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Detection of people behind obstacles using UWB radar

ABSTRACT

We describe architecture and design of a through-the-wall UWB radar. The UWB radar is applied for the detection of people hidden behind obstacles like debris, walls and other non-metallic objects. The detection of people is based on the detection of their movement, cardiatic, or respiratory activity. This is done by the background subtraction techniques. These techniques are known especially in video surveillance, or in ground penetrating radar applications. Their application for the people detection will be shown by a measurement example.

INTRODUCTION

There are a number of situations where the entering of a room or a building is considered hazardous and it is desired to inspect the interior from outside through the walls, an example includes the tracking of people in dangerous environments. Specialized devises using electromagnetic waves can provide significant help in these applications.

The goal of this article is to describe an ultra-wideband (UWB) through-the-wall radar and its application for the detection of people. This radar uses binary sequences (M-sequences) to stimulate the scenario. It detects people by means of electromagnetic waves scattered from their body also if they are hidden behind non-metallic obstacles.

BACKGROOUND SUBTRACTION TECHNIQUES

The electromagnetic waves reflected from people are weak in comparison to the cross-talk between transmit and receive antenna, or to waves scattered from walls, furniture, etc. Therefore, it is essential to separate these weak scattered waves by appropriate algorithms. This is usually done by “background subtraction” algorithms. These algorithms subtract time invariant “background” of the static scenario from measured data. The “background” refers to a signal, which is contributed in all measured impulse responses. It contains especially the antenna cross-talk and waves reflected from static objects. The first step in a background subtraction algorithm is the estimation of the time invariant background. This is a challenging task since the estimation has to deal with following problems in realistic environments:

- the background is in reality time variant signal, the time variation is caused e.g. by undesired antenna movement, or a small movement of static objects in the environment that are not object of interest,
- the environment may contain some object of interest that are not moving and are than encountered as the background.

In video surveillance application there were proposed several techniques that tries to cope with aforementioned challenges. A review of these techniques can be found e.g. in [4]. There can be found methods based on

- averaging, median filtering, running averaging,
- histograms, selectivity
- running Gaussian averaging, mixture of Gaussians
- kernel density estimation, sequential kernel density estimation,
- mean-shift based estimation and
- eigenbackgrounds estimation.

All of these methods use different approaches to estimate the background. From the application point of view, the easiest way is to compute an averaged impulse response from all measured impulse responses. However, this approach is only suitable for off-line processing when the measurement is completed and there is an access to all measured impulse responses. Another approach applies running averaging. Here, the new background estimate is computed from the previous background estimation that is updated with the new measured impulse response. A significant disadvantage of this method is its poor performance in cases where people move azimuthally or staying at one place. In these cases, the reflected waves arrive almost in each measured impulse response with the same time delay and are misinterpreted by the detection methods as a static background. People are therefore almost invisible under such circumstances and with such methods.

Significantly improved performance can be achieved using the background subtraction method based on selectivity. Here, the background estimate is updated adaptively. If the measured sample of the received impulse response is classified as a foreground (target of interest) then it is not used for the background estimation. In this way, the background estimate is not corrupted by the targets that logically do not belong into the background. More detailed description of methods based on running averaging and selectivity applied for the people detection can be found in [5].

LOCATION ESTIMATION

As far as a person is detected by a background subtraction technique, its position can be estimated by an UWB radar consisting at least 2 channels (1Tx and 2Rx, or 1Rx and2 Tx) The problem description of the simplest case of 2D passive location estimation is illustrated in Fig. 1. The aim is to determine passively only by electromagnetic waves reflected from the person its position using a receive antenna array consisting of two antenna elements.

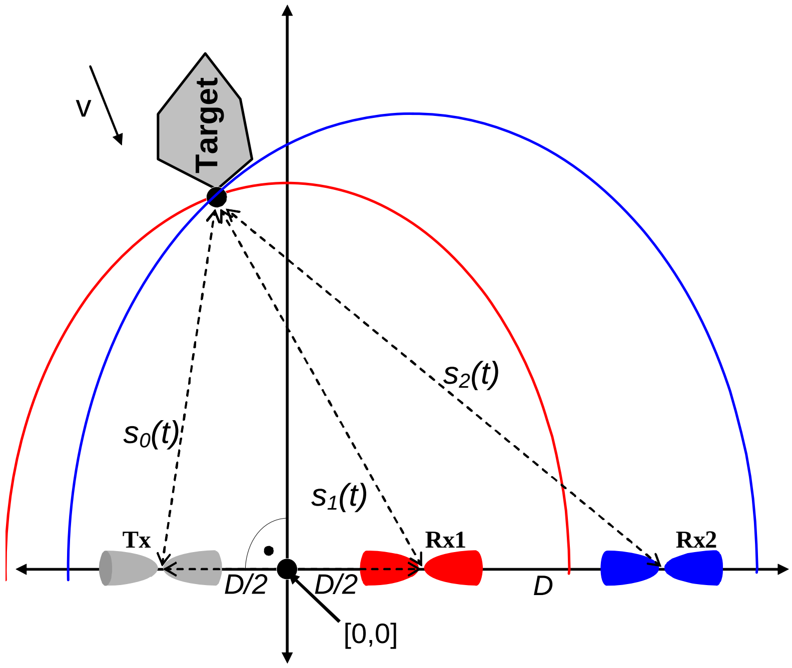

Fig. 1 Positioning - passive approach

The localization system estimates firstly round trip times of electromagnetic waves propagating from the transmit antenna Tx towards the person and reflected back from the person towards each of the receive antenna array elements RxN. Estimated round trip times determine two ellipses whose focal points are determined by the locus of the transmit antenna and the loci of the corresponding receive antennas. Thus, the target position results from the intersection of both ellipses [5].

M-SEQUENCE RADAR ARCHITECTURE AND DESIGN

Fig. 2 presents basic architecture of an UWB radar using M-sequence as a stimulation signal. It is working in the base band covering the spectral band up to half the frequency of the system clock. Controlled by a single tone clock, a digital shift register generates the MLBS signal. Since the MLBS signal is periodical and the measurement scenario can be assumed to be locally stationary, it is possible to acquire the MLBS signal by an under-sampling approach. Here, the binary divider (2^m) determines the under-sampling factor and provides the receiver sampling clock. The measurement data are captured by a Track-and-Hold circuit (T&H), transformed into the digital domain (ADC), optionally synchronously averaged and finally on-line processed or stored for off-line processing. The IR results from an impulse compression, which is performed by the FHT (Fast Hadamard-Transform). The FHT-algorithm is very close to the FFT-algorithm except that it is based on a pure summing of data samples, which promises very fast operation for special hardware implementation.

This architecture was used for the development of the UWB through-the-wall radar system for people detection and localization. It covers the band up to 5 GHz and was developed using SiGe monolithic integrated circuits (shift-register, binary divider and T&H). It has been designed in MEODAT company [6] in cooperation with Ilmenau University of Technology. It consists of one transmitter and two receivers. The extremely linear time axis and the superior jitter and drift behaviour (compared to traditional sequential sampling oscilloscopes) is the result of the synchronous digital controlled sampling. The DSP module of the described experimental systems is based on standard off-the-shelf PCB products. The ADC is a 12-Bit-Video ADC. Fig. 3 shows the radar design, which was constructed in an aluminium briefcase. It contains UWB electronics and three Horn antennas. The antenna side of this suitcase is made of plastic material. The radar system is controlled by a notebook and its graphical user interface is illustrated in Fig. 4. On the right side of the figure, magnitudes of impulse responses measured by 2 receive antennas are depicted. The area on the left side shows the estimated position of a person. The estimation is based on the ToF approach.

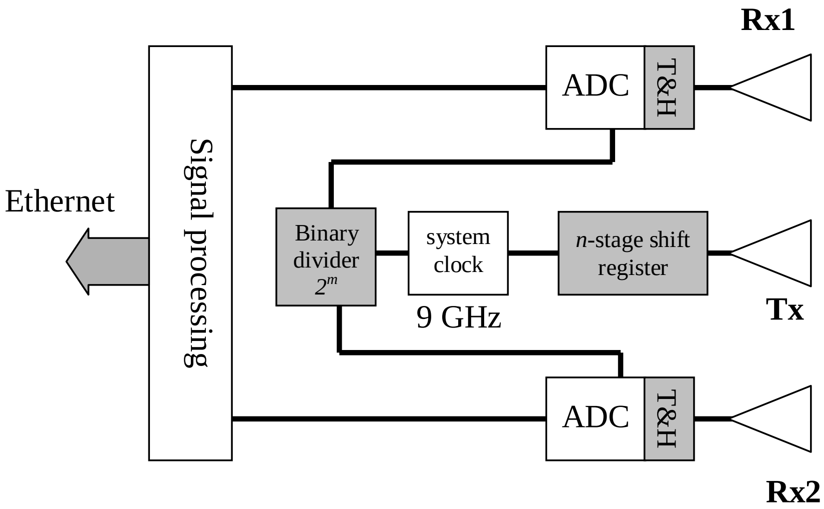

Fig. 2 Architecture of the M-sequence UWB radar

Fig. 3 UWB through-the-wall radar

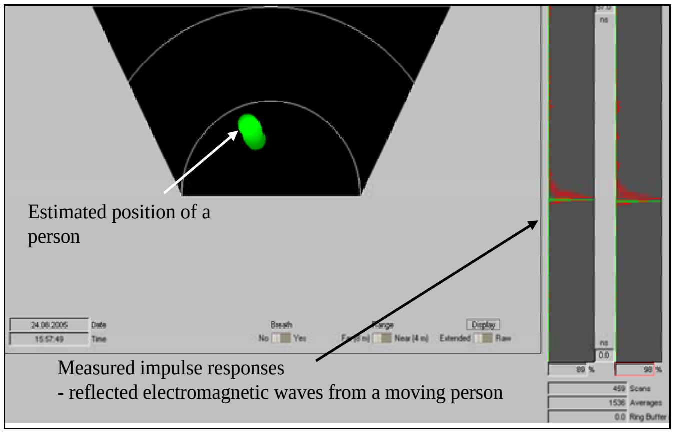

Fig. 4 Graphical user interface

MEASUREMENT EXAMPLES

Firstly, we will illustrate the performance of the background subtraction algorithm based on running averaging and selectivity by a measurement example. In this example, a walking person was hidden behind a wall and was walking along the track that is depicted in Fig. 5. The person stopped its movement for a short time in the middle of the cross and at each end of its branches. The walls were about 20 cm thick made of brick. The 2-channel through-the wall radar described in the previous section was used for the measurement.

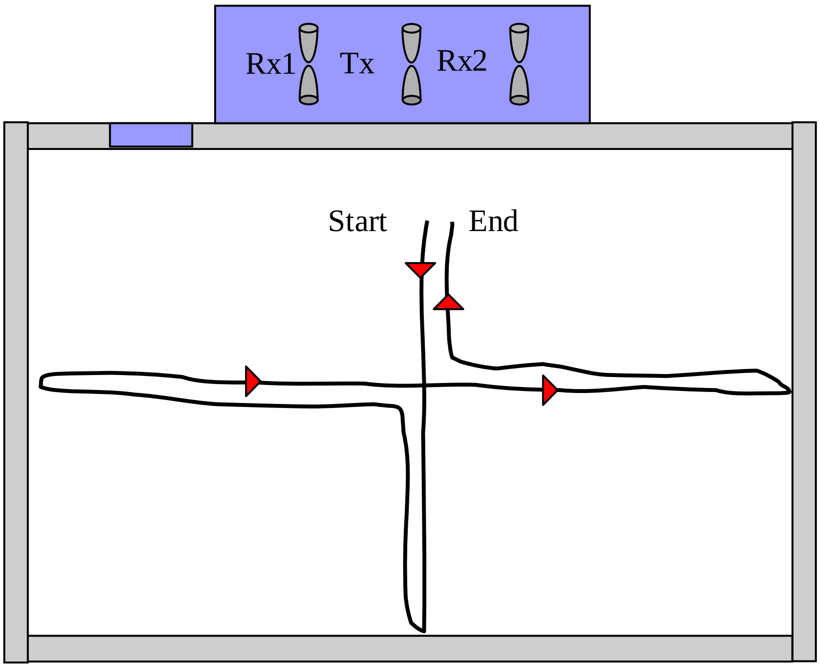

Fig. 5 Measurement scenario

Fig. 6 represents unprocessed measured data obtained from one channel of the radar. The vertical axis is related to the time delay and the horizontal axis is related to the time of the measurement. Thus, one vertical line from this 2D figure represents one measured impulse response. The unprocessed impulse responses show time variance within the whole measurement only if the person was in a close vicinity to antennas. This is caused by the fact that electromagnetic waves reflected from the walking person are too weak in comparison to antenna cross-talk and the scattering from dominant objects such as walls. The time-variant echo coming from the walking person can hardly be observed directly in measured data.

By applying the background subtraction methods we subtract this static background. This brings forward information about the presence of a person in the room and their distance to measurement antennas. Fig. 7 shows the result of the background subtraction based on running averaging. In this figure, all impulse responses are normalized so that the maximum value of each impulse response is equal to one. This way we can also observe weak scattering occurring if the person is far away from antennas. The movement of the person is easy to observe in processed data. The first disadvantage of this method is already visible from Fig. 7. As far as the person does not move, e.g. at the time from 600 to 700 samples, or from 900 to 1100 samples, the reflection from this person vanishes.

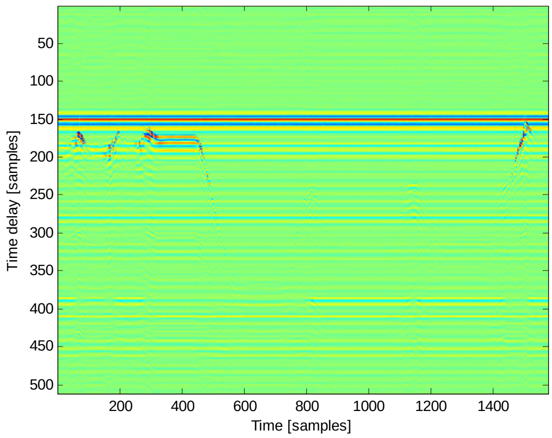

Fig. 6 Measured data

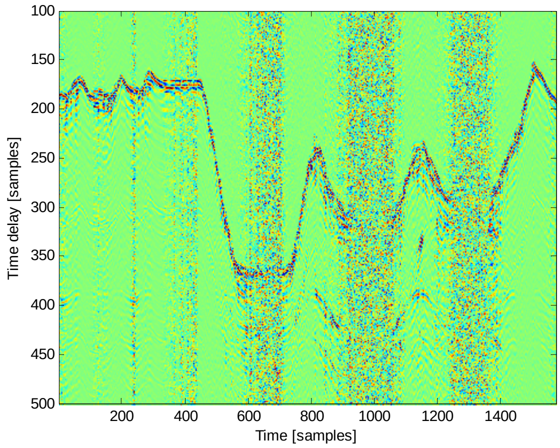

Fig. 7 Data after background subtraction based on running averaging

This is due to the fact that it counts to the static background that is estimated and then subtracted by this method. Another drawback of this method is the decrease of SNR as far as the motion of the person is slower or, if the person is walking in azimuthal direction with respect to antennas. This is illustrated in Fig. 9. This figure compares SNR of waves reflected from the walking person that are detected by running averaging (blue line) and selective (red line) background subtraction method. The difference is evident especially as the person is not moving (e.g. time from 35 to 45 seconds). The results of the selective background subtraction algorithm is presented in Fig. 8. All impulse responses are normalized so that the maximum value of each impulse

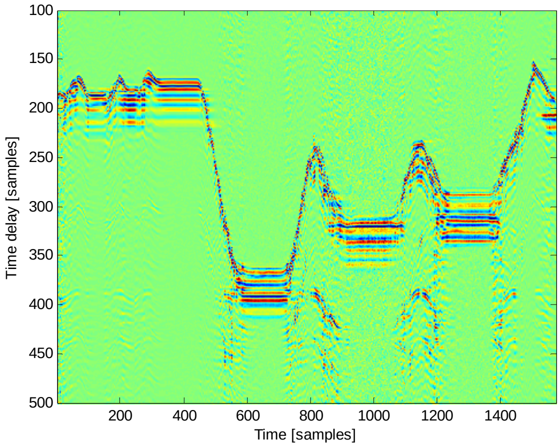

Fig. 8 Data after background subtraction based on selectivty

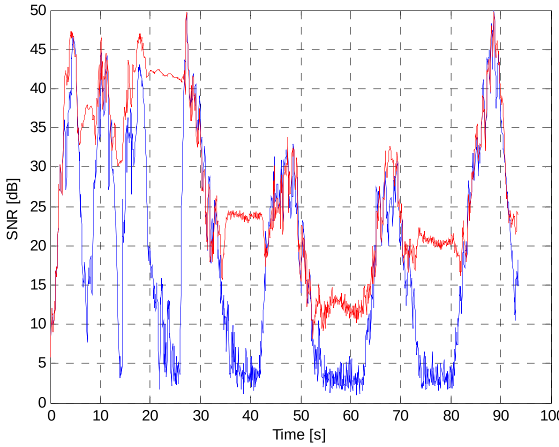

Fig. 9 SNR of the waves reflected from a person and detected by background subtraction algorithms (blue – running averaging, red – selective method)

response is equal to one. The movement of the person was detected also in situations when the conventional method failed to detect waves reflected from the person. As far as a person is detected by means of its movement or respiratory activity they can be localized by the radar offering the multi-channel (two Rx antennas) configuration. An example of the through-wall localization is given by the following measurement. The person was walking in a fully equipped office environment. The UWB radar was situated outside the office behind the wall. Just in front of the wall (from the other side) there was a bookcase containing metallic parts.

Firstly, data from each channel were processed by the background subtraction algorithm. Then, ToF between Tx-person-Rx were estimated using a simple threshold detector. The location of the test person was calculated analytically from the estimated ToFs using triangulation principles and imaging technique described in [7], [8]. The office environment and the result of the location estimation is illustrated in Fig. 10.

Fig. 10 Location estimation

CONCLUSION

The article presented architecture and design of the UWB through-the-wall radar. Presented algorithms for the detection and subsequent localization were implemented in CVI LabView and operate in real-time. They were tested with the described UWB electronics to detect one person in a static scenario. The achieved precision is in an order of 40cm and can be considered as adequate for the localization of humans. The human body has a certain volume and in the case that arms are fully stretched out, it can have dimensions up to some meters. Thus, it is difficult and unnecessary to define a reference point (e.g. head, heart, belly, etc.) and track it.

In the near future, the performance of the radar will be tested for more challenging scenarios containing more people. It is assumed that presented methods will create the basis for the signal processing of measured data but they must be probably adapted to handle the presence of more people.

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