Through-the-Wall Moving Target Surveillance Using GPR

V. E. Ivashchuk, V. P. Prokhorenko
Transient Technologies LLC
Kiev, Ukraine
ive@viy.com.ua

A.A. Pitertsev, F. J. Yanovsky
Electronics Department
National Aviation University (NAU)
Kiev, Ukraine
yanovsky@nau.edu.ua

***Abstract*—This paper contains a brief overview of methods for solving the problem of moving objects surveillance behind the opaque wall. Then application of the ground penetrating radar for this purpose is considered, and the low cost method for detecting moving objects behind the wall, based on the analysis of reflected UWB signal in time domain, is described. Demonstration of real work of the method is carried out using the operational breadboard model of the device with a special signal processing for implementing this method**

Keywords—radar; ground penetrating radar; ultra wideband radar; surveillance; motion detection

I. Introduction

Considerable progress in the area through-the-wall surveillance (TWS) is caused by coincidence in time of two circumstances: a) the increased needs of the modern society caused by increase of requirements to the efficiency of rescue operations after natural cataclysms like earthquakes and volcanic activity, and also intensification of terrorist activity; b) development of new methods for generating and radiation of signals in a wide frequency range, including ultra wideband (UWB) signals, and advent of fast and effective devices of digital signal processing. Thus, an advantageous situation appeared when increase of requirements has coincided with occurrence of new engineering possibilities [1].

That is why through-the-wall imaging has recently become a topic of intense research as it concerns detection and localization of people behind impenetrable walls [2].

Possible applications of such devices are ranging from rescue operations in rubble up to terrorists' movements tracking inside a building as well as other law enforcement operations.

There were different techniques proposed using millimeter electromagnetic radiation, UWB sounding signals, acoustic signals, etc.

This paper will present a brief overview of methods for solving the problem of surveillance behind the opaque wall.

One of methods for detecting moving objects behind the wall, based on the analysis of reflected pulse UWB signal is considered in more details. Demonstration of real work of the method is carried out with use of the operating breadboard model of the device implementing this method. The same device can be used as GPR, and different signal processing algorithms give a possibility of adaptation to different situations.

II. Classification of TWS Methods

Considering radar techniques, first of all it is logical to distinguish between continuous wave (CW) and pulse radar systems. Both kinds of sounding waveforms were used for TWS. Pulse sounding waveforms can be: short pulse (without intrapulse modulation) and long pulse sounding waveforms with intrapulse modulation [3]. Application of short pulses is more frequent for TWS because of technological reasons and absence of range sidelobes worsening signal selection after processing. In work [4], short pulse sounding waveforms with carrier and without carrier (videopulses) were compared, and pulses with carrier were recommended as preferable because (according to [4]) matched filtration or correlation processing with transmitted signals as templates are possible for them in contrast to pulses without carrier. Nevertheless, the disadvantage of pulses with carrier is the growth of signal attenuation in construction materials with increasing frequency, and this disadvantage may have a crucial influence in some cases, particularly for thick and concrete walls. Another classification distinguishes Doppler radars [5] and interferometric radars [6; 7]. Doppler radar usually uses CW sounding waveform but it can be also a pulse (pulse-coherent) system. While the Doppler and interferometric radars are normally narrow band systems, the pulse TWS radars [8; 9] are normally UWB systems. There are also several works on TWS radar based on noise sounding waveforms [10; 11].

Different signal processing algorithms can be used including even SAR principle [12].

Development of the microwave UWB step-frequency radar and application of the radar for through-obstacles object detection and imaging systems is presented in [13]. The radar quickly sweeps through frequency range sequentially generating a set of equally distributed frequencies and collects received signal on each frequency. Sensitivity of the radar for the behind wall objects is improved by build-in hardware first reflection suppression sub-system. Tests of the system have shown its ability to: track position of the target even behind three brick walls; detect breathing and heartbeat of a human throw several meters of soil; obtain image of human behind wall by applying tomography processing to data collected by the radar.

A noncoherent, stepped-frequency TWS system approach, based on a trilateration technique, is presented in [14]. This approach involves multiple independent radar units and, as such, provides flexibility in positioning the units with various stand-off distances and inter-element spacing.

The interplay between coherent and non-coherent data fusion in a widely distributed MIMO sensor network is considered in [15] and seems to be a very interesting topic.

Another attempt to use a MIMO configuration and UWB signals in order to detect scatterers behind a wall is discussed in [16], where method of Decomposition of the Time Reversal Operator (DORT) is proposed for detection and localization of a moving target behind a wall. According to [16] one of the DORT method major strengths is that detection remains possible through a distorting medium.

Spectral variations of the reflections using videopulses are used in UWB radar for human being detection [17]. Novelty of the proposed [17] system radar lies in its large operational bandwidth combined with excellent time stability. It has been shown that due to breathing the range to a person varies within 0.6 cm.

As a rule, operating frequencies in all methods are rather high. They lie in the frequency band of 1 to 4 GHz. Due to strong attenuation of electromagnetic radiation in the material of main walls a thick wall still is a problem.

III. GPR-BASED SYSTEM FOR SEARCHING MOVING TARGET BEHIND THICK WALLS

The proposed UWB system is based on the principle used previously in the prototype of ground penetrating radar (GPR) [18]. However in contrast to GPR, which survey normally a stable situation under the ground, in the system, a motion is the feature to detect people. Actually a living person as any breather is always characterized by a kind of motion including its wiggling and even a movement of the chest when breathing. So, the system should detect any movement. Let us distinguish between two kinds of movement: a) indubitable movements like walking, and 2) small movements, say, caused by breathing.

Actually, presence of a moving target causes change of the situation behind the wall. Let us suppose that we are able to compare the reflected signal over a period of the order of s. In this case we can definitely detect the change of the situation, if a target or any part of the target is changing its position during s. Detection of a movement means presence of the target in the resolution volume.

Two principle problems of this approach are required high resolution of the system and good penetrability of the radiation that is used.

In order to detect small movements a system with high range resolution is necessary. Wideband and UWB technology is suitable to solve the problem of high resolution.

Another problem is to provide a detectable level of reflection from the object behind the wall in spite of twofold passage through the wall. All construction materials and soils cause attenuation of a propagating radiation (sounding signal). Especially important is the fact that the attenuation on average increases considerably when frequency increases. Therefore, for penetration of the sounding signal through the thickness of obstruction, the operating frequency of the system should be as low as possible; and this is one of the features of the accepted approach to design the system. Thus, the system for searching people under the rubble and behind thick walls should use an UWB signal that maximizes the receive power at comparatively low operating frequency.

The operating principle of the system for searching for people behind the wall and under the rubble is illustrated in Fig. 1

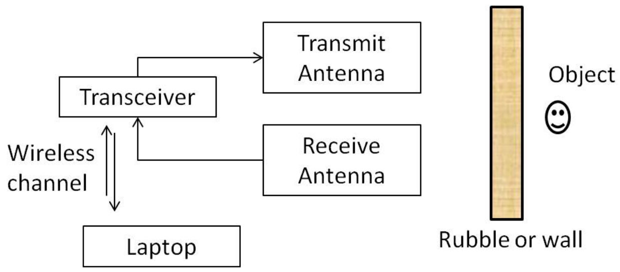

Fig. 1. Operating principle of the system for searching for people under the rubble or wall

The transmitter sends a short UWB pulse into the direction of a wall or rubble. The receiver takes scattering signals from different objects in rubble or behind the wall. The processing system that can be based on a laptop compares the signals over the given time. If the shape of the signals was changed, there was a movement. If there are no changes, that means no target.

The estimated parameters of the system prototype are following:

Frequency range	100 ... 1000 MHz
The pulse duration	1 .. 10 ns
Depth of detection (thickness of a wall)	up to 5 m
Average radiated power	< 250 mW.

IV. RESULTS OF SYSTEM TESTING FOR TWS FUNCTION

The test of the system was done in the building using the plastered brick wall of about one meter thickness. A man was sitting on the chair, making different kind of movements, namely:

test 1: waving his hand from side to side;
test 2: bending the body from side to side;
test 3: just breathing, keeping the body in the stable position.

The result of the experiment is presented in Fig. 2, where the screen of the laptop is indicated. One can see very strong changes in the picture that correspond to test 1 and test 2, as well as comparatively weak but still detectable change of the picture corresponding to the test 3. Horizontal axis in Fig. 2 means time and vertical axis represents range. One can see the changes that happen in the moments of Test 1, Test 2 and Test 3 in the corresponding range bins.

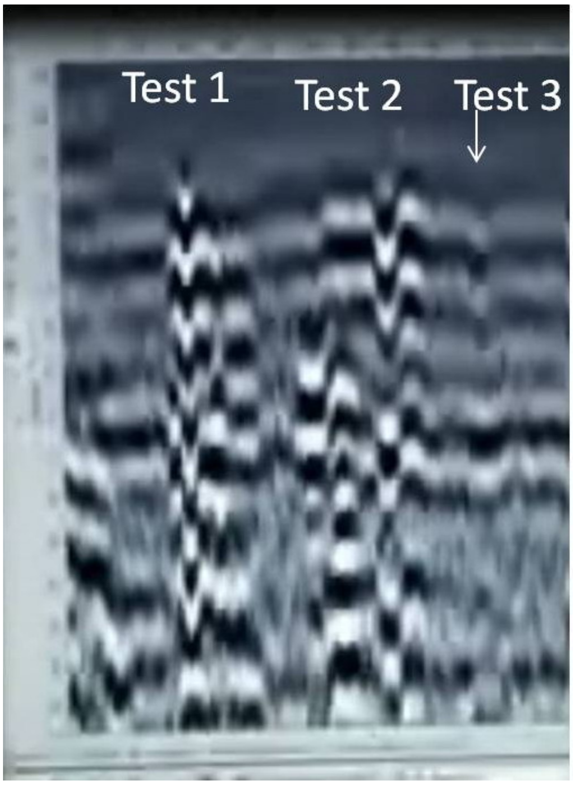

Fig. 2. Imaging of three types of movements (Test 1 is movement of a hand; Test 2 is movement of a body; Test 3 is movement of a chest when breathing)

Another experiment was on detection a person who walked up and down behind the combined (brick and concrete) wall of 1 m thickness. The result is presented in Fig. 3.

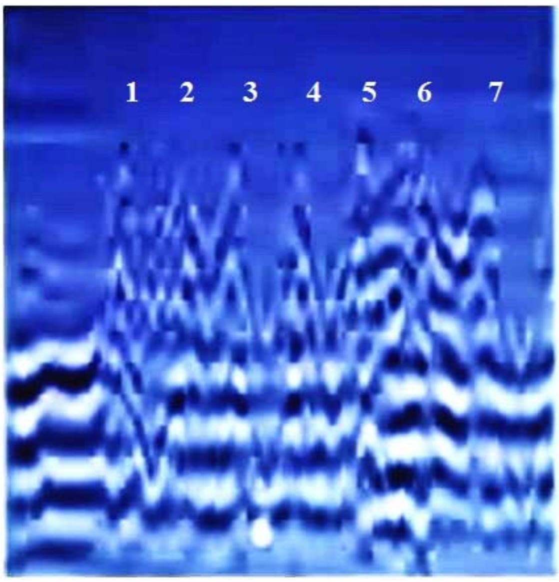

Fig. 3. The image of sequential (in time) situations, when a person went past behind a thick (1 m) wall seven times

One can clearly see significant changes that happened seven times during this experiment.

In case of absence of moving target behind the wall, it would be stable situation that were represented as parallel horizontal bright and dark strips. In the moment of passing a human across the beam of the UWB radar, the processing algorithm detects and displays the changes that are indicated by digits 1, 2, …, 7.

Based on these results we can assert that using such kind of UWB radar device it is possible to detect rather small motions that produced behind a thick wall.

V. Results of System Testing for GPR Function

Application of the same UWB system as GPR was also tested.

A special proving ground was prepared for experimental research capabilities of the device as a GPR. For this purpose the site was chosen where various underground facilities and communications were buried. Among them: the cellar, underground concrete pit for waste water, sewage pipes, plastic gas pipes, electric cables, metal objects. Position and shape of all the objects were well known in advance, and their photographs were done before burying. The aim of the study was to assess the capacity to identify the objects with the specified device simple and modern GPR technology [19].

As an example, a radar image of the underground space is given in Fig. 4. Left vertical axis represents time delay in nanoseconds, right vertical axis shows the corresponding range, that is, the depth in meters. Horizontal axis in the top of the picture shows horizontal distance. The device moved along this axis. The surface level (zero depth) is indicated by blue line.

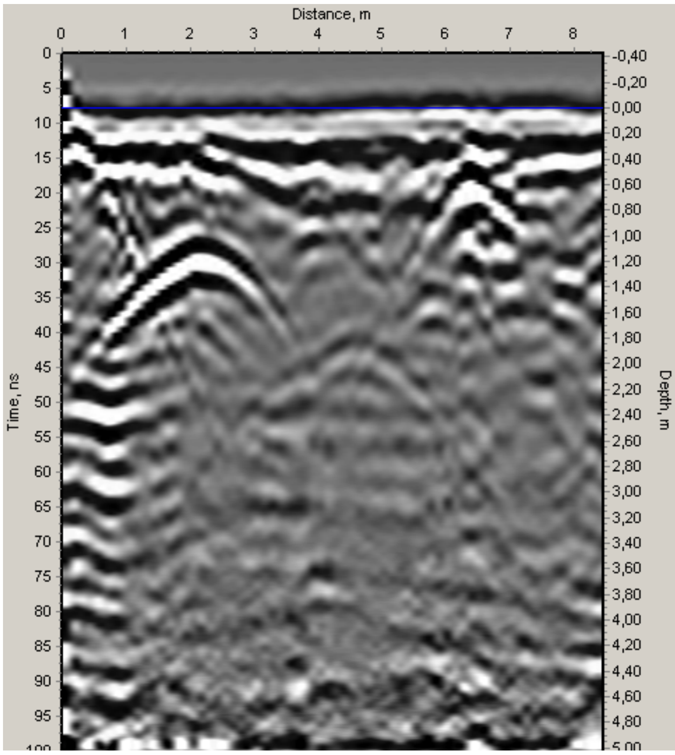

Fig. 4. The radar image of underground profile

This figure represents a typical GPR image. One can see the reflections from the following targets:

- Underground communications line (a cable) at 2 m horizontal distance and 1.2 m depth represented as a top of hyperbola;

- Another communications line at 4.6 m horizontal distance and 1.8 m depth (less contrast);

- Trace of old excavation at 6.4 m horizontal distance and about 0.5 m depth.

Signal processing in GPR mode were done using wavelet filtering ("Mexican hat"), gain control, and Windowed Background Removal that actually implements subtraction of mean value.

The results showed that, with appropriate signal processing, the instrument provides adequate results on detection underground objects.

More examples and analysis are done in [19].

VI. CONCLUSION

There are a wide variety of UWB radar techniques for TWS with different configurations, sounding signals and signal processing. Often they are implemented as rather complicated and expensive devices.

A possibility to detect moving objects under the rubble and behind the thick wall with a simple low cost UWB pulse radar has been demonstrated in this paper. Range resolution has been achieved using UWB signal. Relatively big depth of penetration through the really thick wall has been provided by application of comparatively low frequency.

High sensitivity of motion detection in TWS mode has been provided using special signal processing software that detects even light changes in the shape of the reflected signal during the time of processing.

Similar technique can be used for implementation of GPR and TWS purposes however signal processing and corresponding software should be chosen for every particular situation.

All parameters of the implemented physical demonstrating model can be significantly improved during the research work and modernized prototype development.

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