EVALUATION OF ULTRA-WIDEBAND RADIO FOR IMPROVED PEDESTRIAN SAFETY AT SIGNALIZED INTERSECTIONS

FINAL PROJECT REPORT

by

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16. Abstract

As America's population continues to age, the number of pedestrians with mobility or vision disabilities will increase. The focus of this project was to evaluate ultra-wideband (UWB) radio signaling for the purpose of tracking individuals as they cross an intersection. Working with products from DecaWave, we conducted multiple tests on a test course. Under ideal conditions we were able to achieve a positioning accuracy of approximately +/- 15 cm, not quite as good as the +/- 10-cm accuracy reported by the manufacturer. One possible explanation is the generic antennas supplied with the development kits and, in particular, their proximity to the human body and earth ground. Both cases resulted in signal absorption, leading to degradation in positioning accuracy. Future work would involve the development of antennas tuned to the application and less susceptible to signal loss. If that work was successful, additional software development would be required to exchange positioning information between the pedestrian "tag" and a traffic controller via UWB.

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List of Abbreviations

COTS: Commercial Off-The-Shelf
IC: Integrated Circuit
IMU: Inertial Measurement Unit
NIATT: National Institute for Advanced Transportation Technology
PacTrans: Pacific Northwest Transportation Consortium
PCB: Printed Circuit Board
RF: Radio Frequency
RTLS: Real-Time Location System
TWR: Two-Way-Ranging
UI: University of Idaho
UWB: Ultra-Wideband
WSDOT: Washington State Department of Transportation

Abstract

As America's population continues to age, the number of pedestrians with mobility or vision disabilities will increase. The focus of this project was to evaluate ultra-wideband (UWB) radio signaling for the purpose of tracking individuals as they cross an intersection. Working with products from DecaWave, we conducted multiple tests on a test course. Under ideal conditions we were able to achieve a positioning accuracy of approximately +/- 15 cm, not quite as good as the +/- 10 -cm accuracy reported by the manufacturer. One possible explanation is the generic antennas supplied with the development kits and, in particular, their proximity to the human body and earth ground. Both cases resulted in signal absorption, leading to degradation in positioning accuracy. Future work would involve the development of antennas tuned to the application and less susceptible to signal loss. If that work was successful, additional software development would be required to exchange positioning information between the pedestrian "tag" and a traffic controller via UWB.

Executive Summary

The most recent data available from the National Highway Traffic Safety Administration (NHTSA) show that there were almost 5,000 pedestrian fatalities in 2013, 19 percent of which were pedestrians 65 and older, and as the nation's population continues to age, an increasing number of those pedestrians will suffer from vision or mobility impairments. In 2015, the secretary of the U.S. Department of Transportation, Secretary Anthony Foxx, introduced the policy initiative "Beyond Traffic," outlining a 30-year framework for transportation development. This initiative recognized the rising popularity of alternatives to vehicular transportation, including walking, and the need for increased investments in a pedestrian-friendly infrastructure. In October 2016, Secretary Foxx announced the Smart City Challenge and the distribution of almost $65 million in grants to support advanced technology transportation projects.

During the last 20 years there have been tremendous advances in microelectronics to the point where mobile devices now have significant computational and sensing capabilities. These technologies have most recently led to development of "indoor GPS," or localization and tracking of shoppers in malls, first responders in buildings, and travelers in airports. We were interested in learning whether similar methods could assist impaired pedestrians (vision and/or mobility) safely cross an intersection. In particular, we needed to determine whether the pedestrian could be located and tracked with sufficient accuracy to detect that a pedestrian had veered out of the crosswalk or made it to the opposite curb and, if so, could this information be shared with the traffic controller cabinet to provide navigational assistance or delay signal changes.

After reviewing different approaches, such as Bluetooth, Wi-Fi, etc. we settled on ultra-wideband (UWB) radio signaling. UWB has the distinct advantage of using very short pulses of radio communication at low power, making it much easier to calculate "time of flight" in the presence of multipath reflections, while reducing interference with other devices. Furthermore, there is interest in integrating this technology into smartphones.

We purchased several products from DecaWave, developers of the DWM1000 transceiver ($30), including an evaluation kit consisting of four transceivers mounted on printed circuit boards with support circuitry ($1000). Experiments were conducted with three of the units serving as "anchors," separated by a distance of 15 m, and the fourth as a "tag," carried by a "pedestrian." To date, we have achieved approximately +/-15 cm positioning accuracy, not the +/- 10-cm accuracy advertised by DecaWave under ideal conditions. We believe this is primarily caused by signal absorption caused by proximity to the human body and to earth ground, resulting in a loss of received signal energy and leading to inaccuracies in distance estimates.

Future research will center on two areas. First, and most important, will be the development of suitable antennas, particularly for devices carried by pedestrians. However, anchor antennas, mounted on pedestrian heads, can be significantly larger than those that came with the development kit and must be weatherproof. The other area for research will be software development to exchange positioning information between units and the traffic controller cabinet. In addition to time of flight estimation, the UWB signal can also be used to transmit data. However, the software that came with the development kit was only intended for "proof of concept" and would need to be extended in capabilities.

Chapter 1 Introduction

The ever increasing number of accidents involving pedestrians is a growing concern, particularly as the population ages and develops vision and mobility impairments. At the same time, advances in microelectronics have enabled the implementation of intelligent environments that can respond to individual needs. The focus of this research was to investigate the suitability of ultra-wideband (UWB) signaling for tracking pedestrians as they cross an intersection.

Chapter 2 Literature Review

Localization, sometimes referred to as “indoor GPS,” has continued to grow in terms of research and applications. Possible uses include tracking first responders or military personnel in a building, guiding visitors in a museum or airport, or targeting shoppers in a mall (1). For all of these, some form of wireless radio communication is the underlying technology, be it Bluetooth (2), Wi-Fi (3), or UWB (4), and it can utilize signal strength, time of flight (or arrival), or angle of arrival (5, 6, 7). Similarly, numerous publications are devoted to pedestrian assistance and safety using each of these technologies or a combination, sometimes including an inertial measurement unit (IMU) (8, 9, 10). We chose for this project to utilize products from DecaWave (11). For a discussion of recent advances, refer to the article by Alarifi et al. (12)

Chapter 3 Study Site/Data

Tests were conducted at a variety of sites. The first was in a laboratory and then within a large ballroom on campus. In both cases there were concerns as to signal absorption and excessive multi-path signals due to reflections. Subsequent tests were conducted in an outdoor environments, both on and off campus. A sample test course is described in chapter 4.

Chapter 4 Method

While we purchased a number of products from DecaWave (www.DecaWave.com) the results presented in the next chapter were collected using a TREK1000 Evaluation Kit in an outdoor space.

4.1 DecaWave TREK1000 Evaluation Kit

This kit consisted of four printed circuit boards (PCB), each with a small antenna, and supporting software. Mounted on the PCB was a microcontroller and the DW1000 integrated circuit (IC), the latter of which performed the signal processing needed for two-way-ranging. The software included with the kit will perform 3-D Trilateration for tracking the position of one PCB
(the "tag") relative to the three remaining boards serving as "anchors." One of the anchors can be tethered to a computer for displaying the tag in real-time as well as logging position data in a computer file for later analysis.

4.2 Test Courses

In the final application we would envision four anchors mounted on pedestrian heads at each corner of a four-way intersection. However, for the tests presented in this report we only used three anchors arranged as a triangle, as shown in figure 4.1.

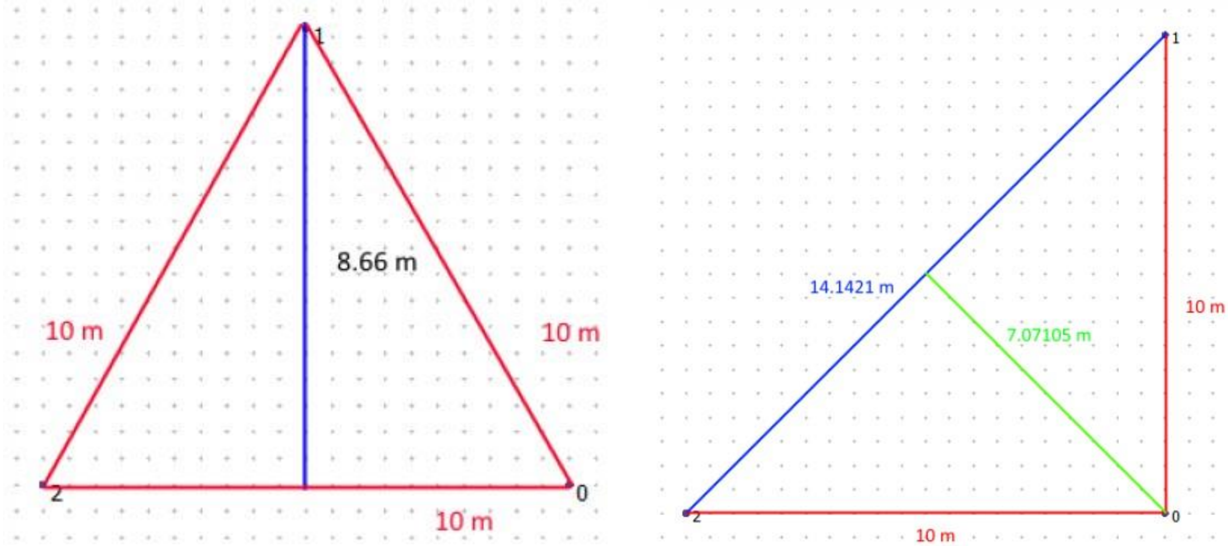

Figure 4.1 Layout of sample test courses used for evaluation

4.3 Data Collection

In general, the tag was moved to positions on the 500-cm grid, and then the location was noted, either by screen captures of the image produced by the tracking software on the computer or by post-processing of the log file. As will be discussed in chapter 5, each tag position produced multiple ranges (~30 samples). Initial tests were performed with the anchors and tag close to the ground, whereas later tests placed the anchors on tripods in an effort to reduce signal absorption.

Chapter 5 Results

It took quite a number of tests before we began to achieve anything close to the accuracy stated by the manufacturer (+/- 10 cm). Initially, much of the inaccuracy stemmed from errors in the “auto-ranging” capability of the anchors. Unfortunately, the source of this was never determined but may have bene due to the version of the application software or the hardware firmware. In an effort to proceed, subsequent experiments were conducted with the anchor positions entered manually.

Once this problem was mitigated, we discovered the sensitivity to tag and anchor position relative to earth ground and the human body. Signal absorption by nearby objects results in a loss of received signal power by the anchors, resulting in ranging inaccuracy. As mentioned previously, this was addressed in later experiments by mounting the anchors on tripods and holding the tag away from the human body. Figure 5.1 shows the results of our final test conducted in December 2016 in an empty parking lot with no nearby buildings. Based on conversations with an RF engineer regarding the characteristics of the COTS antenna that was supplied with the TREK 1000, we used the highest center frequency possible (~6.5 GHz) for maximum received signal power and the lowest possible data rate for minimum error rate (110 kbps). Unfortunately, the tests were instead conducted using one of the preconfigured channels, Channel 2, with a center frequency of approximately 4 GHz.

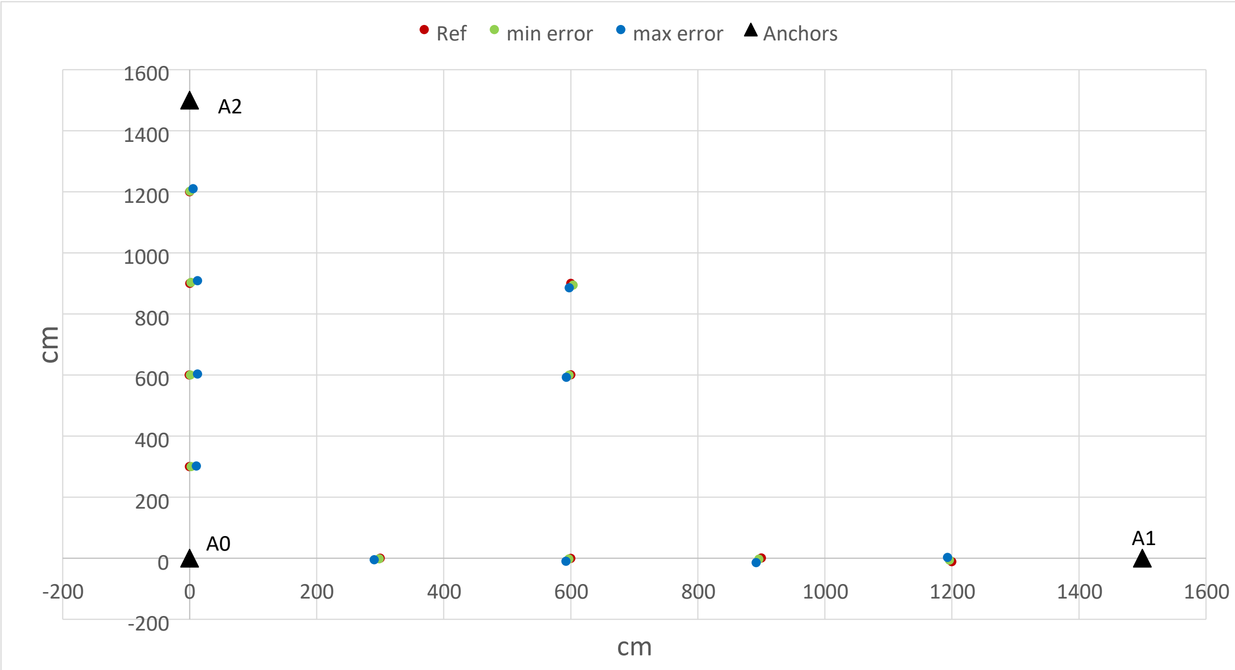

Figure 5.1 Final test on a larger course

Each of the ten test points shown in figure 5.1 produced approximately 30 position estimates. Figure 5.2 shows the minimum and maximum absolute position error for each of the test points. Points 1 through 4 are moving from A0 towards A2 and points 5 through 8 are moving from A0 towards A1. The remaining two points are near the center of figure 5.1.

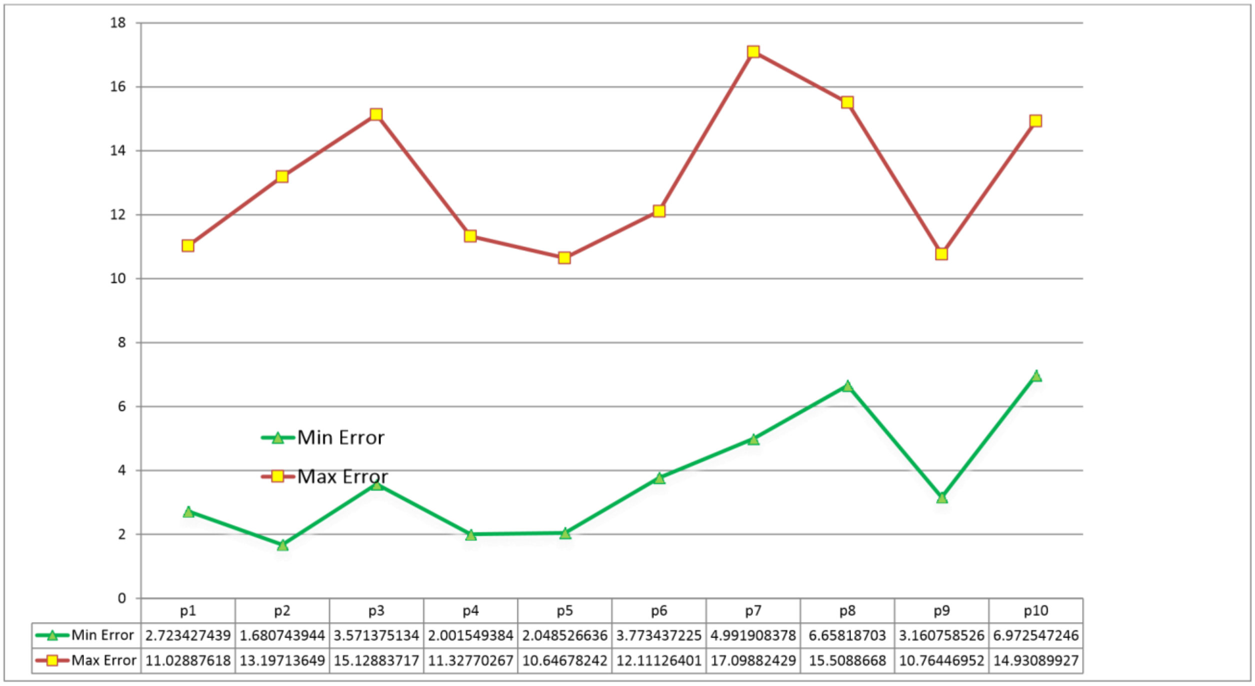

Figure 5.2 Minimum and maximum absolute position error (cm)

Figures 5.3 and 5.4 show the position error moving from anchor A0 to one of the other two anchors, following what would be the path of a pedestrian traversing a crosswalk. In both cases, the minimum and maximum error positions are located in the same direction relative to the reference point, suggesting a bias in the experiment. A plot of all position estimates for each test point—approximately 30 estimates—would be helpful in verifying this. In addition, the last point of figure 5.4 appears to be an outlier in that the reference point is more negative than both the minimum and maximum. In this case there may have been an error in the tag reference position.

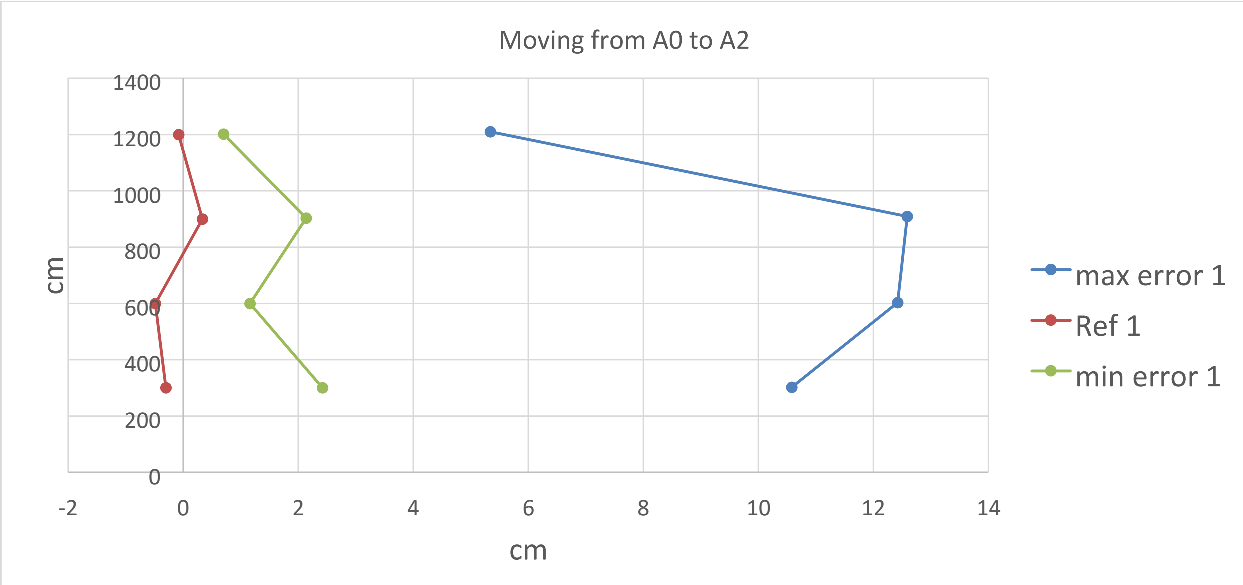

Figure 5.3 Position error moving from A0 towards A2

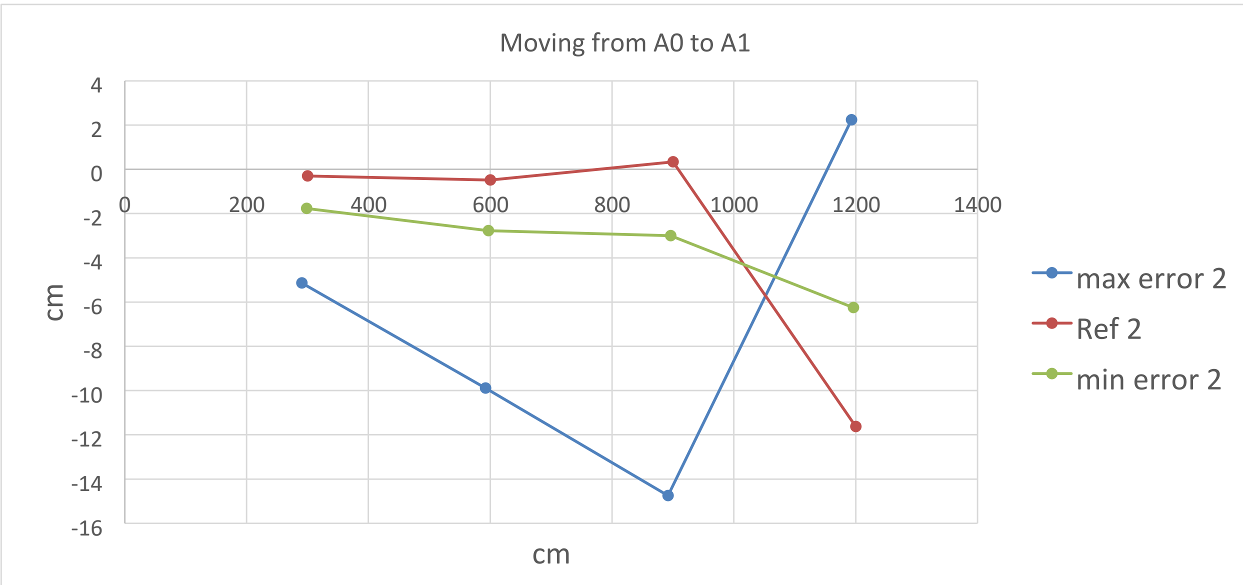

Figure 5.4 Position error moving from A0 towards A1

Chapter 6 Discussion

Our experiments demonstrated that under ideal conditions it is possible to determine the location of a UWB transmitter with sufficient accuracy, a maximum position error of approximately 15 cm from the direction of travel. However, the experiments could have been improved in a number of ways, including selection of the center frequency and surveying of anchor positions. What is left unknown is the distribution of position estimates for each test point, how the position estimate varies with time, and the time required to produce an estimate relative to pedestrian walk time. Insight into both of these questions could be determined from further analysis of the log files that were collected. The manufacturer claims that localization of an object can be accurately estimated at speeds of up to 5 m/s.

Chapter 7 Conclusions and Recommendations

While our initial results are encouraging, there are a number of challenges that would need to be addressed in order to utilize this approach for pedestrian tracking, both technical and non-technical.

7.1 Antenna Design

On the technical side, antenna performance is the most difficult, particularly for a wearable tag. RF design is difficult at best, and we have demonstrated that the orientation of the antenna and the proximity to the human body can have a significant impact on the distance estimate. Furthermore, the printed circuit board must be designed carefully to avoid interference with the UWB signal. Unfortunately, we were unable to evaluate the DecaWave DWM1000 because of insufficient resources. This is a very small and low-cost module (~$20 USD) that includes an on-board antenna and the signal processing IC (DW1000), but it needs an additional microcontroller for operation. There are companies that specialize in wearable UWB antennas for personnel tracking or we could have bought predesigned tags for approximately $45 (quantity of 10). What's not clear is whether the development software is required (~$3125 USD). The anchor antennas would also need to be in a weatherproof enclosure with a suitable power source connection. If the auto-ranging capability is not utilized then the anchor locations would need to be precisely surveyed. Lastly, we did not assess signal reception and the impact on position estimates in the presence of vehicles. When used in a real intersection, through-traffic might affect transmission from the two anchors on the opposite side of the street.

7.2 Software Development

Supporting software is another technical challenge. The development kit came preloaded with trilateration software that would compute the estimated position based on the individual ranges between the tag and the anchors, but if we were to use the DWM1000 to develop our own tag we would need to write the software as well. (DecaWave does provide their software source, but the algorithms would still need to be ported to the tag microprocessor.) Furthermore, results obtained in recent competitions have demonstrated benefits from using sensor fusion from gyroscopes and accelerometers to improve the position estimate. In addition, if we wanted to provide navigational information back to the pedestrian we would need to add that data communication to the UWB signal or use another signaling mechanism such as Bluetooth. This would require additional software development. Lastly, there would be additional development needed to communicate information back to the traffic controller or a “smart” pedestrian controller in the traffic cabinet. The University of Idaho previously demonstrated this using Ethernet over Powerline technology. Ultimately, we would like to be able to share pedestrian information with approaching vehicles using Vehicle to Infrastructure technology.

7.3 Market Acceptance

As presented, users would need to carry a special device, either in their hand or pockets. Given the growing popularity of mobile smartphones, it seems unlikely that users would want to carry something else, although impaired pedestrians would likely be more motivated, provided they could count on the technology availability and reliability. DecaWave is interested in seeing its technology being applied to many environments, but it is unlikely that smartphone manufacturers will include additional components solely for positioning, particularly when there are existing alternatives for “proximity” sensing already incorporated into the phone, e.g. Apple iBeacon. A more recent development is the demonstration of positioning using Wi-Fi. By combining Bluetooth LE, Wi-Fi, and motion sensors through sensor fusion it may be possible to achieve sufficient position estimates for tracking a pedestrian using existing smartphones.

7.4 Intellectual Property

Pedestrian safety has been an active area of research for many years and there may be many patents that address detection of pedestrians and notification in some form. Defending against the possibility of patent infringement may be an insurmountable hurdle for many companies.

In closing, while the different technologies needed to track pedestrians in real-time exist today, bringing them to market at an affordable cost remains a challenge.

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