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A RFID-based Personal Navigation System for Multi-Story Indoor Environments

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***Abstract*—In this research, an active RFID-based personal navigation system for multi-story indoor environments is proposed. Without using complicated three-dimensional positioning algorithms, we employ an existing two-dimensional positioning engine and equip the system with the capability of seamless positioning handoffs between different floors. The handoff process is triggered by monitoring the received signal strength indicator (RSSI) value observed by the RFID reader deployed in the stairway. The usefulness of the proposed system is verified by conducting an experiment in a campus building. What distinguishes our work from other related works is that we focus on the capability of seamless positioning handoffs between floors, whereas none in the literature mentioned this feature, which we regard as a key to improve user experiences.**

Keywords-positioning; handoff; RFID; navigation; RSSI

I. INTRODUCTION

Radio Frequency Identification (RFID) technology has been a very important building block for a great variety of applications that ease our daily life, far beyond its initiative purpose of sheer identification. Payments for public transportations and in convenient stores, home/hospital health care, asset management/tracking, and museum/expo navigations, are only a few common examples that massively incorporate RFID technology in their respective systems. It is also foreseen that RFID is one of the key enabling technologies in the developing Internet of Things (IoT) industry [1], which connects the real world to the Internet.

To support most of these applications, the position of the tracked person or object must be identified. For example, assume that in a museum navigation system, visitors are equipped with both active RFID tags and smart phones. Visitors can be guided to follow a suggested itinerary displayed in the interactive map on their smart phones. Whenever a visitor approaches a specific exhibit, the smart phone automatically begins to play a multimedia introduction to this exhibit. Once a visitor gets lost in the museum, he/she can find the way easily also by looking at the interactive map, which shows not only his/her current location, but also the directions to the exit. Many similar navigation/tour guide systems have been proposed in the literature, such as [2], [3], [4], [5], to name a few. These prototype systems focus on the design of combining RFID and smart devices such as PDAs or mobile phones, however we found that none takes into account the condition of multi-story buildings as the fields of deployment.

To get closer to the real fields of deployment and to improve user experiences in using navigation systems, in this research we consider a multi-story indoor environment and highlight the need for *seamless positioning handoffs* when a user walks upstairs or downstairs in the environment. By seamless positioning handoff we mean that whenever a user walks upstairs or downstairs to another floor, the navigation system shall automatically detect the behavior and then switch the floor plan shown on the smart device. In our previous work [6], the idea of seamless positioning handoff is applied to a heterogeneous positioning system combining both GPS and RFID technologies, in which users switch their locations between outdoor and indoor environments. However we envision that a sound personal navigation system shall provide seamless positioning handoff not only between indoors and outdoors, but also between different floors in an indoor environment. Therefore, we extend our work to support seamless positioning handoff in a multi-story indoor environment.

To achieve the goal, we take the approach of utilizing an existing RFID-based RTLS development platform [7] as the two-dimensional (2D) positioning engine to locate the users on each floor, and then designing the mechanism for positioning handoffs between floors. Albeit in the literature a number of RFID-based three-dimensional (3D) indoor positioning algorithms have been developed (e.g., [8], [9], [10], [11]), the capability of 2D positioning plus positioning handoff suffices for the purpose of personal navigation, while most 3D positioning algorithms are mainly for locating an object in 3-dimensional spaces such as a storage room, shipping container, or coal mines. In the field of our experiment, we deploy several RFID readers on two floors and one reader in the middle of the stairway. By monitoring the *received signal strength indicator* (RSSI) of specific RFID tags carried by the users, the navigation system is aware that the users are in vicinity of the stairway. Specifically, when a user is approaching the stairway, the RSSI of the tag will climb over a predefined threshold. If this condition is met and the mode of handoff is set to be "automatic", then the floor plan displayed on the mobile device will be replaced by the one which the user is heading to; if the mode of handoff is "manual", then the navigation

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system will prompt the user for confirmation of positioning handoff.

The rest of this paper is organized as follows. In Section II we will describe the related work. The design of our personal navigation system is shown in Section III. The experimental study of this application is then shown in Section IV. The conclusions of this work are presented in Section V.

II. RELATED WORKS

In this section, we review some related works for the purpose of personal navigations and tour guides. We discuss their main features along with the differences compared with our work.

Wang *et al.* [2] proposed a framework for museum guide systems consisting of RFID and handheld devices. In their demo system, visitors carry a PDA with a plug-in Compact Flash (CF) RFID reader, which is able to read the passive RFID tags attached to the exhibits. After reading the tag, the PDA then shows text, pictures, with audio explanation about the specific exhibit. Deguchi *et al.* [3] proposed a "SoundSpot" audio guide system for museums. The system features a speaker array that can transmit necessary acoustic information to persons only within specific spaces and not to those within other spaces in quiet locations. In their implementation, active RFID technology is used to track the position of moving users.

Kuo *et al.* [4] discussed various aspects with regard to applying RFID technology to the U-Museum project carried out in the National Palace Museum, Taiwan. When a visitor with the U-Museum Card (RFID tag embedded) is detected in front of an exhibit, the handheld device can provide multimedia content or e-learning courses to the visitor. The RFID tags are also attached to the outer of positive films in the image archive so that a specific film can be found easily. The work proposed by Huang *et al.* [5] takes the same approach as in [2], where users hold PDAs with RFID readers. What distinguishes their work from the others is that a recommendation system based on the collaborative filtering method is included in [5]. By gathering the information about what the visitors have viewed, the system can therefore recommend the visitors more related exhibitions.

Apart from the above, the Nokia Research Center also demonstrated an indoor navigation system in the Nokia World 2010 [12]. By deploying positioning beacons in the indoor environment, the positioning result can be accurate to 30 cm. However, they did not reveal the technological details regarding what the beacon is and the number of beacons needed to achieve the accuracy. Nevertheless, on the fact that Nokia has also devoted to the research of indoor navigation service, the value of our work is justified to be promising.

In summary, those approaches using the passive RFID technology have the advantage of low cost. However, due to the very limited range of detection of passive RFID, it is less desirable to be used in personal navigation systems which shall be able to track a person throughout the itinerary. On the other hand, although deploying the active RFID technology costs more, it eliminates the need of getting necessarily close to the reader or tag in order to be detected. We believe that as the technology of active RFID gets more popular, the drawback of its higher cost will mitigate. As a result, in our personal navigation system we also use the active RFID technology. What distinguishes our work from all the others is that we focus on the capability of seamless positioning handoffs between floors, whereas none of the above related works mentioned this feature, which we regard as a key to improve user experiences.

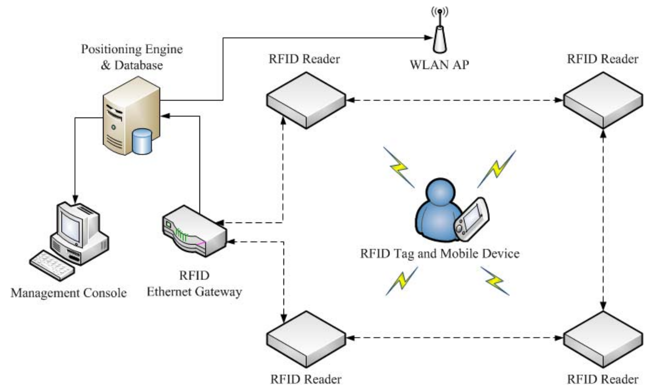


Figure 1. Schematic diagram of the proposed personal navigation system.

III. THE PROPOSED PERSONAL NAVIGATION SYSTEM

A. System Architecture

The schematic diagram of our personal navigation system is shown in Fig. 1 and is described as follows. In the navigation system, a user carries an active RFID tag and a mobile device, respectively. The RFID readers deployed in the building receive the radio frequency (RF) signals of the active RFID tag and then send the RSSI values to the positioning engine through the IEEE 802.15.4 (ZigBee) wireless interface. On receiving these data, the positioning engine then uses its positioning algorithm to compute the user's real-time indoor coordinates. In our prototype system, we use the positioning engine developed by Rifartek [7]. It is a real-time localization framework based on the RSSI and calibrated by object moving patterns. Once the position of the user is determined, the mobile device carried by the user can display the floor plan with the pinpointed user location. Here we use a lightweight laptop computer as the mobile device. It is expected that in the near future iOS-based and Android-based smart phones will be embedded with RFID tags, therefore users in the navigation system no longer need to carry multiple devices.

Whenever the user is in proximity to the stairways, the graphical user interface in the mobile device will either prompt the user to confirm the positioning handoff to another floor, or perform the positioning handoff automatically, depending on the user's preference. After the positioning handoff, the display on the mobile device will switch to the floor plan where the user is heading to. More details regarding positioning handoffs are described in the following sub-section.

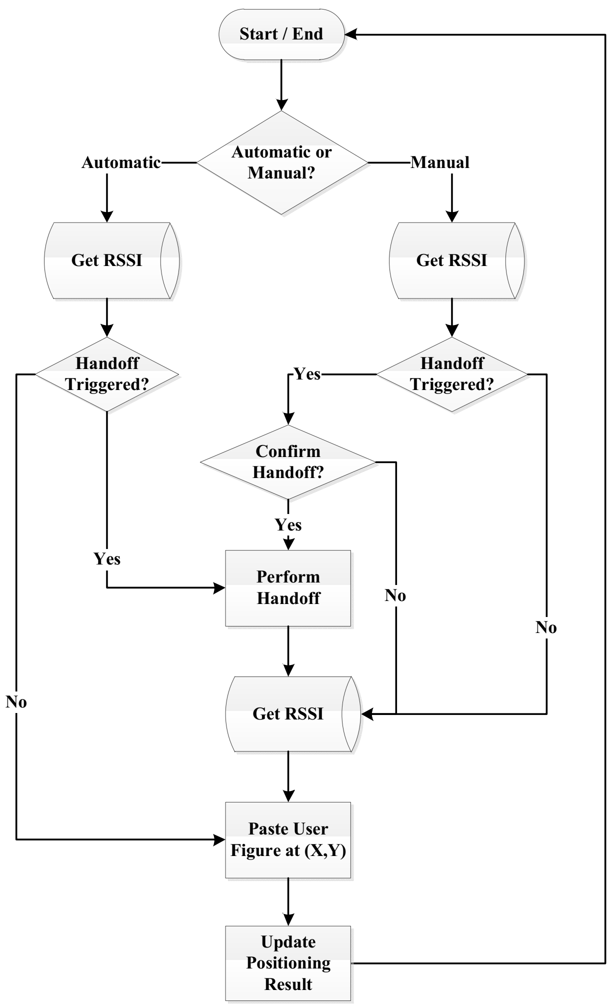


Figure 2. Flow chart for handling positioning handoff.

B. *Handling Positioning Handoffs*

The main focus of this research is that we consider a multi-story indoor environment and try to accomplish the goal of seamless positioning handoffs when a user walks upstairs or downstairs in the environment. To achieve this, we deploy RFID readers not only on the floors, but also in the middle of the stairways. For those RFID readers deployed in the stairways, the received RSSI values serve two purposes: 1) for the positioning engine to compute the indoor coordinates; 2) for the application logic to detect the event of users in proximity to the RFID readers.

As pointed out in [13], RSSI is a promising indicator when its value is above the sensitivity threshold (e.g., –87 dBm for TI's CC2420 chip). A large number of positioning algorithms in the literature also use RSSI to estimate the location of the tracked object (e.g, the well-known LANDMARC algorithm [15]). Therefore, we also make use of RSSI in our application logic to detect the event of proximity of RFID readers and RFID tags. Specifically, when a user with a RFID tag is walking toward a RFID reader deployed in the middle of a stairway, the RSSI value observed by the reader will be increasing. As soon as the RSSI value climbs over a certain threshold, at this moment we may conclude that the user is in the stairway and is about to pass by the reader. Accordingly, the navigation system can perform a positioning handoff for the user, switching the floor plan shown on the display of the mobile device. The flow chart for handling positioning handoff is shown in Fig. 2.

IV. EXPERIMENTAL STUDY

In this section we describe the experimental study of the proposed personal navigation system, including how we determine the RSSI threshold value for triggering the handoff process, and an evaluation of the overall prototype system.

A. *RSSI Threshold for Triggering Handoff*

To determine an appropriate threshold value of RSSI for triggering the handoff process, we conducted an experiment to observe the relationship between the reader-tag distance and the RSSI value. The deployment is shown in Fig. 3, in which we deployed two RFID readers (R_1 and R_2) that are 10 meters apart. Then, beginning from R_1, we place the tag at the location x meters from R_1 (i.e., $10 - x$ meters from R_2), where x starts from 0 and is incremented by 0.5 each time, until x reaches 10. At each location, we measure the RSSI for 10 times and then take the average. Fig. 4(a) and 4(b) plot the measured RSSI at R_1 and R_2, respectively. It is obvious that the relationship between the reader-tag distance and the RSSI value is nonlinear; however we found that the RSSI value will be greater than –45 dBm when the distance is within 2 meters from R_1. Since the reader R_1 will be physically deployed in the middle of the stairway in the next experiment, in the application logic we set the RSSI threshold to be –45 dBm for this particular case. It is worthy to note that to account for the variation of the RSSI values, the handoff process will be triggered only when the RSSI values are observed to be above the threshold for three consecutive times.

Moreover, to realize how the RSSI values fluctuate, we

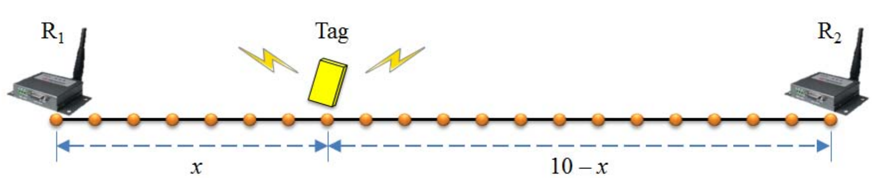


Figure 3. Settings for RSSI measurement.

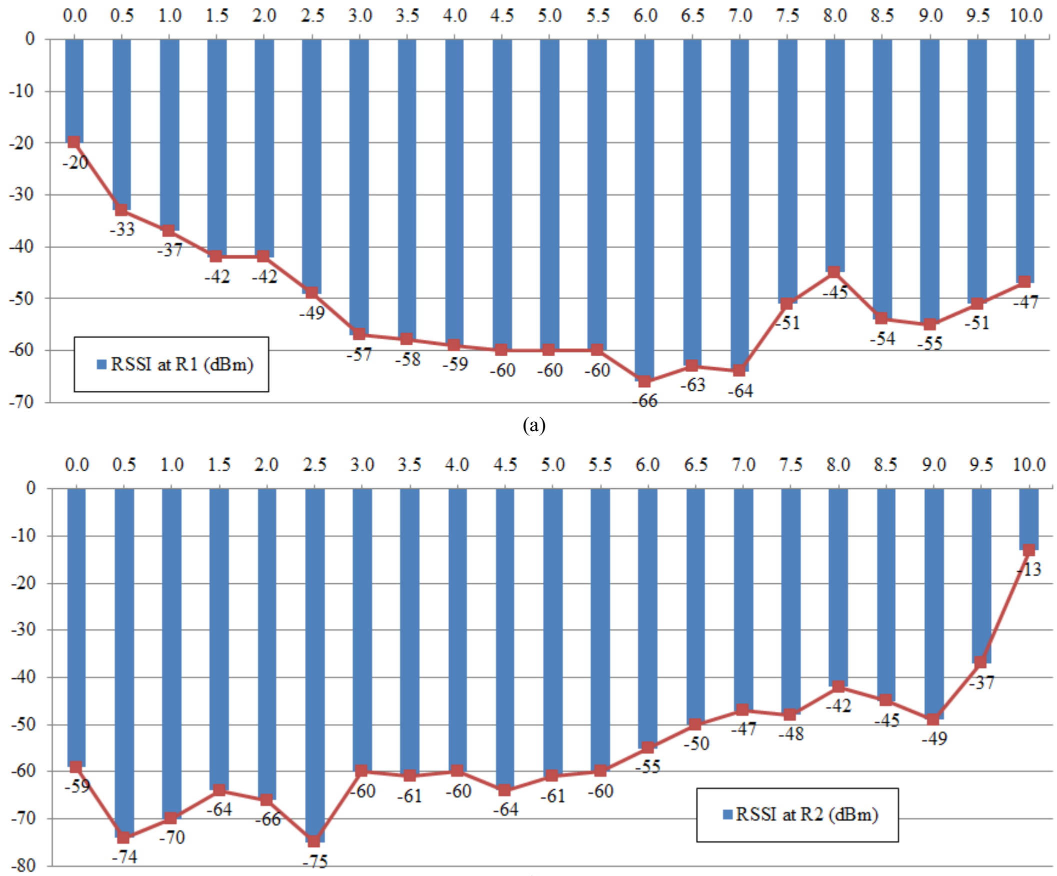


Figure 4. Measured RSSI at R_1 and R_2.

again measured the RSSI values at the distances of 1.5, 2.0, 2.5, and 3.0 meters from R_1, respectively. But, this time at each location we measured the RSSI values for 1000 times at the rate of one RSSI value per second. Table I shows the average and the standard derivation of the RSSI value at each location. We found that to some extent the RSSI value is relatively stable, and this observation is consistent with that obtained in [13].

TABLE I. AVERAGE AND STANDARD DERIVATION OF THE RSSI VALUES

RSSI (dBm)	Distance (meters)			
	1.5	**2.0**	**2.5**	**3.0**
Average	-42.59	-43.02	-48.97	-56.35
Standard Derivation	1.13	0.16	1.69	1.18

B. *Evaluation of the Prototype System*

To evaluate the usefulness of our prototype system, we deployed the system on the 2nd floor and the 3rd floor of the Main Engineering Building in our campus. There are three active RFID readers on each floor, and one in the middle of the stairway. As stated in Section III, the user carries an active RFID tag and a mobile device. The real-time positioning results are updated to the graphical user interface in the mobile device through the campus Wi-Fi network.

Fig. 5 is the graphical user interface shown in the mobile device. Before the user starts the program, he/she can choose the mode of handoff from either *Manual* or *Automatic*. After the mode of handoff is selected and the user presses the *Start* button, a user figure will be shown in the floor plan, indicating the current user location. To be more informative, the positioning results in literal format are shown in the left column of the user interface, which include the day/time information, the current floor number, and the latest (x, y) coordinates. Limited by the rate of the positioning engine that inserts a positioning result into the location database once around a second (i.e., not once per second exactly), for safety our navigation system is designed to fetch the positioning results once every two seconds. In the floor plan shown in Fig. 5, we use the yellow circles to mark the locations of the RFID readers (Reader #3 in the middle of the stairway between 2nd and 3rd floors).

In this experiment a user departed from the position beside Reader #2 on the 3rd floor and walked downstairs. Then, from the 2nd floor the user walked upstairs and returned to the departure point to end the route. Two trials were performed, one for manual handoff and the other for automatic handoff. The complete progress of the experiment

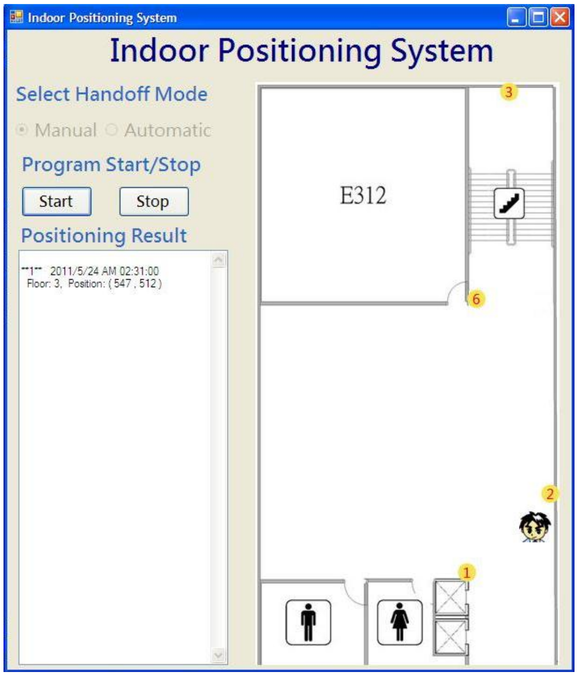


Figure 5. The graphical user interface of the prototype system with the manual handoff mode selected.

was recorded in a video. Fig. 6 shows two snapshots taken at the instances that the navigation system prompted the user for confirmation of handoffs in manual mode. In the trial for automatic mode, the handoffs were performed without user interventions. The results show that the proposed personal navigation system achieves the goal of seamless positioning handoff in the indoor environment.

C. Discussions

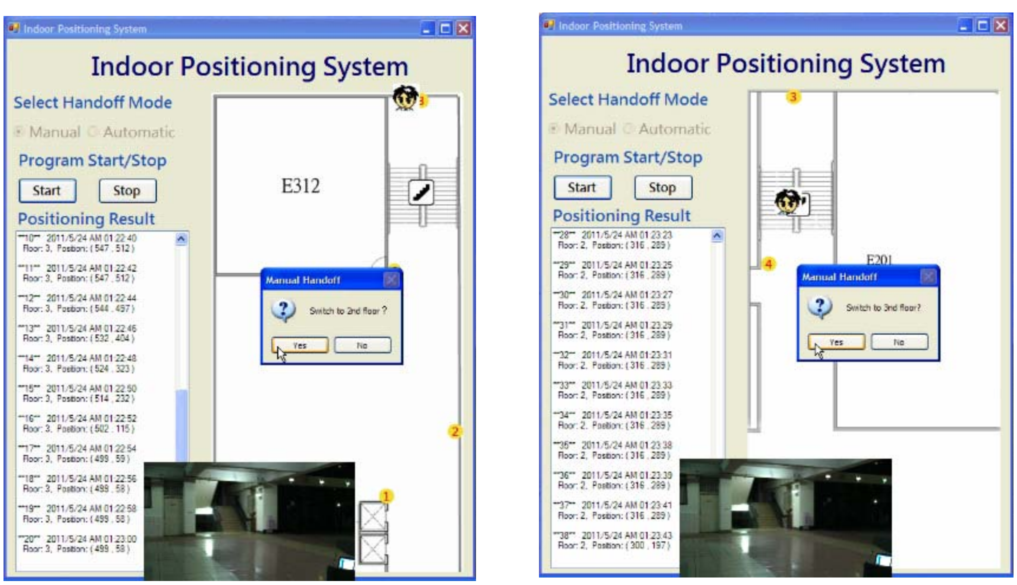
It is interesting to note that although a great deal of existing positioning algorithms utilize RSSI values as the measure for distance estimation, it is also discovered that the positioning precision of using RSSI values for distance estimation is not satisfactory, especially in indoor environments [14]. This is mainly due to signal reflection, scattering and other physical properties, which have impact on RSSI measurement. However, this drawback can be overcome by deploying more readers or reference tags.

It is also observed that different RFID readers with the same reader-tag distance may experience different RSSI values (e.g., in Fig. 4, –57 dBm and –47 dBm for R_1 and R_2 respectively, both at 3 meters away). Therefore, to perform handoffs between different floors correctly, in real fields of deployment we need to evaluate the distribution of RSSI values for those readers deployed in the middle of the stairways. Only when the evaluation is done can we determine a proper RSSI threshold for a specific reader.

Last but not least, as mentioned in the previous sub-section, in our implementation the positioning results are updated once every two seconds. Actually the rate of update is relatively slow for a practical system. To make the personal navigation service more satisfactory, the rate of positioning update shall be assigned at least twice as the current rate.

V. CONCLUSIONS

In this research, we implemented an active RFID-based personal navigation system for multi-story indoor environments. From the experimental study we showed how the RSSI threshold for triggering positioning handoff is determined, and the usefulness of the proposed system is evaluated. The main contribution of this work is that we



(a) (b)

Figure 6. The prototype system prompted for confirmation of handoffs in manual mode. (a) going downstairs from the 3rd floor (b) going upstairs from the 2nd floor

focus on the capability of seamless positioning handoffs between floors, whereas none in the literature mentioned this feature, which we regard as a key to improve user experiences.

We envision that indoor navigation services will ultimately flourish in the near future, and the capability of seamless positioning handoff is a key feature for such systems to be competitive. However, unlike outdoor navigation services that the geographical maps can be captured directly from the satellites, for indoor navigation systems to be practical and popular, a map database consisting of a huge number of indoor maps has to be built in advance. This is by no means a simple task, but at least for the initial stage we expect that indoor navigation systems can be deployed in public buildings such as the airport terminals, exhibition halls, museums, and shopping malls.

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