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Experimental Validation of a LabVIEW-Based SFCW Software-Defined Radar System

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ABSTRACT: Software-defined radar (SDR) provides a flexible and cost-effective platform for implementing and testing diverse radar techniques without hardware redesign. Among these techniques, Stepped-Frequency Continuous Wave (SFCW) radar has shown promise in addressing some of the limitations of Frequency Modulated Continuous Wave (FMCW). This paper presents the experimental validation of an SDR system based on the SFCW technique. The radar system was developed using a USRP N210 with a WBX daughterboard, fully controlled through LabVIEW for waveform generation, data acquisition, and signal processing. Experimental validation was conducted in a controlled indoor environment using a 30 × 30 cm metal target placed at distances from 0.7 m to 1.25 m. According to the data, this research has shown accurate detection at longer ranges, with error rates below 0.5%. However, the increasing inaccuracy at lower ranges highlighted issues in near-field measurements. The findings have confirmed the feasibility of SFCW-based SDR for compact, reconfigurable radar platforms and suggest opportunities for enhancing near-field accuracy through advanced signal processing and calibration.

ABSTRAK: Perisian takrifan radar (SDR) menyediakan platform fleksibel dan kos efektif bagi melaksana dan menguji pelbagai teknik radar tanpa reka bentuk semula perkakas. Antara teknik ini, radar gelombang berterusan frekuensi lanjutan (SFCW) telah menunjukkan kebolehan dalam menangani beberapa batasan gelombang berterusan modul berfrekuensi (FMCW). Kajian ini membentangkan pengesahan eksperimen sistem SDR berdasarkan teknik SFCW. Sistem radar dibangunkan menggunakan USRP N210 bersama papan WBX. Ia dikawal sepenuhnya melalui LabVIEW bagi penjanaan bentuk gelombang, perolehan data dan prosesan isyarat. Pengesahan eksperimen dijalankan dalam persekitaran dalaman terkawal menggunakan sasaran logam 30 × 30 cm yang diletakkan pada jarak 0.7 m hingga 1.25 m. Dapatan penyelidikan ini menunjukkan pengesanan tepat pada julat lebih panjang, dengan kadar ralat di bawah 0.5%. Walau bagaimanapun, ketidaktepatan semakin meningkat pada julat lebih rendah, menyerlahkan isu pengukuran medan. Penemuan ini mengesahkan kebolehlaksanaan SDR berasaskan SFCW pada platform radar yang padat dan boleh dikonfigurasikan semula. Cadangan bagi meningkatkan ketepatan medan adalah melalui pemprosesan dan penentu ukuran isyarat lanjutan.

KEYWORDS: *Software-Defined Radar (SDR), Stepped Frequency Continuous Wave (SFCW), USRP, LabVIEW, Range Detection.*

1. INTRODUCTION

Radar systems are being used widely in sensing applications such as airport surveillance, landslide monitoring, mining, security screening, and health screening. Fig. 1 illustrates how radar operates in sensing applications. Radar operates by transmitting electromagnetic waves. When the waves hit objects, they will be reflected to the radar. The radar receives reflected waves and analyzes them to determine the characteristics of objects, such as size, velocity, and distance. Over time, technological advancements have led to SDR, an evolution of conventional radar systems. While the principles remain the same, SDR differs in how the key functions are implemented. Instead of relying on fixed hardware circuits, SDR shifts key operations, such as waveform generation, signal control, and signal processing, to software. This software-driven approach not only makes SDR highly flexible for testing but also reduces hardware dependency, lowers costs, and allows rapid reconfiguration across different frequency bands and processing techniques [1].

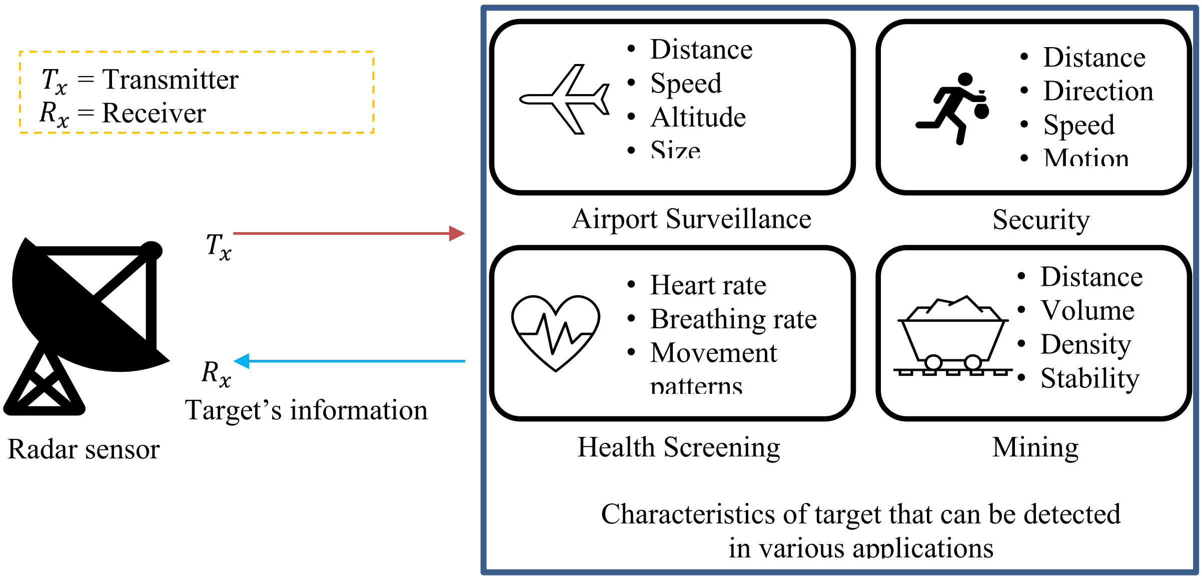


Figure 1. Concept of radars

Among the many radar techniques that can be implemented on SDR platforms, FMCW and SFCW are two of the most widely used. Both approaches can deliver high-resolution, accurate target detection, but they differ in their trade-offs, limitations, and suitability for wideband applications.

FMCW has been widely adopted in SDR research for both near-field and far-field sensing. For example, recent research by [2] has analyzed the performance of an FMCW SDR for maximum-range detection. The research has demonstrated that increasing sweep time extends the maximum detection range in FMCW-based SDR. However, according to [3], for a wide-bandwidth application, increasing the sweep time will result in an inconsistent frequency-sweep rate. On top of that, research in [3] further emphasized that such inconsistencies may degrade detection accuracy. The limitations of FMCW techniques were further identified by [4], who found that power feedthrough was a major drawback, as strong echoes are detected at the receiving antenna due to continuous signal transmission and reception. Beyond these hardware constraints, FMCW techniques often require complex signal processing to mitigate synchronization errors and random delays introduced by SDR communication protocols, as mentioned in [5]. For instance, a recent work on range estimation in [6] has explored the use of unsynchronized FMCW receivers on LimeSDR platforms. The research approach required a complex setup with a direct signal reference between antennas to compute range and was limited to a 58 MHz bandwidth. The findings indicate an average relative error of 2.15% to 4.28%. Overall, these limitations, inconsistent frequency sweeping rate, power feedthrough, and high signal processing overhead make FMCW less suitable for applications that demand both high resolution and reliable detection accuracy.

In comparison, SFCW offers a solution to the power feedthrough issue while providing a stable frequency reference. According to [7] and [8], SFCW has clear advantages over FMCW, particularly in accuracy and resolution. Its potential has already been validated in diverse fields, for example, in hydrological sensing, where [9] employed an SFCW-based SDR using a USRP X300 over a wide 150 MHz to 6 GHz bandwidth to penetrate complex, multi-layered snowpacks and accurately measure both snow water equivalent (SWE) and snow depth. Another field that employs the SFCW radar system is biomedical research, where [10] has demonstrated that SFCW SDR platforms using the BladeRF achieved sufficient resolution for microwave breast cancer imaging, further confirming the technique's potential for precision detection tasks.

Despite these advances in SFCW radar, a clear research gap remains: existing SFCW studies are predominantly application-specific and often rely on complex, high-cost system configurations. For example, [7] employed the high-cost USRP X310 with a complex multi-tone synchronization architecture, which was validated only through loopback testing, without actual target detection in an open environment. Meanwhile, [8] used a custom modular hardware platform that offers limited software reconfigurability. In addition, the system developed in [9] required an 80-second sweep time per scan due to its wide-frequency-range operation, making it unsuitable for rapid-prototyping scenarios. On the other hand, FMCW-based SDR implementations still face fundamental hardware and signal-processing limitations, as discussed above. Consequently, the development of compact, low-cost, and general-purpose SFCW SDR platforms that integrate hardware and software into a unified framework for rapid prototyping and multirange experimental validation remains limited.

To address the gaps mentioned, this research presents the development of a low-cost SFCW radar system using a USRP N210 equipped with a WBX daughterboard as the hardware platform and fully integrated with LabVIEW. The proposed system leverages discrete frequency stepping to avoid synchronization complexities and hardware overhead while ensuring high-precision detection without requiring complex reference signals or specialized delay-mitigation algorithms. The proposed system also offers flexible waveform generation, real-time hardware configuration, and integrated signal processing within a unified framework, thereby enabling effective rapid prototyping and experimental validation. The key contributions of this work are:

- The implementation of low-cost and flexible SFCW radar architecture using SDR technology.
- Experimental validation of target detection accuracy in controlled indoor measurements.
- Analysis of system limitations to guide future improvements, including multipath effects and sidelobe interference.

This research demonstrates that SFCW-based SDR can provide a reliable, reconfigurable platform for radar research, and suitable for rapid prototyping.

2. SYSTEM DESIGN

2.1. SFCW Signal Characteristics

SFCW radar operates by transmitting a train of sinusoidal signals that step uniformly in frequency. When the signals hit a target, they will bounce back to the radar, carrying the phase that determines the target's range. Fig. 2 and Fig. 3 show the key parameters of the SFCW signal. The signal consists of frequency components $(f_0, f_1, \dots, f_{N-1})$ and these frequency components are separated by a fixed frequency step, Δf.

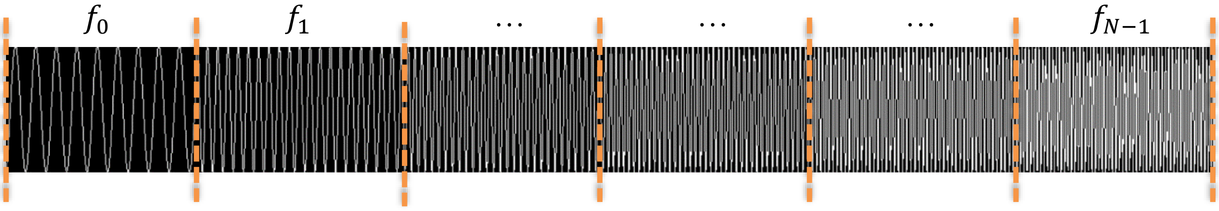


Figure 2. Illustration of the transmitted signals in SFCW radar

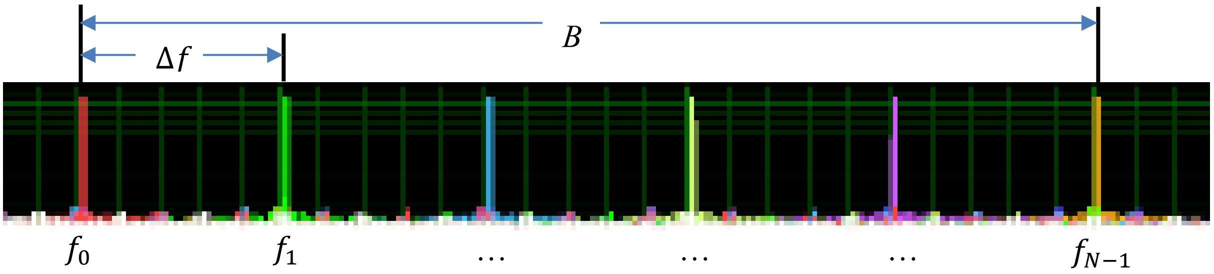


Figure 3. Frequency spectrum of the SFCW signal, highlighting the relationship between step size, number of frequency steps, and total bandwidth

The collection of stepped frequencies in SFCW spans a total bandwidth defined as

$$B = N\Delta f \tag{1}$$

where N is the number of frequency steps. The bandwidth is a critical parameter in an SFCW radar system, as it directly determines the system's range resolution, ΔR. Range resolution is the radar's ability to distinguish two closely spaced targets in range. The range resolution in SFCW radar is given by

$$\Delta R = \frac{c}{2B} \tag{2}$$

indicating that a larger bandwidth improves the system's ability to resolve targets that are close together.

Conversely, the maximum unambiguous range that can be detected using the SFCW system depends on the frequency step size, Δf, which is expressed as

$$R_{max} = \frac{c}{2\Delta f} \tag{3}$$

The SFCW approach is well-suited for far-field applications because its small frequency step size increases the unambiguous range, facilitating high-range target detection. However, this comes at the cost of requiring more frequency steps to maintain the same bandwidth. In this case, it would lead to increases in acquisition time and computational load. Thus, in SFCW radar design, there is a trade-off between achieving high range resolution and maintaining sufficient unambiguous range.

In this research, the finalized design parameters for the SFCW radar system are summarized in Table 1. These values were selected to balance range resolution and unambiguous range while keeping the acquisition time practical for laboratory testing

Table 1. Design parameters of the SFCW radar system

Parameters	System Type	Length [m]
Start Frequency (f_0)	1.12 GHz	Initial transmit frequency
Stop Frequency (f_{N-1})	1.68 GHz	Final transmit frequency (f_0+ (N-1) Δf)
Frequency Step Size (Δf)	20 MHz	Step size between each frequency
Number of Steps (N)	28	Total number of frequency components
Total Bandwidth	560 MHz	$B = N\Delta f$
Range Resolution	ΔR	0.27 m
Unambiguous Range	R_{max}	7.5 m

With the system parameters defined, the next step is to show how to estimate the target range from the received signal.

The target range, R, can be estimated from the phase response, $\emptyset_N$ of the received signal at the frequency f_N, as shown in Eq. (4)

$$\emptyset_N = \frac{4\pi f_N R}{c} \tag{4}$$

From Eq. (4), the target range can be estimated directly from the phase of the received signal at each frequency component. However, in practice, the range profile is more conveniently obtained by applying an inverse fast Fourier transform (IFFT) to the entire frequency-domain dataset, thereby incorporating all frequency steps. In this research, the IFFT method was employed, with the peak locations in the range profile corresponding to the target distances.

To translate the design into practice, the SFCW radar system was implemented on an SDR platform as described in the following section.

2.2. Hardware Implementation

The proposed system employed a USRP N210 with a WBX daughterboard and dedicated transmit and receive antennas; the detailed hardware specifications are listed in Table 2.

Table 2. Design parameters of the SFCW radar system

Components	Details / Specifications
SDR Platform	USRP N210
Daughterboard	WBX (50 MHz – 2.2 GHz)
Max Sample Rate	25 MS/s
Transmit Antenna	Waveguide Antenna
Receive Antenna	Horn Antenna

To manage signal flow and hardware control, the system employed a dedicated software architecture developed in LabVIEW, as outlined in the next section.

2.3. Software Architecture

The radar system was developed in LabVIEW, where all processes, including signal generation, USRP configuration, data acquisition, and initial signal processing, were carried out. LabVIEW was selected for this research because it offers seamless integration with the USRP hardware, graphical programming flexibility for waveform generation and hardware control, and built-in modules for real-time data acquisition. These features make it particularly suitable for rapid prototyping of SDR systems.

Fig. 4 shows the front panel of the developed user interface. The interface allows users to freely configure radar parameters, including operating frequency range, step size, number of frequency steps, and antenna selection. The flexibility of this interface is one of the main advantages of the developed system, as it can be rapidly adapted to experimental scenarios requiring varying radar configurations.

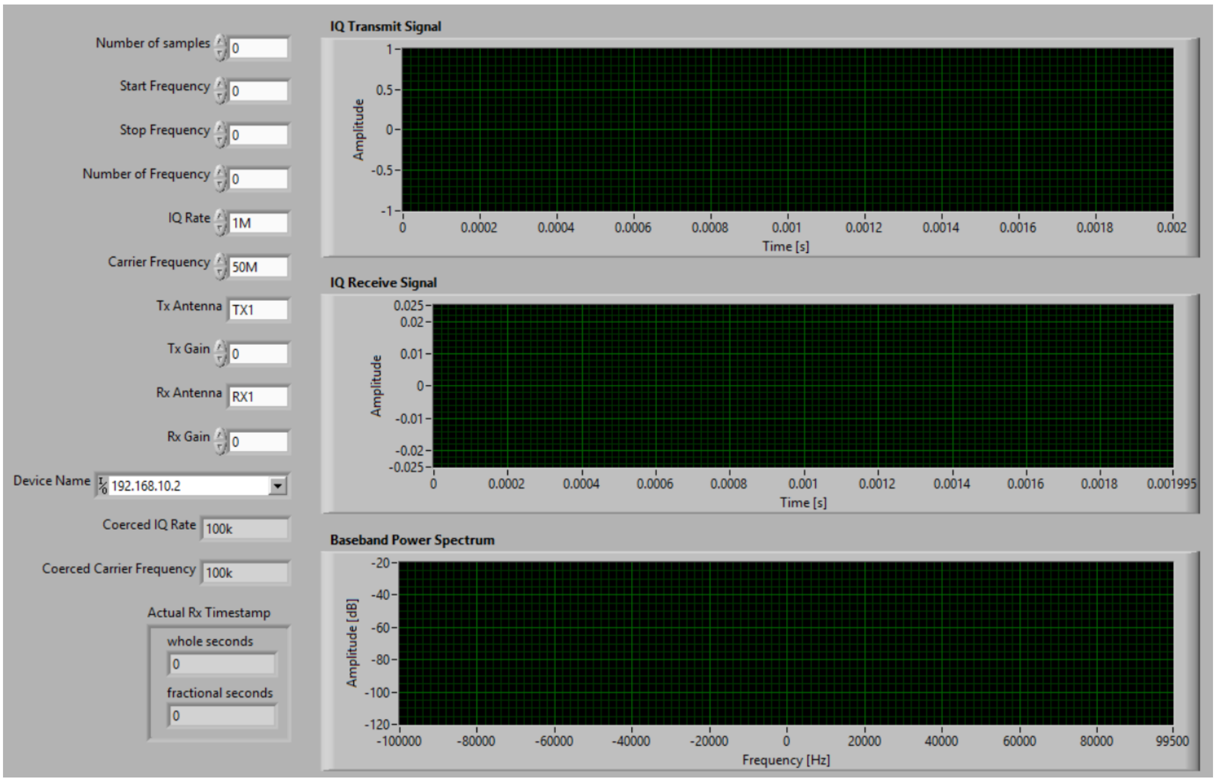

Number of samples 0
Start Frequency 0
Stop Frequency 0
Number of Frequency 0
IQ Rate 1M
Carrier Frequency 50M
Tx Antenna TX1
Tx Gain 0
Rx Antenna RX1
Rx Gain 0
Device Name 192.168.10.2
Coerced IQ Rate 100k
Coerced Carrier Frequency 100k
Actual Rx Timestamp
whole seconds 0
fractional seconds 0

Figure 4. Example of LabVIEW user interface

The corresponding block diagram is shown in Fig. 5 and illustrates the graphical source code that defines the data acquisition process. The program is organized into three main sections. The first section covers waveform generation, the second covers the transmitter chain, and the third covers the receiver chain. This architecture ensures synchronized operation between the transmitter and receiver while maintaining flexibility for future modifications. In addition, the graphical nature of LabVIEW provides a clear visualization of the data flow, simplifying development, facilitating debugging, and enabling real-time monitoring, making it easier to identify and resolve potential system issues.

In summary, the proposed SFCW radar system was designed to balance range resolution and unambiguous range, implemented using USRP-based hardware, and controlled through a LabVIEW software architecture that ensured flexibility and ease of debugging. With the system design established, the following chapter describes the experimental methodology used to validate its performance.

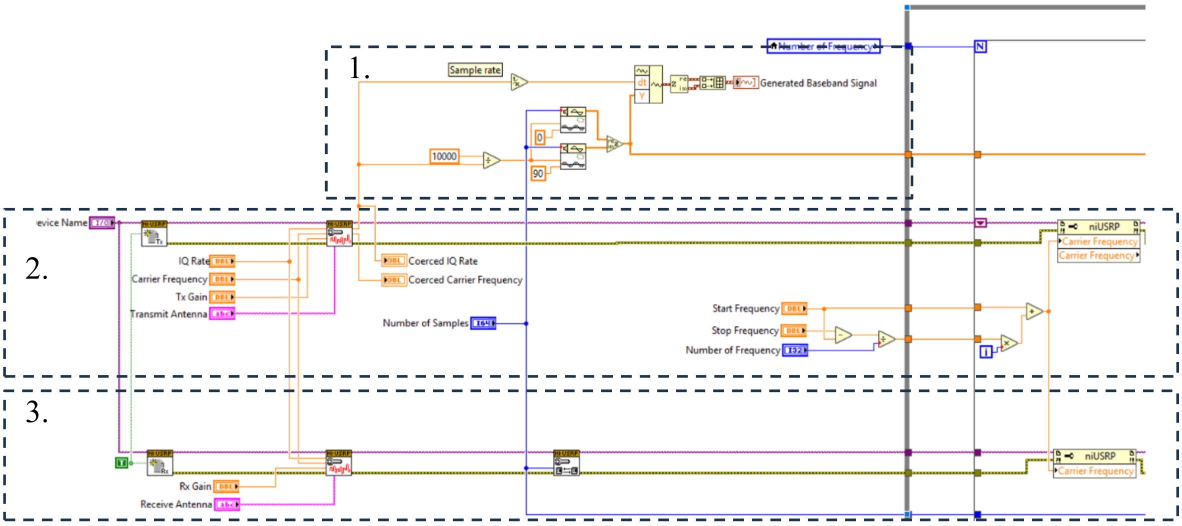


Figure 5. LabVIEW block diagram for the data acquisition process

3. METHODOLOGY

The system was tested to detect a 30 cm × 30 cm metal sheet in a controlled indoor environment, with the SFCW signal parameters summarized in Table 2. An overview of the radar system's transition from initialization to result visualization is shown in the flowchart in Fig. 6. The process comprises four stages: system setup, data acquisition, signal processing, and output.

As shown in Fig. 6, the procedure begins with system initialization, during which LabVIEW prepares the control interface and hardware connections. During the system setup stage, the USRP N210 is configured, and the operating parameters are defined as in Table 2.

The following system setup is the data-acquisition stage, in which SFCW signals are generated in LabVIEW and transmitted via the waveguide antenna. The reflected signals from the metal target are received by the horn antenna, downconverted to baseband IQ samples, and then stored as frequency-domain data for the signal processing stage.

Finally, in the Signal Processing & Output stage, the stored frequency-domain data is exported to LabVIEW for post-processing to obtain the range profile. The range profile enables estimation of the target position, which can then be compared with the actual distance. To obtain the range profile, an inverse fast Fourier transform (IFFT) is applied to the received signals, and the resulting spectrum is then displayed graphically.

To assess the accuracy of this estimation, the experimental setup and validation procedures are presented in the following subsections.

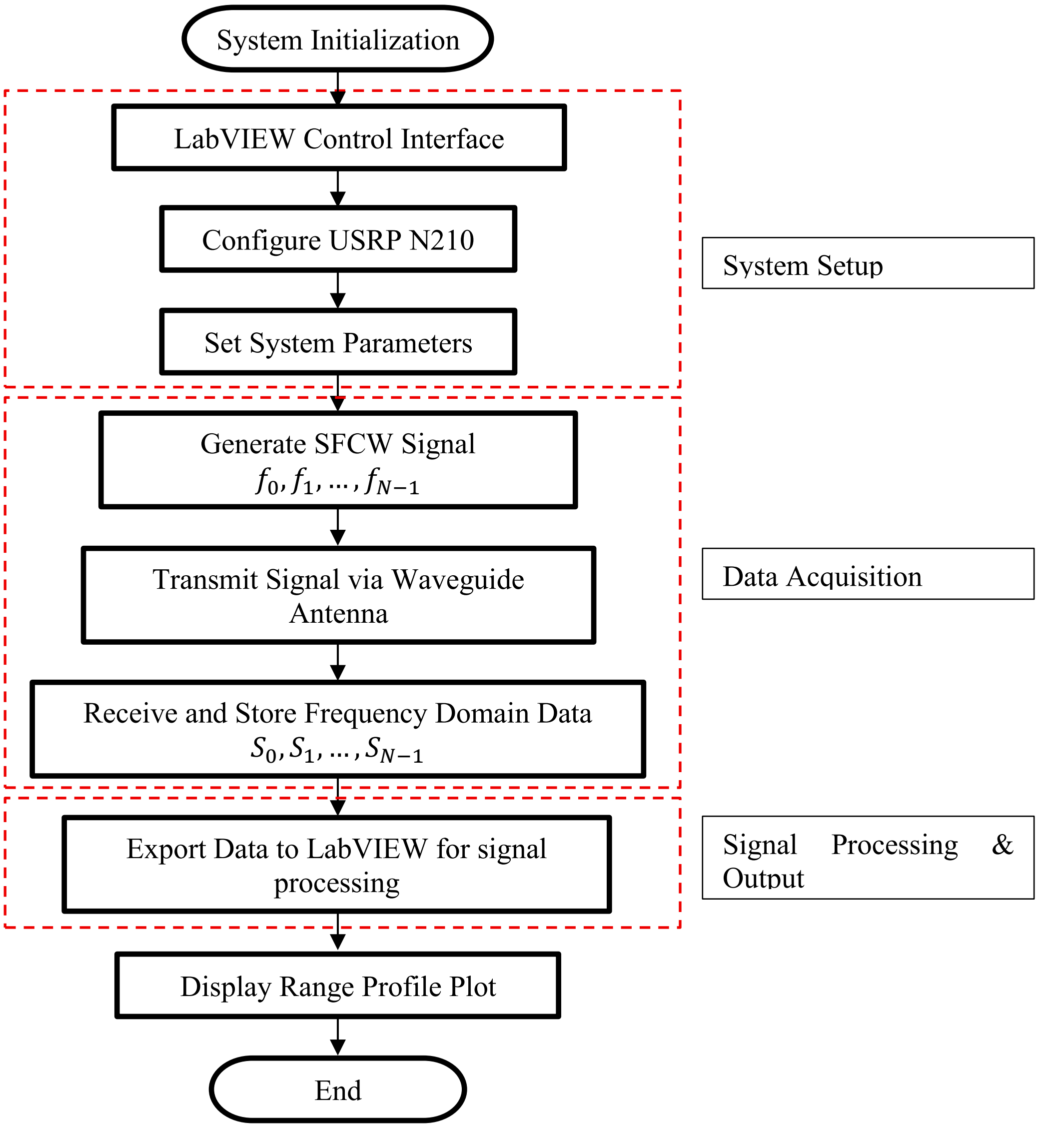


Figure 6. SFCW Radar System Processing Flow for Target Range Detection

3.1. System Setup

The proposed SFCW radar system was tested in a controlled indoor environment to minimize external interference. A metal sheet was used as the target and placed at various distances within the radar's detectable range. The system consisted of a USRP N210 with a WBX daughterboard, a waveguide antenna for transmission, and a horn antenna for reception, all connected to a host PC running LabVIEW for control and data acquisition.

Fig. 7 shows the experimental setup, with the transmitter and receiver antennas aligned toward the metal sheet target. Four tests were carried out, placing the target at 1.25 m, 1.00 m, 0.90 m, and 0.70 m, respectively. These distances were chosen to assess the radar's performance across a range of near-field and mid-range scenarios, enabling evaluation of its ability to accurately detect stationary objects at varying distances.

The experimental procedure began with initializing the radar system through the LabVIEW interface. The USRP N210 was first configured with the appropriate device address, sample rate, and carrier frequency, while transmit and receive antenna ports were assigned accordingly. The operating parameters summarized in Table 2 were set accordingly.

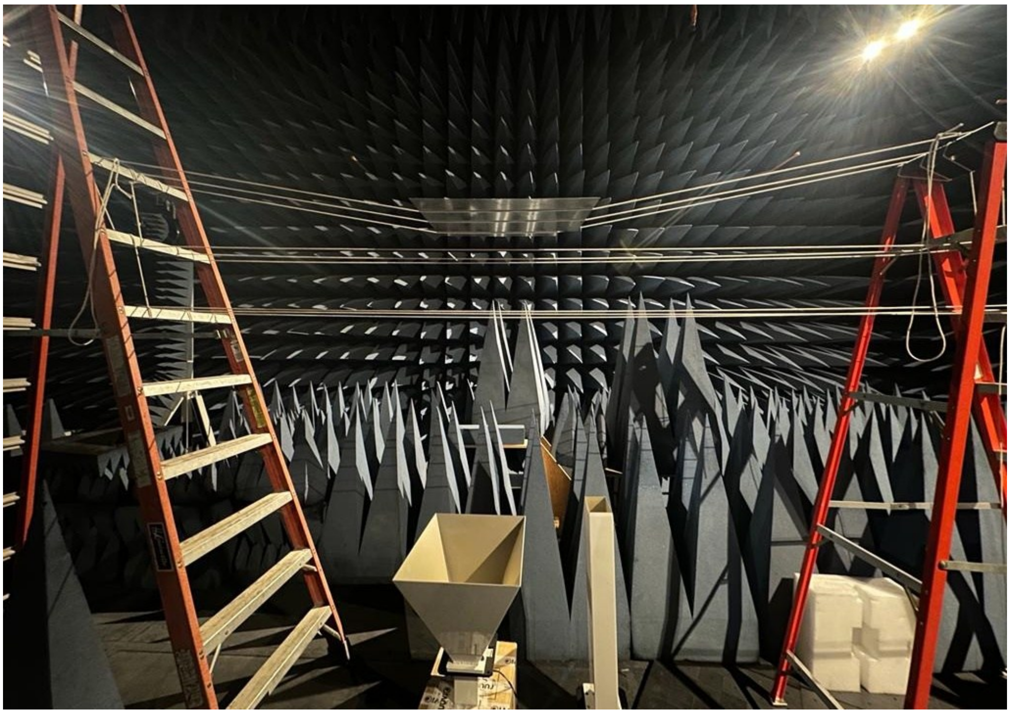
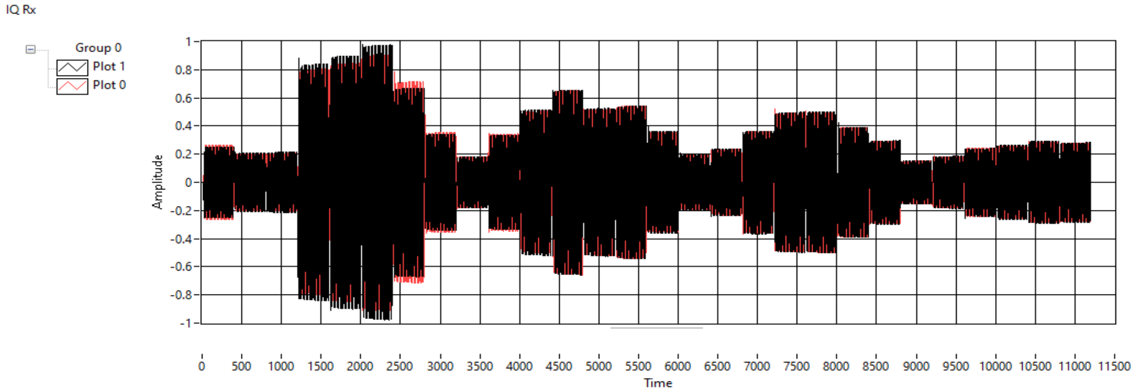


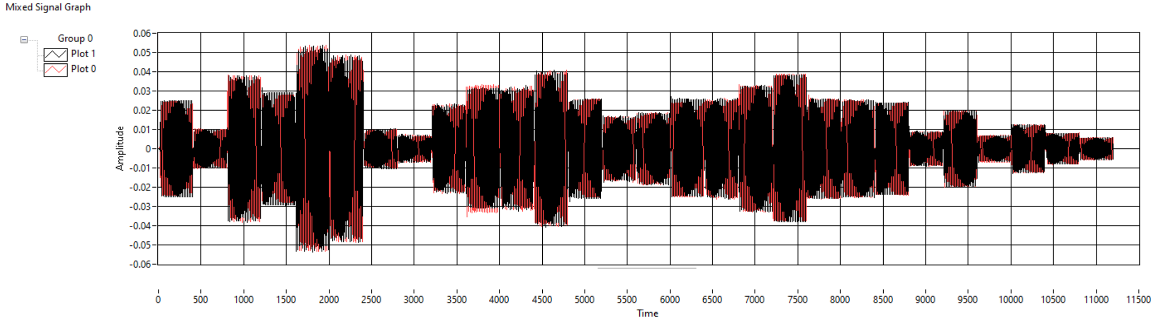
Figure 7. Experimental setup

3.2. Data Acquisition

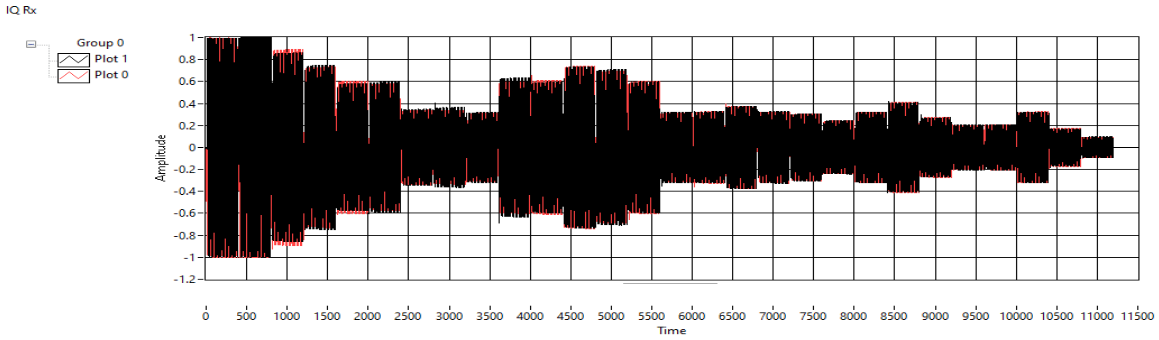
After system initialization, the radar generated SFCW signals, with each frequency step synthesized in LabVIEW and transmitted sequentially through the waveguide antenna. The reflected signals from the metal target were captured by the horn antenna and downconverted by the USRP N210 into baseband IQ samples.



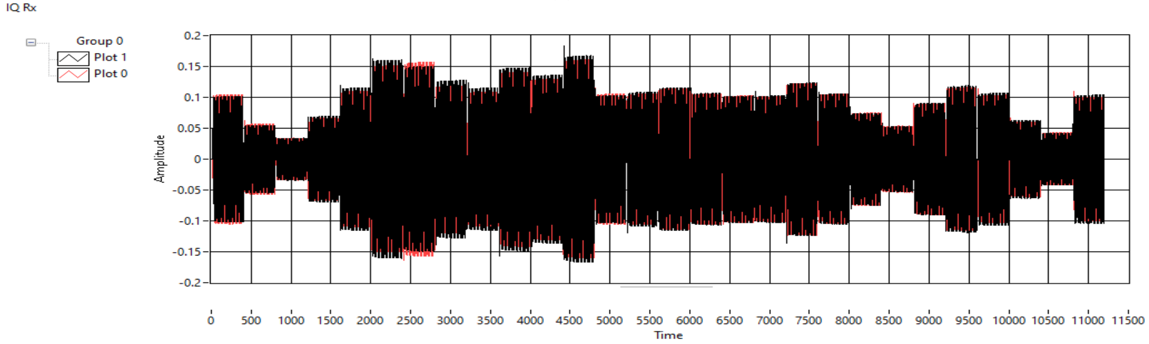
(a) 1.25 m



(b) 1.00 m



(c) 0.90 m



(d) 0.70 m

Figure 8. Received IQ data showing 28 frequency components for the target at (a) 1.25 m, (b) 1.00 m, (c) 0.90 m, and (d) 0.70 m

Fig. 8 (a-d) presents the received IQ data for the four measurement scenarios. In each case, 28 distinct frequency components are clearly visible, confirming that the system successfully received all transmitted frequencies. This validates the proper operation of the data acquisition process and ensures that the subsequent range-profile estimation is based on a complete set of frequency-domain measurements. The acquired data was then stored on the host PC for subsequent signal processing.

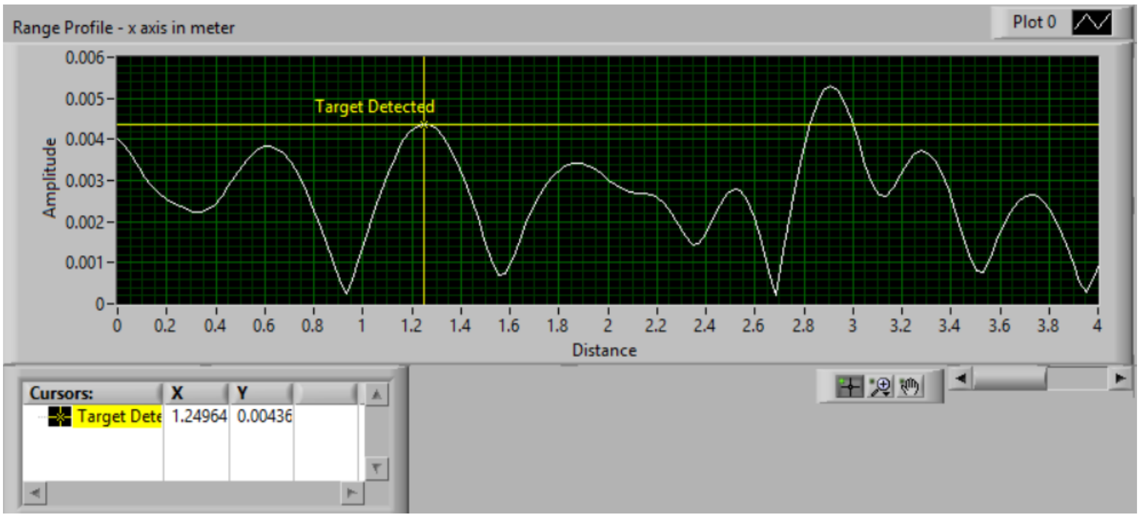
3.3. Signal Processing and Output

The I and Q samples received were saved in text format during acquisition and subsequently recalled within LabVIEW for post-processing. An inverse fast Fourier transform (IFFT) was applied across all 28 frequency steps to generate the target's range profile. The resulting range profile represents reflection power as a function of distance, with peaks corresponding to target locations.

By using the full set of frequency steps, the IFFT-based method provides more accurate and robust range estimation than single-frequency phase analysis. This processing procedure served as the basis for evaluating the radar's performance, with representative range profiles presented in Section 4.

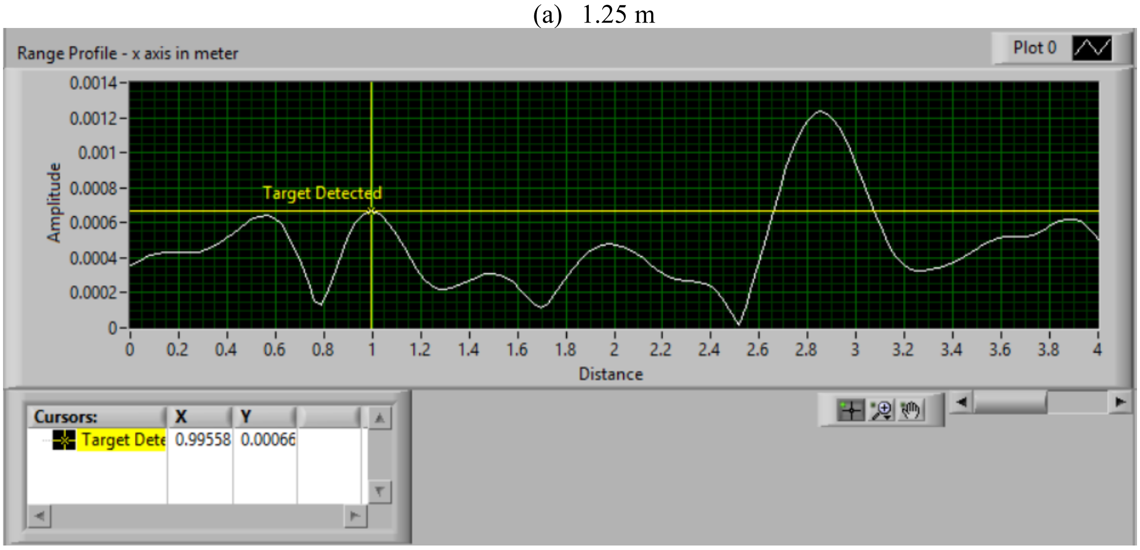
4. RESULTS

The radar system was evaluated by detecting a 30 × 30 cm metal target placed at four different ranges: 1.25 m, 1.00 m, 0.90 m, and 0.70 m. Fig. 9(a-d) shows the corresponding range profiles obtained via IFFT processing. The measured distances were compared with the actual distances, and the percentage of error was summarized in Table 3. Apart from the distance error, spurious spikes that appeared in the range profile also highlighted the need for further refinement of the system.



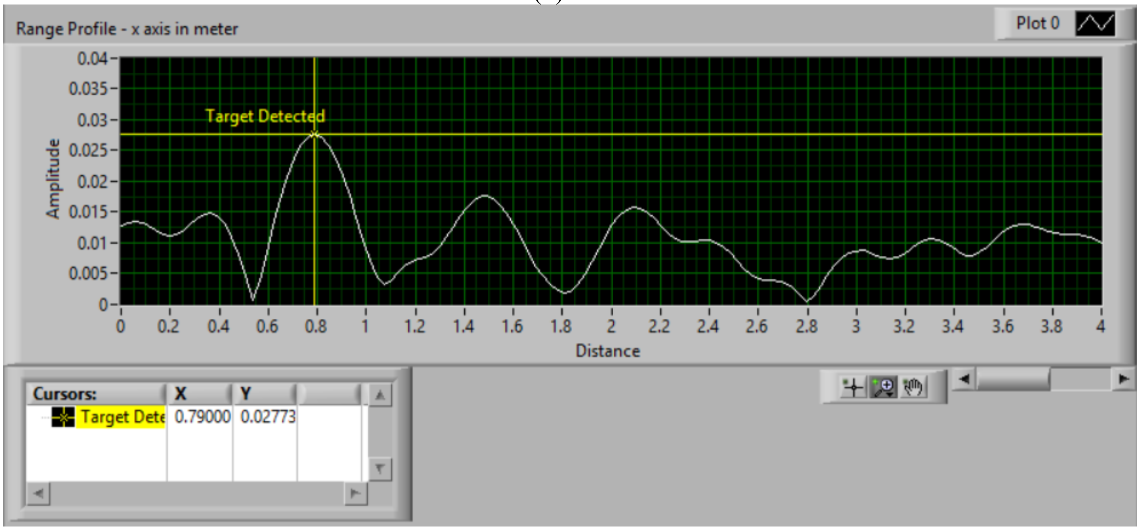
Cursors:	X	Y
Target Dete	1.24964	0.00436

(a) 1.25 m



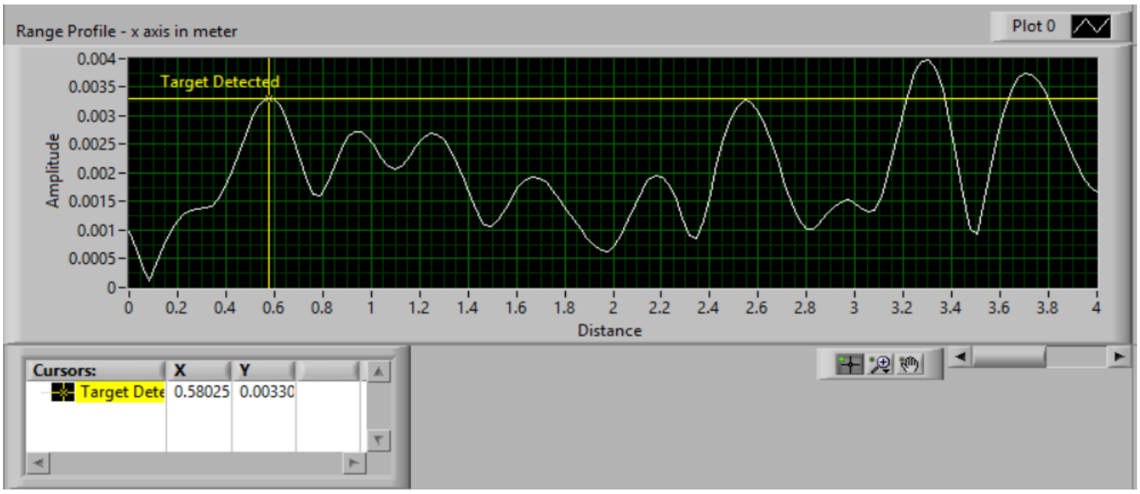
Cursors:	X	Y
Target Dete	0.99558	0.00066

(b) 1.00 m



Cursors:	X	Y
Target Dete	0.79000	0.02773

(c) 0.90 m



Cursors:	X	Y
Target Dete	0.58025	0.00330

(d) 0.70 m

Figure 9. Range profile of the target placed at (a) 1.25 m, (b) 1.00 m, (c) 0.90 m, and (d) 0.70 m

Table 3. Design parameters of the SFCW radar system

Distance, m, (Actual)	Distance, m, (Measured)	%Error
1.25 m	1.24964 m ≈ 1.25 m	0.03% ≈ 0%
1.00 m	0.99558 m ≈ 1.00 m	0.44% ≈ 0%
0.90 m	0.79000 m ≈ 0.79 m	≈12.22%
0.70 m	0.58025 m ≈ 0.58 m	≈ 17.12%

The radar system demonstrated high accuracy at longer ranges of 1.25 m and 1.00 m, with approximately zero error recorded. However, at shorter ranges (0.9 m and 0.7 m), the percentage error increased to 12.22% and 17.12%, respectively.

5. DISCUSSION

The results demonstrate that the proposed SFCW SDR system can achieve accurate range estimation under controlled indoor conditions and reliably detect targets at 1.25 m and 1.00 m, highlighting the effectiveness of integrating the USRP N210 platform with LabVIEW for waveform generation, signal acquisition, and post-processing. It has successfully recorded errors of 0.03% and 0.44%, which are negligible.

The system's performance, however, degraded to shorter ranges of 0.90 m and 0.70 m, with percentage errors of 12.22% and 17.12%, respectively. Several factors may have contributed to these inaccuracies. First, in the experimental setup shown in Fig. 7, the ladder's position might cause multipath reflections in the laboratory that introduce additional echoes, which interfere with the main target response and shift peak positions in the range profile. Second, sidelobes in the IFFT response may have masked the main peaks, generated spurious spikes, and reduced detection clarity. Finally, imperfect calibration between the transmit and receive chains, along with residual system noise, may have affected phase alignment across frequency steps.

Based on the range profile observation in Fig. 9, the presence of spurious spikes further underscores the importance of advanced signal processing techniques. Target isolation could be improved by minimizing sidelobe effects and suppressing false peaks using window functions, averaging, or clutter suppression techniques. Additionally, near-field measurement accuracy would likely improve by calibrating and testing in environments with less multipath interference. Compared with FMCW-based SDR systems reported in prior studies, the proposed SFCW system offers key advantages, as summarized in Table 4.

Table 4. Performance comparison between the proposed SFCW system and existing FMCW SDR systems

Metric	[2] (2024) FMCW	[6] (2026) FMCW	[4] (2023) FMCW	This Research SFCW
Platform	USRP B210	LimeSDR	USRP 2932	**USRP N210 + WBX**
Bandwidth	14 MHz	58 MHz	80 MHz	**560 MHz**
Range Resolution	10.7 m	2.58 m	Not specified	**0.27 m**
Best Range Error	Not Specified	2.15% (avg, >15m)	Not specified	**0.03% (at 1.25 m)**
Near-field Error	Not specified	10-15% (<8 m)	Not specified	**0.44% (at 1.00 m)**
Power Feedthrough	Present	Present	Present (noted as critical)	**Absent**
Sweep Consistency	Inconsistent at wide BM	Requires reference path	Dependent on MIMO sync	**Stable (28/28 steps recovered)**
Software Control	GNU Radio	GNU Radio	LabVIEW	**LabVIEW (unified)**

From Table 4, the proposed SFCW system achieved a substantially finer range resolution of 0.27 m compared to 10.7 m in [2] and 2.58 m in [6]. This improvement shows a direct dependence on the wider effective bandwidth of 560 MHz enabled by the stepped-frequency architecture.

Meanwhile, in terms of detection accuracy, research in [6] reported average relative errors of 2.15% to 4.28% after applying a matched filter and a direct reference signal in an FMCW system on the LimeSDR platform over target distances of 5.27 m to 28.45 m. On the other hand, the proposed SFCW system achieved errors of 0.03% and 0.44% at 1.25 m and 1.00 m, respectively, without a reference signal path. In addition, it confirms that the stepped-frequency approach inherently provides more stable phase coherence across measurements.

Finally, research in [4] explicitly identified power feedthrough as a critical drawback of FMCW, which was addressed by using MIMO synchronization cable between two USRPs. In contrast, the proposed SFCW system has eliminated this issue by transmitting and receiving discrete step-frequency tones rather than continuous signals. Additionally, the SFCW system proposed in this research has demonstrated stability, as evidenced by a 100% frequency acquisition rate, with none of the 28 transmitted frequencies missing. On the other hand, in FMCW systems, achieving stability even at the equivalent bandwidth is difficult due to sweep-rate inconsistencies, as identified in [3]. The summary of the comparison of the existing SDR-based radar system and the proposed radar system is presented in Table 5.

On top of all, this research acknowledged that the proposed SFCW system introduces its own trade-off: in near-field detection, errors were recorded when the target was located at 0.90 m and 0.70 m, warranting further investigation. Nevertheless, the results collectively demonstrated that SFCW-based SDR offers measurable advantages over FMCW approaches for controlled, general-purpose indoor detection over sub-meter to meter ranges in terms of resolution, acquisition stability, and implementation simplicity.

Table 5. Comparative Analysis of Existing SDR-Based Radar Systems and the Proposed Approach

Research	Technique	Platform	Bandwidth	Key Performance Metrics	Limitation Addressed	Contribution & Significance
[2] (2024)	FMCW	USRP B210	14 MHz	Max range estimates 0.63 - 10.7 m (model dependent)	Limited transmit power and sweep time tradeoffs	Evaluates power constraints and sweep-time impacts on SDR-based FMCW radar
[4] (2023)	FMCW (SAR)	USRP 2932	80 MHz	SAR focusing demonstrated and hardware prototype	Power feedthrough and sweep rate instability in wideband	Validated real-time SAR imaging using MIMO cables for strict synchronization
[6] (2026)	FMCW	LimeSDR	58 MHz	Avg. Error: 2.15% - 4.28%	Random protocol delays and sync complexity in unsynchronized R_x	Developed matched filters and magnitude-squaring to handle unsynchronized SDR setups
[7] (2017)	SFCW (GPR)	USRP X310	4500 MHz	8-fold speed increase via multi-tone expansion	Slow data acquisition time and narrow instantaneous bandwidth	Expanded effective bandwidth of standard SDR hardware for GPR applications
[8] (2018)	SFCW (GPR)	Custom modular RF components	Not specified	Error: 0.2% - 2.0%	Lack of experimental verification for modular and portable radar designs	Validated portable SFCW-GPR for buried object detection
[9] (2021)	SFCW	USRP X300	5850 MHz	Validated SWE and snow depth measurements	Diffusion effects and complex layering in multi-path environments	Extended SFCW to environmental monitoring for hydrological cycle sensing
[10] (2020)	SFCW	bladeRF	5000 MHz	Sensitivity: 66 dB DR: 74 dB	High cost and redundant functionality of traditional VNAs	Confirmed SDR viability for precision medical imaging (breast cancer detection)
This study (2026)	**SFCW**	**USRP N210 + WBX**	**560 MHz**	**Error: <0.5% Res: 0.27m**	**Overcomes feedthrough, sweep instability, and synchronization complexity**	**Delivers low-cost, general-purpose SFCW SDR with sub-meter resolution and <0.5% mid-range error, outperforming FMCW baselines by an order of magnitude.**

Overall, the results highlight the strengths of SFCW SDR systems in achieving flexible, cost-effective, and accurate range detection, while also identifying the limitations that must be addressed to extend their applicability to real-world scenarios.

6. CONCLUSION

This work presented the implementation of a low-cost SFCW radar system using a USRP N210 platform controlled through LabVIEW. The system was experimentally validated in a controlled indoor environment, where it successfully detected a metal target at different ranges. The results showed that the system achieved nearly zero error for targets placed at 1.25 m and 1.00 m, confirming the effectiveness of the architecture and signal processing approach.

However, accuracy decreased at shorter ranges, with errors of 12.22% and 17.12% observed at 0.90 m and 0.70 m, respectively. These inaccuracies were primarily attributed to multipath reflections, sidelobe effects, and calibration limitations. While these findings highlight the system's limitations in near-field detection, practical improvements, such as advanced signal processing techniques and more robust calibration methods, have also been identified.

Overall, the research demonstrates that SFCW-based SDR systems provide a flexible and reliable platform for radar research. By combining software-defined control with the SFCW technique, such systems overcome many of the limitations of FMCW approaches and offer strong potential for adaptation to applications in environmental monitoring, biomedical sensing, and security. The near-field errors observed in this work highlight a critical boundary for Indoor Fall Detection and Posture Monitoring; therefore, subsequent studies will investigate the scaling of these models to complex, multi-target environments. Future iterations of this platform will integrate Machine Learning (ML) classifiers directly into the LabVIEW/software environment. By training a convolutional neural network (CNN) on SFCW range profiles, the system could move beyond simple detection to automated target recognition (ATR) and material classification, improving accuracy.

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