Vehicle positioning based on UWB technology

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Abstract. In recent years, with the rapid increase of the number of urban cars, the vehicle internet is becoming a trend of smart transportation. In such vehicle network, accurate location is very crucial in many new applications such as autopilot, semi-autopilot and Car-to-x communications. UWB technology has been used for indoor closed range positioning and ranging widely, while UWB outdoor positioning and ranging research is relatively less. This paper proposed UWB as the vehicle positioning technology and developed a method based on two-way-ranging (TWR) to solve the ranging problem between vehicles. At the same time, the improved TOA method was used to locate vehicles, which has higher precision compared with traditional GPS or LBS. A hardware module is introduced and the simulation results show that the modules are capable of precise positioning for vehicles in vehicle network.

1. Introduction

Ultra wideband(UWB) is a wireless technology that has many advantages such as high data rate transmission, the low power spectral density, low transmission power and large instantaneous bandwidth. These advantages make it attractive in different applications such as tracking and communication, radar and wireless body area network[1]. It is mainly used for short range communications.

In terms of positioning, current positioning systems, such as GPS, or future systems, like the European GALILEO, may not be available or do not have sufficient accuracy in specific areas where may not satisfying the need of future applications in vehicle internet. The poor performance of satellite systems in supporting those applications is mainly caused by attenuation due to signal blocking and/or multipath signals which cause distortion of the direct signal path. The primary reason of performance degradation is not the presence of multipath itself but the fact that multipath cannot be resolved due to the small signal bandwidth used by current positioning systems.

In terms of ranging, UWB is more powerful than others. The main advantages of UWB systems are the usage of ultra-short pulses, either for communication or for ranging systems[2]. Compared with UWB, the absolute location error of GPS may be very large, while the use of ultra-short pulse of UWB positioning can provide a higher accuracy [3] which may reach to centimeter level. In addition, the UWB wireless positioning cost is cheaper[4].

The aim of this paper is to propose a new method of inter vehicle ranging and vehicle location in outdoor areas. The main method used for ranging between vehicles is TWR, and the method of vehicle location in outdoor areas is the improved TOA. This research will be useful on the development of ranging and positioning for future vehicle internet.
2. Proposed Receiver and Transmitter Scheme

2.1. Description and Implementation

We used the DWM1000 module produced by Decawave company because it enables very accurate Time of Arrival measurements of RF signal. The DWM1000 module is based on Decawave’s DW1000[5] UWB transceiver IC. It integrates antenna, all RF circuitry, power management and clock circuitry in one module. The DW1000 is a fully integrated single chip UWB low-power low-cost transceiver IC compliant to IEEE802.15.4-2011. It can be used in two-way ranging or TOA location systems to locate assets. It also supports data transfer at rates up to 6.8 Mbps.

DW1000 consists of an analog front end containing a receiver and a transmitter and a digital back end that interfaces to an off-chip host processor. A T/R switch is used to connect the receiver or transmitter to the antenna port. Temperature and voltage monitors are provided on-chip.

The receiver consists of an RF front end which amplifies the received signal in a low-noise amplifier before down-converting it directly to base-band. The receiver is optimized for wide bandwidth, linearity and noise figure. This allows each of the supported IEEE802.15.4-2011[6] UWB channels to be down converted with minimum additional noise and distortion. The base-band signal is demodulated and the resulting received data is made available to the host controller via SPI.

The transmit pulse train is generated by applying digitally encoded transmit data to the analog pulse generator. The pulse train is up-converted by a double balanced mixer to a carrier generated by the synthesizer and cantered on one of the permitted IEEE802.15.4-2011 UWB channels. The modulated RF waveform is amplified before transmission from the external antenna. The DWM1000 module is shown in figure 1.

![Figure 1. The DWM1000 Module](image1)

![Figure 2. A node consists of a host MCU and a RF Module](image2)

A complete independent UWB node is shown in figure 2, where a host MCU and a RF Module are included. In our configuration, the host is a general ARM Cortex-M4 micro-controller. Each node can act as an anchor or tag. The anchor usually has a fixed location, whilst tag is a mobile node. Each vehicle is equipped with a node, and two nodes can be used for ranging between vehicles. The surrounding environment is configured with more nodes, the location of vehicle can be located. The results of distance measurement can be printed onto the serial port of a PC, and the location result needs several groups of distance. Then the relative position is calculated by the specific algorithm.

2.2. Theoretical Analysis of UWB Ranging

A classical time of arrival based method called two-way ranging (TWR) was originally proposed in [7]. The practical ranging demonstration is described in figure 3.
The leader observes a round trip time $L_{\text{RT}} = T_{\text{RR}} - T_{\text{SB}}$ and a turn around time $L_{\text{TA}} = T_{\text{SF}} - T_{\text{RR}}$, where $T_{\text{SB}}, T_{\text{RR}}$ and $T_{\text{SF}}$ are the leader send-time, receive-time and future send-time respectively. The follower observes a round trip time $F_{\text{RT}} = T_{\text{RF}} - T_{\text{SR}}$ and a turn around time $F_{\text{TA}} = T_{\text{SR}} - T_{\text{RB}}$, where $T_{\text{RB}}, T_{\text{SR}}$ and $T_{\text{RF}}$ are the follower receive-time, send-time and future receive-time respectively. The value of transmission time $T$ is computed at both leader ($T_l$) and follower ($T_f$):

\[
2T_l = (T_{\text{RR}} - T_{\text{SB}}) - (T_{\text{SR}} - T_{\text{RB}})
\]

\[
2T_f = (T_{\text{RF}} - T_{\text{SR}}) - (T_{\text{SF}} - T_{\text{RR}})
\]

The follower or leader can then combine these two resultant round trip times (by averaging) to remove by effects of clock differences. The result is then divided by 2 to get one way trip time.

\[
T = \frac{2T_l + 2T_f}{2 \times 2}
\]

Thus the distance between the two prototypes is: (Here $C$ is the speed of light)

\[
d = T \times C
\]

2.3. The TOA Proposed Approach

Here, it is assumed that input data of the localization phase are represented by the set of TOA$_{i,j}$, $i = A, B$, $j = 1, 2$. Following the geometrical interpretation of the target localization problem, the four ellipses (E$_i$, $i = 1, 2, 3, 4$) with the foci $T_x, R_x$, and with the length of the semimajor axis $c\cdot$TOA$_{i,j}/2$ can be created as figure 4. Then, the target position is obtained as the intersection of the particular ellipses. In the case of a single target scenario, the set of TOA$_{i,j}$ can contain 0-4 elements. Because of TOA estimation error, there are usually more than one intersections. Then, depending on the number of the estimated TOA, the localization of the target by TOA completing method can be described as follows:

Only one TOA or no TOA is estimated. The target position cannot be estimated. The only one TOA$_{A,i}$ for $i = 1$ or $i = 2$, and the only one TOA$_{B,i}$ for $i = 1$ or $i = 2$ have been estimated. The other TOAs are missing. The former TOA is given by $R_{x_A}$, the latter TOA is given by $R_{x_B}$. The target position in the discrete time instant $n$ is given by the intersection of the ellipses E$_1$ or E$_2$ and E$_3$ or E$_4$ in figure 4.

Three TOAs have been estimated. Let us assume e.g. TOA$_{B,1}$, TOA$_{B,2}$, TOA$_{A,2}$ have been estimated and TOA$_{A,1}$ is missing. Then, the ellipses E$_2$, E$_3$, E$_4$ can be created. The target position estimate referred to as $T_B$ is given by the intersection of E$_3$ and E$_4$ in figure 5. After that, TOA$_{A,1}$ = $(||T_xP|| + ||PR_{x_A,1}||)/c$. The final estimate of the target coordinates is obtained as the average of the points $T_A$ and $T_B$ in figure 4.
3. Solution of the Problem

3.1. The ranging problem
To illustrate inter vehicle ranging problem based on UWB, we use the test scenario showed in figure 6. The red callout area is the reference location for the ranging module. The ranging algorithm is implemented on the host microcontroller which controls the DWM1000 module with a SPI interface. This method can be applied in a lot of scenes, such as two cars are moving at the same time, or one car is moving and the other is static. In range measurement, the two modules are identified as a tag and the other as anchor. It should be noted that the ranging module’s configuration height should be consistent as far as possible, otherwise it will affect the ranging accuracy. The implementation is based on the TW-Ranging method mentioned in the previous section.

3.2. The location problem
The TOA method based on UWB can locate the relative position of the car. This relative position is defined as the location of the vehicle relative to a point in the fixed space. The Procedure is shown below with the scenario in figure 7.

The red solid circle represents the vehicle with the ranging module, and the module’s identity is the tag. The black solid box stands for the ranging module that stands as anchor. In the TOA method, 3D positioning requires four points, that is, anchor points. Therefore, in outdoor space, you need to put four identity as anchor point ranging module. Through the method described in the preceding section, the location of outdoor vehicles is carried out. It should be noted that the use of the TOA method in positioning the vehicle, if the anchor and the tags’ clock does not synchronize, there will be slight error. When the vehicle is stationary in a closed outdoor environment, the error does not affect the positioning effect.
4. Simulation Results and Discussion

4.1. The Ranging Simulation
The experiment was conducted outdoors. Transceivers were placed on a 1m high tripod. Between transceivers were LOS. Measurements were taken at known distances from 1 to 30 m. Measurements were taken at different operational modes of the module as in table 1. figure 8 and figure 9 show the distance measurements between transceivers and deviations from the pre-set distance. Denotations M1–M6 represent different types of operational modes.

![Figure 8](image-url) Outdoor distance measurements with non-calibrated module

![Figure 9](image-url) Outdoor distance measurements with calibrated module

**Table 1. Operational modes.**

| Mode | Channel[GHz] | Data Rate [bps] | Bandwidth[MHz] | Preamble[bit] | PRF[MHz] |
|------|--------------|-----------------|----------------|--------------|----------|
| 1    | 4.0          | 110k            | 500            | 1024         | 64       |
| 2    | 4.0          | 6.8M            | 500            | 128          | 64       |
| 3    | 6.5          | 110k            | 500            | 1024         | 16       |
| 4    | 6.5          | 6.8M            | 500            | 128          | 16       |
| 5    | 6.5          | 110k            | 900            | 1024         | 64       |
| 6    | 6.5          | 6.8M            | 900            | 128          | 64       |

Simulation results show that the modules are capable of precise measurements of distances in outdoor environments, where the measurements precision is less than 10 cm in line of sight. Modes from 1–4 returned almost the same precise results under 6 cm on average. Modes 5 and 6 have a channel bandwidth as 900 MHz, there accuracy of the measurements decreased but not exceed 20 cm.

4.2. The Location Simulation

![Figure 10](image-url) RS\(_A\): the true and estimated TOAs

![Figure 11](image-url) RS\(_A\): the true and complemented TOAs
The true and estimated TOA$_{ij}$ for $i = A, B, j = 1, 2$ are illustrated in figure 10 and figure 12. Then, the true, estimated and complemented TOA$_{ij}$ for $i = A, B, j = 1, 2$ are illustrated in figure 11 and figure 13.

TOA’s location method is based on the calculation algorithm whose input is from the ranging data. As shown in the simulation, the complemented TOAs method can restore the missing TOA fragments, more accurately smooth the $R_S^A$ and $R_S^B$ curve, so that the final positioning results are more reliable with higher accuracy.

5. Conclusion

In this paper, we propose a UWB based technique for inter vehicle ranging. Furthermore, the vehicle location of the TOA method is carried out with the ranging data obtained. With the help of UWB’s ability of precise ranging to the distances below 10 cm, UWB modules could be very useful for outdoor vehicle positioning and may have significant potential in vehicle internet over traditional GPS or LBS positioning.

6. Acknowledgements

The study was supported by the National Natural Science Foundation of China (No. 91438120) and the Sichuan Science and Technology Support Program (No.2016GZ0339).

7. References

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