EXPERIMENTAL COMPARISON OF TWO UWB RADAR SYSTEMS FOR THROUGH-WALL TRACKING APPLICATION

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ABSTRACT
There are several types of ultra wideband (UWB) radar systems which can be used with advantage for the purpose of detection and tracking of persons moving behind obstacles. The intention of this paper is to test in real conditions performance of an impulse UWB radar in comparison with an M-sequence UWB radar for the mentioned application. For that purpose a through-wall measurement with two persons walking in fully furnished room was realized and corresponding signals acquired by different types of UWB radar systems have been consequently processed and analyzed.

Keywords: *Impulse radar, moving targets, M-sequence radar, through-wall, tracking, UWB radar*

1. INTRODUCTION

Earthquake, fire or avalanche takes every year its toll in the form of extinct human lives. These are factors whose formation one cannot usually control. However, if such events occur, it is possible to alleviate their consequences and especially to prevent loss of life. One way to protect human lives is the usage of ultra wideband (UWB) radar systems [1]. Their key feature is a good penetrating ability of electromagnetic waves transmitted by these systems through the majority of typical construction materials. Usage of radars operating in the frequency band up to 5 GHz allows one to detect and track targets moving behind an obstacle (e.g. wall, debris, snow, fog, smoke or dense vegetation cover) as well as locate living, but otherwise static persons [2]. Radar systems of this type are useful not only in the area of safety and protection of human life, but also in monitoring the area for military and security applications (e.g. detection and localization of landmines using ground penetrating radar), in civil engineering, in archaeology for detection of artefacts or even in medicine for the non-invasive medical diagnosis [3], [4].

UWB radar systems operate on different principles [5]. Those mostly applied are the sweep or step sine technique [6], the pulse excitation [7], the stimulation by pseudo random codes [8] or by natural noise [9]. In recent years, UWB pseudo-noise radars using maximum-length-binary-sequence (MLBS or M-sequence) as the stimulus signal have been advantageously used for through-wall applications [10], [11]. [12]. Alternatively, benefits of impulse UWB radars as the classical UWB-approach applied for decades have been reported in many works [13], [14], [15].

The aim of this paper is to compare the performance of both mentioned UWB radar systems during a through-wall tracking of moving targets realized under the same measuring conditions. For that purpose the paper is divided into three sections. Firstly, the UWB radar technology is defined and the principles of different kinds of radar systems are briefly explained in Section 2. Consequently, the procedure of UWB radar signal processing is outlined in Section 3 and applied on signals acquired by impulse and M-sequence UWB radar in Section 4. Finally, the results evaluation as well as the ideas for improving of the achieved outputs are discussed in the conclusion of this paper.

2. UWB RADAR SYSTEMS

An important application area taking advantages of UWB technology is represented by radar systems. Thanks to the widening of frequency band and consequential rise the information capability of a radar system, UWB radars get the following new features in comparison with that of conventional radar systems operating in a relative narrow frequency band: better measurement accuracy and spatial resolution, higher radar immunity against all passive interference and against extraneous electro-magnetic radiations and noises, increase of target detection probability and reliable target tracking resulted from increasing target radar cross section (RCS), increase of radar operation security and good penetration ability of transmitted electromagnetic waves through different materials [16].

2.1. UWB frequency band specification

The acronym UWB refers to a technology which make use of signals occupying a very large bandwidth of frequency spectrum [17]. The Federal Communications Commission (FCC) defines a UWB device as any device where the fractional bandwidth B_f is greater than 0.2 or which occupies the absolute bandwidth B greater than 0.5 GHz. The fractional and absolute bandwidth is defined as follows:

$$B_f = \frac{2(f_u - f_l)}{f_u + f_l}, B = f_u - f_l,$$

where f_u and f_l are the upper and lower cut-off frequencies of the emission point $L_{cut-off} = -10$ dBm (Fig. 1).

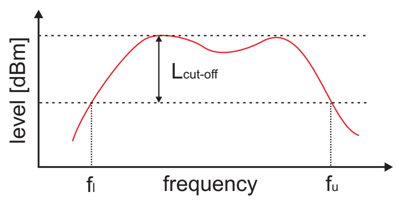

Fig. 1 Illustration of basic parameters for fractional and absolute bandwidth evaluation

2.2. UWB radar principles

Although a great deal of different UWB radar aproaches exist, many of them are excluded from practical usage due to cost, size, power consumption or due to insufficient technical parameters. Currently, three principles seem to be favored in UWB radar applications. These are the frequency modulated continuous wave (FMCW) method, the impulse technique and the MLBS approach [18].

Since the FMCW method provides only the real part of the frequency response function which results in incomplete information about the test object, this method is useful mostly for simple measurement tasks and therefore will be excluded from the following considerations.

Impulse UWB radar systems are advantageous in applications in which the power consumption is a critical parameter and which require only a simple - preferably non digital - data interpretation. On the base of their elementary device architectures, the following disadvantages can be listed: integration of pulse power amplifiers cause some problems, non equidistant sampling by non-linear ramps, jitter by noisy ramps and comparator noise, drift by comparator offset voltage, not useful for carrier modulation. However, they offer a real-time operation [19].

The MLBS approach is advantageous where a sophisticated data processing is needed and highly stable data are required. Power restrictions should play an inferior role in such applications. Furthermore, due to the well distributed signal power, the base band module can be used in conjunction with modulators to shift the stimulation spectrum to a higher frequency band (carrier based systems). MLBS technique is closely related to the impulse technique but it joins the advantage of that technique (simple layout, high measurement speed) with those of the sine wave approach (high stability, low crest factor signals) [19].

3. RADAR SIGNAL PROCESSING

The general task of radar signal processing is to extract required information from the gathered radar signals. In case of the through-wall radar, this information can be divided into two parts - knowledge of the presence and position of people and knowledge about the conditions of the interior of a room or building. The presented paper is intended on investigation of moving objects. Moving targets cause time varying components in the scattered data. This data must be filtered out from the received signals and assigned to a specific target. The challenge is that a huge amount of data must be processed in real-time and that the back scattering effect of moving targets is usually quite weak compared to the static scattering by walls, furniture etc. Moving people often cause a noticeable trace in the radar data but if they are motionless, only the breathing or heartbeat can betray a person. If variations caused by a person are detected in the data it is also possible to fix the position of the person and consequently realize tracking. The big challenge is to recognize weak signals scattered by multiple moving or breathing targets and to separate different individuals if lots of people are involved into the scene, especially if they are crowded placed [20].

3.1. Complete UWB signal processing procedure

In [21] a complete signal processing procedure for the purpose of through-wall detection and tracking of moving targets by means of M-sequence UWB radar has been proposed. As the signals acquired by the M-sequence and impulse UWB radar system have both form of the impulse responses of the environment through which the stimulus signals were propagating, the same processing procedure can be directly applied also for signals obtained by means of the impulse UWB radar.

The signal processing procedure consists of several phases, namely background subtraction, target detection, time of arrival (TOA) estimation, target localization and target tracking. These phases are responsible for elimination of stationary clutter (methods of background subtraction, e.g. exponential averaging), taking a decision about the target presence or absence (methods of detection, e.g. constant false alarm rate (CFAR) detector), estimation and association of distances from the same target (methods of TOA estimation, e.g. trace connection), estimation of target positions (methods of localization, e.g. direct method of calculation) and finally monitoring of target motion over time (methods of tracking, e.g. multiple target tracking (MTT) system) [11], [21].

4. EXPERIMENTAL RESULTS

To compare performance of two different kinds of UWB radar systems for through-wall tracking application an extensive measuring campaigne with approximatly 30 various scenarious was realized. Due to limited space of this contribution only one representative scenario was chosen for demonstration. During it the signals were acquired first by the experimental M-sequence UWB radar (Fig. 2(a)) and then by the experimental impulse UWB radar (Fig. 2(b)), both equipped with the same three horn antennas (1 transmitting antenna Tx and 2 receiving antennas Rx1 and Rx2).

(a) (b)

Fig. 2 UWB radar systems: (a) experimental M-sequence UWB radar, (b) experimental impulse UWB radar.

The M-sequence UWB radar system has the system clock frequency of about 4.5 GHz, which results in the operational bandwidth of about DC - 2.25 GHz. The M-sequence order emitted by radar is 9, i.e. the impulse response covers 511 samples regularly spread over 114 ns. This corresponds to an observation window of 114 ns leading to an unambiguous range of about 17 m. The measurement speed gets approximately 13 impulse responses per second (Fig. 2(a)).

The impulse UWB radar is represented by the digital sampling converter SD10806 with pulse generator head GZ1117DN-50. The converter enables maximum 8 channels, each with bandwidth of about 0.1-6.5 GHz. The sampling frequency of it is maximum 500 kHz. The maximum length of time window is 100 ns with the delay of maximum 3000 ns. The number of samples in the time window is maximum 4096. The emitted signal by pulse generator head is approximately Delta function with amplitude of 30V and width of 50 ps with maximum repetition frequency of 1MHz. During the measurement the following parameters were chosen: the sampling frequency 500 kHz, the length of time window 100 ns with delay 44 ns, the number of samples 512 and the unambiguous range of approximately 15 m. The measurement speed gets about 7 impulse responses per second (Fig. 2(b)).

4.1. Measurement scenario

A part of school dining room of approximate size 6 m x 21 m was was chosen for measured area. As can be seen from Fig. 3, the room was furnished with high wooden chairs and tables with metallic legs. Within the analyzed scenario two persons, labeled as target A and target B, were moving between tables according rectangular trajectories depicted in the measurement scheme in Fig. 4. Target A walked counterclockwise through nearer positions P5-P4-P1-P2-P5, target B clockwise through farther positions P5-P8-P9-P6-P5 (Fig. 4).

The UWB radar system was located behind 0.35 m thick brick wall (inside the adjacent classroom, Fig. 2). All antennas were placed along a line with Tx in the middle of Rx1 and Rx2 with distances between adjacent antennas setting to 0.4 m. There was no separation between radar antennas and the wall (Fig. 2, Fig. 4).

Fig. 3 Interior of the measured area: a view from the wall behind which the UWB radar system was located

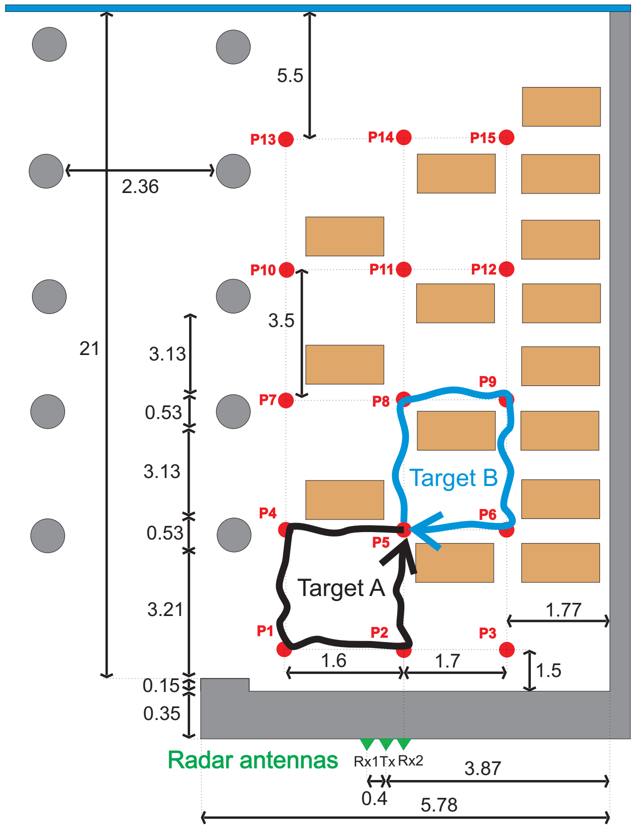

Fig. 4 Schema of the measured area with the antenna layout and the target trajectories

4.2. Processing results

The raw radar signals corresponding to the described scenario and obtained by the first receiving channel Rx1 of the M-sequence UWB radar and the impulse UWB radar are depicted in Fig. 5(a) and Fig. 5(b), respectively. They have a form of radargram, i.e. a two dimensional picture, in which the vertical axis is related to the number of samples and the horizontal axis is related to the number of received impulse responses. As the radargrams of receiving channels symmetricaly located around Tx are wery similar, in the next only radargrams from channel Rx1 are shown. In the radargrams depicted in Fig. 5(a) and Fig. 5(b), just the cross-talk signal and the reflections of the emitted electromagnetic wave from the wall can be viewed, forasmuch as they are very strong in comparison with the weak signals scattered by the moving targets.

The radargrams are markedly changed after the phase of the background subtraction when the primary traces of moving targets have arisen (Fig. 5(c) and Fig. 5(d)). The primary target trace consists of multiple reflections from a moving target which can be directly recalculated to distance between Tx-target-Rx1. In Fig. 5(c), a typical occurrence within a multitarget scenario can be observed. It is related to the strong reflections from target moving nearer to the radar antennas. These reflections are represented by the almost continuos trace belonging to person A in the bottom part of the radargram in Fig. 5(c). The event can be explained by the fact that person A was all the time moving

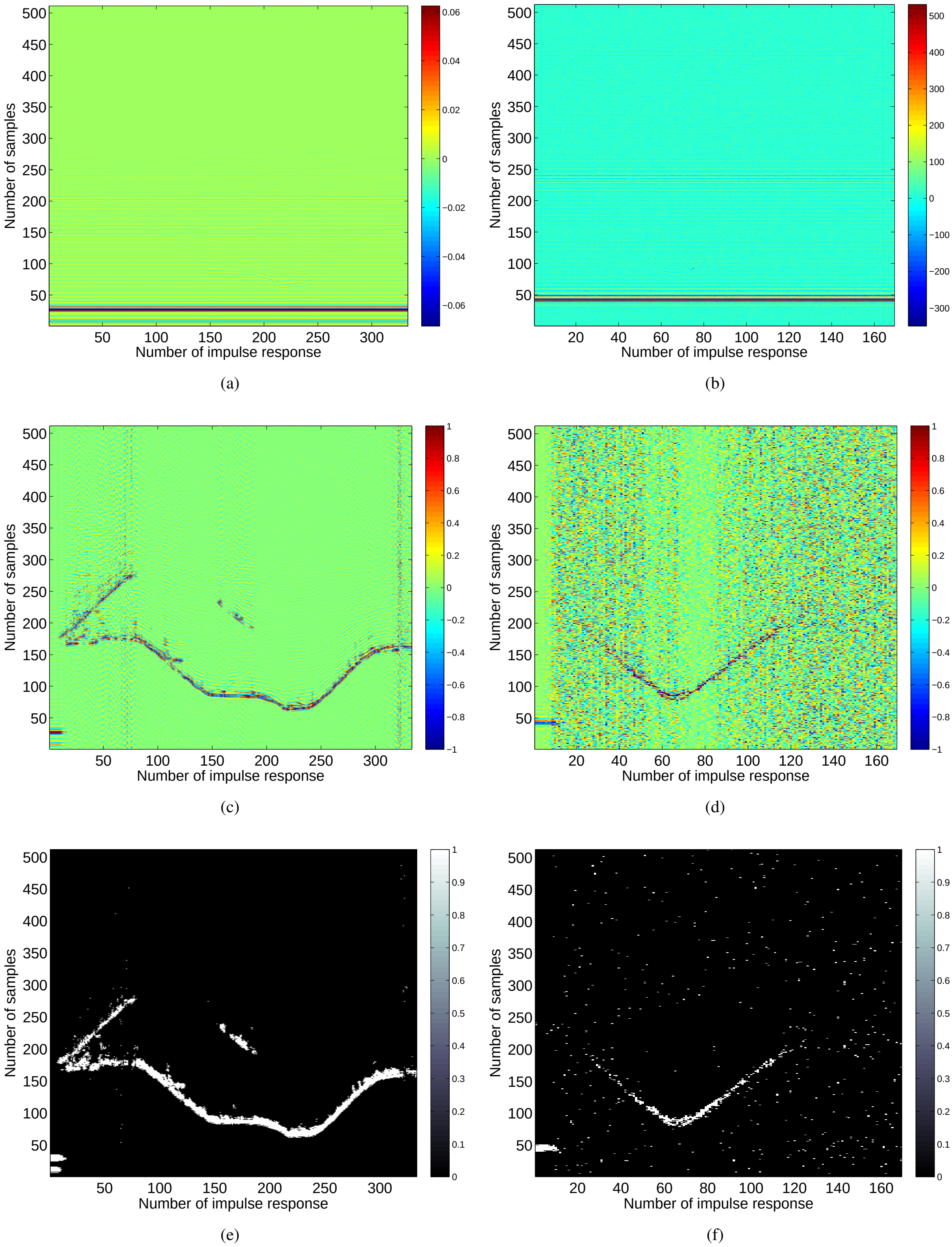

Fig. 5 Radargram from Rx1 containing: (a) raw radar signals acquired by the M-sequence UWB radar, (b) raw radar signals acquired by the impulse UWB radar, (c) signals with subtracted background for the M-sequence UWB radar, (d) signals with subtracted background for the impulse UWB radar, (e) detector output for the M-sequence UWB radar, (f) detector output for the impulse UWB radar.

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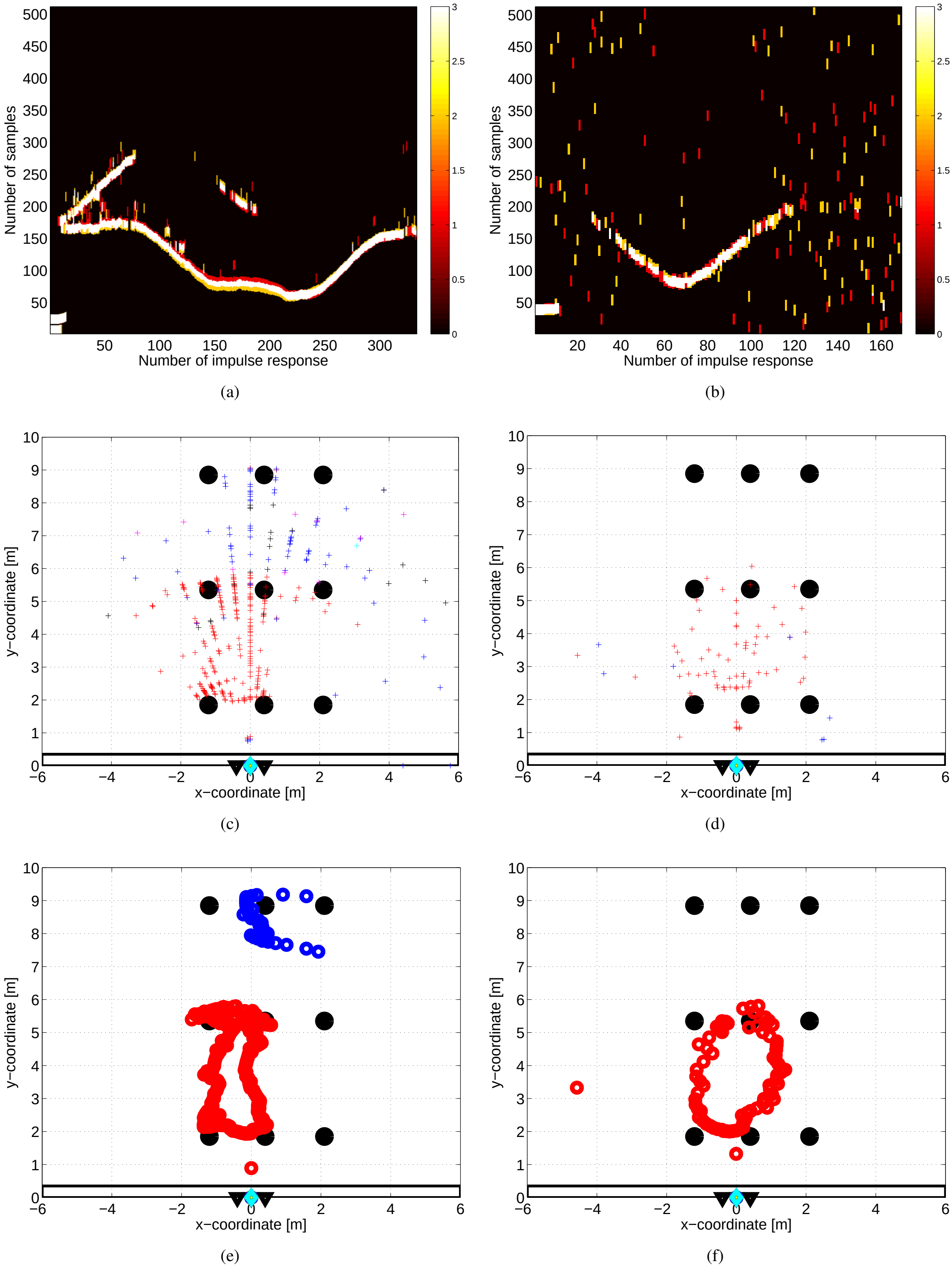

Fig. 6 The outputs of the signal processing phases. Joint radargram with associated traces (depicted by white colour) obtained by connection of traces from Rx1 (depicted by red colour) and from Rx2 (depicted by yellow colour): (a) output for the M-sequence UWB radar, (b) output for the impulse UWB radar; Estimated target locations: (c) for the M-sequence UWB radar, (d) for the impulse UWB radar; Final target tracks: (c) for the M-sequence UWB radar, (d) for the impulse UWB radar.

almost in front of the antennas. By contrast, the trace of person B in Fig. 5(c) is visible only at the beggining of the measurement and partially in the middle part. The reason is the bigger distance from the radar antennas, the presence of the furniture around which target B was moving and mostly the effect of mutual shadowing between targets [22]. The shadowing effect occured when target A was moving from position P2 to position P5 and obstructed propagation of the transmitted signals to target B. The signals with subtracted background obtained by the impulse UWB radar contain far less information (Fig. 5(d)). In the noisy signals only the primary trace of one target was partialy found.

The detector outputs for both UWB radars are shown in Fig. 5(e) and Fig. 5(f). The target traces confirmed by the CFAR detector are now represented in the binary code by values "1" and depicted in the radargrams by white colour. The traces are similar to the ones from the previous phase of signal processing, no harmful artifacts, such as cable reflections or shadows arising due to a strong reflector, have been highlighted. By comparing Fig. 5(e) and Fig. 5(f) it can be observed that the detector output from the impulse UWB radar (Fig. 5(e)) includes more false alarms and the target trace is much weaker and discontinous as that one from the M-sequence UWB radar (Fig. 5(f)).

A similarity of radargrams obtained by both receiving channels can be seen in Fig. 6(a) and Fig. 6(b), where the traces belonging to the same target are depicted by white colour. Primary estimated and artificially widened TOA from Rx1 and Rx2 are outlined by red and yellow colour, respectively. Their conjuction implies that the both receiving antennas captured the relevant reflections. Not associated TOA are considered to be the false alarms and therefore they are not utilized in the consequent processing for computation of target locations. In such a way it is avoided to the ghost generation.

The target locations computed on the basis of estimated TOA couples are depicted in Fig. 6(c) and Fig. 6(d). They correspond with the areas were the persons truly were moving, only few redundant target locations appeared outside them. The applied MTT system provided the final target tracks which are depicted in Fig. 6(e) and Fig. 6(f). In the case of application of the M-sequence UWB radar the system correctly identified two targets and genereted continuos track of the nearer target (Fig. 6(e)). The impulse UWB radar was able to detect and track only one person (Fig. 6(f)). The resulted track is also continuos, but because of half amount of estimated target locations the final track does not follow a manoeuvring of the person so precise as the track obtained by the M-sequence UWB radar. However, in the case of both UWB radar systems it can be concluded that although the estimated tracks are not complete they parts correspond very well with the true target trajectories (Fig. 4).

5. DISCUSSION/CONCLUSIONS

Through-wall tracking of moving targets by the UWB radar systems is still a subject under investigation. Almost every year the papers describing novel hardware or software solutions in this topic appear. It is very hard to distinguish which approaches really work in the real conditions and which are good only in theory. According to our best knowledge the performance comparison of different UWB radar systems for through-wall application based on real radar signals was not yet published and analyzed in details. This fact was the main motivation for generating of the presented contribution.

As UWB radar systems for comparing, the M-sequence and the impulse UWB radar were chosen. The former one because of our good experiences with it during many measuring campaigns, the latter due to good references from the literature. In the theoretical part of this paper, the main principles as well as the signal processing procedure for both radars were outlined. Processing of the measured UWB radar signals had confirmed that the same signal processing procedure originally designed for the signals acquired by the M-sequence UWB radar can be without any change of parameters directly used for processing of the signals acquired by the impulse UWB radar.

The second important conclusion can be made on the basis of final experimental results. In the paper, the measurement scenario of two people walking in the furnished dining room tracked by the UWB radar located behind 35 cm thick brick wall was demonstrated. The analysis of this scenario as well as almost 30 similar scenanarios has proved that the M-sequence UWB radar achieves better results than the impulse UWB radar. The main disadvantage of the impulse UWB radar was short real range in which the radar was able to receive reflections from moving objects (approximately 6 m from the obstacle). The improving of this drawback can be probably achieved by enhancement of the signal to noise ratio by the utilization of external amplifiers, better software setting of the system parameters enabling acquiring more impulse responses per second or averaging of received signals how it is exploiting in the M-sequence UWB radar.

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