UWB RANGING PERFORMANCE TESTS IN DIFFERENT RADIO ENVIRONMENTS

O. Gremigni*, D. Porcino †

*Philips Research Laboratories, Redhill,UK, ottavio.gremigni@philips.com
† Philips Research Laboratories, Redhill, UK, domenico.porcino@philips.com

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Abstract

This paper presents field trials carried out with a Low Data Rate Location Tracking Ultra Wide Band Impulse radio testbed developed within the project PULSERS. Ranging measurements have been conducted in environments with different propagation conditions: multipath-free (anechoic chamber), Line-of-Sight (LOS) and Non Line-of-Sight (NLOS). Results show very accurate ranging performance (better than 50cm in the 1-sigma point with un-encoded and raw data). Up to now none of the existing narrow-band systems can provide similar accuracy. Moreover filtering can be applied to overcome the presence of large errors due to synchronization problems thus leading to a very accurate short-range distance measurement system.

1 Introduction

Ultra Wide Band (UWB) technology is increasingly considered an ideal radio system to enable accurate indoor positioning and drive innovative applications such as asset and people tracking or ambient intelligent sensing ([1], [2]). The Integrated Project PULSERS (Pervasive Ultra-wideband Low Spectral Energy Radio Systems [3]) has investigated – also the features and merits of UWB Pulse radios for accurate distance measurements. During 2005 the project partners developed an FCC-compliant UWB testbed for checking on the field the potential performance of such technology in the presence of real environments, obstacles, people.

For this Low Data Rate, Location and Tracking (LDR-LT) technique, classical wideband short pulse radios have been chosen due to their inherent excellent timing discrimination, which allowed timing resolutions of the order of 1ns. The platform was built with in mind a requirement of 30cm resolutions coupled with a useful data rate of 12.5 Mbps. This platform was first shown publicly during the PULSERS Workshop at the IST Summit 2005 [4] and has since then been used for practical experimentation in typical UK office environments, within the premises of Philips Research Laboratories (PRL), Redhill. This paper presents the ranging performance of the PULSERS LDR-LT platform with results obtained during an extensive campaign of measurements, which took place in the autumn and winter 2005.

The aim of this project from its start was to build up a simple testbed to analyse the ranging functionality in several different environments. The emphasis was on a low-cost architecture, which could allow future developments of intelligent commercial sensors. The mechanism chosen for ranging calculation is a simple two-way time of arrival (TOA) detection based on non-coherent energy collection, where the transmitter and receiver units are both capable of exchanging wireless data to allow synchronisation and clock error removal. While this system might need slightly more symmetrical 'tags' than other ranging devices (as the PAL system [5], [6]), it is also user-friendlier in the set-up not requiring any site calibration or fingerprinting of any type. The PULSERS method used for determining the exact location of the receiver is also much simpler than the combination of Time Difference of Arrival (TDOA) and Angle of Arrival (AOA) used in systems such as Ubisense Location tags [7] and does not require any extra conventional control channels.

The rest of the paper is organized as follows: Section 2 describes the main features of the PULSERS LDR-LT demonstrator and its functionalities; Section 3 illustrates the environments in which the measurements took place as well as the setup of the system. Sections 4 and 5 present the main results obtained respectively from the raw measurements and with a simple filtering technique employed to improve the final ranging performance.

2 System description

Each of the two LDR_LT hardware platforms used at Philips Research Laboratories (PRL) for ranging tests is composed by the following devices (see Figure 1):
1 UWB Transmitter; 1 UWB Receiver; 1 FPGA (for baseband processing); 2 Analogue-to-Digital (ADC) converters; 2 Wideband Antennas.

The whole system is divided into two main parts: RF section and Baseband processing.
The RF section includes the transmitter, the receiver and the antennas and it deals with analogue UWB pulses. The baseband contains the FPGA processor card which is mounted on a personal computer (PC) and it is in charge of processing digital data coming from the ADCs and providing all the features needed to enable data demodulation and ranging.

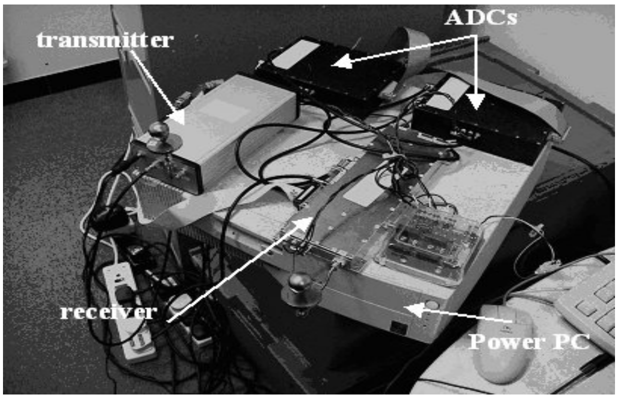

Figure 1: PULSERS LDR-LT platform

2.1 Transmitter – the pulse generator

The transmitter generates short (with a time duration of around 500 picoseconds) low-power (with a peak-peak voltage of around 1 V) pulses that produce a noise-like spectrum whose bandwidth spans from 3 to 5 GHz. The pulse shape and its spectrum at the output of the transmitter are shown in Figures 2, 3.

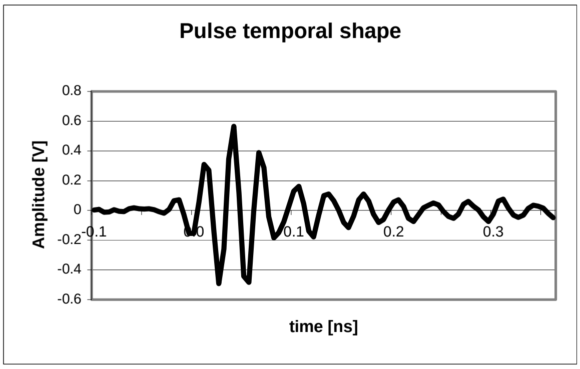

Figure 2: Temporal pulse shape

Figure 3: Spectrum of the transmitted pulse

2.2 Receiver – RF Front-end

The RF front-end part of the receiver is based on a non-coherent energy detection scheme. The block diagram in Figure 4 illustrates the main components of this device.
The received pulse is filtered to lower out-of-band interferers and then amplified with a 30 dB Low Noise Amplifier (LNA). The output of the second stage bandpass filter is then split into two separate branches for processing at different resolutions: the data demodulation and ranging branches.

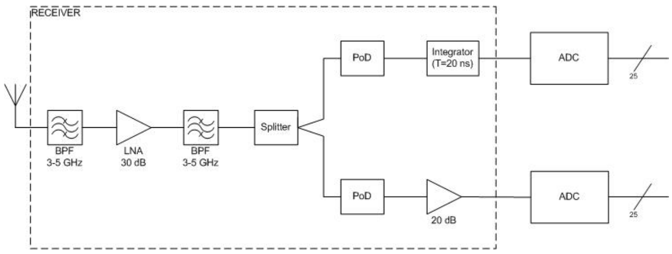

Figure 4: The RF-Front of the PULSERS LDR-LT Platform

The demodulation branch comprises a Power Detection circuit (PoD) and an integrator, whereas the ranging one has PoD and an amplifier with fixed gain of 20 dB. The PoD is based on a Schottky diode followed by a capacitor and a resistor (to avoid leakage). This circuit acts like an envelope detector and the signal coming out from this device has a lower bandwidth with respect to the input UWB signal to match the ADC bandwidth of 900 MHz.

The integrator in the demodulation branch is needed to achieve signal synchronization; it has an integration window of 20 ns, which can be shifted in steps of 4 or 8 ns. In the integration strategy followed by this structure the best starting integration time is the one that leads to the higher recovered signal energy. In the ranging branch there is no integrator as the signal is amplified and sent to the ADC without any further processing. The integrator is replaced by the sampling window approximately 1 ns wide. More details on the demodulation mechanism are reported in Sec. 2.4.2.

2.3 Antennas

The LDR-LT demonstrator employs four omnidirectional antennas (two for each platform, one for the receive and one for transmit path). For the experimental campaign some UWB printed antennas manufactured by TDK have been employed.

2.4 Baseband Processing

The baseband part of the receiver includes an FPGA card mounted on a PC. The baseband processor is responsible for all the features as synchronization, demodulation, ranging and framing. Data from RF modules (both transmit and receive paths) are conveyed to the FPGA via ribbon cables.
The user can set the values for some basic parameters (e.g. type of modulation) of the platform through application software developed by PULSERS partners. The software allows writing such values into the FPGA registers through a custom interface allowing exchange of data with baseband.
In the following sections we will focus on the synchronization algorithm for ranging and demodulation.

2.4.1 Modulation

The modulation used in the LDR-LT platform is a 2 disjointed pulse position modulation (2 DJ-PPM), where ‘disjointed’ means that time slots do not overlap. According to the largest data rate available of 12.5 Mbps, the smallest pulse repetition period is 80 ns, and this leads to the choice of a 40 ns time slot per symbol.

2.4.2 Demodulation and ranging synchronization

The synchronization algorithm has to find out the best value for the integration start time. A scan of the preamble sequence is carried out by shifting the integration window (20 ns wide) at steps of 4 or 8 ns[1]. The time shift whose integration value is higher corresponds to the best start time for signal integration. This value is fed to the demodulator block.

Once symbol synchronization has been achieved, frame demodulation starts. After the synchronization process has been successfully completed, the ranging algorithm starts.
The aim of the ranging process is to seek for the first path arrived within a given demodulation window (i.e., within a symbol time slot).
The signal at the output of the PoD circuit of the ranging branch is fed to the ADC. The sampling time of the ADC is approximately 1 ns and it can be shifted by 1 ns steps thanks to custom designed delay lines, this leads to a maximum resolution of 30 cm. The achievable resolution of the system is 1ns even if the clock period of the LDR-LT demonstrator is 40ns as the ranging process is carried out over a set of symbols, assuming the channel unchanged during this period. Samples are taken starting from the demodulation window’s position at steps 1 ns apart. The peak value with the shortest delay and amplitude above a certain threshold is considered the first path arrived.

2.4.3 Two way ranging algorithm

The algorithm used to calculate the distance between the platforms is a simple two way time estimate process.
As shown in Figure 5, the T1 and T2 time intervals are evaluated by means of four timestamps: Tx1reg, Tx2reg, Rx1reg, Rx2reg. The first two timestamps are 25 bits long and have a resolution of 40 ns (they record the symbol time of frame transmission), whereas the last ones are 32 bits long and have a resolution of 1 ns (5 bits are used to represent the delay of the estimated first path, 1 bit indicates the path position in the neighbouring timeslot).

A complete description of the ranging algorithm follows:

- Start of ranging: device I sends a ranging frame to device II and a timestamp TX1reg is stored in a register;
- Device II receives the ranging frame, a timestamp RX2reg is stored;
- Device II answers the ranging frame, including the receiving timestamp RX2reg as well as the transmission timestamp TX2 in the data field of the frame;
- Device I receives the answer frame, estimates a receiving timestamp RX1reg and extracts the timestamps of device II to be stored in registers;
- After this cycle the four register values are passed to the application software, which calculates the distance with the formula in (3).

$$T1 = \{Rx1reg(31:7) - Rx1reg(6) - Tx1reg(31:7)\} * 40\text{ ns} + Rx1reg(5:0) * 1\text{ ns}. \quad (1)$$

$$T2 = \{Tx2reg(31:7) + Rx2reg(6) - Rx2reg(31:7)\} * 40\text{ ns} - Rx2reg(5:0) * 1\text{ ns}. \quad (2)$$

$$D = 0.5 * (T1 - T2 - offset) * 30\ [cm]. \quad (3)$$

The first seven bits (0..6) of Tx1reg and Tx2reg are set to zero. The parameter ‘offset’ takes into account all the delays due frame processing. The ranging cycle is performed once per second and it lasts 1/2 ms.
The accuracy for the doubled distance is 30 cm, hence for the single distance results in a maximum resolution of 15 cm.

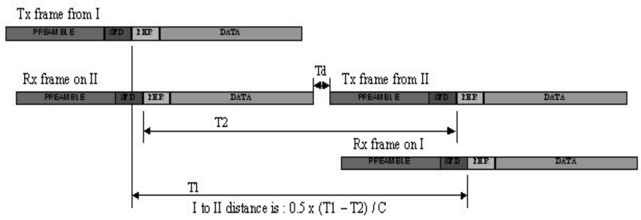

Figure 5: Two Way Ranging algorithm

3 Environments and Measurements Setup

Measurements were carried out at different premises in PRL building. The main results presented in this paper are obtained in ideal conditions within an anechoic chamber, in a typical office room (LOS) and through a wooden partition (NLOS) between two adjacent rooms. Pictures in Figure 5 illustrate the environments were tests took place. During measurements one platform is moved along a marked track with markers placed every 30 cm, whilst the other platform remains at a fixed position. The equipment was placed onto and moved with two trolleys whose heights are 90 and 105 cm.

A recording time of a fixed length (typically 15 mins) had been set for each measured distance to get several estimates per measurement point[2]. In this set of experiments no coding was employed to protect data from channel errors, therefore some measures could be wrong. Furthermore due to occasional synchronization errors, a ranging cycle could fail and in this particular case no distance value is available at the output. As a consequence it is impossible to achieve a fixed number of valid distance values per each measurement. This is why it has been decided to set a constant recording time

[1] The shorter step leads to a more sharp synchronization, whereas the larger leads to faster but less precise results

[2] Ranging cycles are carried out once per second.

rather than fixing the number of samples per each measured distance. The amount of valid (i.e. fully synchronised) measures will be showed while presenting the results.

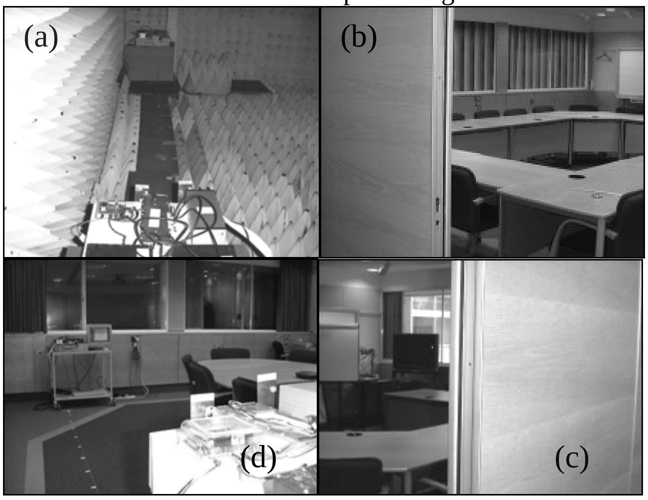

Figure 6: Clockwise (a) anechoic chamber room (b) wooden partition dividing on one side a large conference room and (c) on the other side a small conference room (d) conference room (approximately 570 × 570 cm).

4 Results

A discussion is presented for each of the three environments under investigation followed by general conclusions.

A. Anechoic Chamber

The anechoic chamber test is extremely useful as it represents the upper bound for the LDR demonstrator performance. The absence of multipath scattering leads to the lowest possible errors, as the system is sensitive to multipath effects due to its non-coherent energy detection scheme.

The mean error has a peak value of 12 cm at a distance of 390 cm (see Fig 7). For all other measurements the error is lower, showing clearly that a UWB LDR system can achieve an excellent ranging accuracy even with a low complexity receiver. Same indications are also given by the plot of cumulative distribution function of errors of Fig 8, which confirms errors below 30cm up to 6m tx-rx distance.

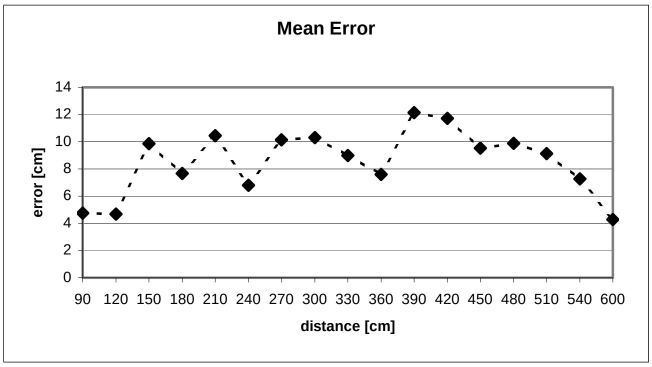

Figure 7: Ranging mean error for anechoic chamber test

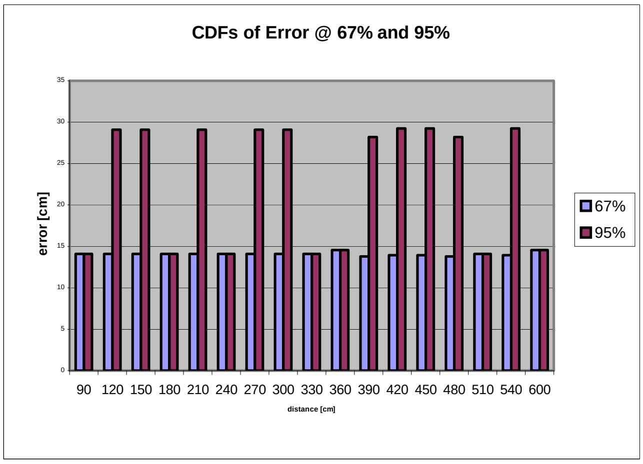

Figure 8: One-Sigma and Two Sigma Error points at different distances for the Anechoic chamber tests

The experiments were then repeated also in 'real' environments, with multipath into play.

B. Conference Room

This environment had been chosen because it embodies the features of a typical medium-size conference room and can help doing a Line of Sight (LOS) analysis in a cluttered environment. Figure 9 illustrates the plant of the room along with the position of its furniture. The platform close to window had been held in fixed position and the other one had been moved along a straight track as shown in Figure 9.

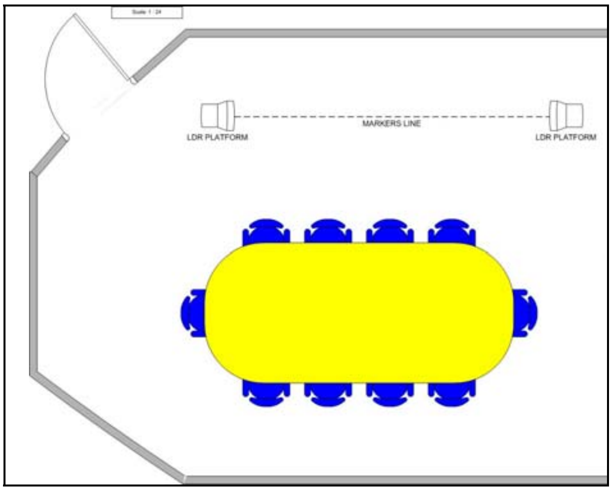

Figure 9: Plant of the conference room where tests took place. Position of the platforms and track are shown along with the furniture present in the room.

From Figure 10 we can notice that measurements at 270, 330 and 510 cm present higher error values with respect to rest. Moreover the standard deviation at 330 and 510 cm reaches large values, whilst the error's variation at 270 cm is within a reasonable range.

The explanation for some high values of standard deviation could be that some out of range measures occurred due to channel errors or peak misdetections. The 270 cm case as an example should be interpreted as failed measure because of its low value of deviation for the error distribution. Such errors are probably due to multipath effect as they are not present in the anechoic chamber test.

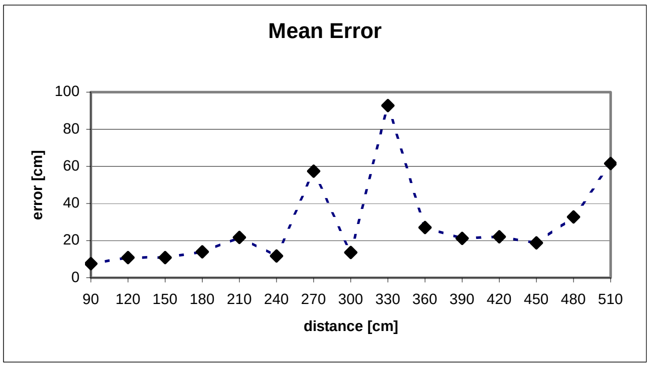

Figure 10: Ranging average error for office room test

It is worth to notice that, excluding the aforementioned measurements, the mean error is well below 40 cm, thus indicating that the LDR platform is able to achieve a noticeable accuracy.

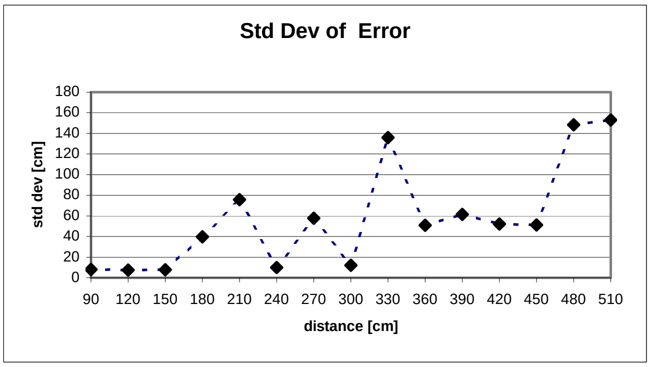

Figure 11: Error standard deviation for office room test

C. Intra-room Partition Test

This test has been useful to check the performance of the demonstrator in a NLOS environment. The partition separating the two conference rooms (see Figure 5 (b) and (c)) is wooden. It has a width of 8 cm with two panels joined to create a sound-proof and robust separation of two adjacent environments. During the tests the partition was closed and each platform was positioned in one of the two separate rooms.

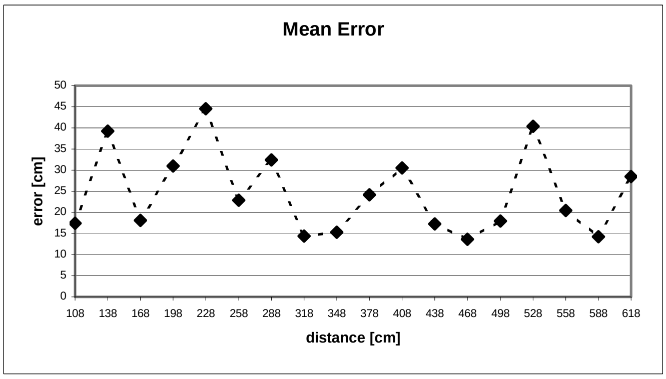

Figure 12: Ranging mean error for partition (NLOS) test

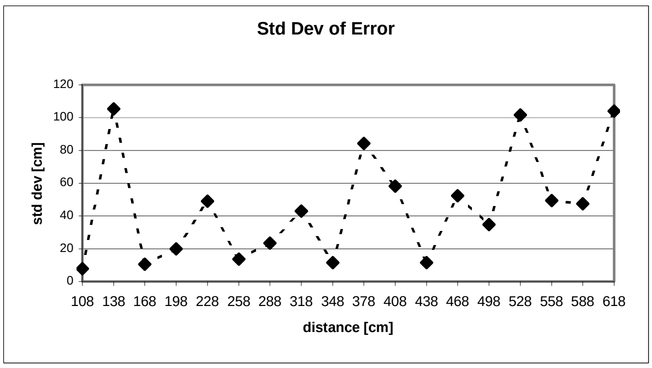

Figure 13: Error standard deviation for partition (NLOS) test

From Figures 12 and 13 it is clear that the system performs quite well in such environment, even if there are some measurements where there could be improvements. For example 138 cm, 378 cm, 528 cm and 618 cm could perform even better with filtering as their error's deviation was relatively high (above 80 cm) and this means that peak misdetections or demodulation errors could have occurred causing some values to fall out of range.

5 Improving the performance using filtering

While the system performance is generally quite good with accuracies in the ranging estimations as shown in the previous section, it is clear that the lack of any coding and the use of straight unfiltered raw data could cause errors and the consequent appearance of few spurious measurements which would influence the reliability of the worst few percent of the cases.

To improve the performance we decided to implement a post-processing basic filter. This filter consists in the moving average of five consecutive measures where the estimated distance and the incoming value is taken into account if its relative error does not exceed the 50% threshold.

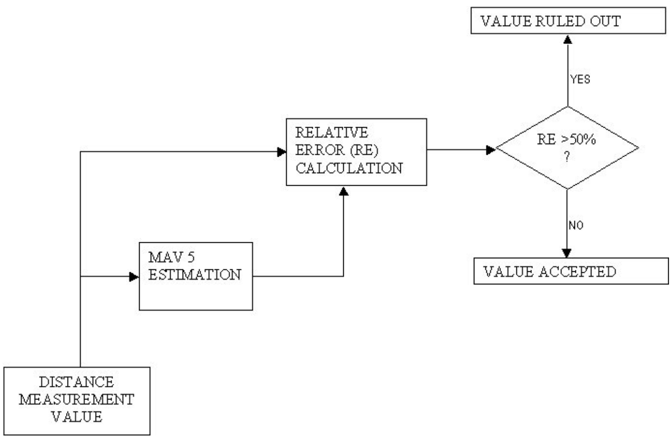

Figure 14: Block diagram of the filter used to improve measurement accuracy

Applying filtering to the results of the anechoic chamber test –as expected- does not bring any improvements, as there were no odd values. Different is the situation in the case of the ranging measurements in the conference room and NLOS conditions.

Figures 15, 16 shows the effect of filtering on the mean error for the conference room case: distances at 330 and 510 cm have now a lower error as well as a reduced standard deviation. The measurement at 270 cm still has a high error value and the error distribution deviation remains unchanged, therefore we conclude that this measurement is wrong. The analysis of CDF of the error distribution support the conclusions we have just drawn: the number of out-of-range measurements have been almost completely ruled out from the estimations of 330 and 510 cm, as now the range of errors has been decreased to 100 cm from more than 500 cm. Unfortunately the same result is not encountered at 270 cm, confirming that the measurement is definitively wrong.

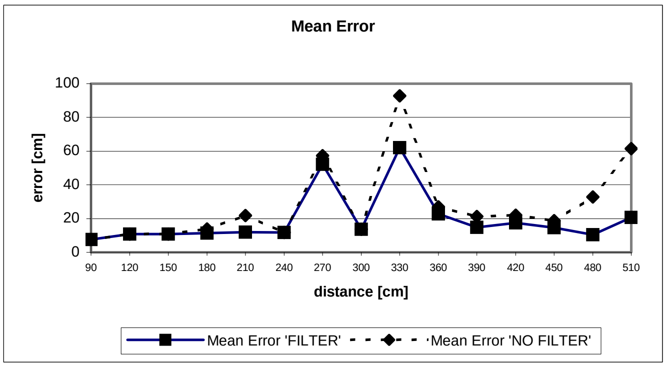

Figure 15: Effect of filtering on error – Conference Room

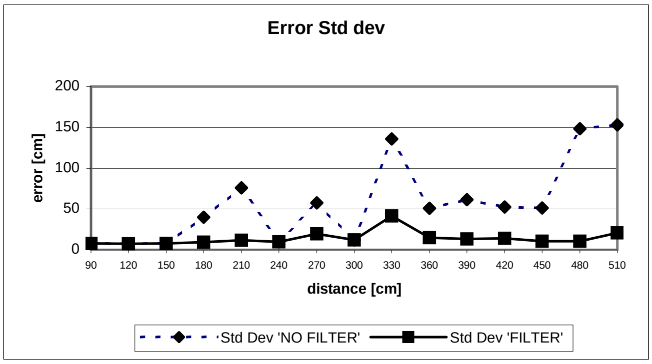

Figure 16: Effect of filtering on standard deviation – Conference Room

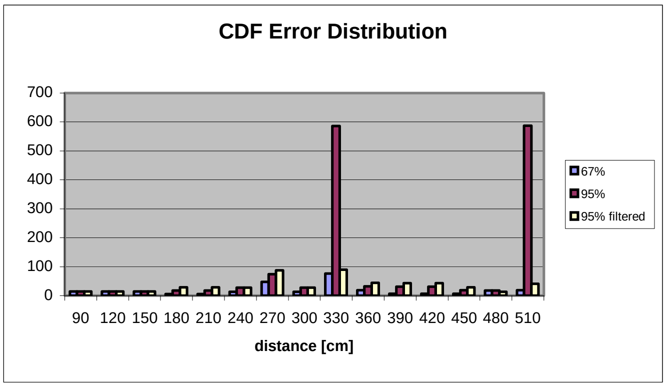

Figure 17: Effect of filtering on error – Conference room. Comparison between CDFs of the error before and after filtering.

The filter has been also applied to the results of the partition test. Figures 16 and 17 show that a noticeable improvement is achieved for the measurements with high error and variance, i.e. 138 cm, 378 cm, 528 cm. It is worth to point out that the distance measure at 618 cm is unaffected by filtering and this could mean that the filter is unable to remove clusters of close-by wrong values.

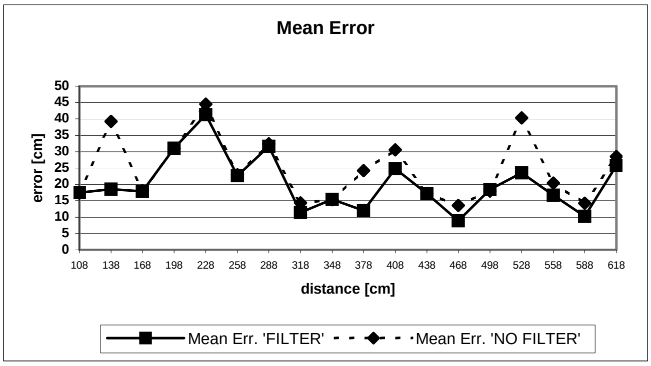

Figure 18: Effect of filtering on error – Partition test

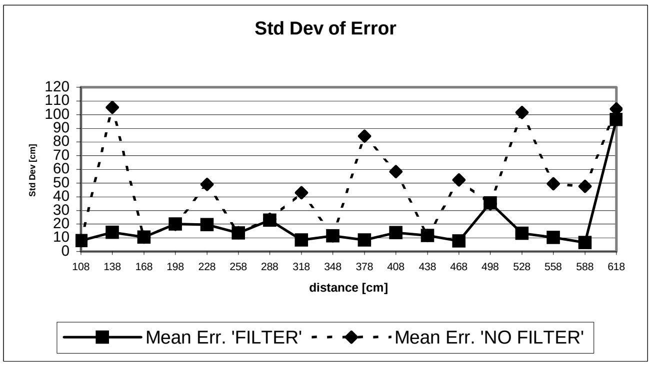

Figure 19: Effect of filtering on standard deviation – Partition test

6 Conclusions

The PULSERS LDR-LT demonstrator was able to achieve an excellent ranging accuracy (with a relative error below 5% up to 6 meters) in a multipath free environment such as the anechoic chamber.

Tests held in more realistic premises where multipath was present have shown that 'raw' measurements can present larger errors, but still lead to accuracies far better than any narrowband system. Even a very simple energy collection and two-way time of flight device as presented in this paper is capable of good distance measurements from simple raw un-encoded data.

Data filtering helps improving such accuracy even further, removing spurious measurements that might occur with this low-cost platform.

The low complexity of the receiver and the absence of coding make the system sensible to multipath, the synchronization process needs to be improved as well, but these impairments do not compromise the final results which are still good enough to enable intelligent sensing applications and asset tracking.

The introduction of a coding mechanism, coupled with other more advanced filtering techniques could lead to exceptional performance, nonetheless our results show that short distance ranging is already feasible with low complexity equipment today.

7 References

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