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THROUGH-THE-WALL SURVEILLANCE TECHNOLOGIES

Yanovsky F. J., Ivashchuk V. E., and Prokhorenko V. P.

National Aviation University, Kiev, Ukraine
E-mail: felix.yanovsky@ieee.org

Abstract

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

Keywords: Through-the-wall radar, UWB radar, GPR.

1. Introduction

The possibility to see through obstructions that are opaque to visible light always was very attractive for human. However until recently such vision seemed impracticable dream. Now several approaches to solve different problems of through-the-wall surveillance are known.

Considerable progress in this area is caused by coincidence in time of two circumstances: a) the increased needs of the modern society caused by activization of terrorist activity, and also increase of requirements to the efficiency of rescue operations after natural cataclysms like earthquakes and volcanic activity that became more frequent; 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. In other words, demand increase has coincided with occurrence of new engineering possibilities.

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 [1].

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 [18, 21], UWB sounding signals [19], acoustic signals [20], 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.

2. Methods of Through-the-Wall Radar Surveillance

In this overview we restrict ourselves to the consideration of radar techniques only.

First of all it is logical to consider continuous wave (CW) and pulse radar systems. Both kinds of sounding waveforms were considered to be used for Through-the-Wall Surveillance (TWS). Pulse sounding waveforms can be: short pulse (without intrapulse modulation) and long pulse sounding waveforms with intrapulse modulation [2]. 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 [3], short pulse sounding waveforms with carrier and without carrier (videopulses) were compared, and pulses with carrier were recommended as preferable because (according to [3]) 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 [4] and interferometric radars [5, 6]. 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 [7, 8] are normally UWB systems.

There are some works on TWS radar based on noise sounding waveforms [9, 10]

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Various signal processing algorithms can be used including even SAR principle [11] and compressed sensing technology [22].

Development of the microwave ultra-wide band step-frequency radar and application of the radar for through-obstacles object detection and imaging systems is presented in [12]. 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 [13]. 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 [14] 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 [15], 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 [15] 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 [16]. Novelty of the proposed [16] 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.

3. System for Searching People under the Rubble and Behind Thick Walls

The proposed UWB system is based on the principle used previously in the prototype of ground penetrating radar (GPR) [17]. 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 t 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 t 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

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
Maximum depth of detection (thickness of a wall) up to 5 m
Average radiated power< 250 mW

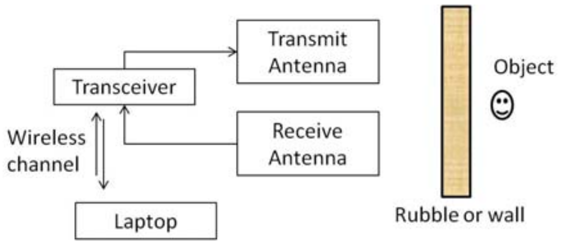

Fig. 1. Operating principle of the system for searching for people under the rubble or wall.

4. Experimental Testing of the System

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 test 3.

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.

5. Conclusion

There are a wide variety of UWB radar techniques for TWS with different configurations, sounding signals and signal processing.

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. Range resolution is achieved using UWB signal. Relatively big depth of penetration through the thick walls is provided by “low” frequency.

High sensitivity of motion detection is provided by special signal processing software. All parameters of the implemented physical demonstrating model can be significantly improved during the research work and modernized prototype development.

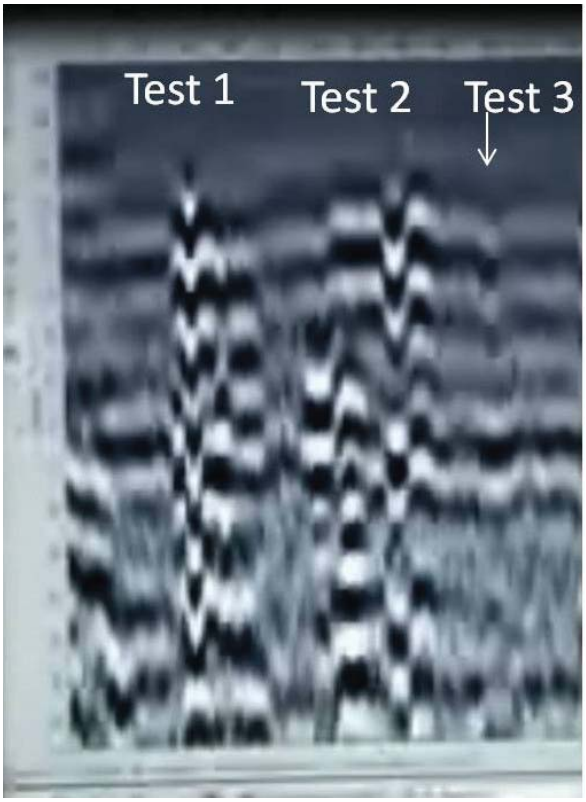

Fig. 2. Imaging of three types of movements (Test 1 is movement of a hand; Test 2 is movement of a body; Test 3 is movement of a chest when breathing).

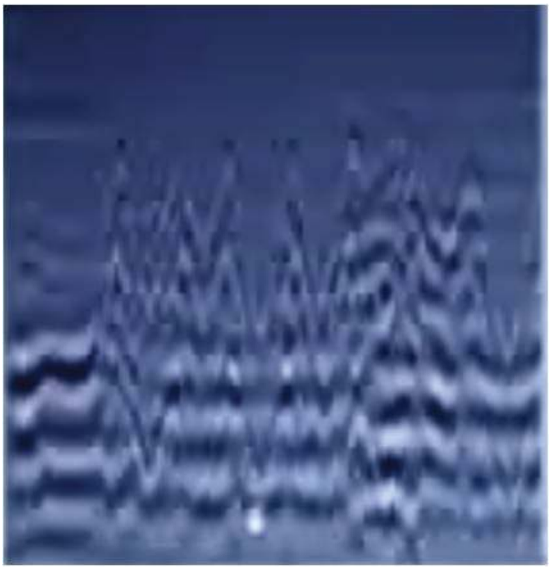

Fig. 3. The image of sequential (in time) situations, when a person went past behind a thick (1 m) wall seven times.

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