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# Indoor Human Monitoring System Using Wireless and Pyroelectric Sensory Fusion System

**Ren C. Luo**, **Ogst Chen**, **Cheng Wei Lin**
Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan
E-mail: renluo@ntu.edu.tw; jchen@ira.ee.ntu.edu.tw; wezger@hotmail.com

***Abstract*—Indoor human monitoring is important for providing various services for individuals. In this research, we propose an indoor monitoring system based on wireless and pyroelectric infrared (WPIR) sensory fusion system which can be embedded and integrated with the traditional fire/smoke detector where they are usually installed on the ceiling by the use of pyroelectric motion sensor and low power wireless communication device.**

**Basically, each of radio frequency (RF) localization system and pyroelectric infrared (PIR) monitoring system provides the coarse information of individuals' location respectively. We develop a sensor network based localization method called WPIR intersection algorithm to determine the fused position from PIR and radio frequency signal localization system which utilizes received signal strength (RSS) model.**

**We have developed and experimentally demonstrated a wireless pyroelectric sensory fusion system and WPIR intersection algorithm which can be applied in multi target tracking issues against pure PIR sensing system. Furthermore, WPIR intersection algorithm provides higher accuracy than PIR or RF localization respectively.**

**With the proper localization and tracking in the indoor environment, the provisions of appropriate services for people can be realized.**

**Keyword: wireless pyroelectric infrared (WPIR) sensory fusion, pyroelectric sensor, data fusion, localization**

## I. INTRODUCTION

THE indoor location information of residents is important for HVAC (heating, ventilating and air conditioning) system, illumination, humidity control and so on. There are a lot of researches discuss the indoor localization systems[1-5], however, most of them suffer from imprecision, multiple targets tracking or expensive implementation cost.

In this paper, we propose an indoor monitoring system based on wireless/pyroelectric infrared sensory fusion system. This system integrates wireless communication module, microcontroller, smoke sensor, pyroelectric infrared and temperature sensor as new type of fire detector which can be used to substitute the original fire detector and install on ceiling. The system architecture of iSensor system is shown as Fig.1.

We design a low power wireless device, which can substitute the traditional badge/identification card (ID card) and wear on people. In the real world that the pyroelectric sensor system provides inaccurate position information and suffers from multi target monitoring. RF localization model also offers imprecision location information. The obtained location information from pyroelectric sensor and RF propagation model can be improved through WPIR system and WPIR intersection algorithm to generate a more reliable estimation of occupants, as shown in Fig. 2. According to the recognized position of people, the provision of appropriate services to the residents or individuals can be realized.

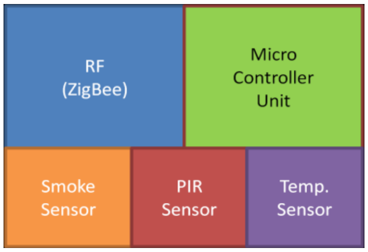

Fig. 1 System architecture of iSensor system

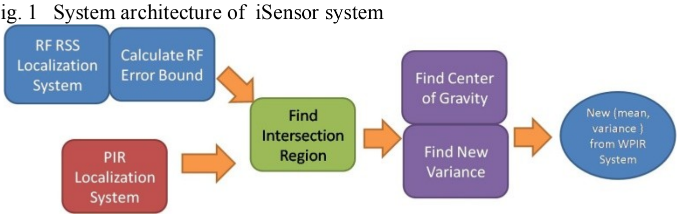

Fig. 2 Architecture of location information obtained from WPIR system

This paper is organized as follows. Section II discusses the related researches. Section III presents the hardware architecture of our system. Section IV describes the position information which obtained from radio propagation model. The wireless pyroelectric sensing system is discussed in section V. Section VI presents our experimental results. Finally, summary and conclusion are presented in section VII.

## II. RELATED WORKS

There are lots of researches discuss the indoor localization system. The researches such like Active Badges[6], Active Bats[7], and Easy Living[8], which use infrared sensors, ultrasonic sensors, and vision sensors, respectively. MotionStar[9] uses a DC magnetic tracker, and RADAR[10] uses wireless local area network for localization. Smart Floor[11] uses pressure sensors to measure proximity to a known set of points.

Table 1 is the comparison with other indoor tracking method. Active Badges[6] use inexpensive infrared sensors to transmit signals and to provide information about their location to a centralized location service through network of sensors. But infrared signals are limited by line of sight. Active Bats[7] uses ultrasonic sensors to locate the people in 3D environment, but this system suffer from multi targets localization. Easy Living[8] uses multi camera to identify the

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location of people, but limited with line of sight issues, privacy issue and high installation cost. MotionStar[9] uses magnetic sensor to locate target, however this method suffers from multi target identification and environment noise. RADAR[10] uses inexpensive radio frequency localization method to identify targets, but this system is imprecision in locating targets. Smart Floor[11] which use pressure sensors to monitoring people, however the implementation cost is expensive and suffers from multi targets localization. WPIR interaction algorithm can monitor multi targets with good resolution and installation cost is relative inexpensive.

Table 1 Comparison of localization method

| Method | Sensor Type | Multi Targets | Accuracy | Cost |
|---|---|---|---|---|
| ActiveBage[6] | IR | Good | Medium | Low |
| ActiveBat[7] | Ultrasonic | Poor | Good | Low |
| Easy Living[8] | Camera | Medium | Good | High |
| MotionStar[9] | Magnetic | Poor | Poor | High |
| RADRA[10] | RF | Good | Medium | Low |
| Smart Floor[11] | Pressure | Poor | Poor | High |
| WPIR(our development) | RF/PIR | Good | Good | Low |

## III. HARDWARE ARCHITECTURE

### A. Wireless Communication Platform

iSensor system uses CC2431 which produces by Texas Instrument. The CC2431 is a System-On-Chip (SOC) for wireless sensor networking ZigBee/IEEE 802.15.4 solutions. The chip includes a location detection hardware module that can be used in so-called blind nodes (i.e. nodes with unknown location) to receive signals from nodes with known location's. Based on this the location engine calculates an estimate of a blind node's position. The CC2431 enables ZigBee nodes to be built with very low total costs. The CC2431 combines the performance of the leading CC2420 RF transceiver with an industry standard enhanced 8051 microprocessor control unit (MCU), 128 KB flash memory, 8 KB RAM and many other features.

The CC2431 is highly suited for systems where ultra low power consumption is required. This is achieved by various operating modes. Short transition times between these modes further ensure low power consumption.

### B. Pyroelectric Sensor Module

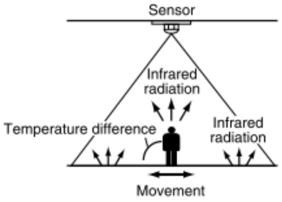


Fig. 3 The operation of pyroelectric motion sensor

Fig. 3 shows that pyroelectric sensor detects changes in infrared radiation which occur when there is movement by a person (or object) which is different in temperature from the surroundings. As this sensor detects temperature differences, it is well suited to detect the motion of people by their body temperature.

### C. Wireless Pyroelectric Sensor System

In this work, we develop iSensor system with CC2431, PIR sensor, temperature sensor and fire/smoke detector which can be integrated as one device as shown in Fig. 4. The design principle can be found in [13].

Fig. 4 The experimental platform integrated with CC2431 and pyroelectric sensor

### D. Wireless Identification Card System

Monitoring people in the indoor environment, a wireless transmission device is required for WPIR sensing system. With this device, the location information can be obtained through radio frequency propagation model and triangulation method. The identification card in WPIR system is a ZigBee/IEEE 802.15.4 transceiver. The ZigBee protocol can provide unique ID for each device in the same ZigBee environment and can be used to track multiple targets.

(a) (b)

Fig. 5 (a) Identification card (b) Wear on human

## IV. RADIO FREQUENCY LOCALIZATION SYSTEM

Received signal strength (RSS) is defined as the voltage measured by a receiver's received signal strength indicator (RSSI) circuit. Wireless sensors communicate with neighboring sensors, and RSS of RF signals can be measured by each receiver during normal data communication, without additional bandwidth or energy requirements. Since RSS measurement is relatively inexpensive and easy to implement in hardware, they are an important and popular in localization research.

### A. Statistical Model

The mean received power in a real world, obstructed channel decays proportional to $d^{-np}$, where np is the path-loss exponent, typically between 2 and 4 [14]. The mean power at distance d is modeled as

$$\overline{P}(d) = \pi_0 - 10 n_p \log \frac{d}{\Delta_0} \quad \text{(III-1)}$$

where $\Delta_0$ is the received power (dBm) at a defined reference distance $\Delta_0$. The difference between a measured received power and its average, due to the randomness of shadowing, is modeled as log normal. The log normal model is based on a wide variety of measurement results [15-17] and analytical evidences [18].

### B. Cram´er Rao Bound Formulation

The Cram´er-Rao (CRB) bound provides a means for calculating a lower bound on the covariance of any unbiased location estimator which uses connectivity RSS method. Such a lower bound provides a useful tool for researchers and system designers.

The CRB can be used as a benchmark for researchers who are testing localization algorithms and the bound's functional dependence on particular parameters helps to understand the behavior of cooperative localization.

A detailed derivation of the CRB is provided in [19]. The most important advantage of the CRB is that the lower bound on estimation variance can be calculated without ever considering a single estimation method. All that required is to calculate a CRB in the statistical model of the random measurements, i.e., $f(X|\theta)$, where X is the random measurement, and $\theta$ are the parameters that are to be estimated from the measurements. Any unbiased estimator, $\hat{\theta}$, must satisfy,

$$Cov(\hat{\theta}) \geq \{E[-\nabla_\theta(\nabla_\theta \ln f(x|\theta))^T]\}^{-1} \tag{III-8}$$

where $Cov(\hat{\theta})$ is the covariance of the estimator, E[·] indicates expected value, $\nabla_\theta$ is the gradient operator with respect to the vector θ, and superscript T indicates transpose.

## V. WIRELESS PYROELECTRIC SENSOR INTERSECTION ALGORITHM

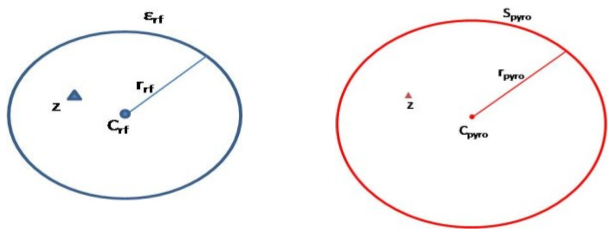
### A. Single Target Localization in WPIR System

The coordinates of WPIR sensors and PIR sensing region can be obtained when they are installed. The location of target can be estimated through RSS technology and pyroelectric sensors respectively. For radio frequency localization, we adapt ZigBee/CC2431 protocol chip which can generate device identification information within wireless packets. These ZigBee packets help on identifying targets.

Since the measurement from RF signal exist noises, the estimation will be distributed within a certain range, and we denoted as $\varepsilon_{rf} = \{z \in c \,|\, |z| \leq r_{rf}\}$. Here $\varepsilon_{rf}$ is probable region of target and can be obtained from CRB function, $r_{rf}$ is the trace of error region, $C_{rf}$ is the estimated coordinate and z is possible location of target.

For pyroelectric sensor localization model, while pyroelectric sensor turns "on" which means there is pedestrian in the pyroelectric sensor detection region and illustrated in Fig. 6(b).

$S_{pyro} = \{Z \in c \,|\, |z - c_{pyro}| \leq r_{pyro}\}$ $S_{pyro}$ is the detection region of pyroelectric sensor, $r_{pyro}$ is radius of detection region, $C_{pyro}$ is the location of pyroelectric sensor and z is the possible location of pedestrian. Any detection of pedestrian for this PIR sensor will report the coordinate of this sensor.



(a) (b)

Fig. 6 (a)RF error bound (PIR sensing system)

The estimated coordinate reported from WPIR sensor can be represented as shown in Fig.7. When pyroelectric sensor turns "on", and RF localization system reported coordinate around this PIR sensor which means there might have intersection region happen and can be represented as $o = \{z \in c \,|\, |Z - C_{pyro}| \leq r_{pyro} \cap |Z - C_{rf}| \leq r_{rf}\}$ , Fig.7 illustrated this concept and shaded region O is intersection region. The new covariance of this intersection area can be obtained from CRB bound function. And new mean $C_o$ of this intersection region can be obtained through center of gravity (CoG) equation (IV-1).

$$c_o = \frac{\iint_o z\,dxdy}{\iint_o 1\,dxdy} \tag{IV-1}$$

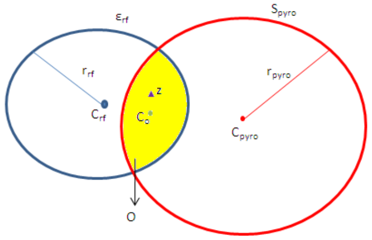
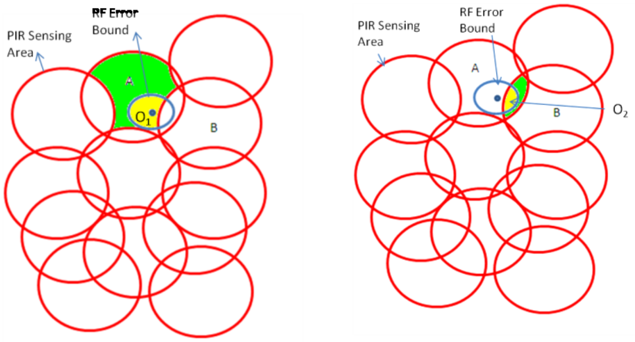


Fig. 7 Find CoG from WPIR System

Combined with RF and PIR sensor localization system, the reported coordinate of target will approach real target than RF or PIR sensor localization system and error bound are also be reduced. We will obtain new estimation with mean and covariance from WPIR intersection algorithm

We implement wireless pyroelectric sensor localization system in indoor environment and deploy as random installation as shown in Fig. 8. If target approaches the region of AB, and PIR sensor localization system report that the target is in region A, the possible region of pyroelectric sensor A is marked by green area, and RF localization reported possible coordinate with error region will be intersected as new possible coordinate with error region as $O_1$. Otherwise, the PIR sensor A and B both report with "ON" signal which means the target is in overlap area of AB as shown in Fig. 8 (b) green marked region, the wireless pyroelectric localization system will report new intersection region with estimated coordinate as $O_2$ in Fig. 8 (b). The accuracy can be improved in both cases for standalone pyroelectric or RF localization system respectively.

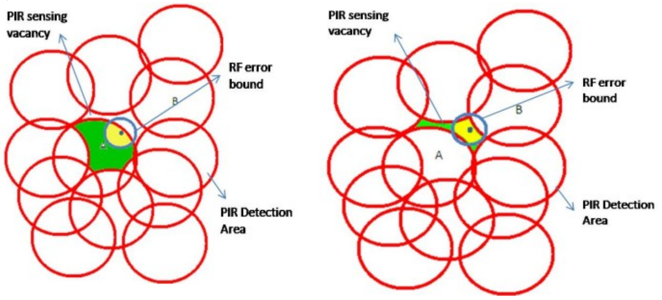


(a) (b)

Fig. 8 Random deployment for WPIR system

The WPIR system also operates if PIR sensing areas are not in full coverage situation. These vacant zones can be calculated after WPIR sensors are installed because the detection area and location of PIR is known. Fig. 9(a) is showed that RF reported coordinate around the sensor A. and no other sensors reported target is found. It can be claimed that the target is in the sensor A, and then find the intersection area and CoG of the overlap region to obtain new estimation.

Fig. 9(b) is showed that based on previous reported information of target, if there are no any PIR sensors find the target, it can be claimed that the pedestrian is in the PIR sensing vacant region, and then use this vacancy to make intersection with RF reported position and error ellipse to find the WPIR system reported coordinate and error region. Therefore, we make a conclusion that sensing vacancies are also beneficial for accuracy improvement in WPIR sensing system.



(a) (b)

Fig. 9 Sensing vacancy localization for WPIR sensing system

If boundary conditions of environment are known, the boundary is also beneficial to improve the accuracy of human localization. Fig. 10 illustrated this situation, when targets are detected by PIR localization system and RF error ellipse take intersection as yellow shaded area. It can be found that the imprecision of RF error bound is reduced by WPIR intersection method. Fig. 10 illustrated that when only PIR sensor B reports "on", the error bound of RF will be reduced as yellow region in Fig. 10 and find the CoG of this area as new estimated coordinate of target.

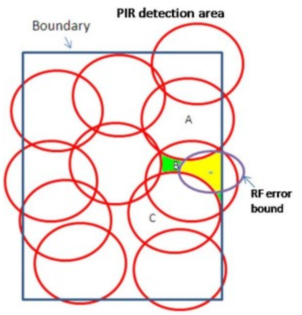
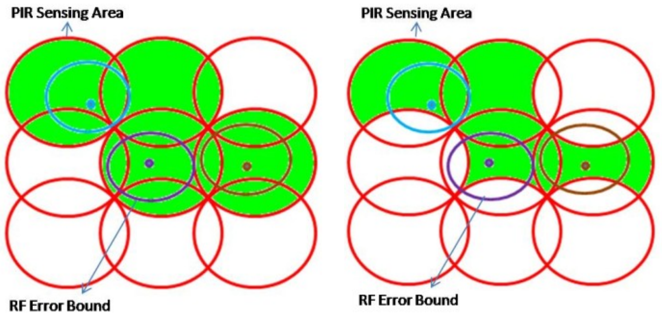


Fig. 10 Boundary condition for WPIR sensory fusion system

### B. *Multi Target Tracking Strategy in Wireless Pyroelectric Localization System*

WPIR localization system also helps on multi target tracking (MTT) issue. In wireless pyroelectric localization system when targets approach in adjacent pyroelectric sensing region, the multi-target tracking strategy will be turned on.

As shown in Fig. 11 (a), when three RF targets and four pyroelectric sensors reported "ON" in the testing field. For the same reason as "reported pyroelectric less than or equal to RF targets", there is obviously no target in the leaf-shape intersection of reported pyroelectric (green circle area) area and non-reported area (white area) of adjacent sensor. Thus the possible region of three targets can be reduced as shown in Fig. 11(b). Final result is shown as Fig. 12(yellow area), the system will use the reduced RF error bound to obtain new estimation with mean and covariance.



(a) (b)

Fig. 11 (a)Reported PIR more than RF targets (b) Eliminate impossible regions

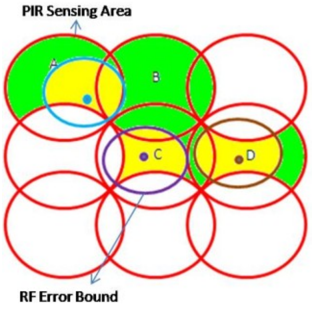


Fig. 12 Reduced RF error regions for multi targets

## VI. EXPERIMENTAL RESULTS

The experimental setup with investigation area is 30mx30m. The prototype of wireless pyroelectric sensory system is installed on the ceiling. The red circles indicate the sensor units in Fig. 13. 16 sensors are placed at the specific position for primarily test.

Testing target walk pass through the WPIR monitoring region and the reported trace by PIR tracking system are as shown in Fig. 14. The mean square error of PIR tracking system is 1.76m.

Fig. 13 Experimental setup

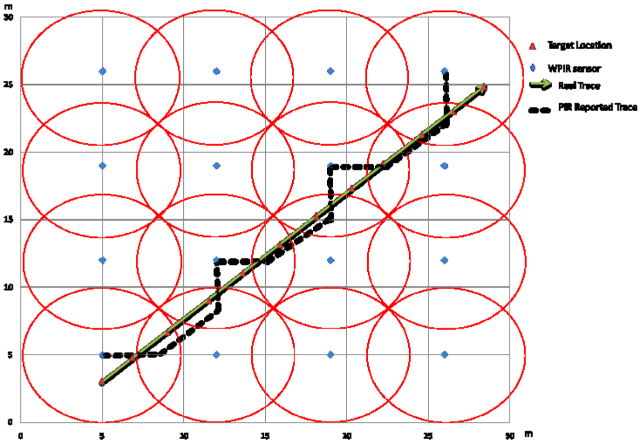


Fig. 14 PIR reported result for human pass through monitoring region

The blue diamonds in Fig. 14 are WPIR sensor positions and locations are known. The green solid line is real trace for testing target, black dash line is the reported trace from PIR sensing system.

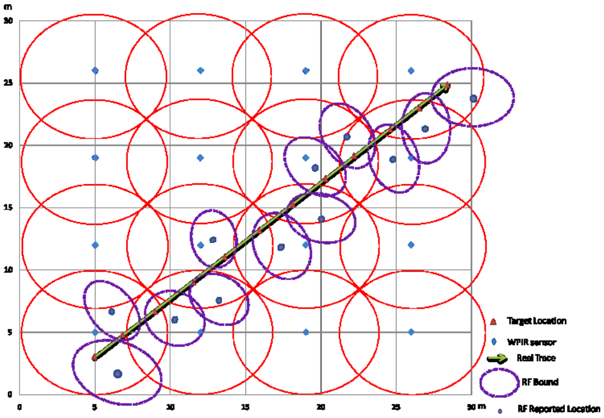


Fig. 15 WPIR reported result for human pass through monitoring region

Fig. 15 is the RSS localization system reported position. The purple circles are the reported location from RSS localization mechanism, dash purple ellipse is the error bound of reported RSS location, and mean square error of RSS system is 2.16m. The star marks in Fig. 16 are the calculated target position from WPIR intersection algorithm. The mean error is 0.97m

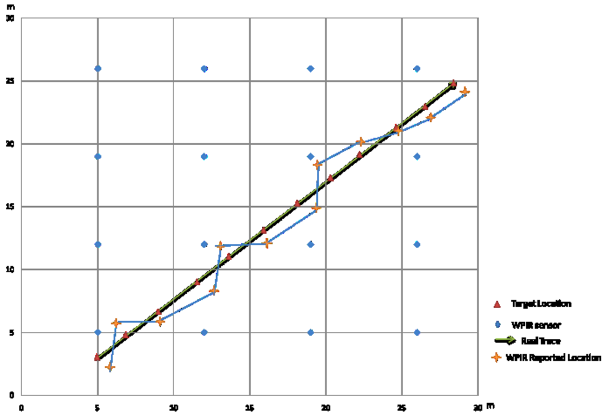


Fig. 16 RF reported result for target moving around the monitoring region

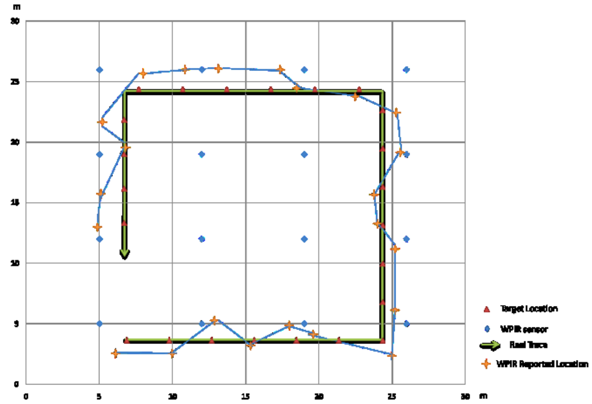


Fig. 17 WPIR tracking result for target moving around the monitoring area

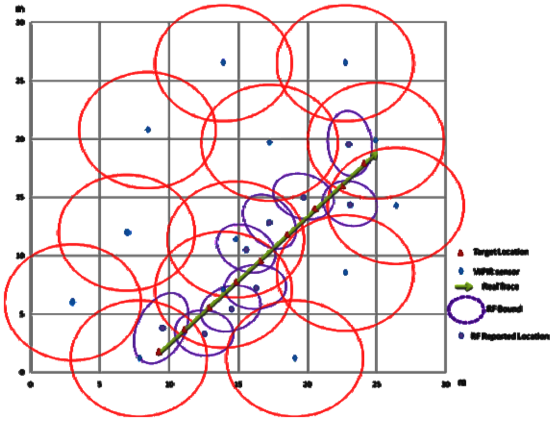


Fig. 18 RF reported result for random WPIR sensor deployment

Next, we test human move around the monitoring region, the mean errors for PIR and RF system are 1.82m and 2.08m respective. The represented symbols are the same as mentioned above. Fig. 17 is the reported result from WPIR system and mean error is 0.82m. It is quite good improvement for WPIR tracking system.

We also test random deployment for WPIR tracking system as shown in Fig. 18. There are sensing vacancies for PIR monitoring system around (12,17) and (20,15), therefore the mean error for PIR monitoring is not evaluable. In this scenario, mean error for RF localization system is 2.12m. The mean error for WPIR monitoring system is 0.85m as shown in Fig. 19.

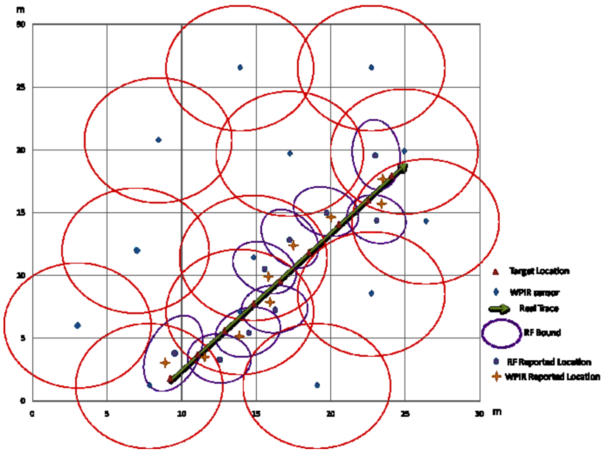


Fig. 19 WPIR reported results for random WPIR sensor deployment

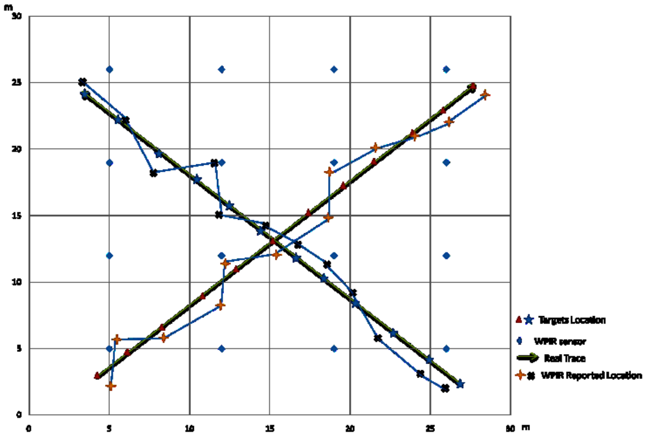


Fig. 20 WPIR tracking result for multi target tracking

Fig. 20 is multi-target tracking experimental result, PIR sensing system cannot operate, and mean error for RSS localization system is 2.21m. WPIR intersection algorithm for multi-target tracking system error is 1.03m.

## VII. CONCLUSIONS

Indoor human tracking is important for providing services for people. However, indoor human tracking method is still a problem for office, factory or home service. PIR monitoring system suffers from multi target identification and radio frequency localization system is notorious for its imprecision.

In this research, we develop wireless pyroelectric sensing system which integrates with wireless module, microcontroller, PIR sensor, temperature sensor and fire/smoke detector as iSensor device. iSensor can be used to install and substitute original fire/smoke detector on ceiling. We also develop WPIR intersection algorithm for locating pedestrians. We test several scenarios such as regular deployment, random deployment, sensing vacant region, boundary effect, single and multi target. WPIR intersection algorithm provides high accuracy than PIR or RF localization respectively.

The integrated WPIR fire detector can be implemented on ceiling for human tracking or other sensor network applications. With information obtained from WPIR monitoring system, various services can be provided to residents.

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