ON THE POSITIONING CAPABILITY OF UWB SYSTEMS

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ABSTRACT

A time-domain measurement experiment that illustrates the positioning capability of ultra wideband (UWB) systems is illustrated. Both measurement setup and measurement locations are detailed. The paper highlights the challenges that limit the utilization of the high precision of UWB systems. These challenges include multipath, pulse dispersion, and the antenna effect on the pulse-shape due to angles of transmission and arrival.

1. INTRODUCTION

Ultra wideband (UWB) systems use precisely timed, extremely short coded pulses transmitted over a wide range of frequencies [1,2]. Although UWB technology had some old roots, UWB communication is a relatively new technology.

UWB technology supports integration of services. One of the services and applications that can be integrated with UWB communications is positioning [3-5]. Narrowband technology relies on high-frequency radio waves to achieve high resolution. Unfortunately, high-frequency radio wave has short wavelength and cannot penetrate effectively through materials. On the other hand, UWB receiver can time the transmitted pulses to within a few thousand billions of seconds, and still promise good penetration through materials.

There are many scenarios for how UWB positioning can be utilized. For example, UWB can work as an augmentation to the Global Positioning Satellite System (GPS). Time modulated UWB signals are superior to the GPS resolution by three orders of magnitude. This could result in sub-centimeter range resolution. UWB signals are immune to multipath, which is a major problem for GPS receivers in the vicinity of buildings and large topographic features. Moreover, UWB systems are proposed to have better wall-penetration capabilities. If reference stations are equipped with UWB technology, precise location could be determined especially within buildings and areas were GPS fails to operate. Precision positioning allows aircraft to locate and monitor their position relative to other aircrafts and relative to the ground. A GPS augmented with UWB technology will allow an instrument landing even under inclement weather. The technology is also being tested to look inside closed rooms.

UWB technology is also promising in other positioning applications such as automobile collision avoidance. More sophisticated applications are expected due to the recent developments in UWB technology.

This paper starts by presenting the time-domain measurement setup and procedures. The results of the measurements are then highlighted. Multipath, pulse dispersion, through-the wall and other positioning challenges are then discussed.

2. TIME-DOMAIN MEASUREMENTS

One of the essential properties of time domain measurement techniques is the ability to distinguish discontinuities and time separations between them. A schematic illustration of the components of a time domain measurement system is shown in Figure 1a. The pulse generator triggers a sampling oscilloscope as the pulse enters the system under test. The figure displays the measurement locations of both **t**ime **d**omain **r**eflection (TDR) and **t**ransmission (TDT) measurements. By measuring the transmission time, one can estimate the distance between the transmitter and the receiver. In the case of the used Gaussian-like pulse input, which has frequency spectra that extend to dc, the time-domain resolution depends on the rise-time of the pulse, which is inversely related to the pulse's bandwidth.

An experimental setup was established to evaluate the performance of UWB system capabilities. It consists of a pulse generator that furnishes pulses to the transmitting antenna. Radiated pulses propagate through the channel and are captured by the receiving antenna. Received pulses are acquired by means of a sampling oscilloscope and a data acquisition unit. In addition to the time delay that is used to estimate the position or distance, the received signal suffers attenuation and dispersion whose degree depends on the characteristics of the channel as well as the radiation patterns of both transmit and receive antennas. The details about the setup are discussed in the next subsection.

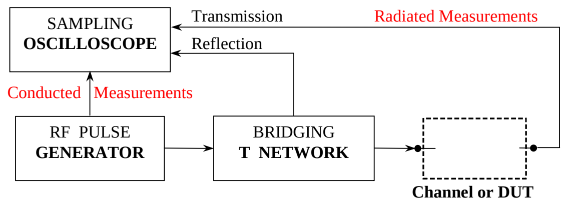
2.1 Measurement Setup

Time domain measurements were performed using a sampling oscilloscope as a receiver and a Gaussian-like pulse generator as transmitter. The setup is shown in Figure 1b. The width of the excitation pulse is less than 100 ps. Offset calibration is carried out with a matched load before performing any measurements. The original data were over-sampled in the time domain with 10 ps/sample which results in a noise tail in the frequency domain. The acquisition time window was set to 100 ns which contains 10K points. A total of about 400 profiles were collected. The spatial width of the used pulse in our measurements is much smaller than the one used in previously published measurements. The spatial width is small enough to make the line-of-site path always resolvable from any other multipath component.

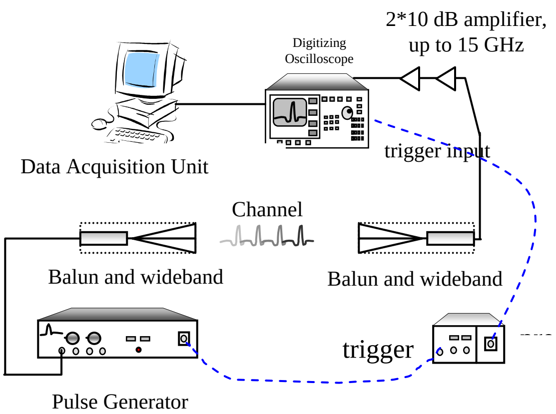
In indoor environments, the time varying part is typically due to human movements. By conducting measurements during low activity periods and by keeping both the transmitter and the receiver stationary, the channel can be treated as being quasi-stationary. This allows us to average 32 measurements, thus effectively canceling out the noise.

The antenna is preceded by a *balun* which converts the unbalanced coaxial terminals to two terminals feeding the signal to the balanced antenna terminals. The baluns and the antennas, on both the transmitting and receiving sides, have sufficient bandwidth such that the spectral characteristics of the pulse signal are not degraded. Two different sets of measurements were performed based on TEM horn antennas and biconical antennas. Details about the antennas can be found in [1]. Both transmitter and receiver antennas were placed on plastic moving carts at an elevation of about 1.25 m above the floor. Styrofoam slabs were used to adjust the elevation without introducing reflectors around the antenna. The TEM horn antennas were aligned for maximum boresight reception. The advantage of using TEM horn antennas is that they are ultra wideband radiators designed and optimized for time-domain impulse response measurements. TEM horn antennas emulate sectored antenna proposed for gaga-Hertz frequency indoor application. The TEM horn antenna has very narrow beamwidth and thus is highly directional. With TEM horns fewer multipath components are received, and almost none from behind the receiver. On the other hand, biconical antennas are omni-directional and are more likely to be used in mobile applications. The biconical antennas used in this investigation are not designed as impulse antennas but they are impedance matched over a very wide bandwidth.

The triggering signal was carried by a coaxial cable to the sampling oscilloscope. As the distance between transmitter and receiver increased the loss and dispersion in the triggering cable increased too, resulting in a higher jitter. An effort was made to use higher quality cables and minimum possible length for the triggering cable. A personal computer was used to store and post process the data.



(a) General TDR and TDT measurement setup



(b) Illustration of the time domain measurement setup

Figure 1. Time domain measurement setup

As the distance between the receiver and the transmitter increases, the need for a wideband amplifier becomes more pronounceable. Two low noise wideband amplifiers were used at the receiver side. Each amplifier has a again of 10 dB and a 3dB-bandwidth of 15 GHz. Different sets of antennas or different sizes in conjunction with different various sources for generating pulses can also be used. The setup can be manipulated to handle multiple antennas for diverse positioning and communication examples.

2.2 Measurement Locations

The measurements were carried out in two buildings on Virginia Tech Campus, namely; Whittemore Hall and Durham Hall. The former building comprised mainly of offices and classrooms. Most walls are made of drywalls with metallic studs. Some walls at certain locations including stairwells are made of cinderblock and poured concrete. In Durham Hall, interior walls are largely made of drywalls and cinderblocks. The floor is covered with ceramic tiles in hallways and with carpet inside the rooms.

In Whittemore Hall, the measurements were performed in three different floors; along the hallways on the second floor, in a narrow corridor on the fourth floor and in a conference room on the sixth floor. Blue prints are shown in Figure 2. Additional details and photographs of measurement locations are provided in [1]. In Durham Hall, all measurements were carried on the fourth floor. Five different transmitter locations were considered. For every location, measurements at different receiver locations were performed. Different scenarios are considered. Line-of-site (LOS) and non-line-of-site (NLOS) topographies are of paramount interest. Room-to-room, within the room and hallways are all typical indoor environments. Shadowing effects can also be assessed in some scenarios.

(a) Whittemore Hall (second floor only).

(b) Durham Hall (Squares represent transmitter locations, circles represent receiver locations)

Figure 2. Blueprints of measurement locations.

3. TESTING RESULTS

In order to validate the positioning capability of the UWB positioning system, the distance between the receiver and the transmitter where measured using conventional tape measure. Other positioning technique which is comparable to UWB in terms of accuracy was not available. The distance between the two antennas is measured relative to the middle of the antenna aperture.

First, a reference measurement is conducted with a small distance where the receiver antenna is located in the far field relative to the transmitting antenna. Let us call this reference distance d_f, and the time where the signal is detected the reference time, t_f. Second, the receiver is moved to the intended test location and the time when the signal is received is referred to as t. Now the distance between the receiver and the transmitter, d, can be approximated as:

$$d = d_f + (t - t_f)c \tag{1}$$

where c is the speed of light in free space. Comparing the conventional measurement with the result of the UWB system, give a general idea wither we are getting the correct position or not but cannot be used for to quantify the error in the position.

The accuracy of the positioning technique depends on the method of making decision on the delay. It is expected that utilizing advanced signal processing techniques will improve the decision. If the delay of the signal is based on searching for the maximum signal, a correct decision would have a maximum of 5 ps error which is half the time step. This translates to a maximum of 0.5 mm.

For the 400 hundred positions examined, the distance for all LOS cases were correctly evaluated except for one case where the receiver was very close to the side wall and the reflection from the wall turned out to have a maximum value as in Figure 3 . When examining NLOS scenarios one has to use more advanced decision making and signal processing techniques to estimate the delay of the signal. As the signal propagates through the walls it suffers from signal attenuation, dispersion and multiple reflections. The difficulty when using the biconical antenna is more pronounceable than the case of the directional TEM horn antenna.

The next section is dedicated to highlight some of the difficulties and challenges when maximum accuracy is desired.

4. UWB POSITIONING CHALLENGES

To get the fine resolution offered by UWB systems, one has to develop signal processing techniques that mitigate the challenges due to the imperfection in the medium between the transmitter and the receiver. Multipath, obstructions, antenna effect are among those challenges that were observed during the experiment.

4.1. Multipath

In general UWB signals are very immune to multipath. However, there are cases where the transmitter and/or the receiver are very close to a wall or table that causes pulses from different multipath to overlap and reduce the timing and positioning capability of the system. Figure 3 illustrate one such scenario.

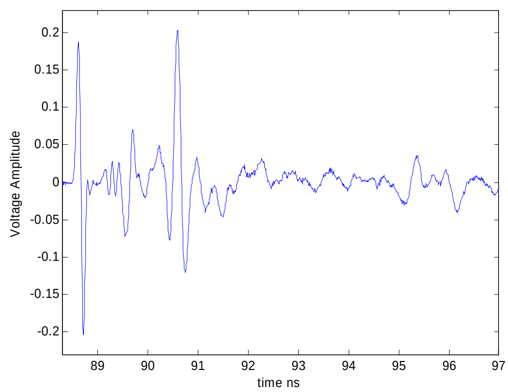


Figure 3. Received profile with strong multipath components

4.2. Multiple Reflection and through the wall propagation

Propagation through free space was assumed in the previous analysis. This assumption could reduce the accuracy of the positioning in indoor applications. It is known that the dielectric of the obstructions and their thickness will introduce delay in the propagation path.

The thickness of the objects in the path is critical to the measurement when high accuracy is desired. On the other hand, very thick walls may cause high losses, resulting in weak signal levels that cannot be accurately measured. To illustrate the effect on the delay, amplitude and pulse shape, different materials were tested. Wood, glass, blocks, bricks, and other construction material were inserted in the path between the transmitter and the receiver antennas. First, a free-space measurement is conducted, then the slab or material under test is inserted and the through-signal is acquired. The complete set of measurements is presented in [1]. Here two examples are presented to illustrate the effect of the obstruction material on the signal delay and hence positioning capability. The former example, a typical wooden door, represents a relatively homogeneous material. The thickness of the door is 4.45 cm. The latter example is for typical construction concrete blocks. The thickness of the wall made of concrete block is 19.45 cm with air gaps caused by the holes in the blocks. Figure 4 illustrates the free-space and through measurements for the two cases.

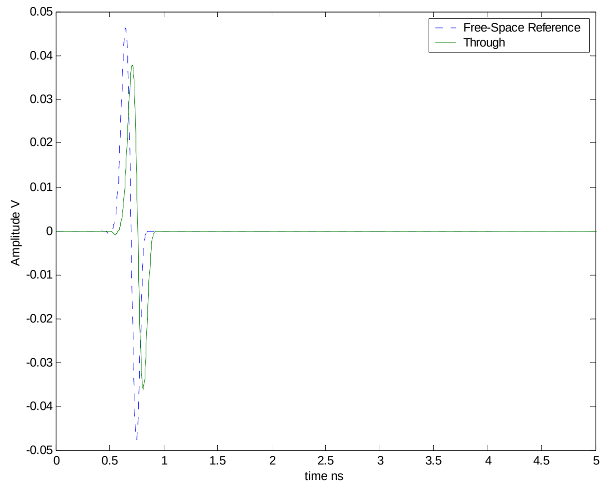
4.3. Angle of Arrival and Antenna Effect

It should be noted that previously presented radiated measurements are for boresight direction. However, in practical cases, the antenna pattern plays an important role for both the receiver and the transmitter. To illustrate this, the effect of the angle of arrival, different experiments and scenarios were considered.

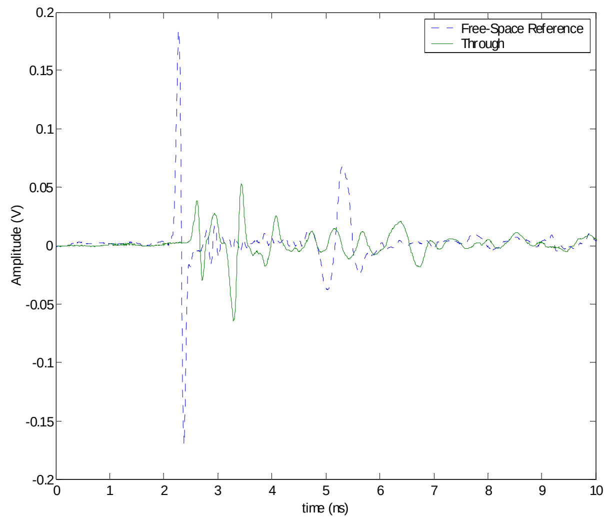
One scenario is to investigate the effect of vertical rotation of an antenna (E-plane scan). In this case, the transmitting antenna is kept fixed at a height of 1.03 m above the ground, whereas the receiving antenna at the same height is rotated along the elevation angle, θ. Measurements are performed at different angles; namely $\pm 15^0$, $\pm 30^0$, $\pm 45^0$, $\pm 60^0$.

The schematic diagram embedded in Figure 5 demonstrates the first two multipath components that are expected to be captured in time domain. Spherical lines covering the receiver represent the rotation in the vertical direction as well as the antenna far-distance electric field lines. Negative angles refer to rotation towards floor, and on the other hand, positive angles in the reverse direction. When the receiver antenna is tilted more towards floor – i.e. negative angles, – the line-of-sight pulse and the reflection off the floor tend to move toward each other and vice versa. Another interesting feature is the broadening of the original pulse when compared directly to the boresight reception.

Another scenario would be to investigate the effect of horizontal rotation of an antenna (H-plane scan) [1]. A more comprehensive characterization can be done in an anechoic chamber. Usually, antenna characterization is done in the frequency domain for only specific frequencies. For accurate time domain applications, such task requires a huge number of frequency measurements.



(a) Wooden door (time-gated)



(b) Concrete blocks

Figure 4. 'Free-space' and 'through' measurements to illustrate the delay and pulse deformation.

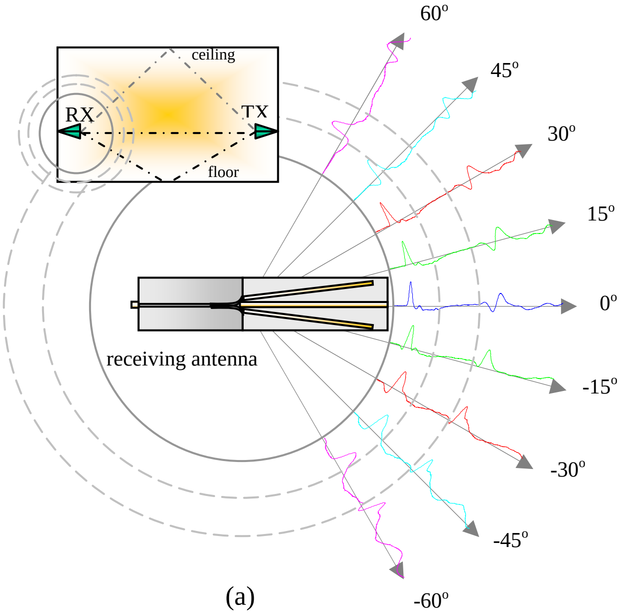
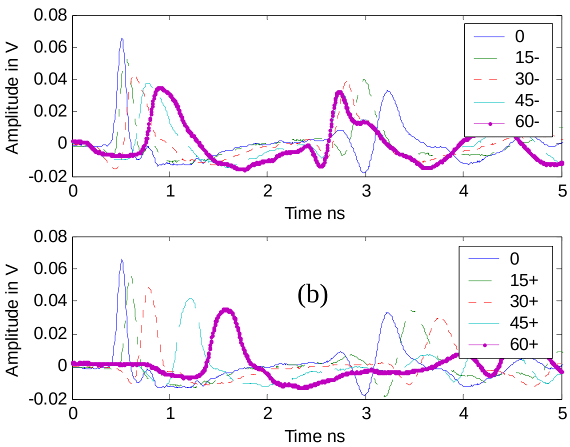


Figure 5: (a) Received waveforms at different receiver elevation angles. (b) Waveforms are redrawn for clarity and comparison.



5. CONCLUSIONS

In this paper an experiment that illustrates the potential of UWB communications system to integrate positioning capability was detailed and discussed. Multipath, obstructions and angle of transmission and reception relative to the antenna were among the highlighted challenges towards full utilization of UWB system positioning capability.

Acknowledgment

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6. REFERENCES

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