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***Abstract*—A safety monitoring and accident warning system for underground construction site has been designed in our previous work based on wireless sensor network. Real-time localization of mobile targets is crucial for tracking the related incidents. However, the current RSSI-based localization approach struggles to achieve the required performance. This is due to the limited ranging accuracy of RSSI devices. In this paper, we investigate various ways of improving the localization accuracy and propose our solution of a hybrid UWB-assisted approach. We argue that a hybrid UWB-assisted RSSI ranging has the best overall performance for our application. We show with both mathematical analysis and demonstration system that, instead of implementing a full UWB network, our approach can improve the accuracy to our desired level with only a small number of additional UWB anchor nodes.**

Keywords—wireless sensor network, UWB, localization

I. INTRODUCTION

The construction industry is one of the most hazardous industries in many countries [1]. It has been widely accepted that accidents are just the tip of an iceberg and henceforth understanding the cause of the accidents is of great significance for accident prevention [2]. Moreover, many organizations had attempted to develop programs to identify and benefit from accident precursors, which were defined as the conditions, events and sequences that preceded and led up to accidents [2]. However, the potentials of focusing on precursors on construction have not been fully realized [3][4]. In the meantime, it has been shown that the information of location about workers, equipment and material is highly related to accident precursors on construction sites [5][6]. In other words, the changing site information captured by localization and tracking technologies can alert workers to danger, which means that a worker's or object's location, tracked on a real-time basis using localization and tracking technology, can be automatically compared with previously identified dangerous regions and moving objects [7]. This would effectively warn the worker, and help to avoid any possible collisions when the worker gets close to the dangerous region or object [8].

As an attempt in our previous work to address such needs, we have designed and implemented a construction site safety monitoring and accident warning system based on ZigBee wireless sensor network [6]. The system integrated sensors and RFID to track various environment conditions and object identities as well as localizing vital mobile targets based on the received signal strength indicator (RSSI) generated with the network nodes' RF transmitters. Initial field trial has revealed that the localization performance is not stable and needs further improvement. The field requirement analysis carried out has suggested that the safety warning feature requires a maximum error variance between 1-2 m^2. We have investigated various ways to improve the localization accuracy of our system. In this paper, we present our current solution of UWB-assisted localization approach. The idea is to add a small number of UWB ranging modules into the existing network system to improve the localization performance, while at the same time avoiding either a dense network deployment or porting the system to another network backbone completely. In support of our design we analyse the system's expected performance with theoretical models of ranging measurement, location estimation and node connectivity and coverage to show that the UWB-assisted approach largely improves system performance and requires very few additional node deployment.

The remainder of this paper is organized as follows: in section II we introduce some useful background and related work; section III discuss the design concept and analyse the expected system performance by benchmarking two primary approaches: increasing anchor node density in pure RSSI approach and integrating additional UWB anchor nodes; We then discuss the node coverage and deployment requirement in section IV and a demonstration system is presented in section V before we conclude the work.

II. BACKGROUND AND RELATED WORK

A. Localization in wireless sensor networks

The adoption of wireless sensor networks has been growing rapidly in the industry in the past few years. It provides a full wireless solution for most monitoring and control applications with low cost hardware, self-organized and low maintenance network architecture and low energy consumption. Just as its name suggests, the monitoring capability of a wireless sensor network usually depends on the type(s) of sensors carried on board its sensor nodes. As more and more information systems looking to provide the answer to the 4Ws, which are Who, What, When and Where, location information has become one of the most important piece of information required by many applications. However, integration of location tracking is not so straight forward comparing to normal sensors. The most widely used localization system is the global positioning system (GPS). Such system is highly standardized and the receiver cost is affordable thanks to its massive production. However, it does not work indoor or underground because the

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satellite signal cannot penetrate the obstacle presented. Wireless sensor networks in such environment have to implement its own mechanisms. A comprehensive review of the primary ranging methods and localization algorithms used for indoor WSN is presented in [9]. In particular, UWB localization has been studied in [10][11][12]. However, those work focus on systems with full UWB network backbone, which does not apply directly to our existing system. In our work we are trying to adopt the UWB in addition to the existing RSSI measurement to form a hybrid localization scheme. Hybrid localization is a term that has been adopted in some existing work, such as [13][14][15], where most of them focus on higher level integration of hybrid data post-processing methods or localization algorithms rather than combining different ranging approaches. Solution in [16] integrates various ranging techniques, but only uses them separately in different areas. A hybrid scheme presented in [17] combines GPS and GSM ranging measurement, which has promising performance but does not apply to our application. Reference [18][19] discussed more generalized hybrid schemes, however both work are based on the assumption that all the adopted ranging methods are implemented on all anchor nodes, which differs from our idea.

B. Localization accuracy and Cramer-Rao Lower Bound

The procedure of locating a mobile node is commonly the calculation of the target's location using predesigned algorithm based on a set of range measurement between the target and a certain number of anchor nodes. Many different ranging measurement approaches were investigated in the past few decades, each with its own model of relationship with actual distance and error variance. Based on those measurements various localization algorithms have also been proposed to estimate the location of mobile nodes. However, with a certain type of ranging method, regardless of what localization algorithm is used, there is accuracy limit that any system or algorithm cannot surpass. Such limit can be described by the Cramer-Rao Lower Bound (CRLB). In statistics modelling and estimation theory, CRLB is present a lower boundary on the variance of any unbiased estimator of a parameter. It is usually expressed by the inverse of the fisher information of the observation. The concept behind it simply that the accuracy of estimation is limited by the amount of information carried by the observation used by the estimator. In multidimensional space, the fisher information is given in the form of a matrix (FIM) and the CRLB is expressed as the inverse matrix of FIM:

$$\mathrm{CRLB}(\hat{\theta}) = (FIM_\theta)^{-1} \quad (1)$$

Where the fisher information matrix is given by:

$$FIM_\theta = -\mathrm{E}\left[\frac{\partial^2}{\partial\theta^2}(\ln f(X,\theta))\right] \quad (2)$$

In which $f(X,\theta)$ is the probability density function of observation X. As the range measurement result is usually modelled as a random variable related to the true distance between the target and anchor node, the localization process can therefore be considered as an estimation process of the target location based on a set of range measurement observations (known as observation vector) and a known probability distribution function of the location vector. In this case, the localization performance can be evaluated with statistical model by finding out its theoretical limit of accuracy using CRLB. As we are interested in the accuracy of the overall estimated location, its variance can be given as:

$$CRLB_d = E[(\hat{x}-x_0)^2 + (\hat{y}-y_0)^2] = trace[(FIM_\theta)^{-1}] \quad (3)$$

As for any unbiased and non-correlated estimate of target location, the CRLB provides an effective and relatively uncomplicated way of calculating such limit to establish a localization system's performance benchmark. The CRLB of single ranging method has been investigated in the literature [20][21][22]. Attempts to derive CRLB of hybrid approaches are also presented in [18][19]. However, our analysis differs from those previous works as we add a different number of additional anchor nodes rather than implementing additional ranging methods on all existing nodes.

III. DESIGN CONCEPT AND THEORETICAL ANALYSIS OF LOCALIZATION PERFORMANCE FOR SYSTEM DESIGN

A. Improving localization accuracy

In this paper we focus on improving the localization accuracy of our RSSI-based system. People usually think that with more/dense anchor devices the localization accuracy can be constantly improved by keep increasing the density of anchor nodes. It is generally true that the accuracy will be proportional to the density of anchors nodes deployed. However, as we will show in the next section in our theoretical analysis, such improvement slows down quickly after the network density reaches a critical level. Moreover, due to the low energy and low data rate nature of wireless sensor networks, increasing node number too much will result in increased data transmission delay and reduced network life.

On the other hand, it is possible to improve accuracy with better designed localization algorithms. However, as bounded by CRLB, there is a limit to which the localization accuracy can be improved. In other words, with a certain type of ranging method, the amount of information in the measurement from anchor nodes limits the accuracy of location derived from it.

Another way of improving accuracy is to take multiple measurements and use time correlated algorithms. Time correlated algorithms, such as MCMC and [23], have proved to be successful in navigation systems. However, such approach relies heavily on assumptions of target movement characteristics, such as speed and direction. These parameters can be very difficult to predict for tracking on site targets. Moreover, WSN usually have a low data rate, which means taking multiple measurements for each one of the location estimations will lead to long delay. Therefore, in order to increase localization performance, new ranging approach has to be adopted.

B. Ranging approaches

In order to put more information into one set of measurement, one way forward is to introduce different ranging method with higher accuracy. RSSI measurement is the most widely used ranging approach. This is mostly because of the fact that it is a native measurement that can be taken from the RF transmitters already on board of the wireless sensor nodes. However, due to the low power of RF transmitters used in wireless sensor networks, RSSI measurement can be very unstable, especially in indoor, underground or other multipath environment. In order to improve the accuracy, we need more accurate ranging approach to be introduced.

Reference [9] reviewed most of the available ranging methods for wireless sensor networks, with many of them capable of achieving accuracy higher than RSSI. However, not all of them are applicable in our construction site monitoring system. Ultrasound and infrared sensors give precise ranging measurement, but the angle between the transmitter and receivers is very strict. They also come short in their transmission range, which is just a few meters. This means that the network would have a very dense deployment, which is something we have been avoiding. Image processing technology requires fast communication links and doesn't work well in the underground site with limit lighting. The only technology that was considered to be technically sound for our system is the UWB RF ranging approach. UWB radio makes use of an ultra-wide frequency band, resulting in very high transmission rate that leads to fine time resolution and resistance to multipath fading. UWB radio is capable to carry out both AoA and ToA measurement. The AoA measurement needs fine-tuned receivers on the mobile target to be in relatively stable position, which is not always easy to have in our case. Therefore we choose the UWB ToA measurement as the additional measurement approach to be adopted.

C. UWB-assisted vs UWB-based: a Hybrid approach

When UWB was first introduced it was supposed to be low cost and with low energy consumption. However, the current UWB ranging kits do not hold that promise. In fact, UWB ranging modules are among the most "luxury" wireless RF ranging devices today. It is technically feasible to port the whole ZigBee-based wireless sensor network monitoring system on to a full UWB network, as presented in [11]. However, the cost of the system would be significantly higher than the original implementation.

On the other hand, most of the current ZigBee-based wireless sensor network nodes operate on battery power at mW level, which makes the system deployment quite straight forward. However, the current UWB ranging modules usually consumes a much higher power at Watt level. The high energy consumption of the UWB ranging modules means that if the system is ported to a full UWB network, all network nodes will have to operate on mains power. This will further increase the cost and deployment complexity of the system. In this case, we investigate using UWB ranging model in an assistant role and estimate mobile target node location with the hybrid ranging information of both RSSI measurement and the additional UWB ToA measurement.

D. Increasing accuracy in pure RSSI approach

In our ZigBee wireless sensor network system, the original localization scheme relies on the mobile node to listen to the RF channel and to capture the RSSI value of 3-4 anchor nodes nearby. The RSSI measurements are provided by the sensor nodes' RF transmitter. This means it is the native ranging method supported by all of our network devices without the need of any additional hardware. Therefore, one would think that the most straight forward way to increase localization accuracy is probably to deploy more anchor nodes in the same area, or in other words increase the density of anchor nodes. In this case, a mobile target node can be covered by more anchor nodes at the same time so that a larger set of RSSI values can be available to calculate a more accurate location.

To evaluate the possible improvement of adding anchor nodes, we take a look at the CRLB of RSSI based localization system. It is widely accepted that the RSSI value in dB and the distance between the mobile and anchor nodes follows a log-normal distribution.

$$f_R(d) = \frac{1}{d\sqrt{2\pi\sigma_R^2}} e^{-\frac{(\ln d-\mu_R)^2}{2\sigma_R^2}}$$

In which, σ_R and μ_R are path loss parameters between the target node and an anchor node. Without loss of generality, we assume the path loss parameter σ_R and μ_R for all the anchor nodes in the system share the same value, which are given by:

$$\sigma_R = \frac{\ln(10)\sigma_{sh}}{10n_p} \qquad \mu_R = \ln(d_0) + \frac{(P-P_0)\ln 10}{10n_p}$$

Where σ_{sh} is the variance of shadowing, P is the received power, P_0 is the reference power received at distance of d_0, and n_p is the propagation exponent [20]. Let m be the number of anchor nodes whose RF coverage can cover the mobile node at the same time. As the measurement from each anchor node is independent to each other, the joint probability density function of the set of range measurement $D = (d_1, \dots, d_m)$ is:

$$p_R(D) = \prod_{i=1}^{m} f_{R,i}(d_i) = \prod_{i=1}^{m} \frac{1}{d_i\sqrt{2\pi\sigma_R^2}} e^{-\frac{(\ln d_i-\mu_R)^2}{2\sigma_R^2}}$$

Hence, the logarithm of the pdf function is

$$L_R(D) = \sum_{i=1}^{m} -\frac{(ln d_i+\sigma_R^2-\mu_R)^2}{2\sigma_R^2} - ln\sqrt{2\pi\sigma_R^2} - \mu_R + \frac{1}{2}\sigma_R^2$$

Let X be the vector of the mobile node and X_i be the vector of the ith anchor node, the fisher information matrix can be derived using (2) and is given below:

$$I_R = E\left[\sum_{i=1}^{m}\sum_{j=1}^{m} \frac{(ln d_i + \sigma_R^2 - \mu_R)(ln d_j + \sigma_R^2 - \mu_R)}{\sigma_R^4 d_i^2 d_j^2}(X - X_i)(X - X_j)^T\right]$$
$$= \sum_{i=1}^{m} \frac{1}{\sigma_R^2 d_i^4}\begin{bmatrix} (x-x_i)^2 & (x-x_i)(y-y_i) \\ (x-x_i)(y-y_i) & (y-y_i)^2 \end{bmatrix}$$

According to (3) the CRLB can then be computed by:

$$CRLB_R = trace((I_R)^{-1}) \quad (4)$$

To learn the effect of increasing anchor node number on the localization accuracy of our system, we simulate the result of (4) in Matlab, with the number of anchor nodes covering a mobile node from 1 to 20. The result is presented in Figure 1. The result shows that while the number of anchor node increases the accuracy error bound decreases rapidly at the beginning but such trend quickly slows down after the anchor node number reaches 4, which is our current implementation. We also notice that the lower bound does not reach our desired accuracy before the anchor node number goes pass 10. This means to have the possibility of achieving our desired accuracy using just native RSSI measurement, the network deployment has to ensure that the mobile target node is covered by at least 10 usable anchor nodes in the operating area. Such a dense deployment could lead to various issues, such as longer transmission delay due to network congestion, increased complexity in system design, deployment and maintenance and more risk and reduced system robustness in underground construction site. Therefore, what the CRLB analysis has suggested is that RSSI measurement itself simply doesn't hold enough information for achieving our required localization accuracy with a practically viable network deployment. In this case, more accurate ranging approach has to be brought in.

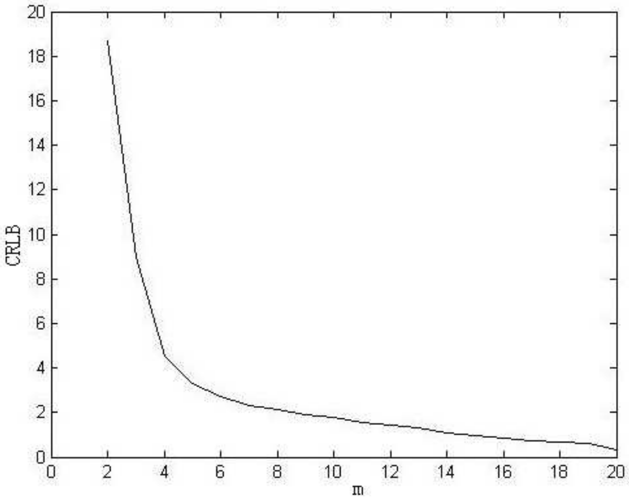

Fig. 1. CRLB of 1 to 20 RSSI anchor nodes. σ_R=4, n_p=2.38

E. Increasing accuracy by using UWB-assisted Localization

The most straight forward way of adopting UWB ranging is to port the whole system into a full UWB network. This means all the network devices are to carry and only to carry UWB radio transmitter that will take over the physical layer of all the network communication. However, UWB radio, especially those that are designed specifically for ranging purpose are expensive and consume relatively high power. To build and deploy a full UWB sensor network system that is at least 3-coverage in underground construction site does not seem to be practically feasible due to its cost and power requirement.

In this case, as we are more interested in improving the performance of an existing implementation a hybrid solution makes more sense. The idea is to deployment only a small number of UWB devices to incorporate with the existing system, so that the localization accuracy can be improved to a desired level, while the cost and added complexity to the system's design and deployment can be kept at minimum. In order to evaluate the achievable performance, we use CRLB again to benchmark the hybrid approach.

In previous section we have discussed the basic range/RSSI model with a log-normal error distribution. For range/ToA model, on the other hand, the ranging error is considered to be Gaussian: $f_T(d) = \frac{1}{\sqrt{2\pi\sigma_T{}^2}} e^{-\frac{(d-d_T)^2}{2\sigma_T{}^2}}$ In which σ_T is the ranging variance and d_T is the actually distance between the anchor and target nodes. Assuming a mobile target is covered by m anchor nodes for RSSI measurement and n UWB nodes for ToA measurement. As the RSSI and UWB measurement are independent to each other, the joint pdf of all estimated ranges $D = (d_1, \dots, d_m, d_{m+1}, \dots, d_{m+n})$ can be given by:

$$p_{R+T}(D) = \prod_{i=1}^{m} f_{R,i}(d_i) \prod_{j=1}^{n} f_{T,j}(d_j)$$

$$= \prod_{i=1}^{m} \frac{1}{d_i\sqrt{2\pi\sigma_R{}^2}} e^{-\frac{(\ln d_i - \mu_R)^2}{2\sigma_R{}^2}} \times \prod_{j=1}^{n} \frac{1}{\sqrt{2\pi\sigma_T{}^2}} e^{-\frac{(d_j - d_{T,j})^2}{2\sigma_T{}^2}}$$

Hence, the logarithm of the pdf function is

$$L_{R+T}(D) = \sum_{i=1}^{m} -\frac{(ln d_i + \sigma_R{}^2 - \mu_R)^2}{2\sigma_R{}^2} - ln\sqrt{2\pi\sigma_R{}^2} - \mu_R + \frac{1}{2}\sigma_R{}^2 - \sum_{j=1}^{n} \frac{\left(d_j - d_{T,j}\right)^2}{2\sigma_T{}^2} + ln\sqrt{2\pi\sigma_T{}^2}$$

The fisher information matrix can be derived using (2) similar to how $\mathrm{I_R}$ was calculated and the result is given below:

$$I_{R+T} = \sum_{i=1}^{m} \frac{1}{\sigma_R{}^2 d_i{}^4} \begin{bmatrix} (x - x_i)^2 & (x - x_i)(y - y_i) \\ (x - x_i)(y - y_i) & (y - y_i)^2 \end{bmatrix} + \sum_{j=1}^{n} \frac{1}{\sigma_T{}^2 d_i{}^2} \begin{bmatrix} (x - x_j)^2 & (x - x_j)(y - y_j) \\ (x - x_j)(y - y_j) & (y - y_j)^2 \end{bmatrix} \quad (5)$$

The CRLB is then be given by: $CRLB_{R+T} = trace((I_{R+T})^{-1})$

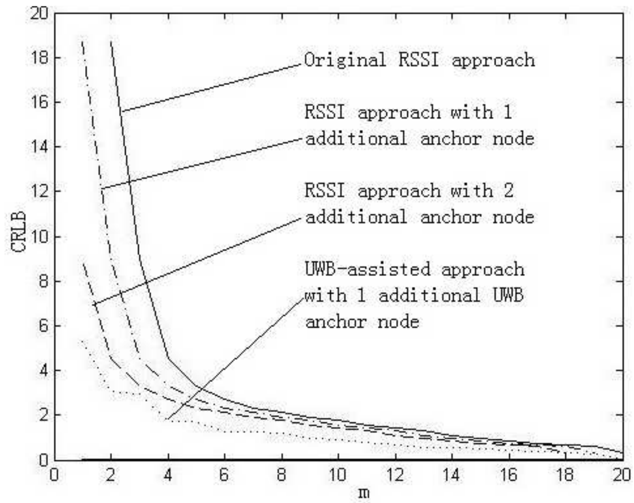

Fig. 2. CRLB of pure RSSI and UWB-assisted localization. σ_T=0.75

To show the effect of adding an additional UWB ranging node on the overall localization accuracy of our system, we simulate the CRLB again for RSSI anchor node number changing between 1 and 20. We also plot the CRLB result of having one or two additional RSSI anchor nodes as well as the CRLB of no additional anchor node in the same figure for comparison purpose. The results show that localization assisted by one additional UWB anchor node has a significantly improved error bound. At the point where we have 4 RSSI anchors and 1 additional UWB anchor node, the error lower bound is reduced to our desired accuracy range at about 1.7 m^2, which would not be possible for a pure RSSI localization approach with less than 10 anchor nodes covering the same target node.

IV. COVERAGE AND DEPLOYMENT

One of the benefits of having a UWB-assisted approach rather than a pure but dense RSSI approach is the saving on anchor node number. In order to achieve an error lower bound within our expected range, a pure RSSI approach would require at least 10 available anchor nodes in each of the 20x20 area. In the theoretical RF disc coverage model this is requiring a 10-coverage network throughout the site. According to [24], the number of active nodes in the network is proportional to its coverage degree. Considering a disc RF coverage model, a 10-coverage network would require more than two times of the anchor nodes comparing to a 4-coverage network. At the same time, using additional UWB anchor nodes will require only one more degree of coverage, with only around 25% increase in anchor nodes.

On the other hand, the UWB ranging modules has a much longer usable measuring range, which is around 3 times of that of the RSSI measurement. Such fact can be explained by the CRLB result in (5), in which the RSSI component (the first part) is proportional to the square level of geometry scale, while the UWB component (the second part) does not change with the scale. Therefore, UWB/ToA is able to maintain a relatively stable error range throughout its communication range. This largely increases the usable range of its measurement, and means that the number of additional anchor nodes will be even less. In fact, in [25] it has been suggested that the node number is in direct proportion to the node sense range (in our case the usable measuring range). In this case, the increase of anchor node number would be less than 10%.

Furthermore, the system's network backbone is still based on ZigBee, so we do not need the UWB nodes themselves to form a fully connected network. This means that the deployment requirement for the additional UWB anchor nodes would be 1-coverage instead of connected 1-coverage. This will further ease the number of additional anchor nodes. The exact increase in anchor node number will depend on node deployment strategy as well as the characters of the actual site map. But in theory in a round site shape with triangle node deployment, adding one additional UWB anchor node to a currently connected 4-coverage network will require roughly a 8% increase in anchor node number. Comparing to an increase of over 100% to move to a 10-coverage pure RSSI approach, using UWB-assisted approach clearly controls the network size and cost and has less complexity for system design and deployment while achieving a better localization error bound.

V. IMPLEMENTATION DESIGN AND TESTBED EVALUATION

We implement our proposed UWB-assisted localization approach on our system test bed to demonstration the feasibility of our design. The network backbone of the demonstration system is based on the NXP JN5148 ZigBee development kits. JN5148 is a low power wireless microcontroller featuring 2.4G Hz RF transceiver and other useful peripherals. In our system we have used JN5148-M00 module together with DR1048 sensor board to establish the main ZigBee network using standard ZigBee network stack. For UWB ranging measurement we have chosen the PulsON 410 module from Time domain. This is one of the few specialized UWB ranging modules that are currently available and allows full module control from standard peripheral interfaces. The P410 can work on battery and is able to provide an accurate range measurement with 2.5cm error deviation at up to 80m range in line-of-sight conditions, and less than 1m error at 30m range in non-line-of-sight conditions.

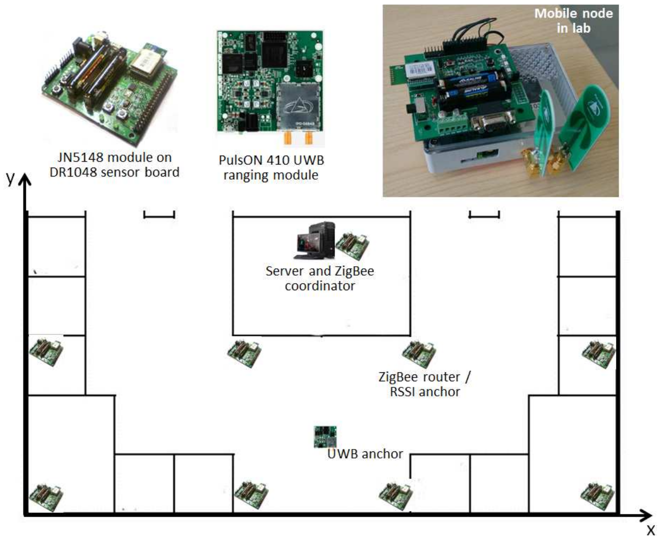

Fig. 3. The devices and demonstration system setup

The system consists of 10 ZigBee network devices. One of them is configured as the ZigBee coordinator and is connected with a server PC via RS-232 serial port. The coordinator is responsible for establishing and organizing the ZigBee network backbone. The other 9 devices are all configured to be ZigBee routers, with one of them acting as mobile target node and the other 8 as anchor nodes. The anchor nodes are deployed in a square grid pattern, with the adjacent anchor nodes separated at about 20m to cover half of the top floor area in our building.

In each localization interval, the mobile node will try communicating with the available anchor nodes nearby and generate RSSI measurement for each of them. It then chooses the 4 highest measurement and send the information back to the server PC via the coordinator, together the corresponding anchor node ids. The server calculates the estimated target coordinate based on the measurement and the anchor node locations that were preconfigured in the system. The calculation is carried out with algorithm similar to [26].

We then add the additional UWB ranging device to assist the localization. A pair of PulsON 410 is used. One module is deployed in the middle of the demonstration area to provide the coverage, while the other one is connected with the JN5148 mobile node via a 3.3V serial universal asynchronous receiver transmitter (UART) port. The JN5148 simply treats the PulsON 410 module as a ranging sensor by sending a ranging request through UART and read the result. The mobile node requests a UWB ranging once in each localization interval and sends it back to the server together with the RSSI measurements. The UWB ranging, which is considered to be much more accurate, is used to calibrate the result calculated from RSSI measurement. This is done by moving the RSSI-estimated location on the shortest line between the UWB anchor node and itself to the nearest possible point that satisfies the exact UWB ranging result. In the program this is achieved by adjust the estimate location to the following position:

$$x_0 = \begin{cases} x_u + \frac{\sqrt{|x_u - x_r|}}{\sqrt{|y_u - y_r|}} \times d, x_u < x_r \\ x_u - \frac{\sqrt{|x_u - x_r|}}{\sqrt{|y_u - y_r|}} \times d, x_u > x_r \end{cases} \quad y_0 = \begin{cases} y_u + \frac{\sqrt{|y_u - y_r|}}{\sqrt{|x_u - x_r|}} \times d, y_u < y_r \\ y_u - \frac{\sqrt{|y_u - y_r|}}{\sqrt{|x_u - x_r|}} \times d, y_u > y_r \end{cases}$$

Where (x_u, y_u) is the coordinate of the UWB anchor node and (x_r, y_r) is the estimated coordinate of the target node based on RSSI measurement. We test the system with the mobile node in different locations within the demonstration area and observed the variance of localization error when the system operates with the UWB assistant anchor node as well as without it. The result shows an average error variance of about 5.5 m^2 for pure RSSI approach and 2.8 m^2 for UWB-assisted approach, which is a significant improve. It hasn't achieved the CRLB benchmark presented in section IV. The variance of the path loss parameters in different environment could be one of reasons, and it also means that there is still potential for the hybrid localization algorithm to be further improved.

VI. DISCUSSION AND CONCLUSION

In this paper we presented part of our design of a construction site monitoring and safety monitoring system based on ZigBee wireless sensor network. We focused on the aspect of mobile target localization and introduced a hybrid UWB-assisted approach as an attempt to improve the accuracy of the original RSSI-based system. We adopt statistics model and CRLB as the tool to benchmark the localization performance. The CRLB of both pure RSSI localization and UWB-assisted localization are derived to compare two different approaches: increase RSSI anchor node density and adding additional UWB anchor node. The CRLB analysis together with the coverage analysis shows that by adding a very small number of UWB anchor node, we are able to achieve a desired CRLB that can only be achieved by doubling the anchor node number in pure RSSI approach. In addition, we implemented and evaluated our design on a real world test bed to demonstrate the feasibility of our design and evaluate the performance. The result of UWB-assisted approach shows that the localization error reduces significantly. Our future work in short term includes improving the hybrid localization algorithm to achieve accuracy closer to the CRLB result; secondly and further development of the demonstration system to make it ready for evaluation in real world construction sites.

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