Application Research of PulsON@ 410 UWB Module on Accurate Locating in Substations

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Abstract. Based on the analysis of problems encountered by PulsON@ 410 RCM modules when used in substation accurate locating, such as automatic discovery of beacons, a self-organizing protocol is put forward to support the creation, maintenance of beacons network. Also solutions from different aspects are presented to dispose of signal collisions in wireless communications. Experimental results prove the effectiveness of the proposed protocol.

Introduction

Transformer substation inspection route monitoring, mistake-entering compartment warning[1] and other scenes have raised centimeter-level accuracy requirements for locating. Existing location technologies, such as GPS[2], mobile phone base station[3], WiFi[4], ZigBee[5], etc., are unable to meet a location demand of such a level. As a no-carrier communication technology, UWB[6] (Ultra-Wide Band) technology that uses non-sinusoidal wave narrow pulses from nanosecond level to picosecond level to do ranging is being more and more widely used in accurate locating occasions such as substation patrol, for it can achieve centimeter-level ranging accuracy within about 10 meters.

During accurate locating of objects with UWB ranging development kits, due to the limitations of ranging technology, there exist such problems as that the beacon nodes can not be automatically found, broadcast is not supported, beacon network configuration is difficult, etc. On the basis of expanding the API interface messages of development kits, a network maintenance protocol is puts forward in this article that supports dynamic networking of beacon nodes; and corresponding solutions for signal conflict that appears in wireless networks from beacon node and mobile node sides are proposed respectively. While taking the utilization of inertial navigation sensor into consideration, the locating accuracy to locate mobile nodes can be further improved on the premise that broadcast is not supported.

Discussed problems

PulsON@ 410 Ranging Mechanism:

PulsON@410[7,8] is a miniature coherent UWB OEM ranging and communication module developed by Time Domain Corporation of the USA. Even in high-multipath and high-reflection environments, point-to-point ranging accuracy can within 2cm.

The controlling host commands the RCM module to send a unique UWB pulse radio frequency signaling to do bi-directional flight time ranging. A complete process of information interaction of using the PulsON@ 410 module to do ranging is as shown in figure 1.

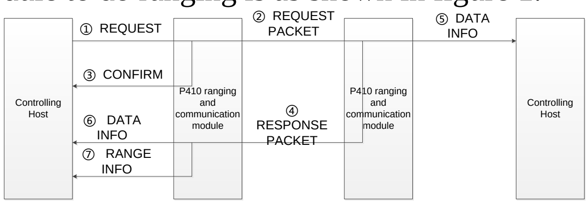

Fig.1 Information Interaction in UWB ranging process

Problems Analysis

There are several problems existed in applying RCM ranging module to locating scenes:

1) The beacon node deployment (including the number of beacons and the position of deployment) in the area that the mobile RCM node module enters is unknown. Therefore, currently the accessible beacon node ID and locating network topology can only be determined through static configuration, which greatly limits the flexibility of locating.
2) Although ranging request message allows for sending ranging packets by broadcast, it has been found through testing that, as UWB responding packets from multiple beacons conflict at mobile RCM, only the distances to the beacon nodes that are closest to mobile nodes are calculated correctly. Hence, currently the only way is polling each beacon node in turn by unicast. The locating accuracy can't be ensured when the node moves too quickly.

As for the first problem, a UWB locating network maintenance protocol based on extended API messages is proposed in Chapter 3; in Chapter 4 a transmission speed adjusting algorithm based on beacon network node capacity is proposed, which will realize accurate locating of mobile objects in unicast mode on the premise that the wireless signal conflict is reduced as far as possible.

UWB Locating Network Maintenance Protocol Supporting RCM Module Self-organizing

There are 2 types of nodes in the UWB locating network: beacon nodes and mobile nodes. A beacon node is an anchor node that is deployed at a fixed position beforehand for responding to the ranging requests from mobile nodes; a mobile node is a RCM module that moves with patrol personnel and does node locating according to the response packets of beacon nodes. In this article, beacon nodes and mobile nodes adopt the completely same hardware: the PulsON@ 410 module.

Workflow of Beacon Nodes

To support the self-organizing of locating network, the workflow of the beacon node part of the protocol is as shown in figure 2.

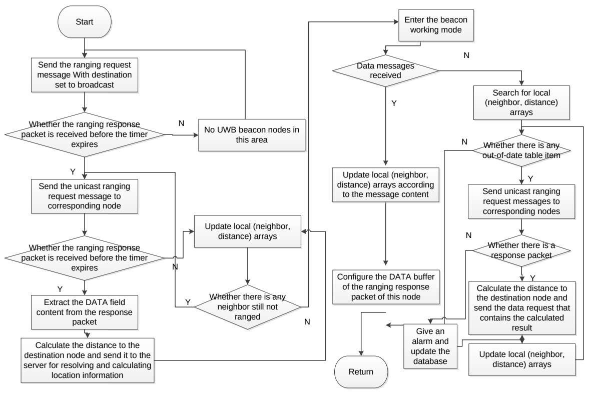

Fig.2 working process of beacon nodes

When it enters the network for the first time, a beacon node acquire the information of the beacon node that is closest to it by sending the broadcast ranging request message whose destination ID is 2^{32}-1. After that, the new node will send a unicast ranging request to the node and calculate the distance to it. Finally, the node will use the (neighbor, distance) information included in DATA field of the response packet to update the local database and accordingly sending the data request message to help the destination node update their neighbor database. Do analogy in turn, until all of the neighbor nodes contained in the local database are polled.

After the initial polling has been completed, the new node will switch to the beacon working mode. In this mode, the node only responds to the received ranging request packet and data request packet. To avoid the problem of abnormal exiting of beacon nodes from locating network, a timer should be added to the table item that is corresponding to each accessible node in the (neighbor, distance) database of the beacon node. When a timer in the table expires, the local node will temporarily enter the normal working mode, send unicast ranging request packet to corresponding destination node, decide whether to maintain or delete the corresponding table item. When the data request packet is received, corresponding timer shall be reset while the corresponding table item in the database is updated.

Workflow of Mobile Nodes

The mobile node periodically sends the broadcast ranging request message to decide whether it enter a UWB locating network or not. Then the mobile node will poll each accessible node and send the distance information to the server side for the resolving and calculating of location.

Extension to the Original API Messages

There are 3 kinds of API messages used in the protocol, including:

i) Ranging Request Message

(RCM_SEND_RANGE_REQUEST)

All of the modules within the area that can be reached by this RCM module will receive this UWB packet and submit data content contained in the packet to the respective controlling hosts. However, only the module with its ID identical to Responder ID will respond use the ranging request response packet. In the scene of ranging, the distance measurement is carried out through assigning the Responder ID to be the destination node ID of ranging. However, in the locating scene, the ID number of the closest beacon node can only be obtained through broadcast ranging request, and by sending point-to-point ranging request packets to this node the topology of the whole network shall be learned. Meanwhile, corresponding Data field content shall be updated to help the current node identify the type of the node that originate the request: 0-beacon node; 1-mobile node.

ii) Data Request Message.

(RCM_SEND_DATA_REQUEST)

The data packet will be received by all accessible nodes and the information in it be submit to the respective controlling hosts. However, no RCM modules will respond to it.

In the self-organizing protocol designed in this article, the node newly entered reports the measured destination node distance information to all of the beacon nodes within the accessible area through this API message. All of the nodes will use the information in it to update the local database and data buffer that response packet uses. In the protocol, for the triple (source node ID, destination node ID, estimated distance) transmitted by using the Data field of this message, the length of the triple will be transmitted by using the Data Size fields.

iii) Ranging Response packet Data buffer Setting Message

(RCM_SET_RESPONSE_DATA_REQUEST)

In the self-organizing protocol designed in this article, the existing beacon nodes in the network will set data buffer through this message according to the local (neighbor, distance) database information to respond to the point-to-point ranging request of the newly entered node. For the triple array sent by using the Data field (source node ID, destination node ID, estimated distance) of API, every two triples will be separated with a tab and the array length will be transmitted by using Data Size fields.

Conflict Avoiding Mechanism

The UWB wireless locating system based on PulsON@ 410 module meets the concurrency requirement to a certain extent, which allows mobile nodes 1 and n in two different areas to be located at the same time, as shown in figure 3. However, due to the characteristics of wireless signal transmission, wireless signal conflict in multiple scenes still exist in the UWB locating system, which is mainly reflected in: scene 1. the "ranging request storm” that occurs during the network maintenance executed by beacon nodes; scene 2. concurrent ranging requests sent by multiple mobile nodes for the same beacon node; scene 3. concurrent responses of multiple beacon nodes to the broadcast ranging request of the mobile node.

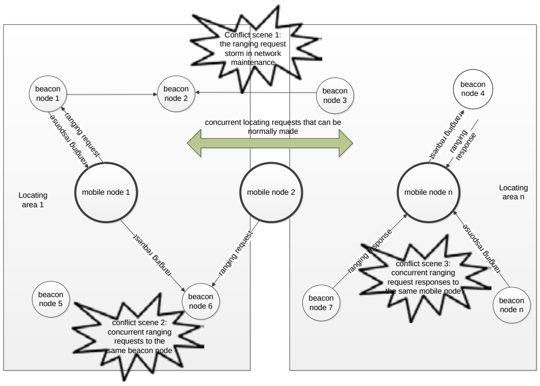

Fig.3 conflict scenes in UWB locating network

Delivery Mechanism of Network Maintenance Request Packet based on Pure ALOHA Technology

The conflict resulted from multiple beacon nodes simultaneously sending ranging requests during the self-organized network maintenance process (scene 1 in figure 3) can be solved by using the random access technology based on pure ALOHA.

In the pure ALOHA network, the average number of the packets successfully sent during the packet transmission time T_0 is defined as the network throughput S[9], while the number of all the packets transferred within T_0 is network load G. Assume the packet arrival rate of the whole system conforms to Poisson distribution. Then the probability of sending out a packet successfully is:

$$P \text{ [packet is sent out successfully]} = e^{-2G} \tag{1}$$

Assume that the confirming information is to be received after R times of T_0 after a packet is sent and the average times of unsuccessful sending of the packet is N_R. Then the average delivery time of a packet is:

$$D = T_0[1 + R + N_R(R + (K+1)/2)] \tag{2}$$

The value of K in formula (2) can be set to 5 in locating scene so as to make N_R basically unrelated with K. The average times N_R of packet retransmission can be represented as:

$$N_R = e^{2G} - 1 \tag{3}$$

It can be seen from above that with a relatively low network load and a relatively large K value the times of network maintenance packet retransmission can be effectively controlled within a reasonable range.

Transmission Rate Control of Mobile Node Ranging Packet

The conflict resulted from multiple mobile nodes simultaneously sending ranging requests to the same beacon node (scene 2 in figure 3) can be solved by controlling the average transmission rate of ranging packets from mobile node.

Set the node number in the UWB locating network as N and the average transmission rate of ranging request packets as R_0, the time for a complete ranging session experiences as T and assume that every node will send ranging requests to other nodes in the network. It is proved[10] that the following formula (4) holds:

$$S = (N-1) * R_0 * T \tag{4}$$

In actual locating networks, as the node roles (some nodes are beacon nodes) and the node parameter configuration (the ranging-forbidding node list is set) are different, node number N is unable to reflect the effective size of the network. Hence, the network effective node number N_{eff} derived through activated ranging link L must be used for the calculation of formula (4), as shown in formula (5).

$$N_{eff} = \frac{1 + \sqrt{4L+1}}{2} \tag{5}$$

The PulsON@ 410 module defines the average transmission rate of ranging request packets as R_0 by configuring the minimum sending interval *minTBT* and the maximum sending interval *maxTBT*.

Setting *minTBT* as the time *T* of a complete ranging session experiences, the maximum sending interval *maxTBT* can be derivated from formula (6):

$$\max_{TBT} = T * \left(\frac{\sqrt{4L+1}-1}{S} - 1\right) \qquad (6)$$

The *maxTBT* of RCM module connected with mobile terminal can be set according to the calculation result of formula (6) to ensure the success rate of ranging.

“Discovering nodes by Broadcast + Locating by Unicast”

In the actual locating situation, when the broadcast ranging packet from the mobile node is received, all of the accessible beacon nodes in the locating area will respond immediately, which will lead to response packet conflict on the mobile node side (scene 3 in figure 3). The scheme “discovering nodes by broadcast + locating by unicast” shall be adopted to solve this problem.

“Discovering nodes by broadcast” means that the mobile node acquires the beacon node information through sending broadcast ranging packets periodically and receiving the DATA field content from the response packet of the closest node. Only by this periodical broadcast method the node information in the patrol area can be obtained dynamically.

After obtaining the beacon node information in the area where it is located, the mobile node will adopt the method “locating by unicast” to send unicast ranging packets successively to beacon nodes for ranging and locating.

Because of the movement of nodes during unicast locating, the scheme will lead to some measurement error. Therefore, the inertial navigation sensor is used to get the initial location, step size and course angle of mobile node, and the node location at the next moment can be compensated with patrol dead-reckoning (PDR). The principle of compensating the node location with the inertial navigation sensor is as shown in figure 4.

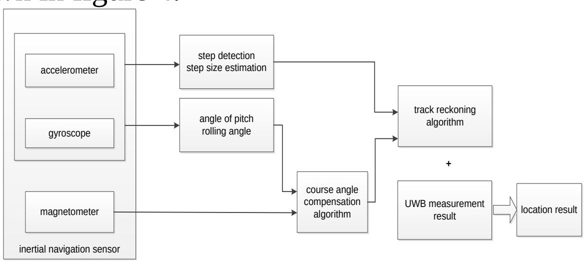

Fig.4 Compensate node location with the inertial navigation sensor

Computational examples and analysis

8 PulsON@ 410 (7 as beacon nodes, 1 as a mobile node) are used to build a UWB trial network. A 9 DOF inertial navigation sensor is assembled on the mobile node to do error compensation.

The information of accessible neighbor nodes can be seen on any beacon node through API interface, as shown in figure 5. Thus the effectiveness of the protocol is proved.

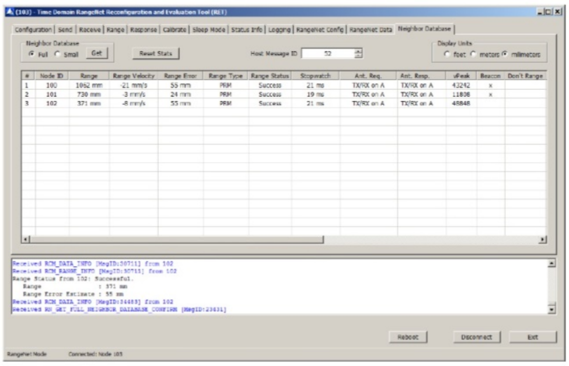

Fig.5 Beacon node neighbor list of self-organized network protocol

The track comparison during the movement of mobile nodes considering inertial navigation and several other locating methods is as shown in figure 6.

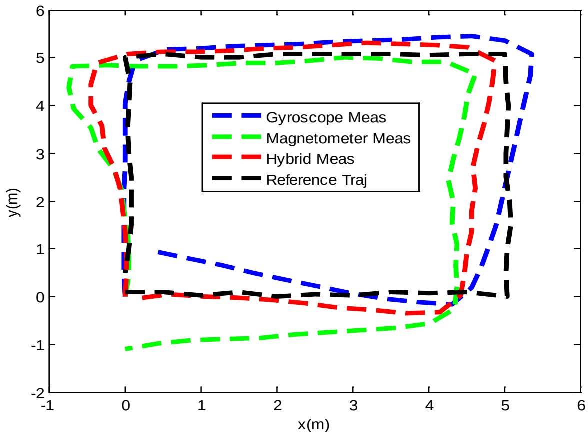

Fig.6 track comparison of several locating algorithms

It can be seen that, with UWB locating algorithm (shown as the red curve in the figure), although there is still some error compared to the standard track, the accuracy is improved compared with other 2 locating methods that only depend on the inertial sensor.

Conclusions

Indoor high accuracy locating technologies represented by UWB technology are applied to scenes such as intelligent substation patrol. Through analyzing the existing problems in the application of UWB ranging module PulsON@ 410 in indoor locating, this article proposes a locating network maintenance protocol that is based on beacon node self-organized network and comes up with a corresponding solution to signal conflict in wireless networks. The effectiveness of the protocol and scheme is verified through experiments. The research result holds guiding significance to practical application of UWB technology in indoor locating scene.

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