Experimental Comparison Study of UWB Technologies for Static Human Detection

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I. Abstract

This paper compares two dominant Ultra Wide Band(UWB) radar technologies Impulse and M-sequence for static human being detection in free space. The hardware and software platform for each system is described separately. These two radar platform performances are tested in real conditions and the results show that M-sequence UWB radar is better suited for detecting the static human target in larger distances.

II. Introduction

As robots and automated machineries are increasingly replacing the manual operations, protecting humans which are working in collaboration with these machines is becoming an important task. A number of technologies have been explored and examined for human detection and tracking such as ultrasound and optic based systems like machine vision and laser scanners [1], [2], [3].

Using UWB radar for human detection can have several advantages to other techniques such as optic based sensors and ultrasound as it does not require line of sight(LOS), it does not jeopardies ones integrity and it is non-dependent on surrounding light and environmental noise like sound. UWB radar can be a stand alone or complementary system in a sensor fusion network that provides a solution to human detection and tracking problems. The purpose of this research is to develop a system being able to protect humans around dangerous machinery in an environment like mines that conditions like lack of light, dirt and fog cause other technologies decrease in functionality.

As UWB radar system pulses has the ability of passing through common building materials, this technique has become interesting for through wall imaging applications such as police raid operations or rescue missions. Some researchers has experimented with UWB radar to detect humans in free space [4]. To be able to detect static human bodies most researchers focus on small scale movements like heart beat or breathing [5], [6] which is a formidable task. To be able to detect a periodic movement like chest movement during breathing or heartbeat the data shall be gathered for a period of time, often for several seconds. This could be challenging in critical safety applications mentioned above when the human detection needs to be in real-time as a robot or the machine shall be stopped before the collision happens.

There are many different types of UWB radar developed by researchers and several available commercially. Currently there are three UWB technologies that is favorable: Frequency Modulated Continuous Wave (FMCW), pulse and M-sequence method.

In [7] Sachs *et. al.* have discussed pulse and M-sequence for UWB technology and summarized that the pulse based UWB systems are preferable in applications with simple data interpretation and low power consumption versus the M-sequence based approach needs more complicated data processing but provides highly stable data.

Following, the characteristics and performance of two commercial UWB radar systems will be discussed, one based on M-sequence (Radarbolaget[1]) and the other based on pulse technology(Time Domain[2]). At last an experiment has been done to show the difference in results in a real measurement situation.

III. Platform Description

Following, some of the most important parameters from the mentioned application view point is described: radar system description, receiver sensitivity, user interface software and antenna design.

A. Radar System

A basic scheme of an M-sequence radar is shown in figure 2. The M-sequence with the speed of 2 Gbps is modulated on a carrier frequency of 2 GHz (RF clock) which makes the operational bandwidth of this radar system approximately 2 GHz(1-3 GHz). Theoretically the radar range resolution is 7.5 cm which can be calculated from eq.1.

$$\delta_r = \frac{c}{2 * f_c} \tag{1}$$

Where c is the speed of light and f_c is the center frequency. A more realistic value for the range resolution is 15 cm when there is at least one range bin between

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

[2]Time Domain is positioned in Alabama, USA provides UWB radar and communication system(http://www.timedomain.com/)

the targets [8]. M-sequence order emitted by the radar is 13, i.e. the generated signal contains $2^{13} - 1 = 8191$ bits. The sampling point is adjustable in time steps of 13.89 ps, which corresponds to an effective sampling rate of 72 GHz. so every received wavelength will be divided into 72 GHz /4 GHz = 18 samples.

The platform consists of a radar processing unit(RPU) and a 14 bits analogue to digital converter. RPU is responsible for processing and synchronization of radar signals. The transmit gain is adjustable and has a maximum value of -10 dBm.

The impulse UWB radar is Time Domain's PulsON 410 Mono-static Radar Module (P410 MRM). A basic scheme of UWB pulse radar is shown in figure 1. The converter enables maximum 7 channels, each with a bandwidth of about 2 GHz(3.1-5.3 GHz) with center frequency of 4.3 GHz.

The radar is equipped with one transmitting and one receiving antenna. Transmit power is adjustable in the range of -31.6 to -12.64 dBm. While the parameters are largely programmable, the default settings (step size = 64 ps(19.1 mm), raw pulse rate = 10 MHz, integration = 64:1 and range window = 5.8 ns) will produce a radar response at the rate of 20 kHz [9].

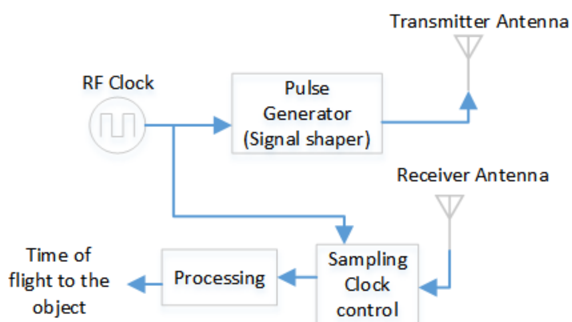


Fig. 1: Pulse radar basic artichecture[7]

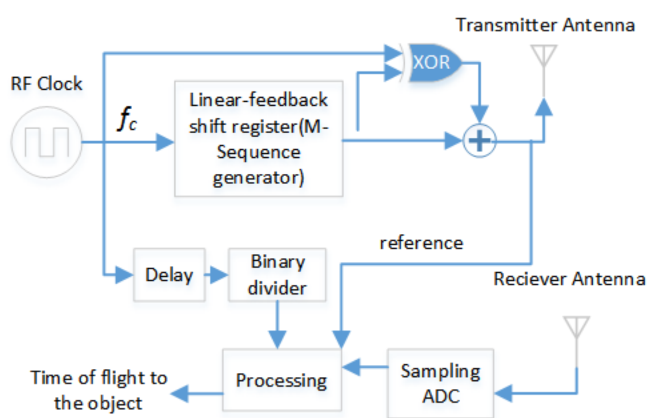


Fig. 2: M-sequence radar basic artichecture[10]

B. Receiver Sensitivity

Receiver sensitivity is a measure of minimum detectable signal by the receiver before the signal disappears in noise. Dynamic range is a measure of the ratio between maximum and minimum power of the receiver so it does not overload or the signal disappears in noise. These two parameters are highly correlated and important for this research, therefor they are chosen to be presented and compared in this section.

There is a function in the radar system to do a self-calibration. This function sends a signal internally from the transmitter to the receiver, making the calibration of the radar system easier. It enables the possibility to measure and compensate for the internal delay caused by electronics. This signal has been used to measure the lowest detectable signal. The measurement shows that the signal starts to fade in noise after 72 dB of attenuation.

Time domain's receiver sensitivity is defined as a function of Pulse Integration Index(PII) in the P410 data sheet. This means the amount of times the signal integrates to increase the SNR. The maximum SNR for radar integration is 75 dB. This parameter is 48 dB for 64:1 (PII=6) (Min Radar Integration) and 75 dB for 32768:1 (PII=15) (Max Radar Integration)

C. Software and Interface

Radarbolaget's data acquisition software is a Windows^{TM} based application that provides the raw scans. The radar system has a USB 2.0 interface.

A Windows^{TM} based MRM service provides raw scans or band pass filtered data for the Time Domain radar system. The radar system has both a serial port and an USB 2.0 interface.

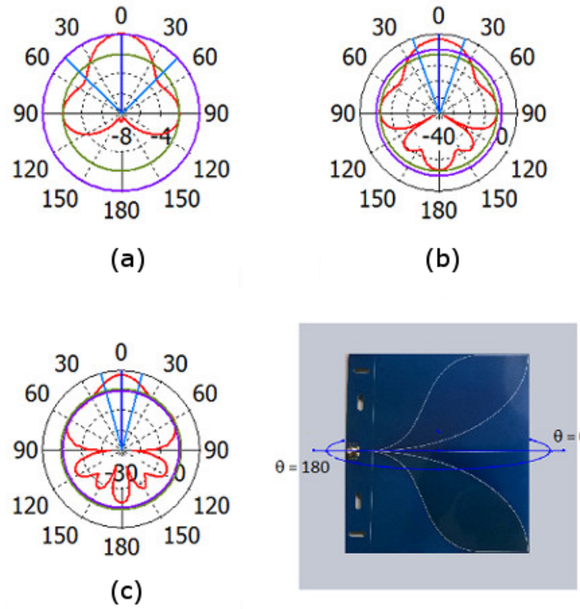
D. Antenna Design and performance

A balanced microstrip Vivaldi antenna shown in figure 3(a) has been developed at The University of Gävle for Radarbolaget [11]. The antenna is especially designed for through wall applications. The connection is a standard SMA connction which is connected to the RPU with a 2m coaxial cable. The antenna measures are 185 x 1 x 213 mm.

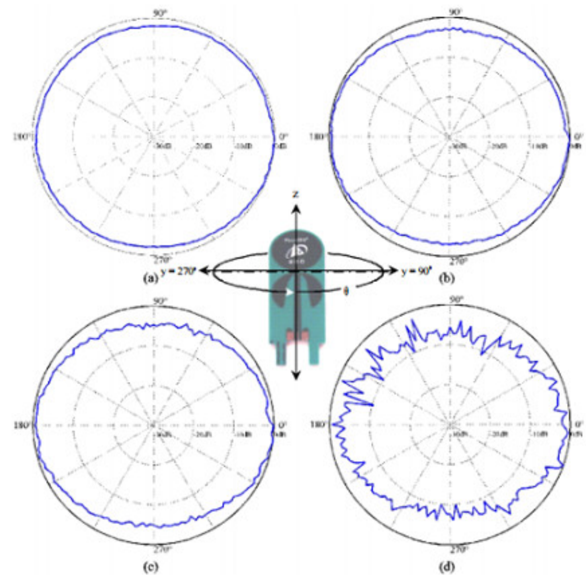
The Time Domain ultra wide band antenna is a Broadspec^{TM} Toroidal Dipole Antenna in figure 3(b), supporting a frequency range of 3.1 - 5.3 GHz. The P410 has two antenna ports. Each port connector is a standard SMA connector. The two ports enable single and dual antenna modes of operation. This antenna provides an omni-directional transmit/receive pattern. The antenna measure are 25.4 x 3.17 x 63.5 mm [12].

IV. Measurement setup

The measurements have been performed in a corridor at the Royal University of Technology (KTH university). The approximate size of the corridor is 2.1 x 24 m . The static human target stands in LOS in front of the antennas. The corridor is not in an isolated area so there are activities in parallel corridors which could have an effect on the measurements. The radar system (including



(1)



(2)

Fig. 3: (1) Radarbolaget antenna elevation beam pattern for a)1 GHz b)2 GHz, c) 3 GHz
(2) Time Domain antenna elevation beam pattern for a) 1 GHz b) 2 GHz, c) 3 GHz, and d) 6 GHz

antennas) is placed inside the corridor whereas computers, people measuring the scenarios, some chairs and tables are placed outside the corridor, separated by a glass door. For Radarbolaget's measurements the antennas are placed 30 cm from each other. The PII= 12 is chosen in Time Domain radar settings, the transmit gain was set to max which corresponds to -12.64 dBm, the scan time is around 110 ms so the number of samples in every scan is 32264.

For every target position the measurements were done for about 5 seconds. The result is an averaged value of these measurements.

V. Results and Discussions

For this study the M-sequence from Radarbolaget and impulse UWB radar from Time Domain were chosen. The former for the good scalability possibilities and our good knowledge of the system and the latter as a reference due to its wide usage in the literature. The experimental results are shown in figure 5. In every measurement, the raw signal is first averaged, then it is subtracted from the measurement of the empty corridor (background subtraction). The x axis represents the distance to the target which is calculated as multiplying the time of flight acquired by the radar device multiplied by the speed of light. The result must be divided by a factor of two as the electromagnetic waves has traveled twice the distance to the target both back and forth.

As it is clear from the pictures that the pulse radar performs well for shorter distances but as the distance increases it is difficult to distinguish the human target from noise and clutter which shows that the M-sequence UWB radar acts superior to the impulse UWB radar specially in detecting the static human in larger distances. This confirms Sachs et. al. in [7] which concludes more stable data in M-sequence approach.

The better signal to noise ratio in M-sequence might be the result of more data bits available in every wavelength which is the result of M-sequence code. This means that the received reflections from the target is a known code sequence which is reflected after a certain delay so the receiver processing unit correlates with that specific sequence. This process reduces the reflections remained from earlier radar sweeps and other interferences. Though this comes at cost of a higher power consumption which is 7 Watts for Radarbolaget versus 4.2 Watts for Time Domain radar.

VI. Conclustion

The experimental results showed that the M-sequence based ultra wide band radar works better for detection of a static human target in real office environment.

VII. Acknowledgement

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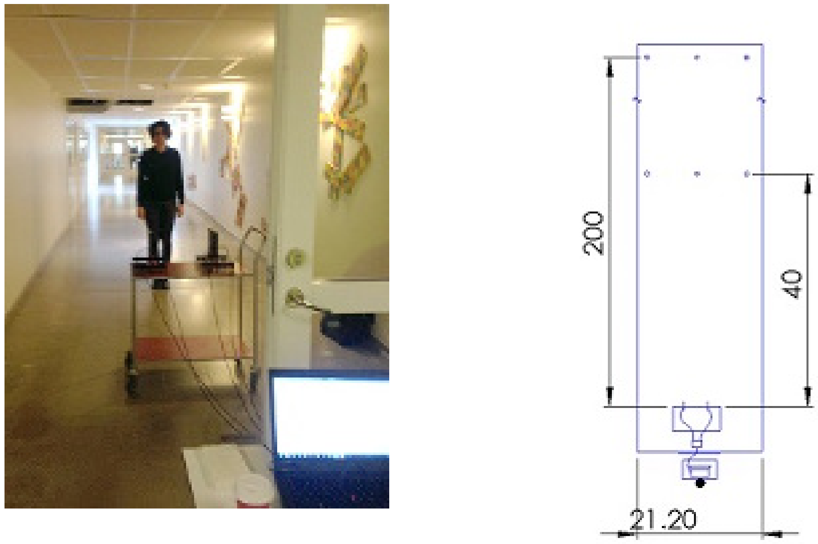

Fig. 4: KTH Corridor

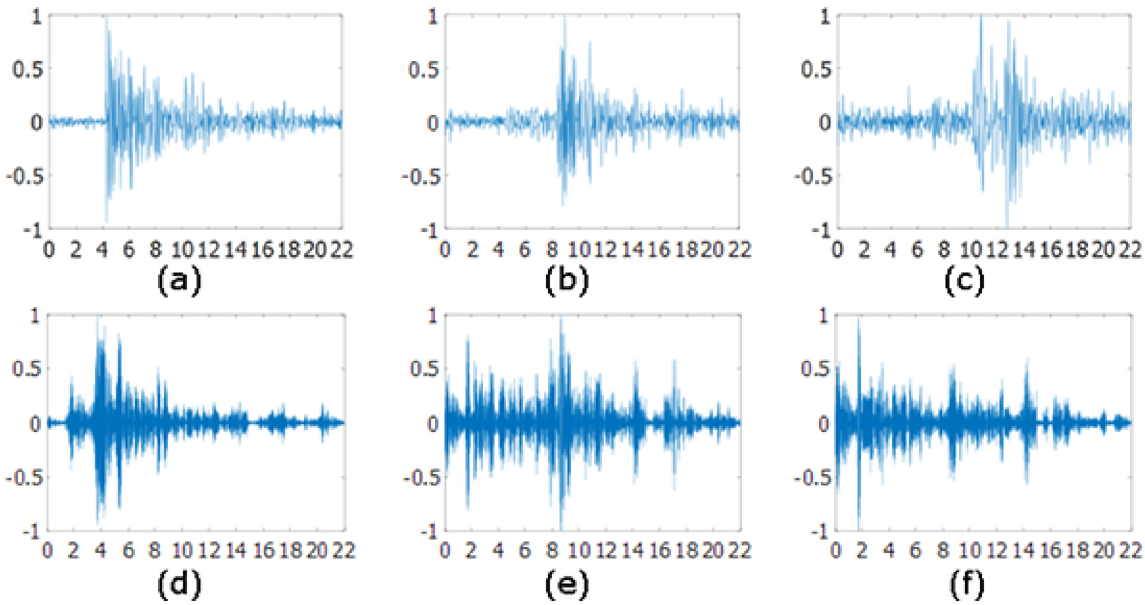

Fig. 5: Accquired signal from Radarbolaget avaraged and background removed when person standing at 4m(a), 8m(b) and 12m(c), Time Domain 4m(d), 8m(e) and 12m(f)

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