Research on Pulse Ultra-wideband Asynchronous Measurement and Positioning Technology

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\textbf{Abstract.} Most of the research is based on UWB synchronous measurement and positioning technology. After understanding the characteristics of each method based on pulse ultra-wideband technology such as intensity method, time method and angle method, the limitations of its application are determined, so another road is taken. A method based on frame round-trip RTT is proposed, and a super-wideband asynchronous measurement positioning model is adopted. This positioning model fundamentally eliminates fiber synchronization in the synchronous measurement positioning system, and the cost is too high. Complexity, limited applicability, etc., it is effective and feasible to analyze the measurement and positioning model through simulation experiments.

\textbf{Introduction}

Ultra-wideband positioning is a wireless positioning technology that calculates the position information of a node by collecting distance or angle information between nodes and then using a positioning algorithm such as trilateration, triangulation or maximum likelihood estimation. Its commonly used ranging technology can be divided into four technologies based on the angle of arrival AOA, based on the received signal strength RSSI, based on the arrival time TOA, and based on the time difference of arrival TDOA. By analyzing its ranging characteristics, a new ranging method is proposed: based on pulse ultra-wideband frame round-trip measurement, this method can fully utilize the ultra-wideband transceiver integration characteristics and avoid the clock synchronization problem in TOA measurement.

\textbf{Analysis of Ranging Location Method Based on Pulse Ultra-wideband}

\textbf{Angle-based Ranging Positioning Method}

Based on the angle of arrival (AOA) ranging, the receiving node obtains the direction of the transmitting node's signal through antenna array or combination of multiple receivers, calculates the relative orientation or angle between the receiving node and the transmitting node, and then obtains the estimated position of the node through a certain algorithm.

Basic AOA positioning method, as shown in Fig. 1, in two-dimensional plane, the unknown node M can use formula (1) to determine its position and calculate the position information of the unknown node after obtaining the angle between the unknown node M and the guide node A and B.

\[
\tan \theta = \frac{x-x_i}{y-x_i} = \frac{y-y_i}{x-x_i}
\]

AOA positioning requires antenna array or multiple receivers for positioning, hardware system equipment is complex, and is not suitable for cost-sensitive wireless sensor network positioning based on pulse ultra-wideband technology, and AOA positioning requires line-of-sight transmission between two nodes (LOS). Even in the case of LOS transmission, the multipath effect of wireless transmission still causes interference to AOA positioning. Most of the current research has given up this complete AOA positioning.
Strength-based Ranging Positioning Method

Measurement positioning of received signal strength based on RSSI (received signal strength indicator). The signal strength of the transmitting node is known. By measuring the strength of the received signal, the propagation loss of the signal is calculated, and the propagation loss is converted into a distance according to a theoretical or empirical signal propagation attenuation model. After obtaining the distance information between the anchor node and the unknown node, the position of the unknown node can be calculated by the trilateration method or the maximum likelihood estimation method.

According to the signal propagation theory, an estimated value of the distance $d$ value can be calculated from the relationship between the wireless signal transmission power and the received power. Knowing the transmit power, measuring the received power at the receiving node, calculating the propagation is good, using a theoretical or empirical signal propagation model to convert the propagation loss into a distance. In free space, the signal strength received from the antenna at transmitter $d$ is given by equation (2):

$$ P_r(d) = \frac{P_t G_t \lambda^2}{(4\pi)^2 d^2} $$

In the formula, the transmitter power, for the receiving power at the distance $d$, and for the gain of the transmitting antenna and the receiving antenna respectively, the receiver power decays with the square distance between the transmitter and the receiver. By measuring the strength of the received signal, the estimated distance between the receiving and receiving nodes can be calculated by using formula (2).

The practical application is more complex, especially the application of location technology in distributed and dense wireless sensor networks. Reflection, multipath interference, non-line-of-sight, antenna gain and other issues will cause significant different propagation losses at the same distance. The empirical formula of formula (3) is usually used in the actual environment.

$$ P_r(d)[dBm] = P_o(d_o)[dBm] - 10n\log_{10}\left(\frac{d}{d_o}\right) + X_s $$

In the formula, the reference signal strength from the transmitter, $n$ is the fading coefficient of the signal propagation path, which is related to the specific environment, and is a random variable of normal distribution caused by the occlusion effect.

At present, relevant papers have carried out the simulation analysis of the ultra-wideband wireless sensor network localization algorithm based on received signal strength [49-52]. After analyzing and comparing the modeling complexity of signal propagation models caused by complex
environmental impacts, reflection, multipath interference, non-line-of-sight, antenna gain and other issues produce significantly different propagation losses for the same distance, and the papers solve these problems, but in general, the RSSI-based measurement and positioning method is rough, and it is only suitable for occasions where the error is not high.

**Ranging Positioning Method Based on Arrival Time Difference**

When the time synchronization between the unknown node and the reference node cannot be guaranteed, the TDOA arrival time difference can be used for ranging. The distance can be obtained by calculating the time difference of the unknown node reaching the two reference nodes, but additional metering equipment is needed to increase the experimental cost.

**Time-based Arrival Ranging Positioning Method**

Based on the TOA (time of arrival) measurement positioning algorithm, the propagation speed of the signal is known, and the distance is measured by measuring the signal propagation time. The TOA can measure the distance between nodes in the following two ways.

a. Measuring signal one-way propagation time

b. The transmitting node records the transmission time of the signal and synchronously informs the receiving node that the receiving node records the receiving time of the signal, measures the propagation time of the signal in this way, and calculates the distance between the nodes by the propagation speed of the signal. This method requires full synchronization of the clocks between nodes.

c. Measuring the round-trip time difference of the signal, the receiving node sends back directly after receiving the signal, and the transmitting node measures the time difference between sending and receiving. Since only one clock is used, the problem of clock out-synchronization can be solved, but the processing delay of the receiving node cannot be estimated in this method. A time error of 1 ns when measuring with ultra-wideband may also bring an error of 10 cm.

d. At present, the TOA-based ultra-wideband measurement and localization algorithm is widely used. As long as the error caused by clock synchronization is solved, the positioning accuracy can be increased to the order of centimeters.

**Frame Round-trip Measurement Technique**

Because UWB is different from traditional radio waves, the transceiver design is relatively simple and easy to integrate. Most UWB transceivers are integrated and integrated. If it is only a unilateral application, the receiving technology or transmission technology of UWB transceivers is a bit waste of resources, it is best to use all resources effectively. The ranging technique based on frame round-trip is proposed for this requirement. Each node can receive or transmit pulses autonomously, and obtain the product between the two nodes by calculating the product of the pulse round-trip time between the nodes and the pulse wave velocity. distance. It is a concept to indicate that RTT (round trip time) for frame round-trip transmission and FFT (frame fly time) mentioned in most existing documents are not too much distinction. The ranging technique based on the frame round trip specifically completes the ranging between the nodes in the following manner.

The main measurement point is that the reference node usually sends a frame of information to turn off the transmitter to turn on the receiver and pass the clock. When the measured point receives the frame information sent by the main measurement point, it immediately responds to a frame of information, and the main measurement point receives the message. Stop the timing after the information sent by the measured point. Note that each time can start from 0. You can also use the standard clock to calculate the time difference to count. The distance between the two nodes is calculated by calculation as shown in formula (4):

\[ d_i = c \times \frac{\Delta}{2} \]  

Where equation (4) represents the distance between the node and the node, which is the time difference, \( C \) is the ultra-wideband signal propagation speed, and the time information contained in
the accurate measurement should be limited to the time of the ultra-wideband signal round-trip, for the receiver and the transmitter. The time spent should be eliminated to minimize the error and measure accurately. It can then be expressed as formula (5):

\[ \Delta = \tau_i + \Delta_i + \tau_j + \Delta_j \]  

(5)

Where equation (5) represents the time consumed by the transmitter, which is the time spent by the node to the node. The time for the node to receive the node signal and then respond to a pulse signal includes, of course, channel decoding, signal decoding, source coding, channel coding, and the like. Time spent from node to node.

Therefore, in order to make the accurate measurement, the time error should be proposed, and the accurate measurement to be obtained should be as shown in formula (6):

\[ d_{ij} = \frac{\Delta_i + \Delta_j}{2} \]  

(6)

For the specific how to eliminate the time difference to ensure accurate measurement should be processed according to different models in the specific positioning model. Here is only the concept and implementation method of the ultra-wideband frame round-trip measurement.

Conclusions

Ultra-wideband has the characteristics of high time resolution, anti-interference ability and superior penetrating power, which can achieve precise positioning. This feature will be a perfect combination for wireless sensor networks. Most of them are now used for ultra-wideband measurement and positioning technology. The research is synchronous, that is, the need to use fiber optic connections between the tags, this method significantly reduces its wide applicability in wireless sensor networks, especially in special environments, sensor nodes are randomly deployed, so a study Ultra-wideband asynchronous positioning system becomes inevitable.

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References


