Indoor Localization System for Lighting Control

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Abstract – The **localization of people and objects in different environments is an essential prerequisite for many applications in navigation, robotics, machine control and monitoring. The limiting factor for many applications is the indoor environment in which the Global Satellite Systems work only partially or cannot function at all.**

Currently radio frequency (RF) based methods are being increasingly implemented for indoor localization. They are relatively inexpensive to install, and are less subjected to the line-of-sight limitations affecting a significant number of other methods.

The research presented in this paper aims to evaluate the possibility for using relatively low-cost and easily expandable RF-based localization techniques for lighting control in warehouse environments. The implementation of the localization system utilizes the RSS of a ZigBee-based sensor network.

Keywords – **Indoor localization, RSS, ZigBee, energy saving, lighting control.**

I. Introduction

The task of locating and navigating people and devices in indoor environments is becoming increasingly relevant in solving different problems in the field of automation.

The global satellite positioning systems have excellent performance for outdoor positioning, but a rising number of applications require good localization capabilities in all sorts of environments. So, indoor localization has become a focus of research and development over the last two decades. Following the logic of satellite navigation development, currently efforts are being focused on improving service quality of indoor environments. Improving the quality and safety of indoor localization and navigation has the potential for opening many new capabilities in the field of automation and energy saving technologies.

Although a number of basic principles of localization and navigation can be used both outdoors and indoors, essential differences between these two environments lead to significant differences in significant differences in the way they perform.

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Major challenges to indoor localization and navigation are:

- rapid environmental changes due to the presence of people and transport vehicles
- multipaths due to reflections from walls, ceilings and equipment
- Non-line-of-Sight (NLoS) conditions
- Fast changing signal attenuation and scattering due to the changing density of objects (especially in warehouse environments)
- High precision needed for some applications.

There are also some aspects which facilitate the indoor localization:

- restricted spaces
- constant geometrical constraints by which a reduction in the accuracy requirements can be achieved
- less strict requirements for the dynamic parameters of the system due to the lower speed of operation in indoor spaces
- Negligible or no impact produced by unfavorable weather effects [1].

Numerous studies indicate that, unlike the outdoor localization and navigation in indoor environments, there is no universal solution based on a dominant technology [1, 2, 3]. Modern systems typically require specialized infrastructure including fixed base stations and mobile nodes.

In a detailed investigation Mautz divides the approaches for indoor positioning into 13 main groups in terms of accuracy, coverage and measuring principle (Table 1). The majority of technologies are based on electromagnetic waves and only a few ones - on mechanical (ultrasound) waves. Here the connection between systems using shorter waves and achieving higher accuracy results is clearly observed [1, 2].

TABLE 1. OVERVIEW OF INDOOR POSITIONING TECHNOLOGIES [1].

	Technology	Typical Accuracy	Typical Coverage (m)	Measuring Principle
1	Cameras	0.1mm	1 – 10	angle measurements from images
2	Infrared	cm – m	1 – 5	thermal imaging, active beacons
3	Tactile & Polar Systems	μm – mm	3 – 2000	mechanical, interferometry
4	Sound	cm	2 – 10	distances from time of arrival
5	WLAN / WiFi	m	20 – 50	fingerprinting
6	RFID	dm – m	1 – 50	proximity detection, fingerprinting
7	Ultra Wideband	cm – m	1 – 50	body reflection, time of arrival

8	High sensitive GNSS	10 m	'global'	parallel correlation
9	Pseudolites	cm – dm	10 – 1000	carrier phase ranging
10	Other Radio Frequencies	m	10 – 1000	fingerprinting, proximity
11	Inertial Navigation	1 %	10 – 100	dead reckoning
12	Magnetic Systems	mm – cm	1 – 20	fingerprinting and ranging
13	Infrastructure Systems	cm – m	building	fingerprinting, capacitance

Currently radio frequency (RF) based methods are being increasingly implemented. They are relatively inexpensive to install and are subjected to a lesser degree to the line-of-sight limitations that affect a significant number of other methods.

By the RF technologies the most frequent positioning principle uses the measurement of the strength of the received signal (RSS) [1, 8]. Such RF based approaches assume that there are some fixed nodes with known location which act as beacon points in order to localize other mobile nodes with unknown location.

The research presented in this paper aims to evaluate the possibility for using relatively low-cost and easily expandable RF-based localization techniques for lighting control in warehouse environments. The implementation of the localization system utilizes the RSS of a sensor network based on the ZigBee standard.

II. Reasons for the Implementation of Lighting Control System

The systems for indoor localization and navigation are already used for the optimization of logistics solutions and transportation tasks in complex warehouse environments.

In this work a more specific application related to energy-efficient lighting control in warehouses is considered. According to the proposed solution, illumination levels in the different warehouse zones are controlled depending on the presence or absence of vehicles or operators in the corresponding areas.

In storage environments with conventional lighting control, lighting is usually left on permanently, regardless of whether logistics activities are performed or not in the warehouse area. This leads to unnecessary energy expenditure for lighting.

For assessing the energy saving potential for lighting, statistical data are used for the energy consumption of one square meter of storage area [13]. Further assessment has been carried out for establishing the typical percentage values of the activity-occupied warehouse area in relation to the total warehouse area by means of the multi-moment observation technique for activity sampling [4]. For this assessment a simplified model of the storage environment has been used (fig.1).

On the basis of multi-moment observations for activity sampling, it is possible to determine with a statistical accuracy of 95% that the percentage of areas occupied by logistics activities most often fluctuates within the range of 35-40%. Only rarely (<10% of the performed observations) are the achieved levels within the range of 60-65%. Even if we take this worse case scenario as a basis for calculations, it can be assumed that the potential for energy saving is definitely over 35%. A number of recent studies show that the installation of sensors and high efficient lighting systems can save between 30-70% on electricity consumption for lighting [13].

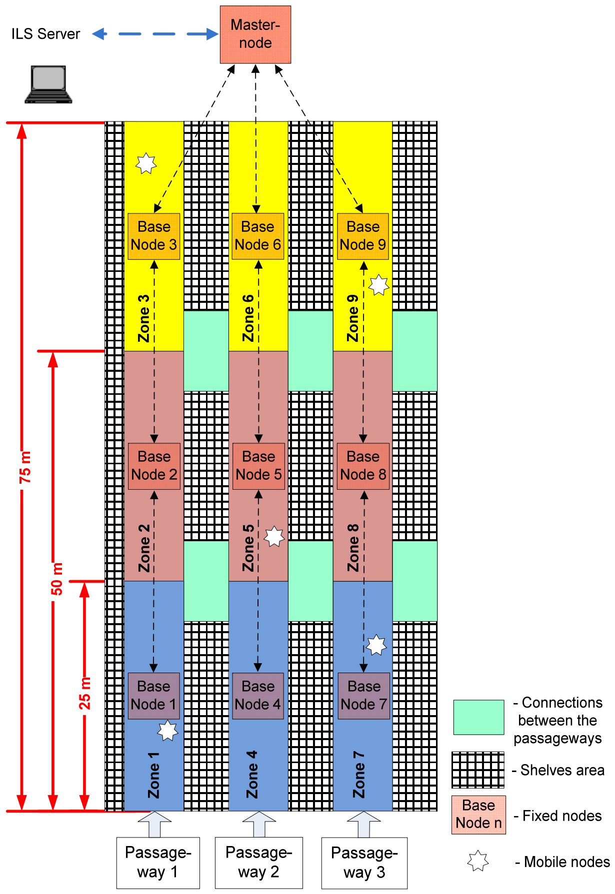

Fig. 1. Model of the storage environment for the multi-moment activity sampling

In other words, typical lighting costs of 3-3.5 euros/m^2 per year will get a potential lighting cost saving in the range of 1-1.25 euros/m^2 per year. For example, for a typical warehouse of about 10 000 m^2 the saving potential will be in the range of 10-12,000 euros, and will steadily increase with the rise of electricity prices. These considerations are also important for the selection of appropriate technology for solving the problem of localization, which is discussed in the next chapter.

III. Localization System Architecture

We use a location estimation technique using RSSI in a ZigBee standard based sensor network.

An approach has been chosen where in each passageway between the storage racks a number of fixed sensor nodes with known positions are mounted. With these the location of the mobile nodes can be determined.

The mobile node is a wireless device which sends packets to the neighboring fixed nodes in the relevant zone and also in the neighboring zones. These fixed nodes measure the received signal strength (RSS) and send the data to the master node. There are usually many mobile nodes and that is why each data packet also contains the corresponding mobile node ID. The master node forwards the data to the Indoor Location Server (ILS), which estimates the position of the mobile node.

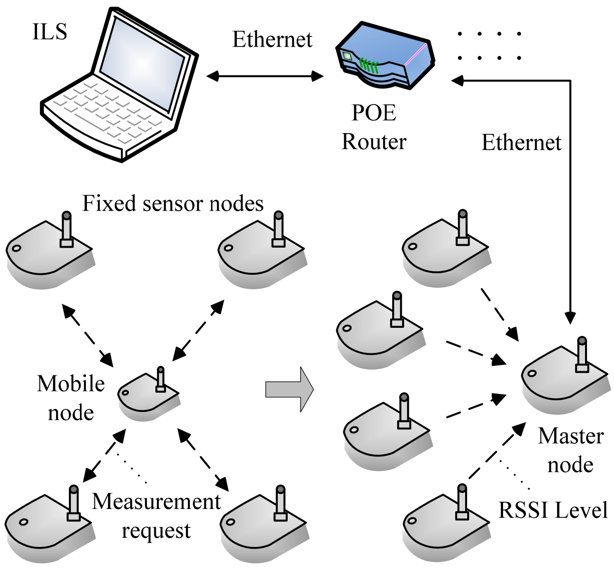

Fig. 2. Localization system based on RSS measurement in a ZigBee sensor network

A. Fixed sensor nodes placement

In this configuration one fixed receiver for each zone is provided. Depending on the accuracy required for the positioning and additional requirements of the particular task, the size of the zone can be chosen. In this implementation the requirements for localization accuracy are comparatively low, and this is why areas with an approximate length of 25 m and a width of about 2.5 m have been selected.

B. Data collection

This system aims to perform position estimation using only information from sensor nodes of a certain constant number. The threshold value of RSSI is set for each sensor node. Then a sensor node transmits a packet to the master node only when the received signal from a mobile node exceeds this value. In this way, the quantity of transferred data can be controlled by changing this threshold value.

The following two kinds of messages exchanged in this system have been defined:

- Messages for requested measurement

These are messages for the need of measuring the received mobile node signal which has been sent to the fixed sensor nodes. The message is then transmitted by broadcasting. To identify the measurement request a sequence number is included in the message.

- Messages for received signal strength

These are messages for reporting RSSI to a master node from the fixed sensor node. They contain the ID of the mobile node and sequence number.

IV. Localization System Implementation

A. Hardware

The all nodes have been implemented based on PINGUINO-OTG. The main features of this hardware module are:

- PIC32MX440F256H 80 MHz microcontroller
- 256KB Flash and 32KB RAM
- Li-Ion rechargeable battery power supply option with build in on board charger
- Reliable work in industrial temperature range.

All devices (fixed, mobile and master nodes) have been implemented based on the ZigBee MRF24J40MA module. MRF24J40MA is a 2.4 GHz IEEE 802.15.4 radio transceiver module. It has an integrated antenna and supports ZigBee and MiWi protocols. The module has a 4-wire SPI interface and it can be connected to the PIC32-PINGUINO-OTG through the UEXT connector.

Because the mobile node is battery powered, the connection with fixed node is not established continuously. Few times in a second, the mobile node is trying to connect with fixed node, and sends its ID, a sequence number and RSSI level. Then it is going in sleep mode.

Fixed sensor node contains two MRF24J40MA modules, one for connecting with the mobile node, and other to connect with master node, and previously fixed sensor nodes. Both modules work continuously. They give also additional information for their state, so if there are problems with some fixed sensor node, they can be found.

In the master node have been added one Ethernet controller with SPI interface ENC28J60, and has its own IP and MAC address. It takes data from attached fixed sensor nodes, and sends it to ILS through Ethernet. The node can be powered using standard wall adapter, or via Ethernet, using build in “Power over Ethernet” (PoE) function (TPS23750). PoE provides both data and power connections in one cable, so the equipment does not require a separate cable for each need [14]. The device consumes very little power, and is classified in Class 1 - very low power device, with consumption of 0.44 to 3.84W.

B. Software

There are two main families of RF based algorithms: range-free ones and range-based ones. Range free algorithms need no prior knowledge of the level of the received signal strength. By contrast, range-based algorithms need an initial calibration for beacon signal strength and location. Range-based algorithms are further divided into several categories, the principal ones being RSSI map-based and path-loss model-based algorithms [6, 7, 8, 10].

By the localization system implementation we use the RSSI map based algorithm. For the position estimation the following procedure is used:

- The fixed sensor nodes are arranged in the warehouse area and their positions are saved in a database on the ILS-Server. The threshold values for the RSS are set to each sensor node.

- A message for measurement request is transmitted to the fixed sensor nodes from a given mobile node.
- Each sensor node measures the RSS by receiving the message for measurement request. If the RSSI exceeds the previously defined threshold value, the fixed sensor node transmits the mobile node ID to the corresponding master node.

A typical method using RSSI mapping is the k-nearest neighboring training based algorithm. In the kNN algorithm, a data set of fixed node RSS values at different sample points is used to train the algorithm and to get the RSSI signature map [9, 12].

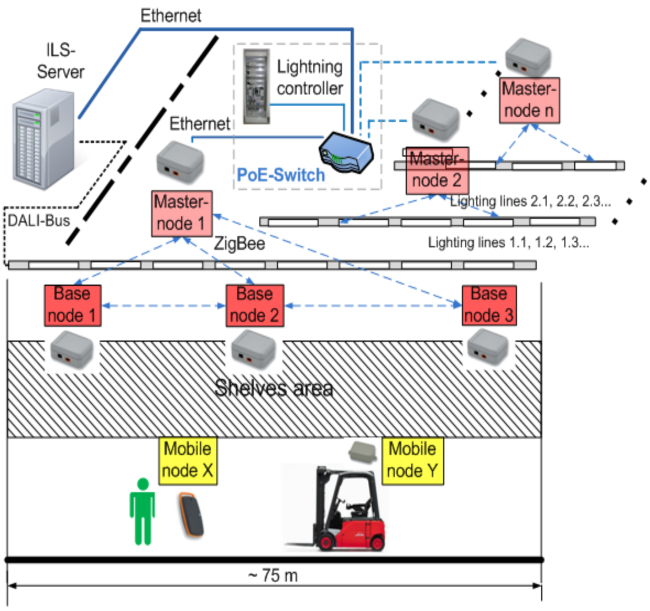

Fig. 3. Overview of the localization system main components

V. Conclusion

In this paper we have proposed a localization system using RSSI in a sensor network based on the ZigBee standard has been implemented.

The system was tested in a real site with over 8,000 m^2 warehouse space. Tests have been conducted for over 2 months. They confirm the supposed potential energy saving potential of over 40% and that the choice of the implementation technology was suitable.

The relatively low cost of radio frequency applications and their strength in overcoming limitations of other techniques suggests that the RSSI based equipment and algorithms are suitable for indoor localization applications, such as lighting control.

The test results have shown that it is necessary to take steps to streamline communications between the fixed sensor nodes to ensure a long-term stable operation of the system.

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