Study of the Environment Effect by M-Sequence UWB Radar on Detection of a Walking Human

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***Abstract*—This paper presents an experimental comparison study of human movement and presence detection in different environments using ultra-wide-band (UWB) M-Sequence radar. The benchmarking measurements are made in an anechoic chamber and repeated in an open office environment. The wave forms of the background noise and scattered amplitudes of a human body are measured and compared. The result is analyzed and discussed. A set of detection algorithms and filters which are developed to track the human movement and presence is presented and the tracking results in these two environments are compared to each other.**

Keywords—ultra wide band, radar, human detection, human tracking

I. INTRODUCTION

The ability to passively track human movement indoors is useful for wide range of security and safety applications such as elderly care, police raid operations and rescue missions. UWB radar is a technology recently having gained attention for its indoor positioning capabilities, due to some advantages such as high ranging resolution, reduction of severe multipath signals and low power consumption.

According to the US Federal Communication Commission (FCC) UWB radar has the fractional band width of $2\times(f_H - f_L)/(f_H + f_L) \geq 0.2$ (where f_L is the lower frequency and f_H the higher), or an absolute bandwidth greater than 500 MHz. UWB radar systems operate on different principles such as Frequency Modulated Continuous Wave (FMCW), pulse and M-sequence method [1]. In this research a commercial UWB radar maximum length binary sequence (M-sequence) system from the Radarbolaget[1] company is used. This system is based on time-of-arrival (TOA) ranging technique. A basic scheme of an M-sequence radar is shown in 0gure 1.

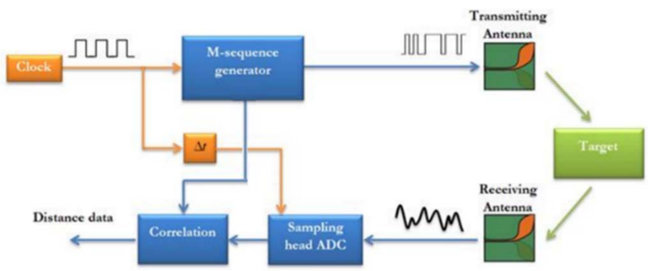

Figure 1 .A basic scheme of an M-sequence radar [5]

Clutter is all unwanted radar return signals. Sources of clutter can be divided into two categories: out-of-band interference which can be detected and removed by traditional techniques such as Fourier transform and bandpass filter. In-band interference and thermal noise is harder to identify and to remove. Clutter return under tracking a human in an office environment is formed by walls, floors, desks and chairs. i.e. by anything but the human in the scenario. The adverse effects are reduction the accuracy and probability of detection, as well as increased shadowing effects. Analysis of the statistical properties of the background noise must be carried out for identification and removal of the in-band interference and thermal noise. A statistical radar clutter model for modern high resolution radars is presented in [2]. Densities such as Weibull or log-normal (1) distributions are shown to provide reasonable fits for measured clutter densities. Log-normal distribution is:

$$f_x(x; \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{ln(x-\mu)^2}{x\sigma\sqrt{2\pi}}} \qquad (1)$$

II. HUMAN RADAR CROSS SECTION (RCS)

The reflectivity of a target can be affected by material, size, shape and incidence angle. The normal radar case is based on reception of the backscattered signal from the target. In the quasi-optical case where the size of the scatterer is much larger than the free space wavelength, its curvature becomes important. For a rounded target such as an upright human body, the horizontal incidence angle is typically not important and an effective radar cross section area can be measured or defined under certain conditions. When the target dimensions (or rather circumference) becomes comparable to the free space wavelength, more complicated diffraction phenomena including the creation of a quadrupolar scattered field occur. The maximum scattered energy may then not be the backscattered part. Rayleigh scattering occurs for even smaller targets and is characterized by an even more reduced backscattering. A walking human is a complicated target because of the complexity of the surface profile, and also different body parts moving in different trajectories with different speeds.

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[1] Radarbolaget is located in Gävle Sweden and develops radar systems primarily for real time through wall monitoring of heating furnaces (http://www.radarbolaget.com/).

RCS of the human body computer model in various postures in the frequency range of 0.5 GHz to 9 GHz and all azimuth angles is studied in [3]. It is observed that for most frequencies, the RCS of the body is in a range between –10 and 0 dBsm, where dBsm is a notation for RCS of a target in decibels; 1 m^2 corresponds to 0 dBsm. It also shown that the posture and amount of fat on the body can affect the RCS, but the average remains the same for different postures. One reason for this is because the main contribution of the radar reflection is typically coming from the trunk.

In [4], N. Yamada *et al* measured the RCS for a human in a band at 76 GHz. While the RCS is changing with orientation, the average intensity was found to be –8.1 dBsm, and as expected, the front and back produced the largest reflection. It is also shown that the type of clothing being worn can then affect the radar reflection.

This paper is focused on the effect of the environment on the probability of detection, and false alarm probability in high cluttered environment when a human is walking along a straight line towards the radar sensor at distanced from 10 to 5 meter.

III. MEASUREMENT SET-UP

The measurements are performed in two different scenarios, one in a semi-anechoic chamber and one in an open office environment.

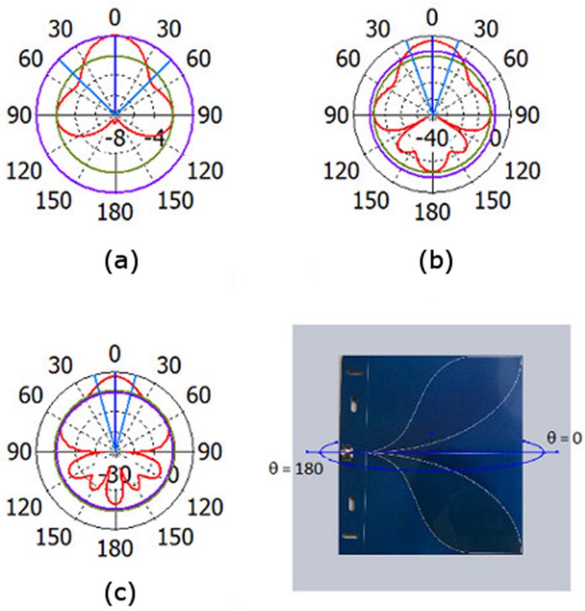

Figure 2. The vivaldi antenna elevation beam pattern at a) 1 GHz b) 2 GHz, c) 3 GHz

The radar source consists of a monostatic UWB M-sequence radar with 2 GHz operational bandwidth from 1 to3 GHz so the range resolution becomes 7.5 cm. The sampling speed can be changed from 20 GSPS to 80 GSPS.

A balanced microstrip Vivaldi antenna shown in 0gure 2 was developed at the University of Gävle for the Radarbolaget Company [5]. The essentially flat antenna measures are 185 mm × 1 mm × 213 mm. The distance between the transmitting and receiving antennas is 30 cm. A metal plate is placed between the transmitter and receiver antenna in order to reduce the direct coupling. A closer top view of the antenna set-up is shown in Figure 3. Though the metal plate can alter the antenna beam pattern and directivity and end (half-plane) diffraction will occur and will to some extent blur the received signal, it been observed that there is an improved discernibility if the target when the metal plate shield is used. However, the first (in time) and the largest reflection amplitude is due to the mutual coupling. This leakage may also to some extent result in secondary clutter.

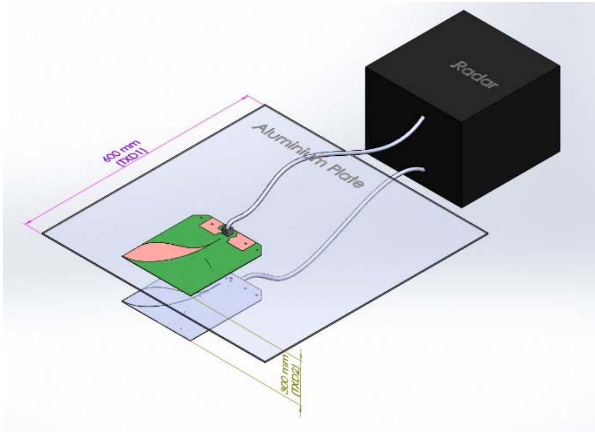

Figure 3. Antennas and their relation with metal plate and the radar device

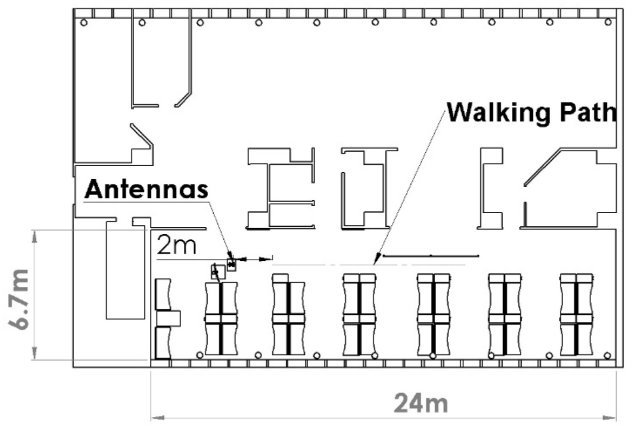

Figure 4: Organisation of the office scenario

The measurements were carried out in a semi-anechoic chamber at DELTA[2]. The clutter is from the floor and receiver noise. The antenna system is set up on a whole-plastic tower. The antennas are installed horizontally on a polystyrene support, with the apparent phase center at a height of 1 meter.

[2] Delta is a testing and consulting company that is performing EMC testing, electrical safety audits, regulatory issues and advice. www.madebydelta.com

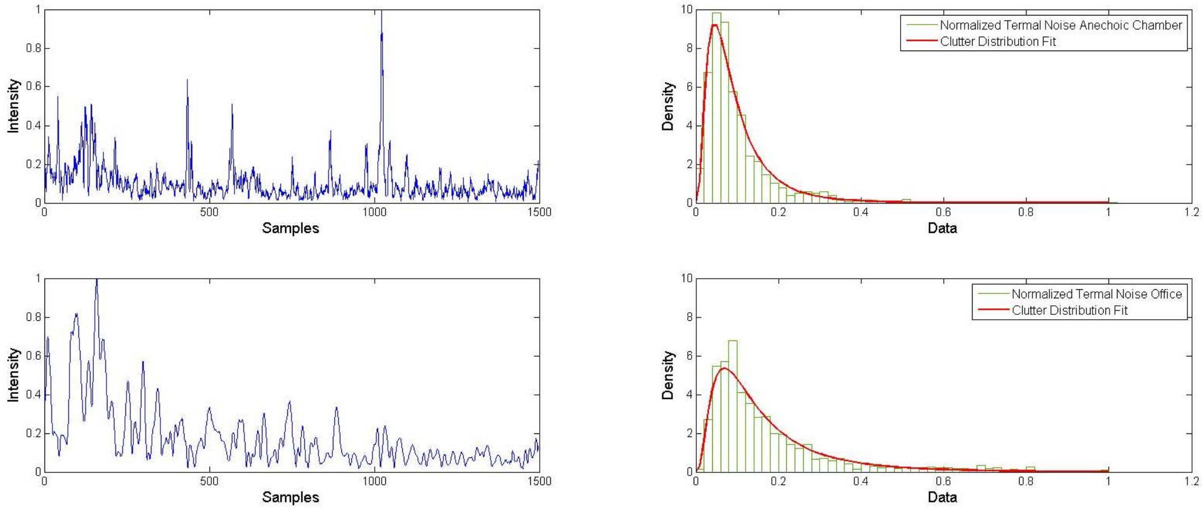

Figure 5. Thermal noise in semi-anechoic chamber (top) and office (bottom)

The polystyrene is glued to the metal plate from the sides. The height is chosen since the antenna lobes will then point straight to the trunk, which the largest target area and thus the maximal radar cross section. The human target walks straight and diagonally in relation to antennas from 10 meter to 2 meter towards the pole. The target position is measured by laser at the beginning and the end of the sequence.

The measurement in the office is carried out in an open office landscape is shown in Figure *4*. The office is furnished with chairs, tables and a metal cabinet. The antenna system is mounted on a wooden table where again the apparent phase center is at 1m height. Same person from the first measurement repeated the same procedure.

IV. PROCESSING

The raw radar data are first used to estimate the clutter density of the two environments and later processed by a series of signal processing algorithms to track the walking human target.

A. Background Statistics

The background data are obtained by calculating the median over a rolling window of 100 elements in the data matrix. Subsequent use of the *dfittool* in Matlab™ of the probability distribution of the background signal resulted in the log-normal distribution.

B. Target Tracking

A series of signal processing algorithms was developed to be able track the target movement. These stages are summarized below. The delay introduced by the electronic circuits is removed from the raw radar scan before the processing. The amount of delay is easy to recognize by the large reflection caused by the mutual coupling.

1) Background removal aims to remove the stationary clutter. The exponential averaging technique is chosen due to its low complexity and good performance [6].
2) Detection will determine if a target is absent or present in a radar reading. Constant False Alarm Rate detector (CFAR) is used. This is an adaptive target detection method described in detail in [7].
3) A multiple target tracking algorithm is developed based on the time each target is present in the radar reading also speed and amplitude of the target. The tracked targets will be remembered by the algorithm even if they are not detected in every frame. Targets that are not detected for long enough will eventually be forgotten.

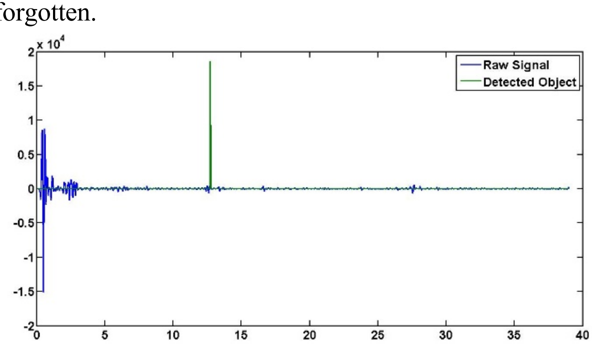

Figure 6: Raw radar data (blue curve) and the detected target (green straight line)

An example of the tracked target versus the raw radar signal is shown in Figure *6*. Observe that the *x* axis is showing the time of flight (TOF) which is twice of the actual distance to the target.

	Office	Anechoic Chamber
Mean	0.17583	0.100749
Variance	0.02696	0.007445
µ	0.000418	0.0002291
σ	2.077e-018	4.790e-019

Table 1: Log-normal distribution parameters for clutter distribution for semi-anechoic chamber and office

	Office	Anechoic Chamber
False alarm	51 %	0 %
Target Missed	1.6 %	0.5%

Table 2: Probability of false alarm and missed target percentage

V. RESULTS AND CONCLUSIONS

As it is mentioned in section II it is clear that the backscattering from in particular a walking human has a complicated behavior versus frequency. In addition, the high permittivity of human tissue for frequencies below the relaxation frequency of water of about 20 GHz provides the potential advantages of polarization sensitivity, good reflection capability and low reflection by clothes. As a consequence, our chosen frequency interval of 1 to 3 GHz is suitable for UWB backscattering measurements. The situation becomes quite different for situations where side-scattering is instead measured. Numerical modelling at the university have shown that the sensitivity to body or body part diameters, i.e. the discrimination, can be improved by dedicated choices of frequency and polarizations. Lower operating frequencies are then needed, typically in the range 70 to 200 MHz. These are then not suitable for the technique described here, and CW systems may be preferred.

With the choice of antennas and frequency in this work, backscattering is considered the best choice. Since two antennas are used, there is then a possibility to specify a distance between them, under the condition that both are directed towards the target space. Obviously, close antennas necessitate some shielding between them. As stated earlier, a simple metal sheet is not the best solution. In analogy, a larger spacing between the antennas will reduce the common space of emission/reception. Using some other wall material between the antennas is difficult with UWB techniques, since broadband functionality is needed – a complicated and expensive structure will add to the costs and make the overall system impractical. Even if the choice for this work is by no means perfect, the measurements and analysis anyway show what is to be expected with this mainly experimental and not theoretically optimized set-up.

The result log-normal fit of the clutter distribution in semi-anechoic chamber and the office is shown in Table *1*. The variance of the measured clutter is in order of 3 lower in the semi-anechoic chamber. As it is shown in Table *2* the result of cluttered environment has a direct effect on the false alarm rate. Most false alarm detection is caused by detecting more than one target in one radar frame which is a direct result of multipath reflections. The missed target percentage is mostly because of the delay in target tracking algorithm before a target is actually recognized as a moving target and not just a sudden increase in amplitude of the raw signal due to noise.

Identical hardware sets and measurement procedures have been tried, but small measurement deviations of e.g. installation of instruments and target location inaccuracies are inevitable. Measuring the position of a walking human accurately in milliseconds is not easy. A reduction of accuracy is reported in complex environment in [8] and [9], but no accuracy difference in our two environments was observed.

Future work includes improvement of signal processing algorithms both in detection and target tracking. Using adaptive algorithms for detection and Kalman filter in tracking presumably will decrease the false alarm percentage and provide better results.

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