DETECTION AND TRACKING OF MOVING OR TRAPPED PEOPLE HIDDEN BY OBSTACLES USING ULTRA-WIDEBAND PSEUDO-NOISE RADAR

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Detection and Tracking of Moving or Trapped People Hidden by Obstacles using Ultra-Wideband Pseudo-Noise Radar

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***Abstract*— Efficient detection of people hidden by walls or rubble is of interest for rescue, surveillance and security operations. A useful method applies an ultra-wideband radar approach for this purpose since electromagnetic waves in the lower GHz-range penetrate most non-metallic materials. The paper gives a short overview of the particular radar conception and shows some experimental results for the tracking of people, detection of breathing people and reconstruction of room interiors.**

I. Introduction

Electromagnetic waves occupying a spectral band below a few GHz show reasonable penetration through most typical building material, such as bricks, wood, dry walls, concrete and reinforced concrete. This allows for the detection of hidden targets e.g. moving, respectively trapped people which can be applied for security and rescue purposes. In the case of security or hostage situations, the idea is to observe closed or dangerous spaces from outside in order to reduce the risk for security forces and potential hostages. In rescue operations, such as following earthquakes or avalanches or during fire, it is usually very important to detect survivors as fast as possible.

The paper will deal with an ultra-wideband device which is aimed to support security or rescue forces. The ongoing work is supported by the EU-project RADIOTECT.

The paper is organised in 4 chapters. First, the device conception will be introduced and then three different scenarios will considered.

II. Device Conception

As mentioned, the operational frequency of the device must be below a few GHz in order to assure reasonable penetration through walls and rubble. Furthermore, its bandwidth must be as large as possible as localisation and tracking performance as well as the suppression of clutter largely depends on it. This leads to the application of UWB-radars as known from other publications [1], [2], [3].

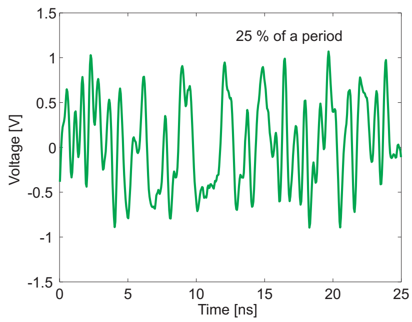

Fig. 1. Time shape of the emitted wave form

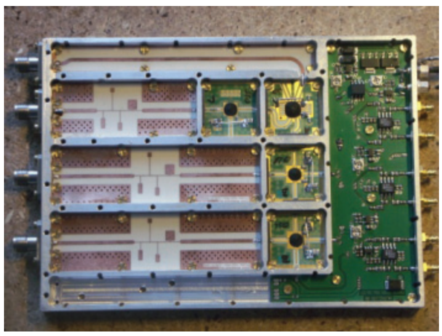

Fig. 2. RF-front end consisting of one transmitter and two receiver channels

In contrast to the known conceptions, our system applies a stimulus signal which is formed from pseudo random codes. As Fig. 1 depicts, this results in a random signal shape which is difficult to detect as well as to perturb. Furthermore, the signal magnitude may be quite low since the signal energy is spread over a large duration rather than concentrated within a short moment as for pulse radars. Consequently, the RF-electronics may be integrated in a low-cost semi-conductor technology. The working principle of the radar system will

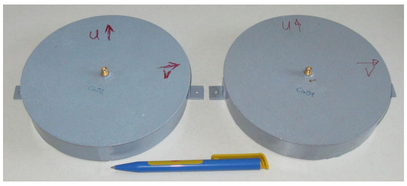

Fig. 3. Spiral antennas for through-wall imaging

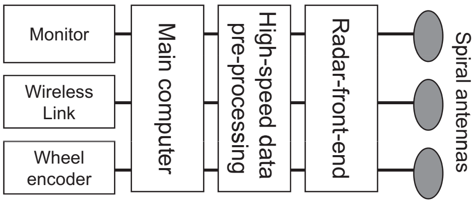

Fig. 4. Schematics of the trough wall imaging radar

not be explained here; the reader is referred to [4], [5]. At the current stage of development, the key components are integrated on single chips which are wired on PCB and housed in a shielding case together with power supply and the IF-stages (see Fig. 2). Its operational bandwidth can be selected up to 5 GHz. For the purpose of the wall penetration, it was limited to about 2.5 GHz. The number of transmit and receive channels can also be selected. Here, it was limited to the minimum number since handheld operation and a small overall size was in the foreground for the application.

The components which largely determine the size of the device are the antennas. Therefore, some hard compromises must be made. On the one hand the antennas should be quite small and light weight and on the other they should work down to low frequencies and avoid backward radiation and crosscoupling. Since it is not possible to find such a compromise which covers all intended applications, a twofold strategy was followed. For through wall imaging with high personal risk and high operator mobility (i.e. security forces or fire fighters) handheld systems with small antennas are inevitable (see Fig. 3. for an example). However, since under these conditions the targets are usually hidden by a dry wall, the lower cut-off frequency of the radar system is as critical.

In the case of rescue operations with buried survivors, the situation is different. The thickness of rubble may exceed a few meters and the material may be wet after heavy rain. A low cut-off frequency of the antenna is of great importance now since it determines the wave penetration into the material. Otherwise, operational procedures would not limit the size of the antennas as strongly. Since the operational band of the radar electronics extends from 8 to 2500 MHz the internal antennas of the handheld system have simply to be replaced by external antennas for rescue operations.

Fig. 4 finally depicts the overall structure of the radar device. The three-antenna-arrangement represents the minimum configuration for localisation and tracking purposes. However, such a configuration suffers from ghost targets if more then one person is within the scenario under investigation. The suppression of the ghosts either requires additional effort in the signal processing or it needs the joint operation of two or more systems. For that propose, the radar devices are equipped with a wireless link and a wheel/wire encoder for the fixing of their mutual position. One of the radar devices or a host system joins all the data and provides a ghost free image. Additionally, the encoder can be used to capture the device position in the case for scanning a wall in order to perform SAR processing.

III. Detection and Tracking of Moving People

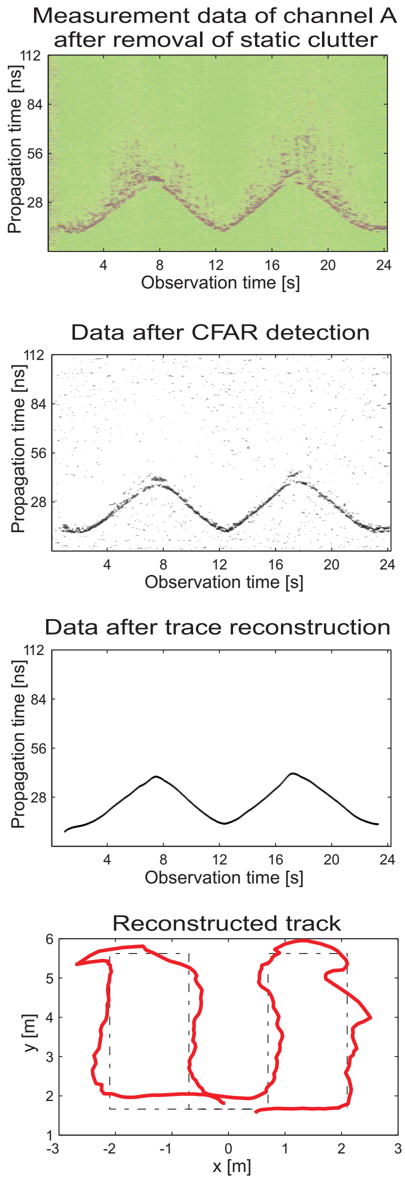

Fig. 5. Data processing steps for moving people tracking

In the considered case, the localisation of a moving target is based on tri-lateration which requires the knowledge of the length of the edges of a triangle built from two reference points (i.e. the receive antennas) and the target [6], [7]. For that purpose the roundtrip time τ_1 and τ_2 - radar device - target

- back to both receive antennas must be determined from the radar data. The required distance information is calculated supposing a known propagation speed of the waves.

However, the waves backscattered from the target are completely covered by strong clutter signals originating from large objects such as construction elements or furniture etc. Therefore, after some pre-processing of the radar data, the first step consists in removing the clutter caused from static objects [8]. This is undertaken simply by high-pass filtering the data in the observation time. However, attention should be paid, because the target will be lost if it does not move. Hence, an adaptive filter approach must be used [9]. Fig. 5 represents the results. In a second step, the radar data is subjected to a threshold by a CFAR approach indicating the target and the corresponding roundtrip time. Outliers and missing points are then removed and finally, the target trajectory is calculated from both signals [8]. It should be mentioned, that the wave propagation through the wall was not respected for simplicity and in favour of on-line processing.

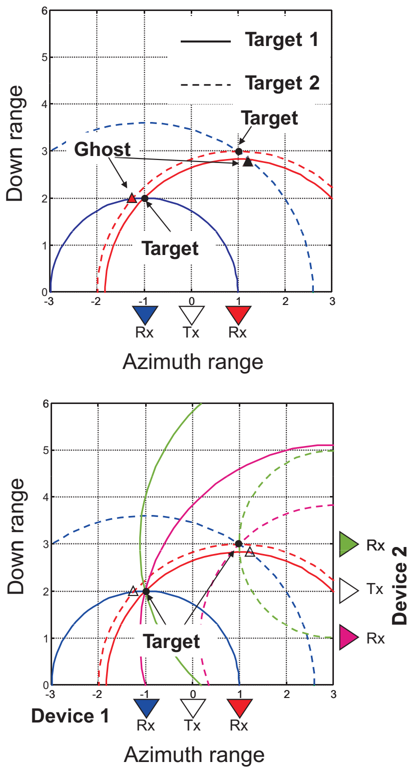

Fig. 6. Creation of ghost targets by a simple 3-element antenna array (above) and their suppression by second radar (below)

As depicted in Fig. 6, the 3-antenna configuration is not robust against ghost targets by its principle. However, by combining two identical devices, the ghosts can be excluded since it is very unlikely that the entire ghosts coincide. Note in the example shown, the second radar has its ghost outside the depicted area. The second radar may also be placed at the same wall.

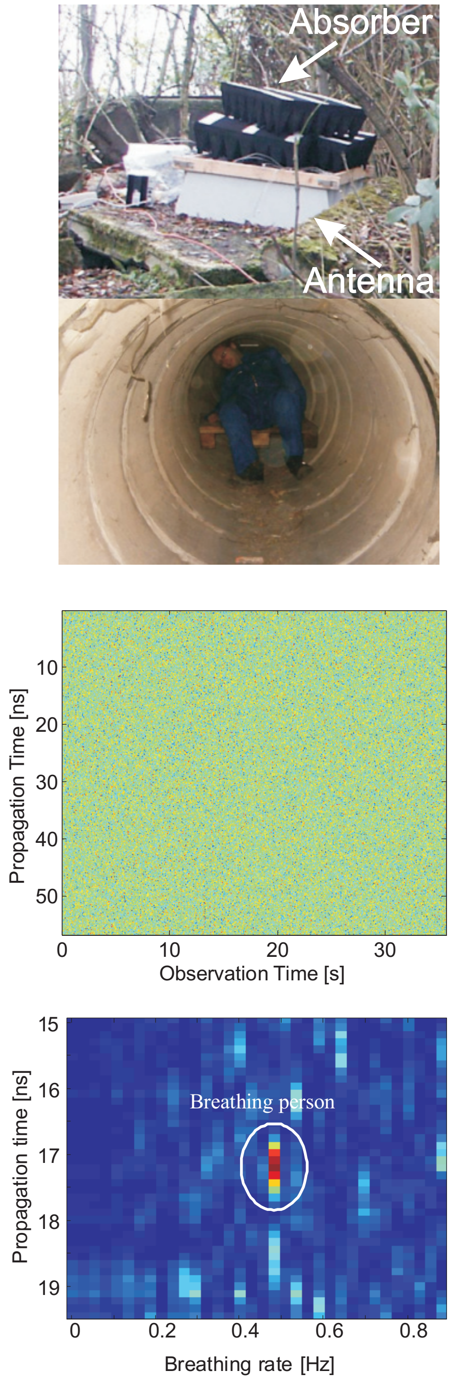

Fig. 7. Experiment with buried victim. Experimental arrangement (above). Radar data after removal of static clutter obviously only noise is visible. Data after enhancement of periodic components (below)

IV. Detection of Trapped People

The detection of trapped people is quite close to the approach described in the last chapter except that body movements are generally more restricted. Therefore, the signal to clutter ratio will further decrease, particularly if the victim is unconscious or tied-up. Then, the only feature to distinguish the victim from rubble or the interior of a room is their small movement due to breathing. For rescue of buried people, the challenges still increase since the waves must penetrate a thick layer of rubble causing additional attenuation and random wave scattering. Hence, the receiver noise and external jammers will limit the detectability of trapped people.

Therefore, some actions must be taken in order to reach the highest sensitivity:

- The detection of small movements is based on observing the variations of steep signal flanks [7]. Consequently, the noise should be as small as possible there. Since jitter provokes additional noise on signal flanks, the short time stability of the radar device is of major interest for such applications. The pseudo-noise radar conception used behaves excellently with respect to this point.
- The illuminated space should be restricted to the search area by using appropriate antennas. Antennas with low suppression of backward radiation will cause false targets due to any movement behind the scene (e.g. moving operator, moving tree leaves etc.).
- Since breathing is a periodic process, it can be enhanced by narrowband filtering in the observation time. In Fig. 7, it is carried out by applying a horizontal FFT on the data after clutter removal. Additionally, a sliding average with a short window was performed over the transformed signal in the propagation time direction since the signal flanks consists of several samples which are modulated in the same way.

V. Reconstruction of Room Interiors

For some scenarios, it is of interest to know roughly the structure of a room and its main interior. Due to the limited size of a handheld radar device, its azimuth resolution is too small for imaging the internal structure. Therefore, a synthetic aperture approach must be applied to improve the resolution. For that purpose, the radar device is moved along a given track outside the observed room and the data is processed by appropriate migration algorithms [10]. Fig. 8 presents the results of a simple experiment. An empty room was scanned in which an aquarium filled with water was placed. The experiments have shown that the wave propagation within the wall falsifies the reconstructed image if it is not considered appropriately. An efficient counter measure is introduced in [11], which is also suitable for on-line processing.

VI. Summary

The article summarises some of our recent work on through wall imaging by pseudo-noise radar and it shows some experimental examples. Successful application of such a device under operational conditions depends upon a number of aspects; the performance of the antennas and of the radar electronics connected with powerful and clever algorithms are as important as the mechanical robustness, weight and power consumption.

VII. Acknowledgement

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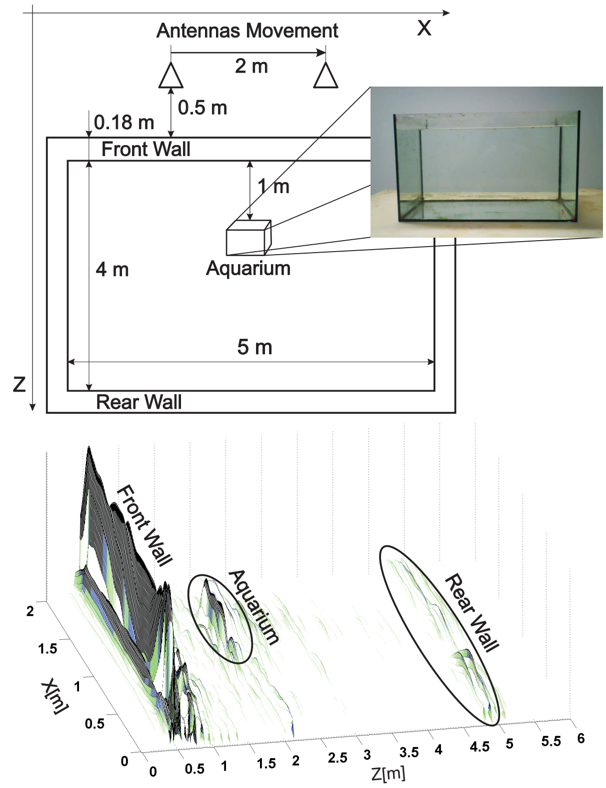

Fig. 8. SAR experiment resulting in correct target positions after respecting wave propagation in the wall

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