Software-defined Ground Penetrating Chirp Radar

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1. INTRODUCTION

This paper presents a practical implementation for low-cost, software-defined Ground Penetrating Radar. The proposed system uses solely a general purpose low-cost SDR platform, two antennas and a PC. **The main advantage of this implementation compared to similar implementations in the literature is the absence of external components/circuits or custom-built RF boards.** The SDR platform is USRP N200 equipped with WBX RF daughterboard. The only external additions are two Vivaldi antennas. The system implements chirp radar operation with a bandwidth of 40 MHz achieving a theoretical resolution of 375 cm in air. Because of the reduction of electromagnetic wave velocity in soil, the resolution improves significantly in practical situations where the wave travels through a high permittivity medium. The resulting system is capable to successfully discover large subterranean voids like caves or tunnels. The paper presents an experimental validation where the proposed system is employed to detect the presence of a tunnel.

2. EXPERIMENTAL SETUP

The proposed hardware consists of a PC and a 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. The choice for this particular antenna is motivated by its wide-band and ease of fabrication[1]. The block diagram of the proposed system hardware is presented 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. The customized part of the signal processing is performed on the computer and is coded, for simplicity, in LabVIEW. The FPGA uses the standard firmware provided by Ettus Research.

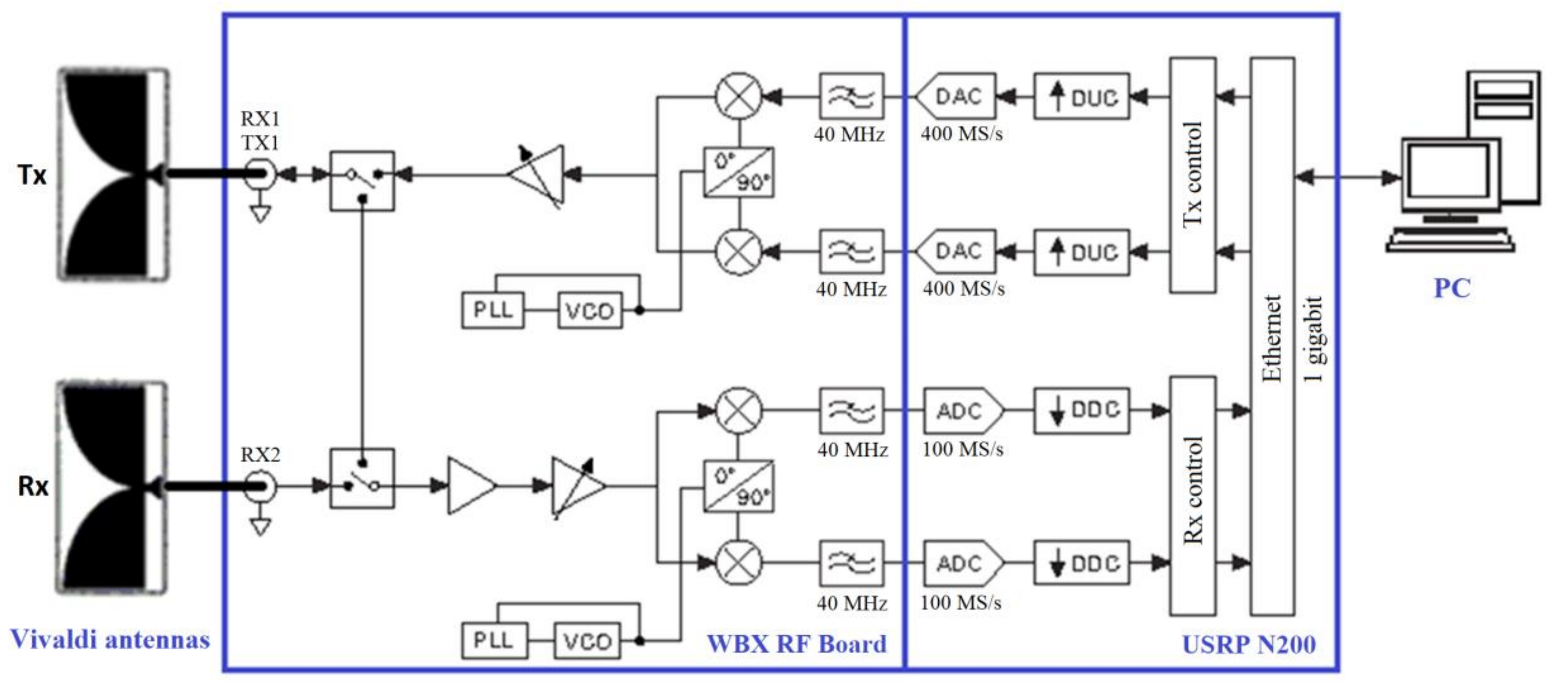

Fig. 1. System hardware – block diagram.

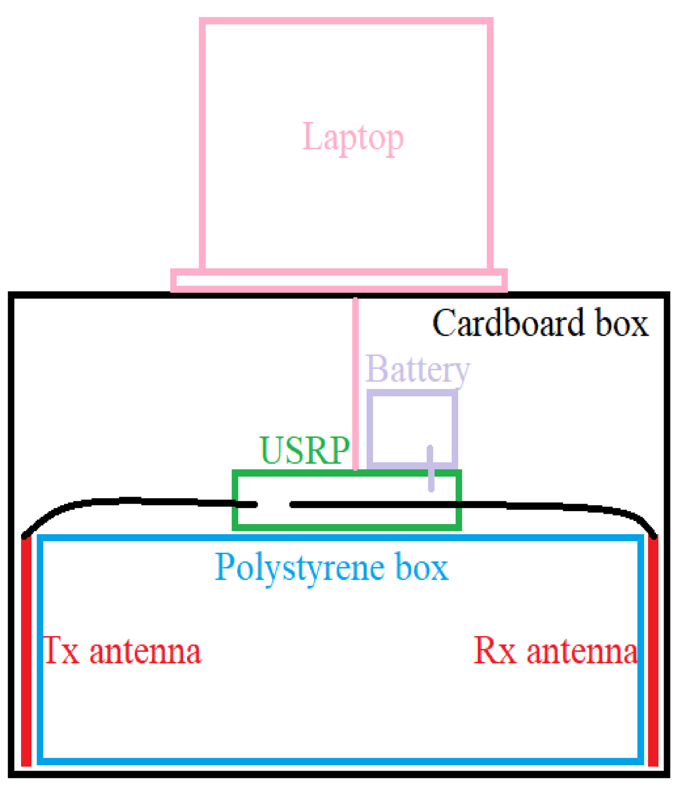

Fig. 2. Experimental setup – practical implementation.

3. OPERATION

The program generates a complex baseband bidirectional linear chirp with a bandwidth of 40 MHz and a duration of 38 μs. The baseband chirp expression is:

$$s(n) = e^{j\pi k\left(nT-\frac{\tau}{2}\right)^2} \qquad (1)$$

where k is the chirp rate 1052631 MHz/s, τ is the chirp duration 38 μs, T is the USRP IQ sampling period 0.02 μs and $n = 0, 1, 2, \dots, N\text{-}1$, where $N = \frac{\tau}{T}$.

The chirp is prefixed with 2 μs of null samples, then is uploaded to the USRP SDR where it modulates a carrier of 500MHz which is transmitted by the transmitter section of the SDR transceiver. The null prefix is needed for skipping the erroneous transient signals from the beginning of the transmission / reception sequence.

Synchronously, the receiver section of the USRP demodulates, samples and sends to the PC the reflected waveform $r(n)$, with $n = 0, 1, 2, \dots, M\text{-}1$, where $M = \frac{Reception\_duration}{T}$.

Then, the received signal is matched filtered by performing the cross-correlation between the received and the transmitted waveform:

$$c(n) = \sum_{k=0}^{N-1} s^*(k) \cdot r(n-(N-1)+k) \qquad (2)$$

The magnitude of the subset of c(n) for $n=N, N+1, N+2, \dots, N+M\text{-}2$ is appended as a new column of the image matrix, which is represented graphically as the GPR image (each element is a pixel):

$$\begin{bmatrix} |c_1(N)| & |c_2(N)| & & |c_i(N)| \\ |c_1(N+1)| & |c_2(N+1)| & \cdots & |c_i(N+1)| \\ |c_1(N+2)| & |c_2(N+2)| & & |c_i(N+2)| \\ \vdots & \vdots & & \\ |c_1(N+M-2)| & |c_2(N+M-2)| & & |c_i(N+M-2)| \end{bmatrix} \qquad (3)$$

where i is the index of the current scan.

The GPR image matrix is populated sequentially by moving the system on a straight line with a step of 1 m between successive scan positions.

4. RESULTS

The chosen test site was a tunnel of 2 x 2 m. The experimental system traveled on the ground above the tunnel on a straight line, perpendicular to the tunnel direction, as indicated in figure 3. Every 1 m a new scan was performed, with a total of 15 measuring points.

Fig. 3. Experimental setup in action.

Based on the construction materials used for the tunnel, mainly concrete, the propagation speed was estimated to approximately half of the light speed in air. This gives a depth resolution δ_r of about 188 cm, enough to distinguish the tunnel.

$$\delta_r = \frac{c}{2 \cdot Bandwidth} = \frac{15 \cdot 10^7}{2 \cdot 40 \cdot 10^6} m = 187.5\ cm \qquad (4)$$

The resulting image is depicted in figure 4. The tunnel is clearly visible in the center of the image.

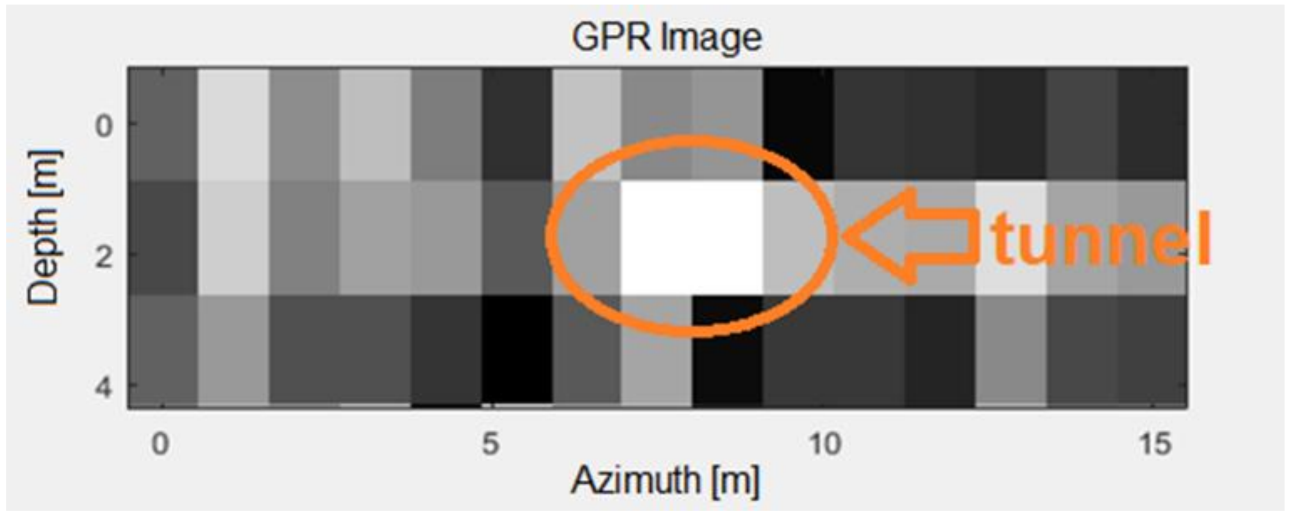

Fig. 4. Experimental results.

5. CONCLUSIONS

The system proposed in this paper implements a ground penetrating radar using exclusively a low-cost software-defined radio, with no additional components. Although the reduced instantaneous bandwidth limits the resolution of the generated image, the result is still useful in certain scenarios like the detection of large buried objects or underground voids.

REFERENCES

[1] Anchidin, L., Topor, R., Tamas, R. D., Dumitrascu, A., Danisor, A., Berescu, S., "Improvement of antenna decoupling in radar systems, " 7th SPIE Conference on Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies (ATOM-N 2014), Constanta, Romania, SPIE Paper No. 9258-39, SPIE Tracking No. OMN14-AO100-39, 6 pages (2014).

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