UWB Radar for Human Being Detection

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ABSTRACT

UWB radar for detection and positioning of human beings in complex environment has been developed and manufactured. Novelty of the radar lies in its large operational bandwidth (11.7GHz at –10dB level) combined with high time stability. Detection of respiratory movement of a person in laboratory conditions has been demonstrated. Based on experimental results human being radar return has been analysed in the frequency band from 1 GHz to 2 GHz. Novel principle of human being detection is considered and verified experimentally.

INTRODUCTION

Ultra-wideband radars are used nowadays for different applications such as subsurface sensing, classification of aircrafts, collision avoidance, etc. In all of these applications the ultra-high resolution of UWB radars is essentially used. One of these applications is detection of humans trapped in buildings on fire, in collapsed buildings or avalanche victims. Despite of relatively small scope of this application, it has large social importance. Very similar to the human detection application is another UWB radar application, namely remote cardiography (measurements of heart beatings). Both applications are based on similar principles.

Detection of human beings with radars is based on movement detection. Heart beating and respiratory motions cause changes in frequency, phase, amplitude and arrival time of reflected from a human being electromagnetic wave. Generally speaking, the changes of amplitude are negligible. Therefore only frequency, phase and arrival time changes can be used for human being detection. Based on these three features different radar systems have been developed: Doppler radars [1], interferometric radars [2, 3] and video impulse radars [4, 5]. While the Doppler and interferometric radars are narrow band systems, the video impulse radars are ultra wideband (UWB) systems. UWB radar has several key advantages over continuous wave radars:

1) The pulse has a wide frequency spectrum that can easily pass through obstacles.

2) The pulse duration is very small that it has a very high resolution.

3) The short pulse leads to the low energy consumption.

4) It possesses good immunity against multipath interference.

5) It allows not only detect presence of a human being, but also position it.

Two last advantages of UWB radars have not yet been proven experimentally.

In this paper we present development of UWB radar for human being detection and localization in complex environment (building on a fire or collapsed building). Novelty of the radar lies in its large operational bandwidth combined with excellent time stability. Together with a novel principle for motion/breathing detection based on UWB radar return, the above-mentioned hardware features result in reliable instrument for human being detection in complex environment.

DESCRIPTION OF THE RADAR

The radar consists of a pulse generator, a pulse shaper, a sampler unit, a sampling oscilloscope and a control PC. The sampling oscilloscope synchronizes the sampling unit and the pulse generator using trigger pulses. Using a GPIB (General Purpose Information Bus), the measured time signal is

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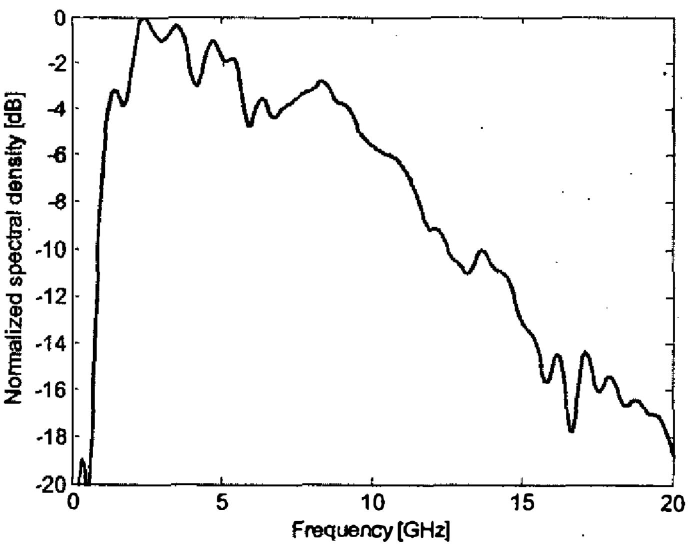

Fig. 1. Spectrum of the probing signal

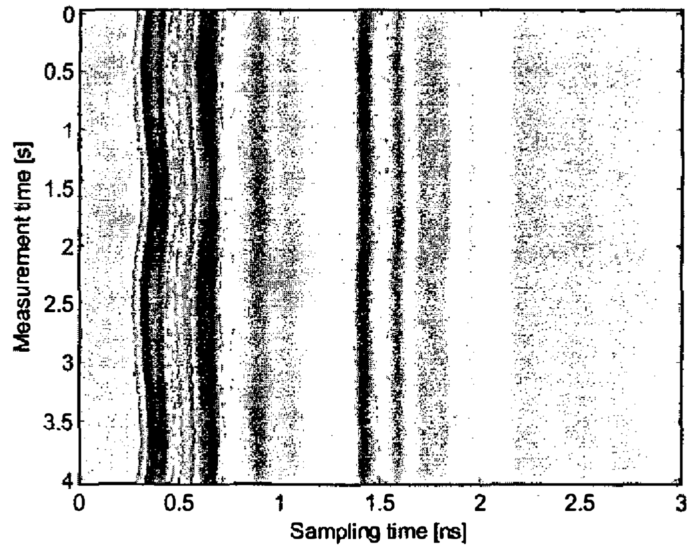

Fig. 2. Example of a UWB pulse reflection from a breathing person. Vertical polarization

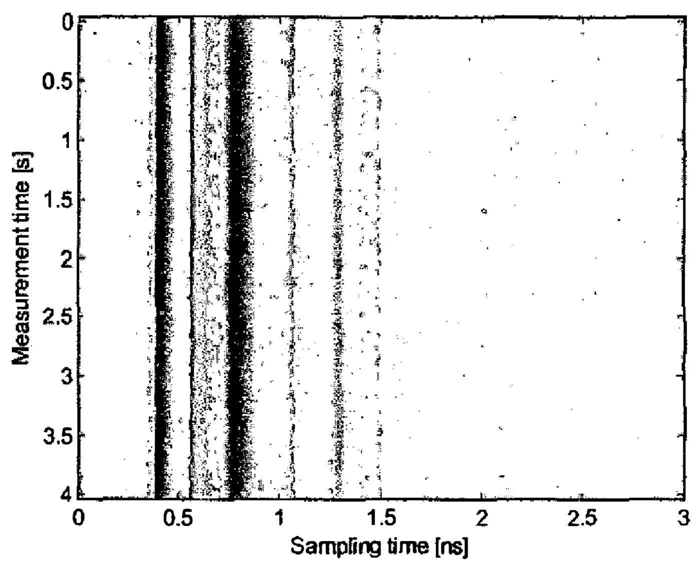

Fig. 3. Example of a UWB pulse reflection from a non-breathing person. Vertical polarization

transferred to a PC where the data is stored for later processing and analysis.

The system bandwidth (as it has been determined by external calibration on metal) equals 11.7GHz (at -10dB level) (Figure 1). From formal point of view, such a bandwidth results in a resolution of about 1.3 cm in free space, which should be just sufficient for detecting small motions of human chest due to breathing. Furthermore, the operational bandwidth (as determined at -10dB level) of the radar starts from 0.9 GHz. This leads to increase of the magnitude of a signal reflected from a human being (see [5]) and improves penetration through walls and/or rubble (which is of importance for e.g., earthquake victim detection).

For the radar for human being detection the second (after the bandwidth) important design issue is choice of the pulse repetition frequency. It affects unambiguous range of the radar (which should be of about 30m at least) and single signal measurement time (which should be of about 5 times shorter than the average breathing period). The time needed for measurement a single reflected signal depends on the pulse repetition frequency, number of samples in the recorded signal and the averaging (stacking) number. For keeping the power budget of the system sufficiently high, high averaging number is desirable. Optimization of these parameters led to a selection of 10 MHz as optimal pulse repetition frequency.

Time stability is third important parameter of the system. The detection can be done based on a series of signals recorded within a short period of time. Within this period of time the system drift should be considerably smaller than a sampling time (which is of about hundreds of femoseconds). Due to use of internal calibration circuits the radar instability is characterized by a time drift of about 5 ps per hour.

Power budget of the radar is determined by the generator output and noise level of the sampling scope. By averaging 256 the power budget equals 100 dB.

Linear dynamic range of the radar is determined by the maximum peak-to-peak voltage (it reaches 2 V), and the maximum RMS noise (i.e., quantization noise) of the oscilloscope is about 4 mV (without averaging). So without averaging the dynamic range equals 54 dB and with averaging 256 the dynamic range increases up to 78 dB.

SCATTERING FROM A HUMAN BODY

In the initial measurements a person has been positioned vertically at the distance of about 2.6m in front of the antenna systems. Such distance allows isolate in time signals due to transmit-receive antenna coupling, reflections from this person and reflections from environment (clutter). The radar worked

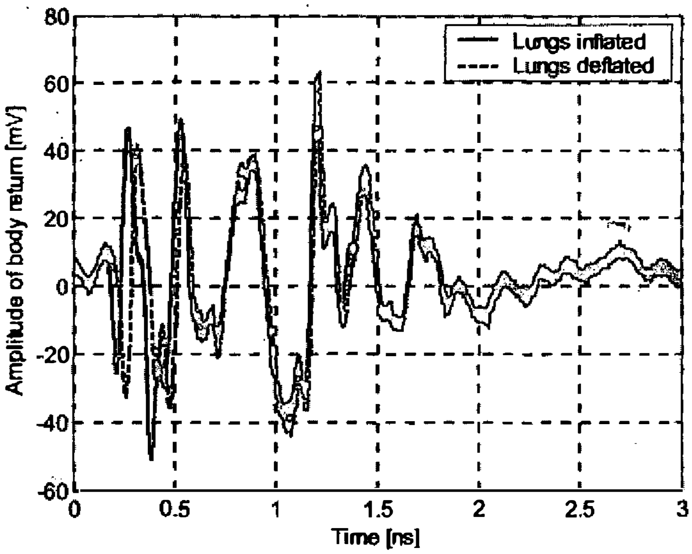

Fig. 4A.

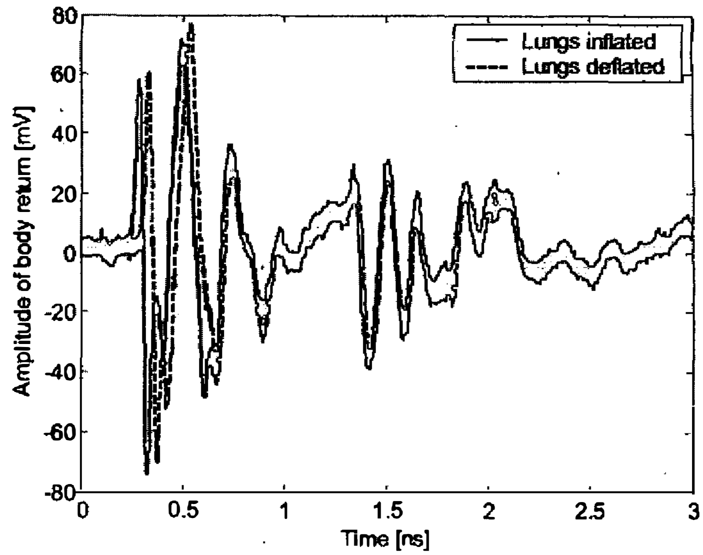

Fig. 4B.

Fig. 4. Examples of signals reflected from a human being

Fig. 4A. Horizontal Polarization of the incident and reflected filed; Fig. 4B. Vertical Polarization

in the continuous mode (each new signal has been acquired immediately after previous one). Averaging 16 has been used in all measurements.

Several sets of 256 signals have been acquired. Some sets correspond to a normally breathing person (Figure 2), while during acquisition of other ones the person kept his breathing (Figure 3).

It can be seen that the radar is capable to detect range variations due to respiratory movements. During one breathing cycle of about 22 signals have been recorded by the radar, which seems to be sufficient in order to observe respiratory movements.

Typical reflected from a person signals for inflated and deflated lungs are shown in Figure 4. Due to high dielectric permittivity and high ohmic losses of a human body [5], the reflected signal is mainly determined by the front reflection. Spatial variations of the chest position due to breathing are clearly observed and have a magnitude of about 0.6 cm. Despite of the fact that these variations are two times smaller in amplitude than the formal downrange resolution of the radar, these spatial variations are clearly resolved by the radar.

The reflected from a human body signal consists not only from the front reflection but also from signals scattered by other parts of the body and a signal due to a creeping wave, which circumferences around human trunk. The latter is delayed by approximately Ins from the front reflection.

Both magnitude and waveform of the reflected signal depends on probing wave polarization. As it can be expected, the front reflection of vertically polarized waves is larger than that of horizontally polarized waves.

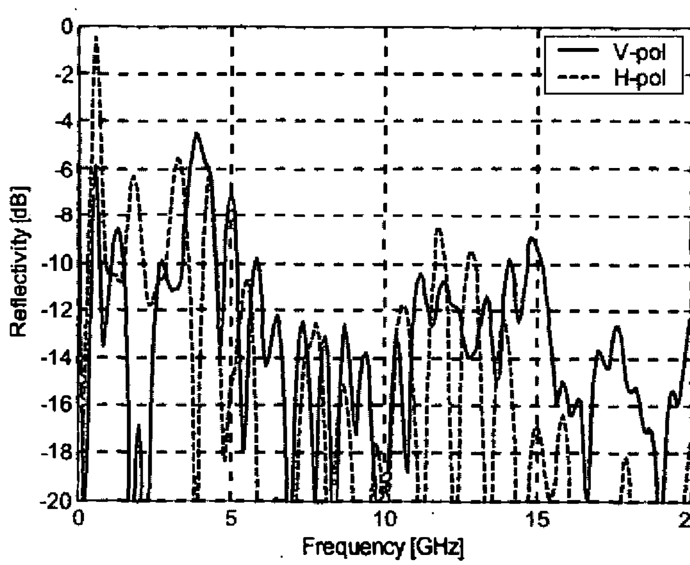

Fig. 5. Reflectivity of a human body

As it can be seen from Figure 5 the reflectivity has been recovered for the frequency range much wider than the radar bandwidth as determined at -10dB level. This is demonstrates that –10dB level is very much arbitrary chosen and does not determine the full bandwidth, which is actually used by the radar. Practical experience shows that reconstruction of spectral parameters from the radar data can be done up to 26 GHz.

In general it seems that the human body reflectivity and the waveform of the human body response does not contain very specific features, may considerably vary from person to person and depends on position of the body and its aspect angle.

MOVEMENT DETECTION ALGORITHM

From the study above it becomes evident that detection of a signal, which is reflected from a human being and arrives within a strong clutter due to multiple reflections from indoor environment, is a difficult issue due to unknown waveform of the signal and unknown time of arrival. Published so far results are based on cyclic variations of the time of arrival of some part of measured signal (Figure 2). Such a detector requires long observation time (at least a few seconds), very dense sampling of the radar return and, probably, human operator supervision. So development of a reliable human being detector is important.

We decided to use a new approach for movement (e.g.. breathing) detection, firstly suggested in [6]. The basic idea is based on the fact that the radar return is a sum of the signals, which are reflected from different objects. The interference of these signals results in dips in the spectrum of the radar return at some frequencies. While all reflectors are still, the interferometric picture in frequency domain does not change in time. However if one of the reflectors moves, interferometric minima in the radar return spectrum are not stable in time. Variations of the spectra around interferometric minima are very large and can be easily detected.

The basic idea is demonstrated by measurement results. Spectral variations of 256 recorded radar returns from a metal sheet (normalized to a radar return itself) are shown in Figure 6. In the frequency band from 1 GHz till 12GHz these variations are of about a few percents. At the high frequencies the amplitude of variations increases inversely with frequency due to radar jitter. Spectral variations of 256 recorded radar returns from a breathing person (staying in the same place where the metal sheet was situated) are shown in Figure 7. Large variations are seen at 8 frequencies within the frequency band from I GHz till 10.6 GHz. In the contrary to jitter-caused variations, the magnitudes of variations due to movements of the reflector are large then 1. This is can be explained by to increase of the spectral minima of the radar return due to time variations of a signal reflected from a breathing person.

In order to evaluate impact of breathing, spectral variations of 256 recorded radar returns from a non-breathing person (staying in the same place where the metal sheet was situated) are shown in Figure 8. Considerable spectral variations can be seen in the figure. They can be explained by minor movement of a person, who keeps breathing. Magnitude of the variations is decreased in comparison with a breathing case, but is much higher than that one for a "frozen" scenario. So for the suggested human being detector breathing is not of prime importance: the detector can detect a person just due to minor movements.

As the suggested human being detector does not use any range information, it can be potentially used also outside the

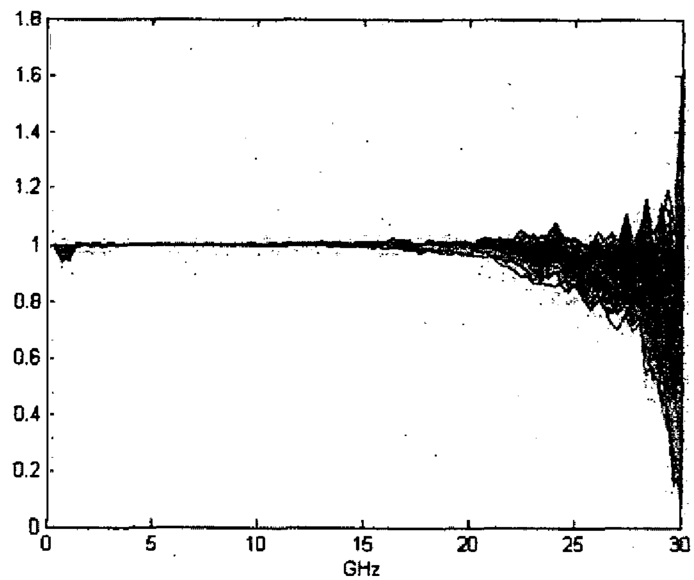

Fig. 6. Spectral variations of a radar return from a metal sheet

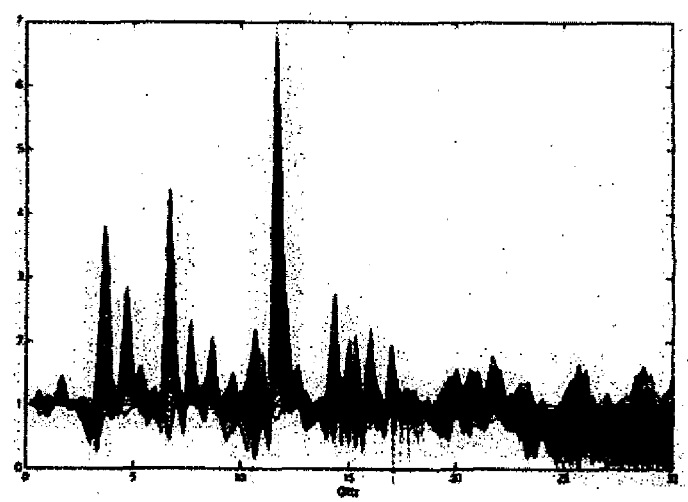

Fig. 7. Spectral variations of a radar return from a breathing person

unambiguous range of the radar. However, if the radar is used not only for detection but also for the positioning of a human being, then the latter can be done properly only within the unambiguous range.

CONCLUSIONS

In this paper UWB radar for detection and positioning of human beings in complex environment is presented. Novelty of the radar lies in its large operational bandwidth combined with excellent time stability. Based on experimental results the radar return from a human body has been analysed. It has been shown that due to breathing the range to a person varies within 0.6 cm. The breathing influences the front reflection from human chest, which is just a part of the radar return from a human body. The reflectivity of a body in the frequency band from 0.5 GHz till 10 GHz decreases with frequency. And for electromagnetic waves polarized along human body the reflectivity is higher than for the waves with orthogonal polarization.

A novel motion/breathing detector has been used in the radar. The detector is based measurements of radar return spatial variations. The detector does not require separation of a body reflection signal from the background and works reliably in multi-path indoor environment.

Next step in research will be development of an antenna array to be used together with multi-channel receiver. As soon as reflected form a human being signal is detected, direction of its arrival will be determined by simultaneous processing of signals coming from different receive antennas within the antenna array. Finally, the positioning of a human being will be done based on the direction of arrival and time of arrival.

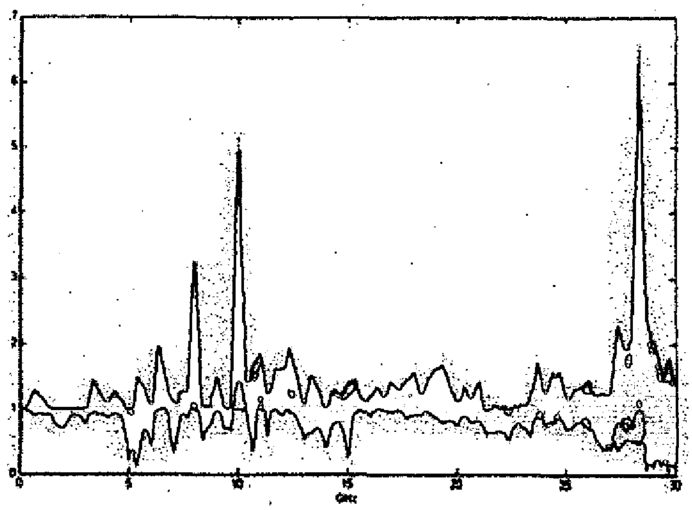

Fig. 8. Spectral variations of a radar return from a non-breathing person

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REFERENCES

[1] M. Bimpas, K. Nikellis, N. Paraskevopoulos, D. Econonou and N. Uzunoglu,
Development and Testing of a Detector System for Trapped Humans in Building Ruins,
33rd European Microwave Conference,
Vol. 3, pp. 999 - 1002, October 2003.

[2] I. Arai,
Survivor Search Radar System for Persons Trapped under Earthquake Rubble,
Proceeding of the IEEE Microwave Conference,
Vol. 2, pp. 663-668, December 2001.

[3] H. Chuang, Y. Chen and K.-M. Chen,
MicroprocessorControlled Automatic Clutter-Cancellation Circuits for Microwave Systems to Sense Physiological Movements Remotely through the Rubble,
Proceedings of the IEEE International Conference on Instrumentation and Measurement Technology,
pp. 177-181, February 1999.

[4] G. Ossberger, T. Buchegger, E. Schimback, A. Stelzer and R. Weigel,
Non-Invasive Respiratory Movement Detection and Monitoring of Hidden Humans Using Ultra Wideband Pulse Radar,
Proceedings of the International Workshop on Ultrawideband Systems and Technologies,
pp. 395-399, May 2004.

[5] C. Gabriel,
Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies,
Armstrong Laboratory (AFMC), Occupational and Environmental Health Directorate, Radiofrequency Radiation Division. Report: AOE-TR- 1996-0037.

[6] S. Efremov and B. Levitas,
On application of a Pulse Method in Detecting the Living Objects,
Proceedings of International Conference on Microwaves & Radar (MIKON 98), Vol. 3, pp. 765-768, May 1998.