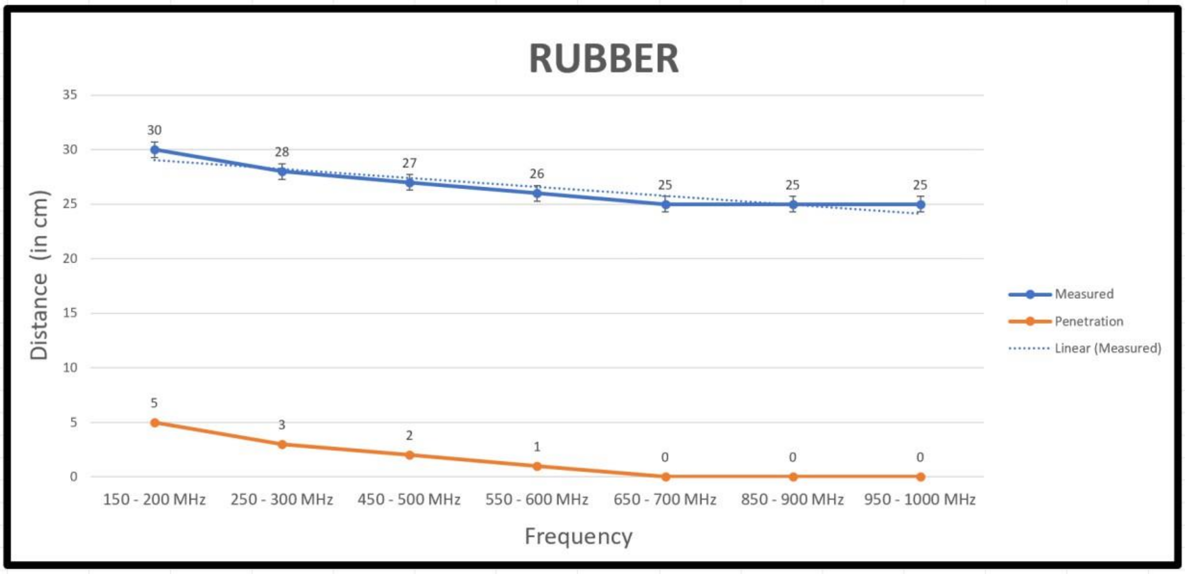

CLOTH
50
45
40
35
30
25
20
15
10
5
0
Distance (in cm)
43
39
34
30
28
27
26
18
14
9
5
3
2
1
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Frequency
Measured
Penetration
Linear (Measured)

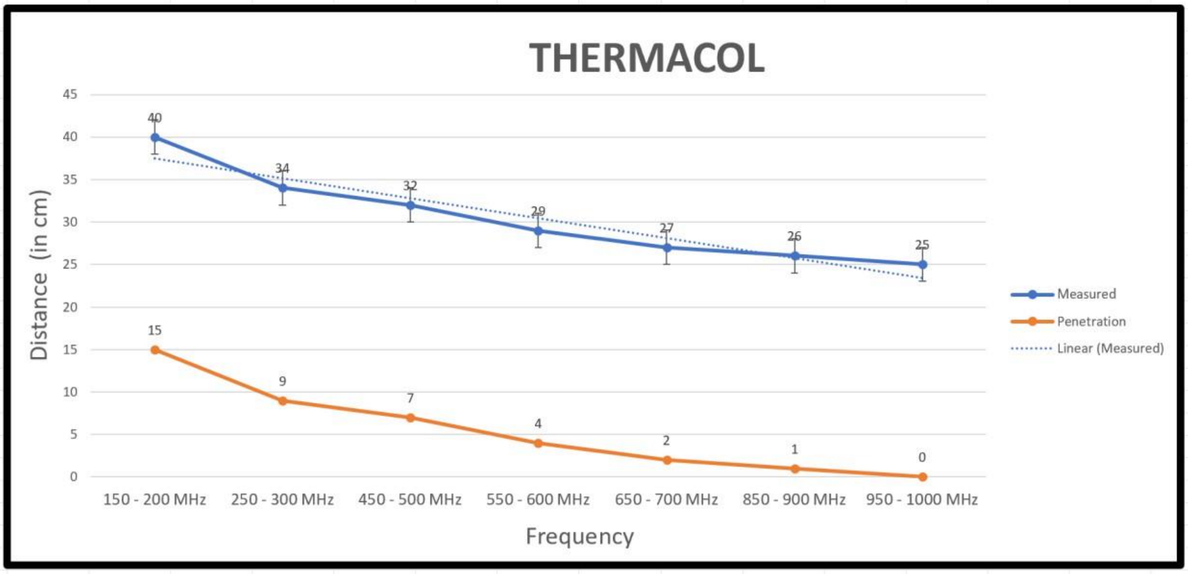

GLASS
35
30
25
20
15
10
5
0
Distance (in cm)
29
27
26
26
25
25
25
4
2
1
1
0
0
0
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Frequency
Measured
Penetration
Linear (Measured)

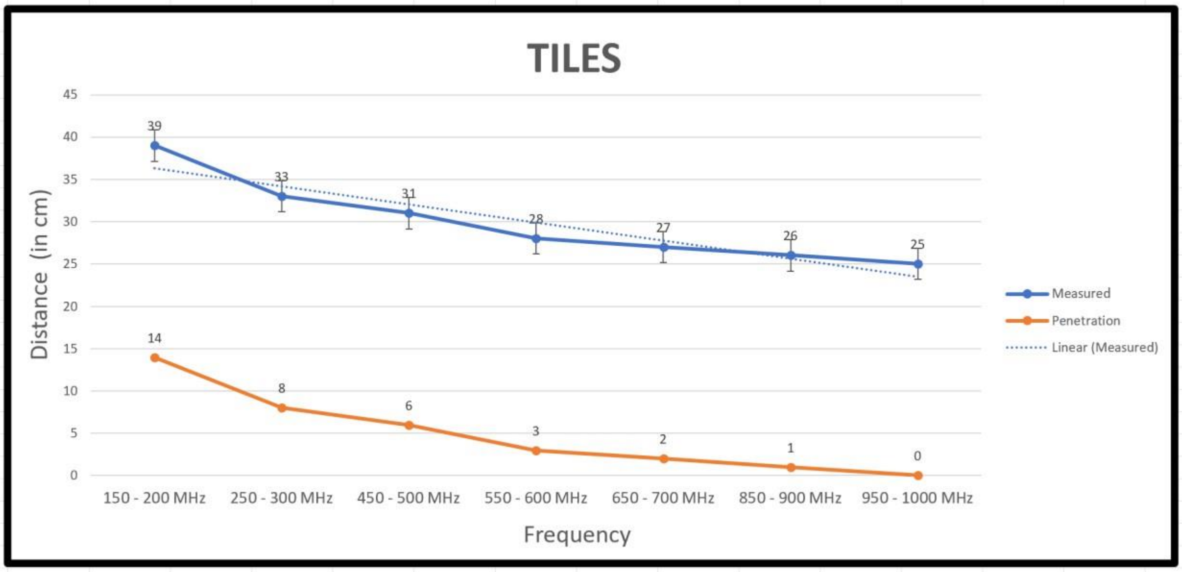

METAL
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)


ROAD
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)


PAPER
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)


RUBBER
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)


THERMACOL
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)
40
34
32
29
27
26
25
15
9
7
4
2
1
0


TILES
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)
39
33
31
28
27
26
25
14
8
6
3
2
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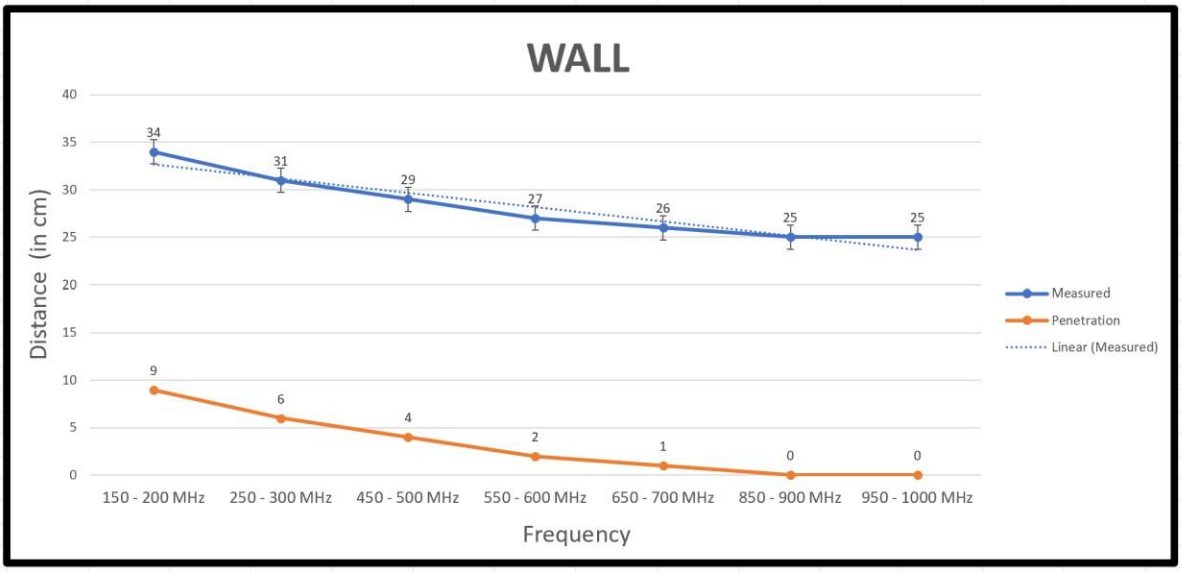
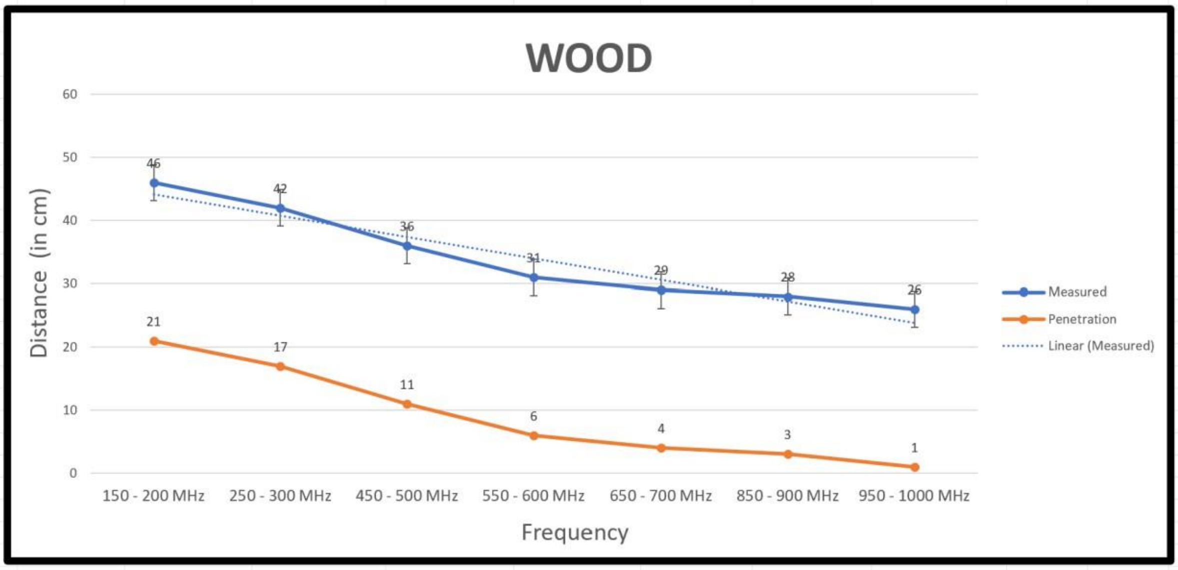

WALL
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)


WOOD
Distance (in cm)
Frequency
150 - 200 MHz
250 - 300 MHz
450 - 500 MHz
550 - 600 MHz
650 - 700 MHz
850 - 900 MHz
950 - 1000 MHz
Measured
Penetration
Linear (Measured)

7.4 Surface Categorization

An intriguing outcome of the analysis is the ability to categorize and differentiate surfaces based on their distinctive penetration characteristics. The system demonstrates a remarkable capacity to discern subtle variations in penetration depth, offering a valuable tool for surface classification.

7.5 Frequency-Dependent Trends

A consistent trend emerged across all surfaces—increasing frequency correlates with a decrease in penetration levels. This universal pattern establishes a foundational principle that informs the behavior of the system. Understanding this frequency-dependent relationship is crucial for real-world applications with diverse materials.

In summary, the analysis of the collected data provides insights into the system's functionality and establishes a framework for leveraging Software-Defined Radios in surface analysis applications. The ability to categorize surfaces based on penetration characteristics opens avenues for practical implementations in varied scenarios.

Chapter 8

Analysis of Data: Unravelling Surface Characteristics

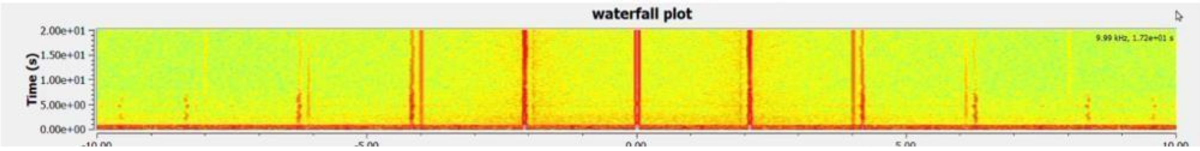
Our pursuit of real-world application led to a critical experiment, evaluating the system's capability to detect subsurface structures. We introduced a metal plate beneath the ground's surface, simulating scenarios where underground objects need identification.

8.1 Overcoming Stability Challenges

A key challenge emerged—ensuring the stability of the system while moving parallel to the ground. Innovative problem-solving became imperative. To address this, we ingeniously utilized cycles and a connecting rod. This setup facilitated smooth and stable movement, ensuring the acquisition of reliable readings.

8.2 Waterfall Graph for Dynamic Visualization

The heart of our analysis lay in the waterfall graph, dynamically plotting time against distance. Despite video limitations, this visual representation proved instrumental in conveying the intricacies of the experiment. Different colours denoted varying distances, offering a nuanced understanding of the system's performance.

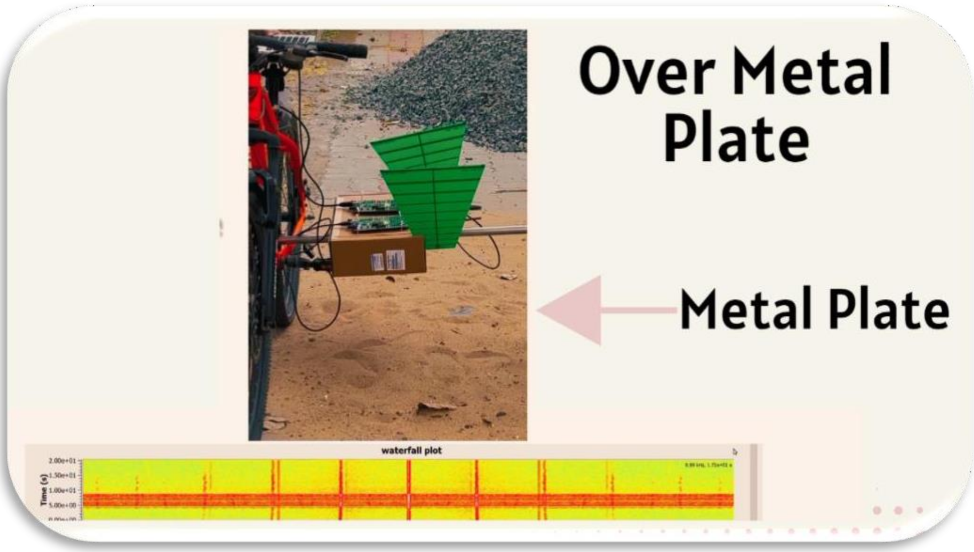


8.3 Real-Time Setup Screenshots

While direct video inclusion in a report posed challenges, we opted for a pragmatic approach—providing screenshots from the real-time setup. These images serve as snapshots, offering glimpses into the system's behaviour during the experiment.

8.4 Analyzing Waterfall Graph

The waterfall graph, showcased in the report captures the essence of the experiment. Each color shift signifies a change in distance measurement. Notably, the red indicates proximity to the metal plate, denoting minimal penetration. Conversely, yellow/green hues represent measurements from the ground surface, indicating higher penetration.

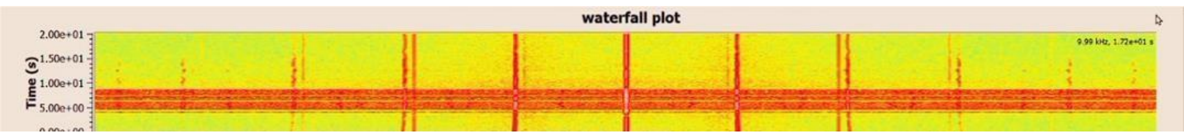


8.5 Methodical Movement Parallel to Ground

A crucial aspect of the experiment involved moving the system parallel to the ground, maintaining a constant distance from the ground. This deliberate approach allowed us to observe how distance readings changed when the metal plate came within the antenna's range.

8.6 Functional Validation and Real-Time Applications

The experiment's success substantiates the system's functional prowess, showcasing its ability to detect objects both below and above the ground surface. This validation underscores its practical applicability in real-time scenarios requiring precise subsurface analysis.



8.7 Summary

In summary, our approach involved conducting a real-world experiment to validate the capabilities of our SDR-based radar system for subsurface detection. By strategically placing a metal plate below the ground surface, we systematically moved the radar setup parallel to the ground, maintaining stability with a carefully designed structure. The transmitter emitted signals in the frequency range of 800 - 900 MHz, and the receiver captured and demodulated the reflected signals for phase difference calculation.

The experiment successfully demonstrated the system's ability to detect objects below the ground surface, offering promising results for real-time applications. The collected data, presented through a waterfall graph, showcased distinct color variations indicating different distances. The red color represented proximity to the metal plate with minimal penetration, while yellow/green hues indicated distances measured for the ground surface with higher penetration.

This real-world validation emphasized the practical applicability of our SDR-based radar system, affirming its potential for infrastructure and environmental monitoring, particularly in subsurface detection scenarios.

Chapter 9

Conclusion: Unveiling the Potential of SDRs in Subsurface Analysis

In subsurface analysis, the application of Software-Defined Radios (SDRs) has emerged as a transformative paradigm, offering a cost-effective alternative to conventional Ground Penetrating Radar (GPR) systems. This comprehensive research aimed to leverage the capabilities of SDRs, explicitly employing a Multi-Frequency Continuous Wave (MFCW) radar system, to probe beneath surfaces and unveil the intricacies of subsurface structures.

9.1 Addressing the Need

The imperative for precise and affordable subsurface analysis is underscored by the challenges posed by existing technologies, notably the cost-intensive nature of GPR. Our research sought to bridge this gap, presenting a viable solution that harnesses the versatility of SDRs for accurate and economical subsurface investigations.

9.2 Navigating Single SDR Limitations

Recognizing the limitations of a single SDR, particularly the inherent phase shift challenges, our approach pivoted to a dual SDR configuration. This strategic enhancement not only circumvented the phase calibration issues but also bolstered the accuracy and repeatability of the phase measurements.

9.3 MFCW Technology Triumphs

Adopting Multi-Frequency Continuous Wave (MFCW) technology proved instrumental in achieving remarkable accuracy, with distance measurements exhibiting a resolution of less than 1 cm. Our system showcased its prowess in providing reliable and repeatable distance sensing by seamlessly integrating dual SDRs operating at distinct frequencies.

9.4 Diverse Surface Analysis

The research ventured into uncharted territory by systematically exploring the impact of operating frequencies on subsurface data collection. Ten different surfaces, ranging from metals to fabrics, underwent meticulous scrutiny across seven frequency pairs. The findings elucidated distinct penetration levels, paving the way for a nuanced categorization of surfaces based on their interaction with the radar system.

9.5 Real-World Validation

Elevating the research from theory to practical applicability, a real-world experiment validated the system's capacity to detect subsurface objects with precision. The experiment, involving lateral movement and stability measures, simulated scenarios where the system could decipher hidden structures, exemplifying its potential for real-time applications.

9.6 Future Prospects and Recommendations

While the current research yields promising results, avenues for future exploration abound. Further refinement of algorithms to mitigate non-linear phase effects, coupled with the exploration of additional frequencies, holds promise for enhancing system performance. The system's scalability for deployment in diverse environments and conditions is a compelling avenue for future investigation.

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