Continuous-wave software-defined radar interferometry

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1. INTRODUCTION

Software-defined radio technology is becoming increasingly widespread and cost-effective. As a consequence, a growing number of technical fields are benefiting from the advantages of this technology[1]. Displacement measurement is an important topic in civil engineering which can benefit from the advances in SDR technology. Interferometric radars capable of accurately measuring small displacements are commonly implemented in a dedicated hardware form[2]. This approach is expensive and the resulting device is inflexible in operation. This paper proposes a practical implementation of interferometric radar using solely a general purpose low-cost SDR platform with minimal external components. The only external additions are two off-the-shelf RF switches, an Arduino Uno microcontroller board, a fixed RF attenuator and two Vivaldi antennas. The result is a very flexible radar system with wide range tunable working frequency and radiated power.

The purpose of the proposed system is to measure small displacements of the monitored target over a long time period. These measurements are extremely useful in the field of civil engineering. Common applications are landslide monitoring or bridge and building deformation analysis.

2. EXPERIMENTAL SETUP

The proposed hardware consists of an USRP N200 platform fitted with a WBX RF daughterboard. This configuration provides a full-duplex transceiver. The transmitter and the receiver sections of the system are connected to Vivaldi antennas and a fixed attenuator through a couple of RF switches. The choice for this particular antenna is motivated by its wide-band and ease of fabrication. The switches are controlled by the computer through an Arduino Uno board as depicted in the block diagram in figure 1 and the practical implementation in figure 2.

The baseband signal processing is divided between the USRP motherboard, mainly the FPGA module, and the personal computer connected to it which also serves as the system's human interface device.

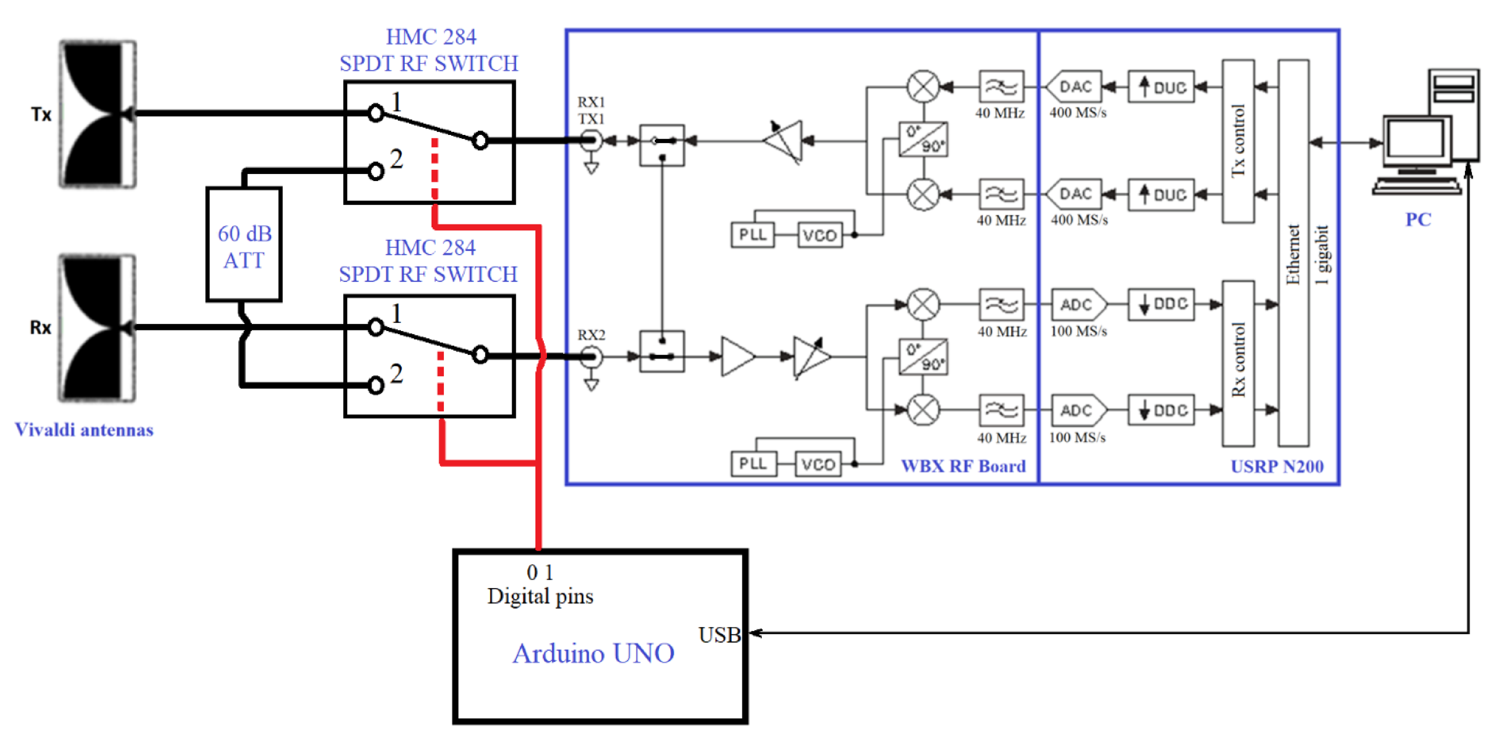


Fig. 1. Experimental setup – block diagram.

Fig. 2. Experimental setup – practical implementation.

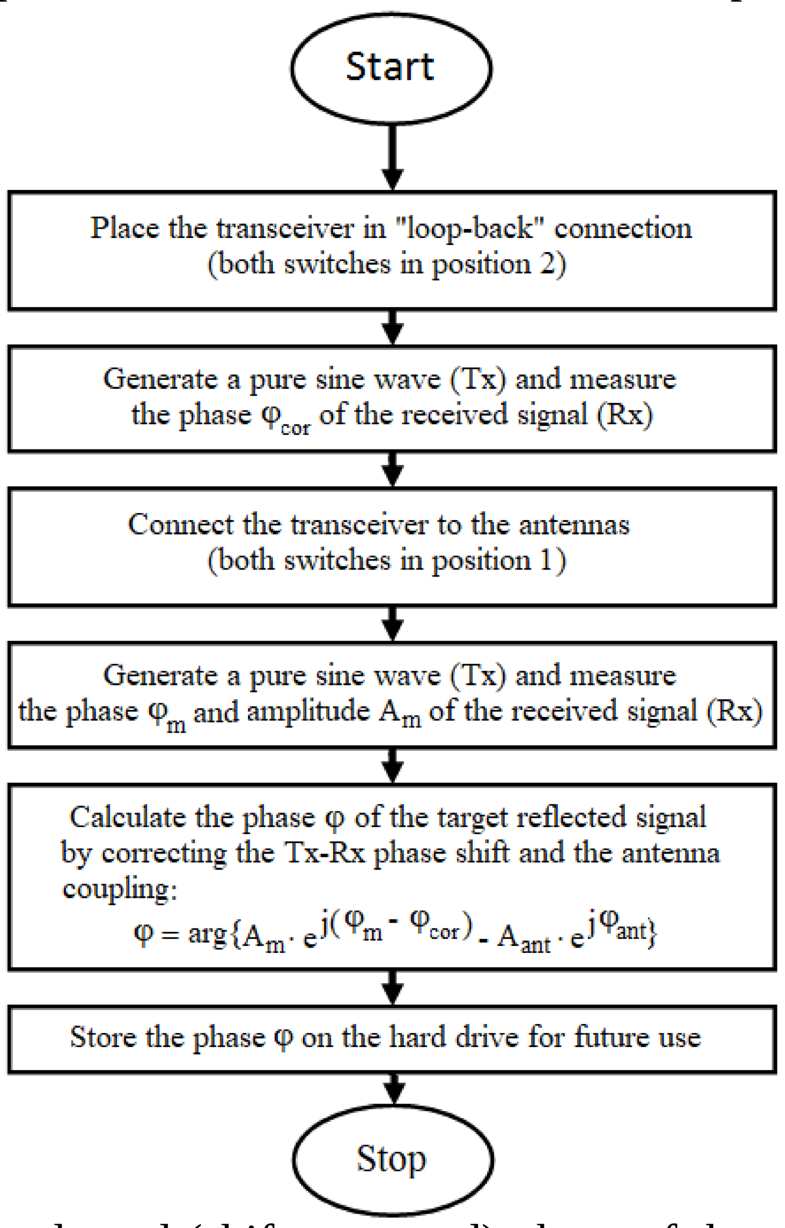
3. OPERATION

The proposed solution transmits a monochromatic radio wave towards the monitored target and measures the phase shift suffered by the reflected wave. The measured phase shift is stored in a file on the hard drive of the computer. After a certain period of time, spanning from minutes to years, specific to the application, with the system placed in the same position, a second phase shift measurement needs to be performed, storing a new result. The system then computes the difference between the two stored phase shifts and determines the displacement. As expected for 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 module) than a quarter of the transmitted wavelength. Due to the fact that in a software-defined radio the frequency is user selectable in a very wide range, the system can be configured to adapt to the magnitude of the expected displacement.

The main difficulty in implementing radar interferometry on a low-cost, general purpose SDR transceiver platform stems from the lack of coherence of the transmitter and receiver sections of the device. This lack of coherence translates in a random phase shift between the transmitter and the receiver sections of the SDR. In order to successfully implement an interferometer, it is imperative to correct this fundamental problem. The proposed solution is to automatically measure and subtract this phase shift from the acquired signals.

The second essential correction is the parasitic antenna coupling. This unwanted effect is corrected by subtracting the coupled signal in an automated correction procedure using both the amplitude and the phase of the received wave.

The complete procedure performed for each measurement is presented in the following flowchart:



A_{ant} and φ_{ant} are the amplitude and (shift corrected) phase of the received signal measured without any target in front of the antennas (or ideally in an anechoic chamber). These values are acquired and stored on the hard drive prior to beginning the operational life of the system. These values will be later used, during operation, for performing antenna coupling correction. The program provides the user with a dedicated function for acquiring the antenna correction data which can be accessed using the *Calibration* button.

For performing measurements, the system has to be pointed towards the analyzed target. Then, clicking on the *Measurement* button triggers the automated procedure that stores on the hard drive, in a user-selectable file, the phase of the received signal.

In order to measure the displacement of the target between two acquisitions, by clicking on the *Compute Displacement* button, the stored phases φ_1 and φ_2 are retrieved from the hard drive and the displacement is computed by the program using the following formula:

$$displacement = \Delta\varphi \frac{\lambda}{4\pi} \quad (1)$$

where $\Delta\varphi = (\varphi_1 - \varphi_2)$ wrapped to $(-\pi, \pi]$ interval.

4. RESULTS

Several displacement measurements have been performed using the experimental setup described above. The experiments employed a metallic computer case, a PCB copper laminate 20 x 30 cm and a disc-shaped metallic ashtray 15 cm in diameter acting as targets. The targets have been placed at distances of 1, 2 and 3 meters from the radar and displacements of 0.5 – 3 cm between successive acquisitions have been successfully measured with millimeter precision.

5. CONCLUSIONS

The method described in this paper can be employed for implementing interferometric radars on low cost, non-coherent software defined radio platforms.

By applying highly reflective targets on facades, building deformations can be measured with millimetric accuracy.

References

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