Software-defined ground-based synthetic aperture radar interferometry

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1. INTRODUCTION

This paper presents an experimental implementation of ground-based interferometric synthetic aperture radar based on the low cost USRP platform and a computer. The purpose of the proposed system is to measure small displacements of the monitored targets over a long time period. These types of measurements are particularly useful in the field of civil engineering and ecology. Common applications are landslide monitoring or bridge and building deformation analysis, as well as glacier movement monitoring. The system implements stepped-frequency radar operation with a maximum bandwidth of 1500 MHz (500 – 2000 MHz). As expected with all interferometric measurements, due to the cyclic nature of the phase shift, the displacement must be smaller than a certain fraction of the wavelength of operation; otherwise the result will be ambiguous. In our case the displacement must be smaller (in absolute value) than a quarter of the transmitted wavelength.

2. EXPERIMENTAL SETUP

The hardware component of the proposed system comprises a PC and a USRP N200 SDR unit containing a WBX RF daughterboard. This configuration acts as a full-duplex wide-band transceiver. The Radio Frequency (RF) input and output of the USRP are connected to Vivaldi antennas and a RF attenuator through a couple of digitally-controlled RF switches. The antennas are selected for their wide-band and simple fabrication. The switches are computer controlled through an Arduino Uno board as depicted in figure 1. The baseband signal processing is divided between the USRP motherboard, specifically the FPGA module, and the personal computer. The computer program is coded in LabVIEW. The FPGA uses the standard firmware which comes with the USRP. Due to the low-cost nature of the SDR platform and its general-purpose destination the system is lacking coherence of the transmitter and receiver sections of the device. This means random phase shift exists between the transmitter and the receiver sections of the SDR. In order to implement the synthetic aperture radar operation, it is compulsory to correct this fundamental issue. The proposed implementation measures and then compensates this phase shift from the received signals in each scan.

The second correction implemented in the system software is the unwanted parasitic antenna coupling. This unwanted effect is corrected by subtracting a previously stored target-less anechoic chamber measurement from every scan performed by the system.

In order to precisely position the radar for each scan a low-cost linear positioning system was designed and constructed. It uses a stepper motor controlled by an Arduino Uno through an electronic driver circuit, a plastic and wood rail and a belt driven wheeled carriage, as depicted in figure 1. The linear positioning system is also controlled by the PC making the process of acquiring an image scan completely automated.

The software flowchart is presented in figure 2.

While in operation, the program displays the continuously updated unfocused radar image computed by performing the Inverse Fast Fourier Transform (IFFT) on each scan. At the same time, the program also stores the acquired data in multiple files, a file for each radar position, in 3 columns format. The first column represents the frequency, the second column is the amplitude in dB and the last column the phase in degrees, similar to Vector Network Analyzers. This makes the data available for applying the synthetic aperture algorithm for focusing the data and for performing interferometric processing on multiple complex focused images.

The synthetic aperture focusing and the interferometric processing of the images is implemented in MATLAB. The focusing section is based on the Backprojection algorithm described in paper [1]. The interferometric processing starts with the computation of the complex interferogram of two images acquired at different moments in time by multiplying the first image with the complex conjugate of the second image, element by element. The result is a matrix of complex elements. The displacements matrix is computed by multiplying the phase of the complex interferogram by the central wavelength of the system's transmitted signal divided by 4π, as in equation (1).

$$\text{Displacement\_matrix} = \text{Angle}(\text{Complex\_Interferogram}) \cdot \frac{2c}{4\pi(f_{start}+f_{stop})} \quad (1)$$

where c is the speed of light.

The displacement matrix is further filtered by applying a mask. The matrix is multiplied element by element with a mask matrix which has zeroes where the absolute value of the complex interferometric matrix is lower than 50% of the maximum of the absolute value of the complex interferometric matrix, and ones in the rest.

In order to test the proposed implementation, a metal cabinet was placed in front of the radar system at a distance of about 2m. A first scan was performed, then the cabinet was moved 4cm closer to the radar and a second scan was conducted. The results are depicted in figure 3.

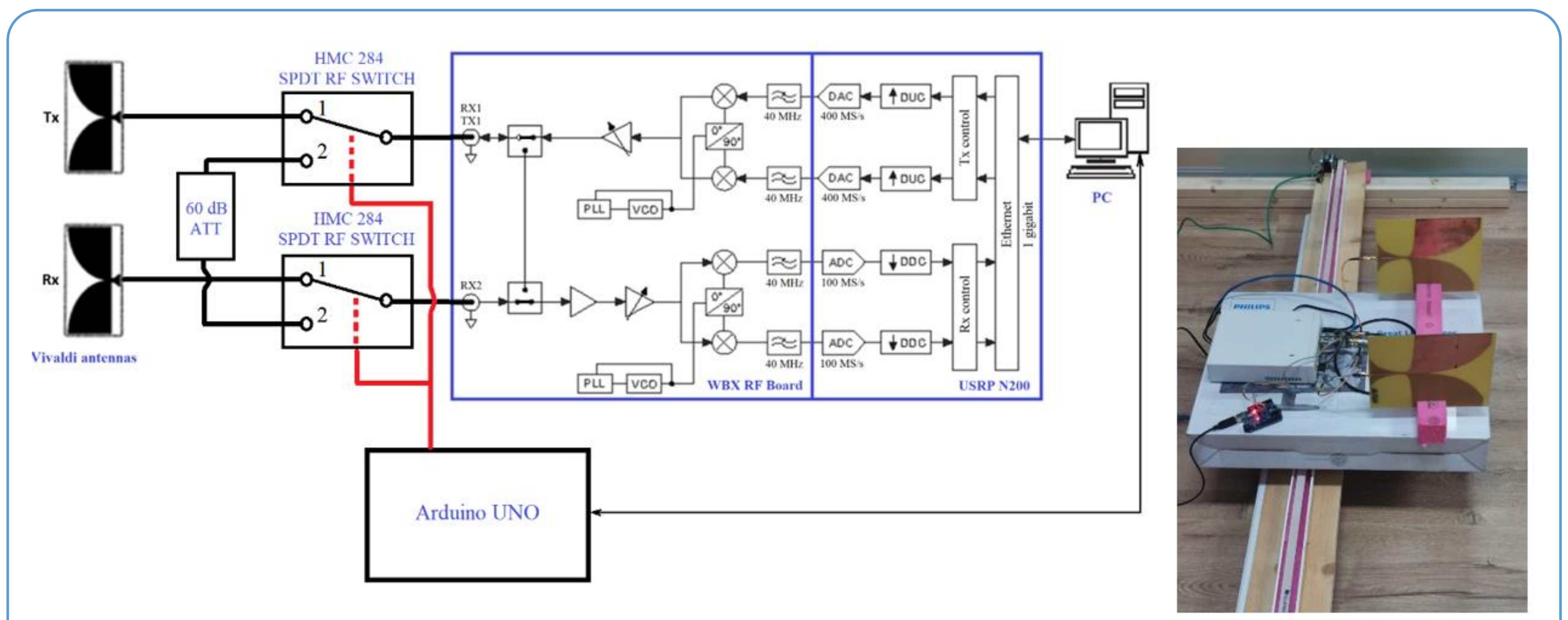

Fig. 1. Experimental setup.

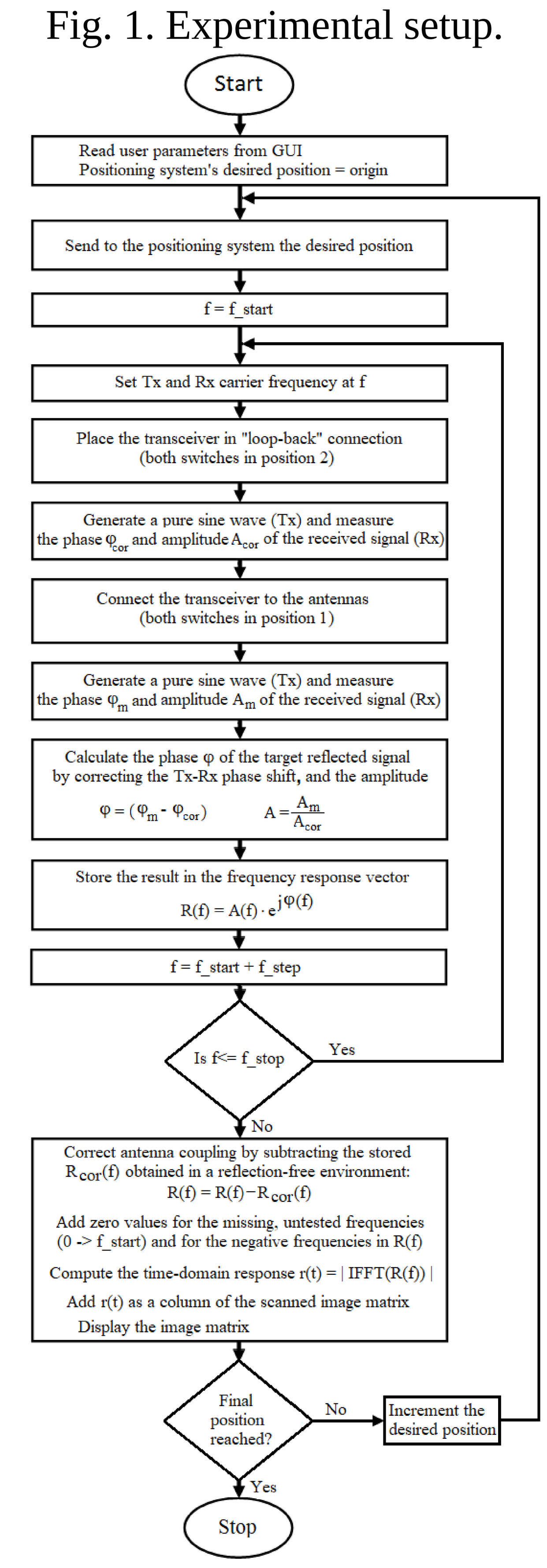

Fig. 2. Flowchart.

3. RESULTS

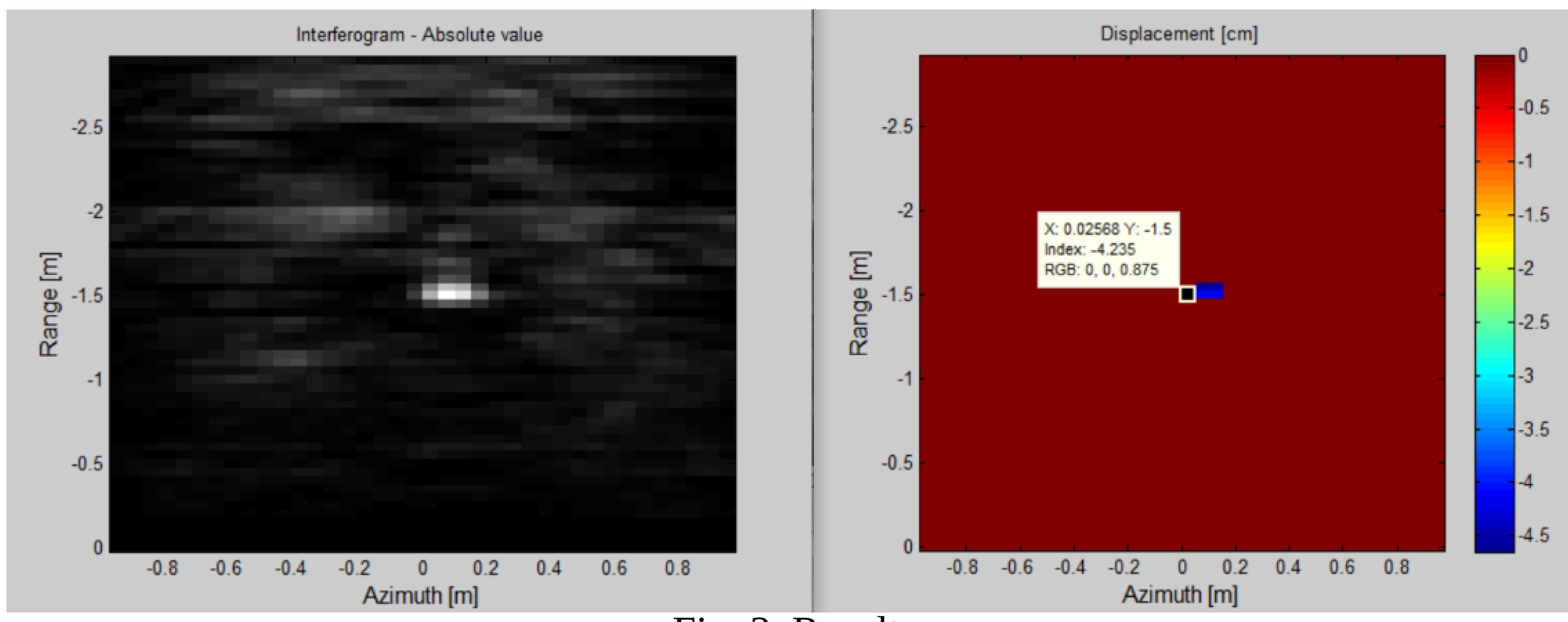

Fig. 3. Results.

The 4 cm displacement of the target is clearly detected and measured.

4. CONCLUSIONS

This paper successfully demonstrates interferometric displacement detection and measurement using low-cost ground based synthetic aperture radar (GB-SAR) based on software-defined radio hardware.

References

[1] Gorham, L. A. and Moore, L. J., "SAR image formation toolbox for MATLAB," Proc. SPIE 7699, Algorithms for Synthetic Aperture Radar Imagery XVII, 769906 (2010).

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