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Membership Management and Positioning Method of Multiple Objects using UWB Communication

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Abstract

Worldwide recently, connectivity of everything became hot issue in electronics engineering to make the Internet of Things (IoT) possible. In a point of IoT, it has been problematic for conventional indoor positioning systems to adopt system where devices can communicate only at the designated time slots. We propose membership management and positioning method of multiple objects using an UWB communication. The simple and unique management algorithm is composed of two stages. In the first stage, a master device sends a signal to each tag devices in order to confirm the communication ability status. In the second stage, the master device sends another signal to the confirmed tags to initiate ranging and positioning. The efficiency of the proposed management algorithm compared to conventional method is proved by experiments in ordinary classroom which exemplifies indoor coverage in buildings.

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Keywords: membership management; indoor positioning system; multiple objects; ultra-wideband communication

1. Introduction

Ultra-wideband (UWB) communication is defined as a wireless technology for transmitting immense amounts of digital data over a relatively wide bandwidth activated by low power for a short distance. Since February 2002, the year when the U.S. Federal Communications Commission (FCC) permitted commercial usage of unlicensed spectrum from 3.1 to 10.6 GHz that occupies range of 7.5 GHz, UWB communication has been powerful technology

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to a large number of real-time wireless applications especially advantage to electronic industries [1]. Furthermore, the UWB communication system would be one of the most essential and vital technology required in order to embody IoT in real life.

The IoT industry is basically focused on three major technologies: sensing technology, wireless and/or wireline communication and network infra technology, and IoT service interface technology. Sensing technology, crucial and fundamental technology to collect information, requires more than a basic level of sensing the elementary characteristics of an object that can be represented by temperature, humidity, heat, gas, luminosity, or supersonic waves. Rather a high level of sensing is required such as remote detection, radar, location, or motion. Real-time location system (RTLS) had been accomplished and applied in outdoors; we can find an example of a success in vehicle navigation. However conventional positioning systems had restrictions only in outdoors because it required a satellite in order to communicate between the device and the server. While some targets are inside the building, the precise locations of the targets are impossible to be determined when line of sight (LOS) of the satellite is not guaranteed. To ensure the consistent LOS within communicational devices, a substitution of the satellite is required. This vital role of the satellite is now implemented to indoor devices called anchors where installed at the verge of communication cell.

Time based schemes are configured for the determination of a tag location. Ranging protocols are based on time of arrival (ToA) obtained by UWB signal pulse travel between the two devices. To compute the distance between the two devices, time of flight (ToF) is multiplied by speed of light. Symmetric double-sided two-way ranging (SDS-TWR) is adopted to the proposed protocol as a ranging method since SDS-TWR do not require time synchronization and also reduces the effect of clock skew on the ranging process [2]. As soon as the distance information between a tag and three anchors is obtained, tag position can be calculated by geometrical trilateration.

Since the UWB signals in the positioning scheme share particular identical frequency, a complete progress of positioning multiple tags requires a method with the purpose of time sharing management. In order to manage time slots or a time sharing, time division multiple access (TDMA) or carrier sense multiple access with collision avoidance (CSMA/CA) have been commonly used [3-5]. TDMA method, one of the representative synchronous indoor positioning systems, is allowable to be adopted in a certain degree of system complexity. To be specific, the increment of reserved time slots on TDMA frame also increases the waste of time when the designated tags are in void status. In other words, the bigger the probability of discarding time slot as numerous tags are designated to the frame, the lower the efficiency of the system managed by the TDMA method. In this paper, we propose an algorithm of membership management and positioning method of multiple objects based on UWB communication.

The proposed management algorithm consists of two stages that are operated consecutively. The first stage performs member registration where master device sends a signal to each tags in order to ascertain whether the tags are capable to communicate with the anchors. Then the tags confirm their status by sending a signal back to the master device as a reply. In the second stage, positioning process is then initiated by the confirmed tags which are triggered after the tags receive another signal from the master device. The second stage can be repeated for preset rounds where the number of the rounds can be easily modified depending on applicable system. In other words, a routine of a proposed membership management algorithm is comprised of a single former stage and several latter stages. The efficiency of the proposed membership management is proved in contrast to the conventional method by experiments in ordinary classroom which demonstrates as an example of indoor coverage in buildings.

2. Membership Management

2.1. System Configuration

RTLS wireless network for membership management is modeled using several communication networks combined as shown in Fig. 1. A network cell consists of portable tags, fixed anchors, a master anchor, a sink node and a task manager. Tag and master anchor hardware are designed as an UWB communication module based on IEEE802.15.4a standard and operated by battery. The anchor hardware is designed as an IEEE802.15.4a standard based UWB communication module with ZigBee module connected via serial peripheral interface (SPI) operated by battery. At least three anchors are required to successfully determine a location of a tag by calculation of geometrical trilateration. Sink node hardware only consists of ZigBee module which gathers ranging data from the anchors in order to manage ZigBee network among the anchors.

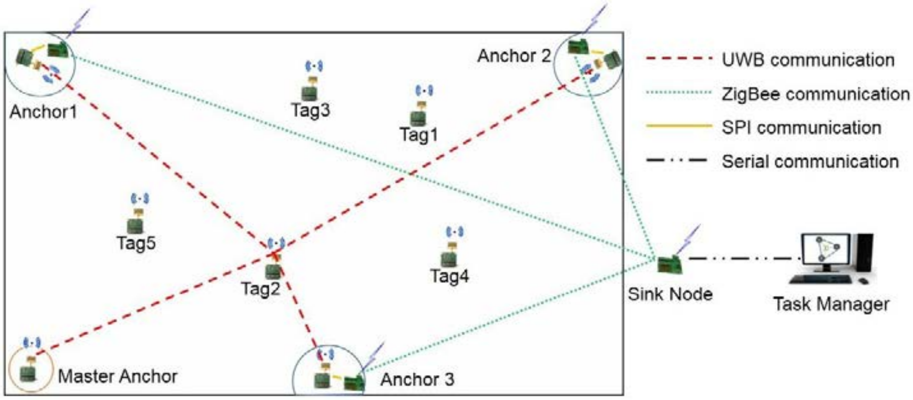

Fig. 1. System configuration for RTLS including membership management.

It is assumed all tag identification (ID) numbers are designated differently to each tag and a master anchor possesses a list of tag identifications in prior to installation.

2.2. The Proposed Algorithm

Membership management algorithm is mainly managed by master anchor as other devices passively begin their specific roles. The proposed algorithm is composed of two stages, member registration stage and ranging stage. Once the member registration stage is proceeded, several ranging stages are operated depending on a performance requirement of the applicable system. We define this repetitive routine as a loop and it is presented as a simplified block diagram in Fig. 2.

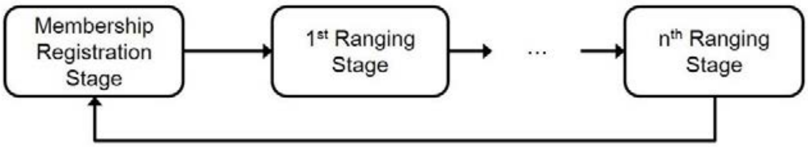

Fig. 2. Simplified block diagram of membership management process.

In the first stage, a master anchor performs a member registration by sending a signal to each tags in order to determine whether the tags are capable to communicate with the anchors (we define this type of signal as a check signal). After the check signal is sent, the master anchor receives the signals back from the tags as a confirmation (we define this type of signal as a check response signal).

In the second stage, ranging and positioning process is then initiated by the confirmed tags which are triggered by a signal the master anchor sends to registered tags to start ranging with the anchors (we define this type of signal as a call signal).

2.3. Algorithm Details

First stage is a member registration stage where master anchor sends a check signal to each tags in order to determine whether the tags are capable to communicate with the anchors. Fig. 3 gives a block diagram on the aspect of master anchor at the member registration stage. The master anchor sends a check signal to each tags according to the list possessed in prior to installation. Once the tag receives check signal, the tag sends check response signal back to the master anchor and is now successfully registered as a member for a loop. The check signal can also be considered as a trigger for the tag to perform a ranging procedure where time slot is guaranteed. The master anchor moves on to next ranging stage after checking all tags.

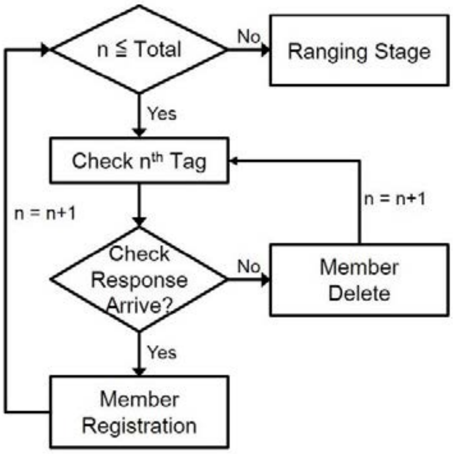

Fig. 3. Block diagram of master anchor at member registration stage.

Second stage is a ranging stage where member registered tags start their positioning procedure triggered by master anchor. Fig. 4 gives a block diagram on the aspect of master anchor at the ranging stage. The master anchor sends a call signal to each tags according to the member list obtained at the first stage. The call signal has a completely identical frame structure of the check signal but a different command carried. Once the call signal is sent, the master anchor guarantees the sufficient ranging time between the tag and anchors while other tags are in standby status. As soon as the second stage is repeated for several designated numbers, it moves on to a new member registration stage.

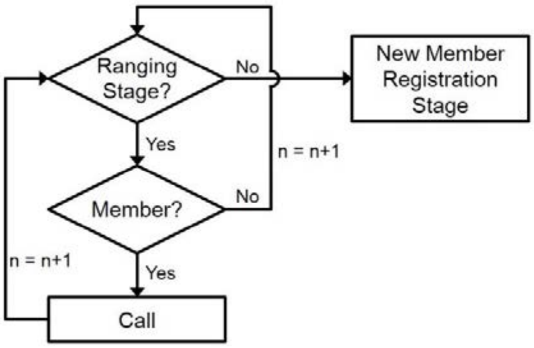

Fig. 4. Block diagram of master anchor at ranging stage.

2.4. Algorithm Applied Example of Multi Tag Positioning

Conventional systems without the proposed membership management must have guaranteed time slots for ranging and positioning as shown as an example in the Fig. 5. (a). There is no separate stage compared to membership management adopted system but only ranging stages repeated. It is concluded that time waste occurs in conventional systems to guarantee useless time slots for inactive or non-existing tag such as tag number two in Fig. 5. On the other hand, membership management implemented system consists of two different stages also shown in Fig. 5. (b). Ranging stage has flexibility in time consumption according to the number of capable tags. This elastic characteristic leads the minimization of time loss.

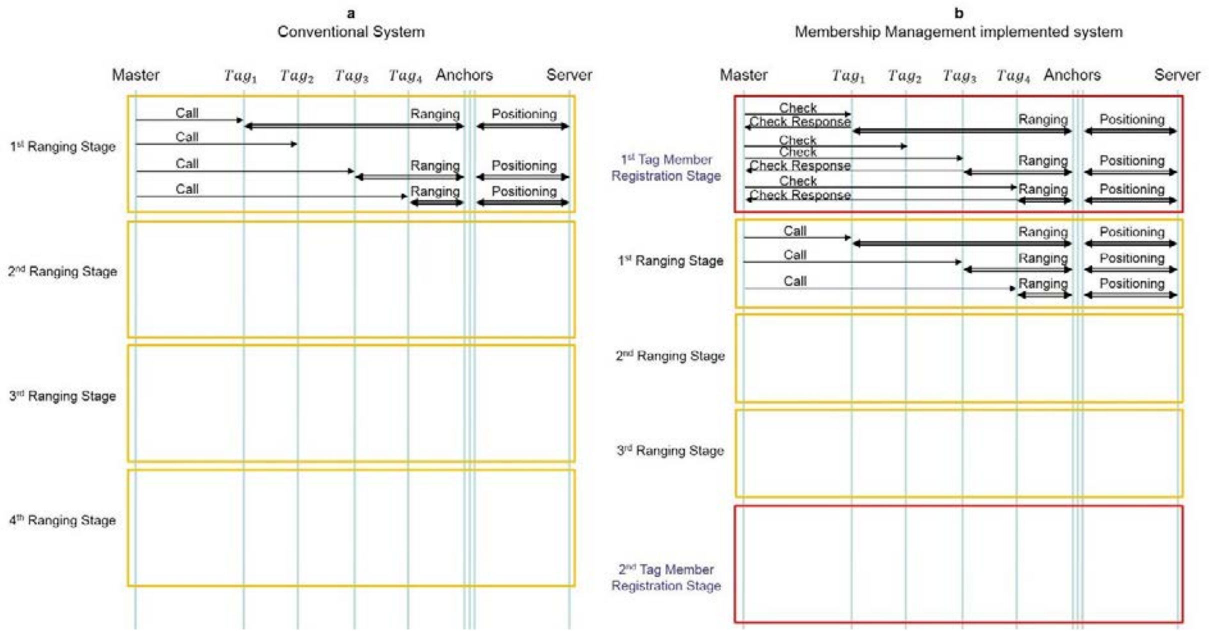

Fig. 5. (a) Time flow of conventional system; (b) Time flow of membership management implemented system.

3. Positioning and Tracking

After a ranging between an anchor and a tag is finished, the received distance value is sent to the sink node. The sink node gather up distance values from every anchors and produce a new combined data for the positioning determination. The output is transferred to a task manager in order to determine the tag position and then start its tracking.

3.1. Positioning

Position of tags is determined by geometrical trilateration and it is calculated at the task manager. Theoretically the position of a tag can be calculated as a single coordinates in two dimensional space if we have at least three distance from the anchors. However, the tag consecutively executes its ranging procedure with each anchors because of its inevitable UWB communication collision. Tiny but still existing time differences at consecutive ranging procedures for tag with movement create the positioning imperfect. Also, since the ranging procedure of the UWB module converts the difference of time stamps of received signals into digital scale, the limitation of decimal or digital value expression cause additional error at positioning. Furthermore, as the anchors are installed at some heights for maximizing LOS, there are differences of heights of the tags and the anchors that makes two dimensional positioning even worse. Therefore, several methods are adopted to enhance system performance to reduce the system hardware error factors to the least.

The height compensation is simply calculated by using the Pythagorean theory. Fig. 6 shows an example of height compensation by applying the theory to transfer ranging data into corrected distance assuming the average height tag held by human is 1.2 m.

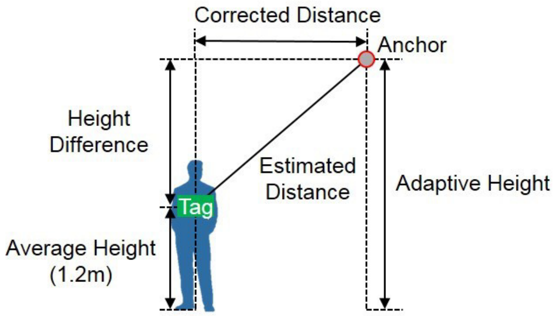

Fig. 6. Height compensation.

In order to determine precise location coordinates of the tag, least square (LS) method is adopted that proved its reliability [6][7]. The LS method is simple and most commonly applied for ToA based active object positioning method where usage of the method is in equal to approximate maximum likelihood (ML) estimation method [8].

3.2. Tracking

The positions of tag that are determined at task manager are produced and location coordinates can be plotted in graphical user interface (GUI). However, a consecutive train of location information would be unrealistic as if the coordinates show rattling movement even with compensation adjustments performed in positioning process. Non line of sight (NLOS) effect, individually different extra multi path signals and inconstant antenna gain occur the compensation worse. In addition to the compensation of system hardware error factors, Kalman Filter (KF) provide improvements at reducing the flickers from the row of locations.

The KF is a very effective method at linear positioning system by combining rattling location data and operate estimation of the status in which the KF algorithm uses a recursive data processing that consists of two phases, state prediction phase and state update phase [9]. However, KF is not capable to overcome restriction at nonlinear system since the tags shifts in various random directions with diverse velocities. Many researches has proved Extended Kalman Filter (EKF) is one of the most adopted solution to solve the KF limitation at position determination and tracking at nonlinear systems [10-12]. Therefore, EKF is adopted to the RTLS system as a final compensation procedure in a purpose of providing realistic placid tracking.

4. Experiment Analysis

4.1. Experiment Environment

Membership management algorithm is implemented to the system that contains according device categories; tag, anchor, master anchor, sink node, and task manager. We experimented with actual UWB modules, ZigBee modules, and a personal computer as a task manager. UWB communication module is configured as EVB1000 board and antennas set named as EVK1000 kit made by DecaWave. ZigBee module is composed of CC2538-CC2592 Evaluation Module Kit (EMK) board made by Texas Instruments. We set an experiment environment as an ordinary classroom with fairly thick concrete wall that represent as an example of indoor building area shown in Fig. 7.

Fig. 7. Experiment environment set in ordinary class room.

We set the region of the tags positioning and tracking as 10 m×10 m square region. Tag modules are installed at necklace type wearable or can be held independently by human. Anchor modules are installed at 2 m height at the tip of each tripod. The anchors are located in triangular formation, the two modules at neighbouring corners of the square region and one module at the 6 m far from another neighbouring corner aligned at the virtual line between the rest corners. Master anchor is located at the middle of the region.

4.2. Tracking Multiple Tags

Five mobile tags were designated as a list for tracking. We experimented by comparing total number of successfully determined positions between the conventional system and membership management implemented system. The conditions of deciding a location determination to be successful are satisfactory on zero communication loss at UWB, SPI, ZigBee, or serial communication and no smaller value of error distance between previous and present locations than predefined excessive positioning error distance. We configured the loop of this system with one member registration stage and four ranging stages.

4.3. Systems with Different Member Registration Stage to Ranging Stage Ratio

The required time for positioning the tags during a loop is shown in Fig. 8 with the comparison of a system without membership management and the systems with the different member registration stage to ranging stage ratio. The number of the activated tags is transferred as a percentage scale. Fig. 8 shows that as this ratio increases, apparently the total required time increases so that the time no longer take advantage in case of high percentage of activated tags. However, the member registration stage is generally not greater than the ranging stage in realistic system so that membership management bring advantage to the system by no time loss on low activation ratio of the tags. In can be concluded that the average performance of the membership management adopted system is superior to the system without the management.

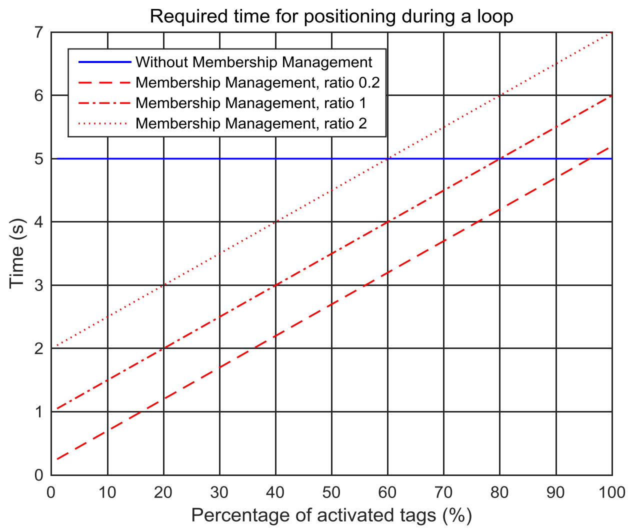

Fig. 8. Required time for positioning during a loop where member registration stage to ranging stage ratio is fixed.

4.4. Systems with Different Percentage of Activated Tags

The required time for positioning the tags during a loop can be comprehended in other means as shown in Fig. 9 where the percentage of activated tags is fixed.

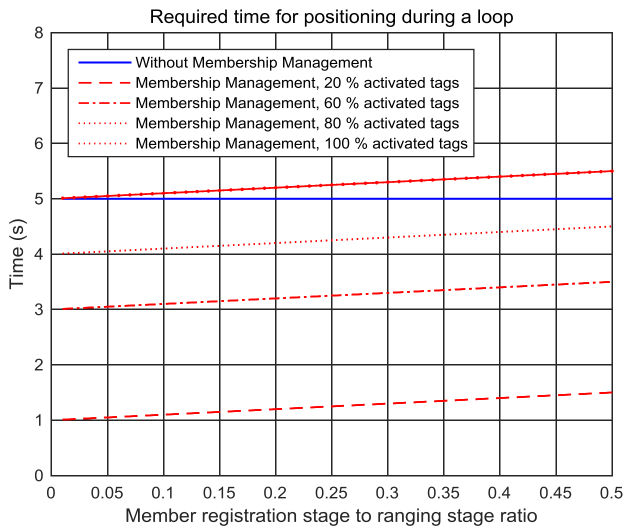

Fig. 9. Required time for positioning during a loop where the percentage of activated tags is fixed.

While the system without membership management show constant time regardless to member registration stage to ranging stage ratio, the membership management adopted systems have time increments according to the ratio. Regarding the systems with realistic member registration stage to ranging stage ratio, membership management definitely leads huge time advantage for efficient positioning and tracking of multiple tags unless high percentage of activated tags.

5. Conclusion

In conclusion, the adaptiveness of the proposed membership management method for multiple objects bring notable time advantages to the system. The proposed method benefits the implemented system to increase its positioning accuracy due to minimization of discarded time slot for inactive tag at conventional system. Furthermore, the proposed management can lower the power consumption by removing any chance of unnecessary signal transmit failures that are anticipated after the member registration stage. We also conclude that the system may have trade-off between the capability of tag numbers and efficiency loss. As a future work, we consider developing advanced algorithm to reduce the struggle of the system where huge time consumption is expected at member registration stage to operate immense number of registered tags.

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