Pulse Detection Algorithm for Line-of-Sight (LOS) UWB Ranging Applications

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Pulse Detection Algorithm for Line-of-Sight (LOS) UWB Ranging Applications

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***Abstract*—This paper presents an algorithm for precise determination of the distance between a pair of transmitting and receiving antennas using FCC conforming ultra-wideband (UWB) pulses. Indoor line-of-sight (LOS) measurements up to 24 m were conducted at Research Technoplaza, Nanyang Technological University, Singapore. The proposed algorithm is developed using Matlab to post process the captured waveform. Significant improvement of accuracy is observed in determining the time of flight using a combination of match filtering and peak search technique, achieving centimeter level accuracy. Ranging results show a worst case standard deviation of 2 cm for distance up to 8 m and 10.6 cm for distance up to 24 m.**

***Index Terms*—Peak search algorithm, ranging, ultra-wideband (UWB).**

I. Introduction

HIGH accuracy centimeter level positioning is made possible by the introduction of ultra-wideband (UWB) technology. This is because UWB technology uses subnano seconds pulses for transmission that is more robust under conditions with multipath interferences compared to narrow band signals [1]. However, short distance multipath interference under indoor environments with low signal power level still poses a challenge in detecting the signal using conventional peak or first pulse detection techniques. The fundamental problem results from the ability to extract the right UWB signal at the receiver under multipath conditions. This is because the transmitted pulse can potentially be distorted, cancelled, or look similar to a reflected pulse from previous transmissions. Studies have been carried out on the multipath resolution techniques in UWB systems under varying environments and the classification of the ranging errors to consistently extract the correct signal for ranging applications. Woo and Dong [2] modeled this ranging method using estimation of the time of arrival (TOA) in simulation. Denis *et al.* [3] studied the line-of-sight (LOS) and non-line-of-sight (NLOS) measurements in the frequency domain and suggested statistical models for range estimation errors for path detection strategies such as first path detection and strongest path detection. Joon-Yong and Scholtz [4] introduces a TOA measurement algorithm utilizing generalized maximum-likelihood estimation for the detection of the direct path signal.

This paper utilizes the first peak above a dynamic threshold value technique on the time domain measurement results to detect the direct path signal. The measurements were carried out within the premises of Research Technoplaza in the vicinity of the Positioning and Wireless Technology Center (PWTC), Nanyang Technological University, Singapore. It was part of a program to characterize the UWB channel [5]–[7]. Part II presents the measurement setup and environments and part III describes the post processing techniques used in this paper. Part IV finally discusses the specific UWB ranging issue in LOS environments, providing experimental results, and statistical data.

II. Measurement Setup and Environment

A. Measurement Setup

The measurement test bed setup is shown in Fig. 1. A signal generator (E4438C) is used to drive the impulse generator with a 33 MHz signal. The generated pulse has a peak-to-peak voltage of 1.4 V and a 50% pulsewidth of 120 ps. A 3 dB 7-Stage Wilkinson power divider operating from DC-15 GHz is used to divide the generated impulse into two similar signals. One of which would be shaped by a fifth-order bandpass filter to ensure that the transmitted signal is FCC conforming as shown in Fig. 2. The other signal is used as a triggering signal for a Digital Sampling Oscilloscope, which would also be the reference signal to calculate the time of flight.

The FCC conforming pulse is then transmitted via an omnidirectional knight helm's shaped UWB antenna with a gain of 3 dBi. To ensure minimum pulse distortion at the receiving end, a TEM horn antenna is used. The received signal is further amplified by 50 dB before being captured by the digital sampling oscilloscope. The impulse generator, filter, and both antennas are fabricated in-house at PWTC.

The captured signal which is an average of 64 samples is then downloaded into a laptop and processed by the proposed algorithm via a GPIB connection. During the measurements, the receiver setup was moved along a marked track in varying step sizes with respect to a specific marked point at the bottom front of the setup. The transmitter setup remains in a fixed position throughout the whole process. The antenna heights at both ends are set to be 1.34 m.

B. Measurement Environment

Measurements were carried out at several locations in the Research Technoplaza. Two sets of measurements were conducted. They are namely the short-range measurements (up to 7.4 m)

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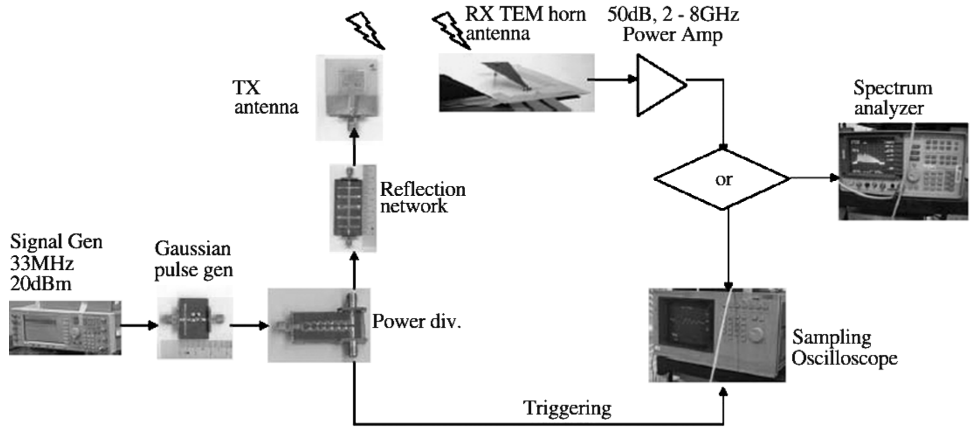


Fig. 1. Measurement test bed setup.

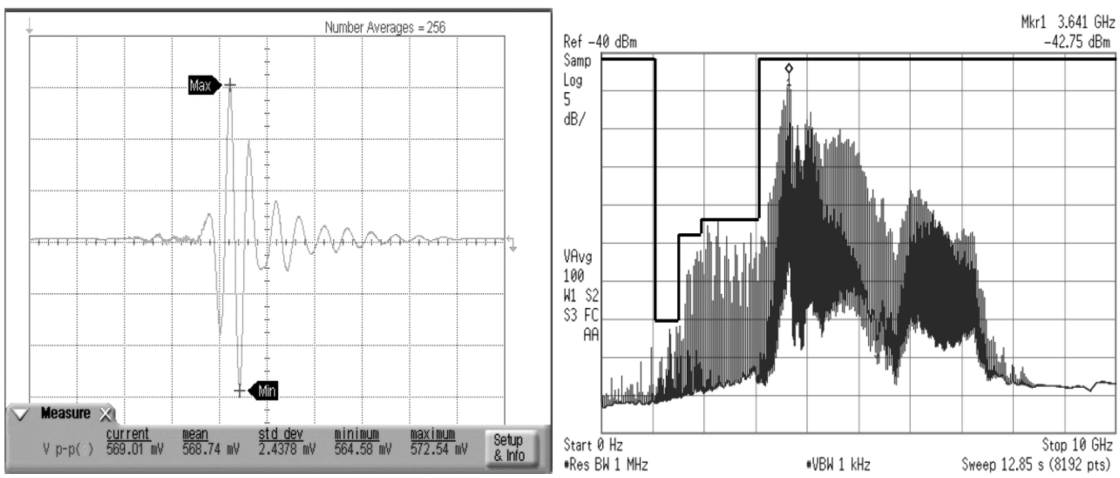


Fig. 2. Transmitted signal and spectrum.

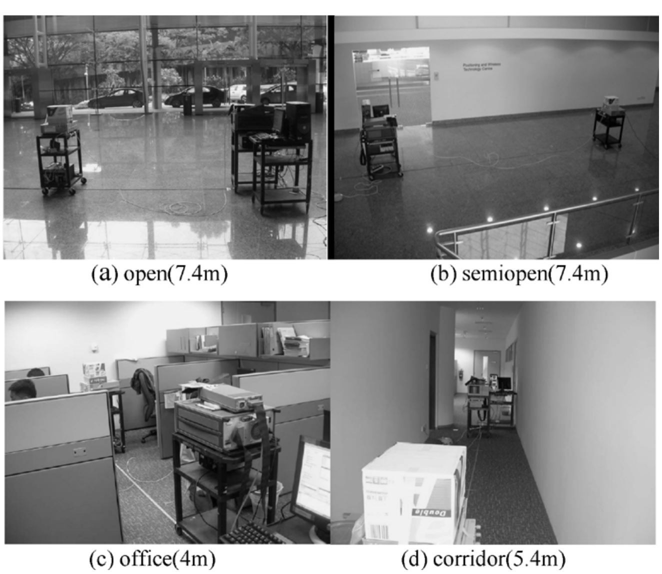


Fig. 3. Short-range LOS channel measurements environment. (a) Open (7.4 m). (b) Semiopen (7.4 m). (c) Office (4 m). (d) Corridor (5.4 m).

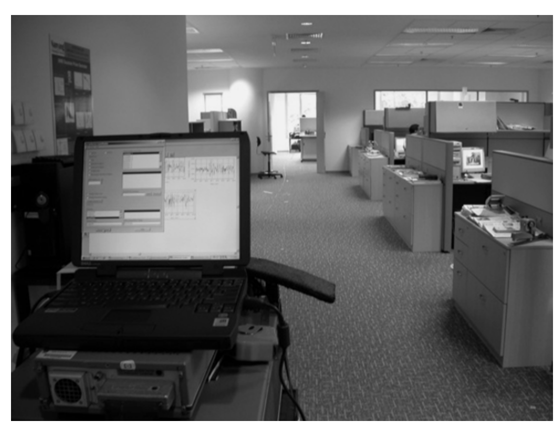


Fig. 4. Medium-range LOS channel measurements—office (24 m).

and the medium-range measurements (up to 24 m). The notation used for each different environment is as follows: ⟨ nature of environment ⟩ (⟨ distance ⟩). Short-range measurements were conducted in the Research Technoplaza foyer which is a wide open space with 20-m high ceiling categorized as open (7.4 m) [Fig. 3(a)]; PWTC reception area which is an open space with a wall on one side and a 3-m high ceiling categorized as semiopen (7.4 m) [Fig. 3(b)]; an area in PWTC's office, which has a walkway between two sets of cubicles categorized as office (4 m) [Fig. 3(c)]; and a corridor area with a doorway to the pantry categorized as corridor (5.4 m) [Fig. 3(d)].

TABLE I
MEASUREMENT ENVIRONMENT

Environment	**Range (m)**	**Number of points**
Short-range measurements		
Open (7.4m)	7.4	36
semiopen (7.4m)	7.4	36
office(4m)	4	20
corridor(5.4m)	5.4	27
Medium range measurements		
open(24m)	24	24
office(24m)	24	24

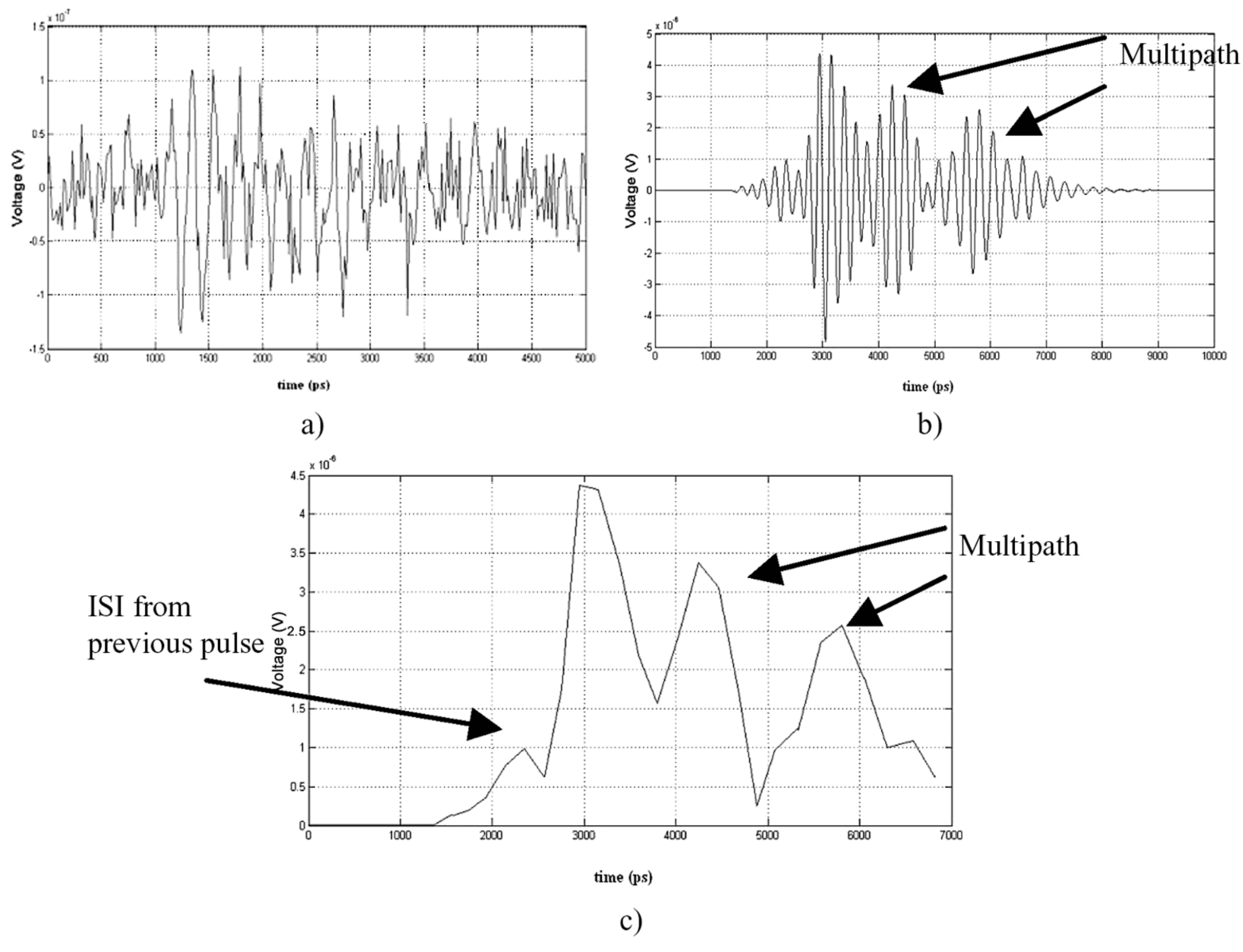


Fig. 5. Match filtering and envelope detection using Matlab. a) Received UWB signal. b) After matched filtering. c) Match-filtered signal's envelope with multipath components.

Medium-range measurements are conducted at two sites: the Research Technoplaza foyer, which was also used for the short-range measurement categorized as open (24 m) and the PWTC office area, which is in a different location from the short-range measurement categorized as office (24 m). The PWTC office area used for medium-range measurement is shown in Fig. 4. It consists of a wall with a walkway 2-m wide, approximately 10 m from the transmitter on one side, and a combination of cubicles and desks on the other side. A doorway was present along the measurement route at approximately 15 m from the transmitter. All measurements were carried out under LOS environments.

The range for the measurements and the number of measurement points are shown in Table I.

III. ALGORITHM

The development of the peak detection code is presented below. The received raw UWB signal in Fig. 5(a) is used as the input for the algorithm. Signal after match filtering is show in Fig. 5(b) and envelope detection in Fig. 5(c).

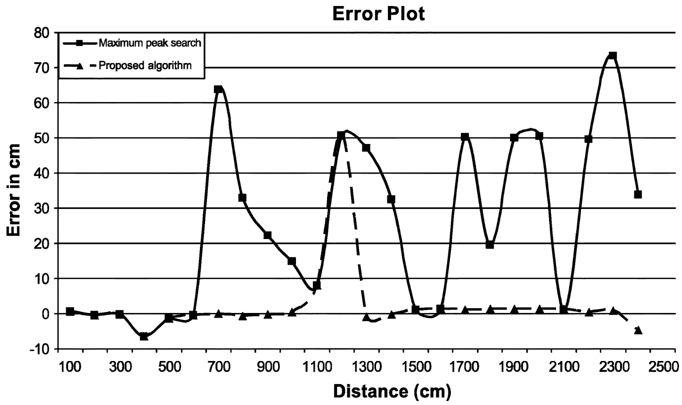
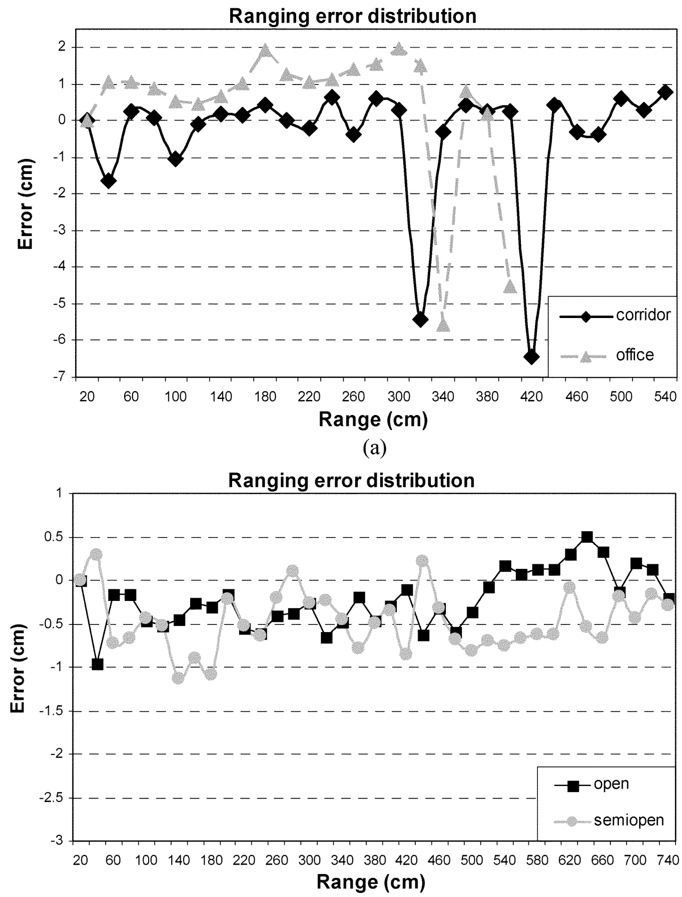


Fig. 6. Comparison between actual error and processed error (office).



(a)

(b)

Fig. 7. Ranging error for short-range measurements.

The algorithm written using Matlab is as follows:

1. Match filtering [Fig. 5(b)]

$$\widehat{y}(t) = y(t) \otimes g(t) \tag{1}$$

where $y(t)$ is the received UWB signal and $g(t)$ the template signal is the UWB pulse captured before the transmitting antenna.

2. Determine the envelope of the match-filtered signal, $\widehat{y}(t)$ via a modulus operation with low-pass filtering [Fig. 5(c)]

$$e(t) = |\widehat{y}(t)|_{\text{Lowpass}}. \tag{2}$$

3. Determine threshold value with respect to the peaks of the envelope signal $e(t)$

$$\gamma = \alpha \times \max\left[e(t)\right] \tag{3}$$

where α is the dynamic threshold factor. The dynamic threshold factor used to mitigate intersymbol interferences between pulses can be determined from the power delay profile of the channel model. It is generally between 0.45 to 0.65 depending on the pulse repetition rate as well as the environment condition. A value of 0.57 has been selected to process the received raw UWB pulses.

4. Determine the first peak of the envelope which is above the threshold

$$\widehat{t} = f\left[e(t)\right] \tag{4}$$

where $f[\cdot]$ is a function to determine the first peak for $e(t) > \gamma$ and γ is the threshold value.

5. Convert delay to distance

$$\text{dist} = (\widehat{t} - \tau) \times c \tag{5}$$

where τ is the system delay of the measurement equipment and $\mathrm{c} = 2.99792 * 10^8$ m/s (speed of electromagnetic propagation in free space).

IV. Results

Results in Fig. 6 show the difference between using a maximum peak search technique and the proposed algorithm using the same received UWB signal. We can observe that out of the 15 points with positive ranging errors, the proposed algorithm is capable is correcting up to 14 points reducing the error of each point to a minimum. Therefore, we can conclude the algorithm works effectively in reducing ranging errors which have a positive ranging error.

Results in Fig. 7 show the performance of the proposed algorithm in the presence of multipath signals on UWB signals for short-distance ranging. Multipath effects are more evident in the corridor and office environments due to obstructions and doorways. The variations of error in the office shown in Fig. 7(a) can be attributed to the presence of partitions on both sides of the receiver. Larger error deviations are caused by the 2-m wide walkway separating two sets of partitions. The corridor measurements also show the multipath effects of the uniform structure of walls on both sides broken by a doorway to a pantry.

The open and semiopen show more consistent error distribution and high ranging accuracy due to the uniform nature of the environment [Fig. 7(b)].

Results from the medium-range measurements in Fig. 8 indicate significantly high accuracy along the measurement paths for the open (24 m) environment. Results are also similar for the office (24 m) measurements except for a large error deviation occurring at the 12-m measurement point. The doorway and a 2-m wide walkway along the measured path is responsible for this phenomenon. The structures induce multipath signals to the extent of seriously distorting the received UWB pulse. The

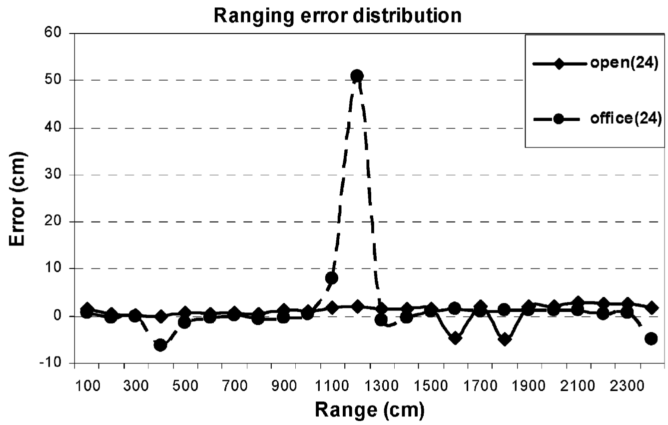


Fig. 8. Ranging for medium-range measurements.

TABLE II
MEAN AND STANDARD DEVIATION OF RANGING ERRORS

Environment	Mean error (cm)	Std. Dev. Error (cm)
Short-range measurements		
Open (7.4m)	0.479	1.094
semiopen (7.4m)	0.503	0.575
office(4m)	1.433	1.945
corridor(5.4m)	0.810	1.698
Medium range measurements		
open(24m)	1.677	2.077
office(24m)	3.571	10.648

summary of results is presented in Table II for both short- and medium-range distances.

V. CONCLUSION

An algorithm is introduced to effectively extract the location of a UWB pulse for ranging applications. It is based on the peak search technique using matched filtering and envelope detection with the original transmitted UWB pulse signal to reduce ranging errors. From the experimental results using time domain UWB signals for short-distance ranging, the mean maximum ranging errors calculated, range from 0.479 to 1.433 cm with standard deviations of 0.575 to 1.945 cm. For applications in the medium-distance ranging, the average ranging error is 1.677 cm for open space with a standard deviation of 2.077 and 3.571 cm for office with a standard deviation of 10.648 cm.

Results have displayed the robustness of UWB under multipath conditions. Together with the algorithm developed, ranging can be achieved with relatively high accuracy. However, errors still fluctuate where the multipath environment changes drastically, as seen in the large deviations in ranging errors [(Figs. 6 & 7]. This is an inherent characteristic of the indoor radio environment. Future work will include an in-depth study of the existing algorithm to incorporate statistical probability from measured data.

REFERENCES

[1] J. Foerster, "Channel Modeling Sub-Committee," IEEE, Piscataway, NJ, P802.15-02/490r1-SG3a, Final Rep., Mar. 2003.

[2] W. C. Chung and D. S. Ha, "An Accurate Ultra Wideband (UWB) ranging for precision asset location," in *Proc. IEEE Conf. Ultra Wideband Systems and Technologies*, Nov. 2003, pp. 389–393.

[3] B. Denis, J. Keignart, and N. Daniele, "Impact of NLOS propagation upon ranging precision in UWB systems," in *IEEE Conf. Ultra Wideband Systems and Technologies*, Nov. 2003, pp. 379–383.

[4] J.-Y. Lee and R. A. Scholtz, "Ranging in a dense multipath environment using an UWB radio link," *IEEE J. Sel. Areas Commun.*, vol. 20, no. 9, pp. 1677–1683, Dec. 2002.

[5] L. Rusch, C. Prettie, D. Cheung, Q. Li, and M. Ho. (2003) *Characterization of UWB propagation from 2 to 8 GHz in a residential environment* [Online]. Available: http://www.intel.com/technology/comms/uwb/docs.htm

[6] D. Cassioli, M. Z. Win, and A. F. Molisch, "The ultra-wide bandwidth indoor channel: from statistical model to simulations," *IEEE J. Sel. Areas Commun.*, vol. 20, no. 6, pp. 1247–1257, Aug. 2002.

[7] S. Yano, "Investigating the ultra-wideband indoor wireless channel," in *Proc. IEEE VTC Spring Conf.*, vol. 3, 2002, pp. 1200–1204.