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Research Paper

A Mobile Object Tracking Scheme by Wired/wireless Integrated Street Lights with RFID

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Abstract

Since a sophisticated location determination technology (LDT) is necessary for accurate positioning in urban area environments, numerous studies related to the LDT using the RFID (Radio Frequency IDentification) technology have been implemented for real-time positioning and data transferring. However, there are still lots of unsolved questions especially regarding what to use as base stations and what are corresponding results under the intrinsic complexity of alignment and configuration of components used for the RFID positioning. This study proposes the street light fixtures as base stations where the RFID receivers will be embedded for the mobile tracking scheme. As street light fixtures are usually installed at a certain distance interval, they can be used as base stations for the RFID receiver installation. Using the principle of the single row triangle network, the RFID receiver organization is determined based on the experiments such as recognition distance measurement and tag position accuracy estimation at inside and outside of the single row triangle network. The results verify that the mobile tracking scheme which uses RFID-embedded street light fixtures, suggested and configured in this study, is effective for the real-time outdoor positioning.

Keywords : RFID, Street Light Fixture, RFID SLiF, Mobile Object Tracking, Ubiquitous Positioning System

1. Introduction

Accurate positioning is one of the essential factors to enhance conveniences in ubiquitous computing environments. Among many technologies, the positioning technology using RFID (Radio Frequency Identification) has been actively researched for last a couple of years. So far, the positioning using RFID has been generally utilized in very limited areas such as factory automation, logistics tracking system and others which are mainly for indoor use (Choi and Lee, 2007; Finkenzeller, 2010; Zhang et al., 2010; Farid et al., 2013). However, in these years, there are increasing demands for outdoor use of this prospective technology (Priyantha et al., 2000; Savi Technologies, 2005; Cha et al., 2007; Jung et al., 2009; Bolic et al., 2010).

In applying the RFID for outdoor positioning, there are two questions to be solved. One is what to select as a facility on which the RFID receivers should be installed and the other is how to geometrically layout these facilities. Therefore, these questions should be fully and properly addressed at the first onset before an RFID-embedded position tracking system is physically implemented.

With this background this study tries to answer the questions. RFID SLiF method has been proved through various experiments for alignment and location of RFID tags and receivers including the height and the mobile tracking on roads. Thus, firstly a selection of the best facility for RFID installation among many urban facilities is investigated. Once the idea to install the RFID receivers on SLiFs as reference stations is set up, the next thing to examine is where to install the RFID and arrange the SLiFs. The appropriate height of the place in which the

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RFID is equipped is examined. In the latter step, the single row triangle network is tested as the SLiFs usually located along the roadsides. Lastly, after the set of experiments, the proposed mobile position tracking method is implemented on both a curved section and intersections using the results derived from the experiments conducted to determine the SLiF layout.

2. Background

So far researches based on the RFID technologies are mostly done for indoor positioning and very few are done for outdoor. Thus in this literature review several remarking cases for the indoor positioning are introduced, whereas only one for the outdoor positioning. Indoor positioning using the RFID has been studied to solve the problem that the conventional GPS or systems using mobile communication networks have since weak signals cannot sufficiently track objects indoors in these systems. Ni et al.(2003) proposed a LANDMARK system that applies a reference position to a RFID receiver location to adjust a positioning value and the advantage of the LANDMARK system is to reduce the number of RFID receivers.

Intel Corporation performed a GUIDE project using an applied RFID in robot travelling. The project presents a system which can perceive the presence of an activity pattern of a human in a building. In the project, researchers try to achieve a higher level of recognition of the robot’s position and produce an environment map using RFID. In the GUIDE project it is reported that higher position accuracy is achieved by using RFID in comparison to using the conventional positioning sensors (Yoo, 2006).

The RFID positioning technique for outdoor implementation has been researched in the centre of how to provide diverse types of service. The most commonly discussed topic for the outdoor RFID application is the efficient and stable tracking of a property or freight. Another application of an extended RFID is in the LEGOLAND park system using RFID with TDOA (Time Difference of Arrival), which prevents children from being missed at an amusement park with the area of 230,000 m2 in Denmark. The park reviewed solutions that could provide real time positioning in a population dense area and confirmed that the TDOA technology combined with the RFID is valid (Ho et al., 1993; Kong et al., 2004; Lee, 2006). With the RFID system, customers who come in with children in LEGOLAND can use facilities of LEGOLAND without any worry so that it is expected that they can attract more customers and raise their reputation.

3. Proposed position tracking method using RFIDs on SLiFs

3.1 Facility for the RFID installation

The position tracking method using the RFID requires active RFID receivers installed on SLiFs and passive RFID tags in moving objects. Street lights which have been established regularly should be the high-quality reference stations of the RFID tracking since the accurate position information of the street light is already achieved and maintained in database through the national GIS project. Data with coordinate system organize networks for position tracking along the street with a certain interval and the electric power supply for the street light satisfies the operating power of an active RFID tag.

Because facility used as a position reference station is applied to a reference location, among several facilities such as a SLiF, roadside tree, signal lamp and manhole, the evaluation on technical feasibility is performed to select the most appropriate one in this study. Criteria of this evaluation are verified through the position accuracy, reliability of facility, usability of information, availability of data acquisition in real-time, electricity and communication stability, expansibility and availability for connection, and cost efficiency.

After evaluation, the street light ranked the highest score is selected as the best facility for the reference station as shown in Table 1. The roadside tree has good marks in position accuracy and reliability and usability of information criteria, but it is rated the lowest at cost efficiency because RFID SLiFs set on roadside tree need an additional electric power

Table 1. Evaluation of the technical feasibility

Items	SLiF	Roadside tree	Signal lamp	Manhole
Position accuracy and reliability	●	●	●	△
Practical use of information	●	●	●	●
Availability of data acquisition in real-time	●	△	△	△
Stability of electricity and Communication	●	○	●	△
Expansibility and availability for connection	●	△	△	●
Cost efficiency	●	○	△	△

● = good, △ = middle, ○ = bad

supply. Especially, the worst evaluation is brought by the environmental damages of street trees. The signal lamp generally has good scores, but each distance between lamps is all different, which did not satisfy distance criterion because the maximum range of RFID data transmission reaches 200m. When a RFID receiver is installed lower than a RFID tag height, location tracking is impossible, so a manhole is scored lower in the evaluation.

In ubiquitous environments, the street light and its fixture can be used as a transmitter for the information communication. In this study the SLiF is defined as u-TIP (Ubiquitous wired/wireless Total Information Pole) and mobile tracking device which combines a RFID tag, a RFID receiver and a SLiF is defined as RFID SLiF. u-TIP contains the meaning of ‘the transformation of position information’ in ubiquitous environment as well as its basic concept of ‘wired/wireless integrated information fixture’.

3.2 Configuration of wired/wireless integrated street light using RFID

RFID with an optical cable is installed to track the location of a moving object, and the wired/wireless integrated communication network plays an important role for the data transfer. Fig. 1 describes the physical structure of integrated information about the SLiF with wired/wireless RFID. The RFID SLiF is divided into two parts a wireless network part receiving the position information signal and a wire network part that the extracted location information is transmitted to a management server (Location server).

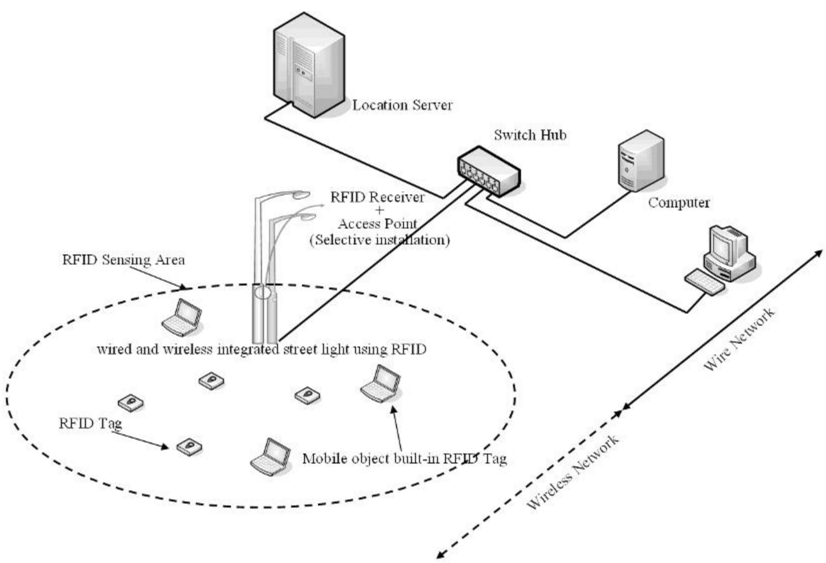

Figure 1. Physical structure of the SLiF with wired/wireless RFID

3.3 Data acquisition of RFID SLiF location

Position data of the SLiFs are extracted from a digital topographic map with 1/1000 scale, which has passed the measurement test by the national GIS project. Standard topographic codes supplied by National Geographic Information Institute of Korea are employed to extract the position data of SLiFs. Information about SLiF location is also extracted from a SLiF layer by standard topographic codes in ArcGIS program. After extraction of coordinate data which contain location information among the attribute values, the location data of SLiFs are collected as a table format.

3.4 Moving object tracking methodologies

The tracking method of the RFID SLiF used a RFID-based wireless positioning technique and active tags are installed on mobile objects, which include the wireless AP as a transmitter of position information. The position tracking method adapts the TDOA algorithm which calculates the distance between SLiFs with at least three RFID receivers and a RFID tag through geographic relation and time differences of a signal. In this methodology, signal propagation time is used instead of absolute time and once the difference of signal delay is obtained, it enables to define hyperbolas that have two reference points as focal points. Based on the TDOA algorithm, the location tracking system using RFID receivers and tags are designed in this study with the location of the moving object which is an intersection point of hyperbolas. As mentioned earlier, RFID receivers are used as reference points by attaching to SLiFs and the location of a moving object is determined by the signal propagation delay measured using the RFID tag on moving objects.

4. Choice of installation alignment

4.1 Experiment outline

RFID SLiF alignment is determined along the road where the SLiFs are installed in the street. This study adapts the principle of the single row triangle network because triangulation network is mainly used in measurement of narrow and long place such as route, riparian, and tunnel surveying. The triangle network also has an economic advantage because the number of observation points is less for its distance. The device of AeroScout RFID real-time position tracking system determines the position of a moving object by using distance and time differences of a signal. Several experiments are performed to determine the way to align RFID SLiFs, an appropriate distance as the recognition distance, and the optimal height on a SLiF. In addition, position accuracy between inside and outside receivers in a single row triangle network is compared.

4.2 Estimation of recognition distance

The RFID SLiF consists of RFID receivers and a network which recognizes position and transfers the position data, which the device can recognize a signal within about 200 m or 300 m radius using a current technology in the outdoors. Therefore, the location tracking system using the RFID SLiF is practicable if an optical cable network is included in the SLiF especially for newly constructed cities such as the u-City. Since the RFID SLiFs do not have a wired network, the wireless AP transferring distance as well as RFID receiver’s communication distance is one of the important factors in data processing. Thus this experiment of recognition distance is processed to examine an ideal distance by combining RFID receiver’s recognition distance and communicable distance of AP. In Table 2 installation distance of a RFID receiver on the SLiF is illustrated by changing from 50 m to 250 m. The height of a RFID tag is considered to be 1m high, taking the seat height on a vehicle and human hand’s height while walking into account.

The recognition distance of a signal is examined in a four-lane road at Seoul National University, and its illustration is shown in Fig. 2(a). The transmission interval of the tag signal is set at every single second. A program where the position data received from the tag are converted into the Microsoft Excel format is developed to perform statistical analysis of the data.

To analyze how different the distances between real positions and the data received by receivers are, the root mean square error (RMSE) is calculated as shown in Table 3.

Since the RMSE is shown to be lower as the distance between RFID receivers decreased, it is verified that the position is determined more accurately when the distance between RFID receivers is closer. In particular, when the distance is gradually changed from 250m to 200m, to 150m, and to 100m, the RMSE becomes remarkably lower. However, the decrease ratio is shown to be slow less than 100 m of a distance as shown in Fig. 3. It is proved that the ideal distance between position tracking receivers is shown to be 100 m in terms of cost efficiency and data processing for installation of RFID receivers in the experiments.

Table 2. Result of recognition distance

Distance	250m	200m	150m	100m	50m
Distance error (RMSE)	66.94m	21.30m	17.69m	4.66m	1.81m

Table 3. Result of installation height

Position / Height	Inside of the triangle network		Outside of the triangle network	
	Tag ①	Tag ②	Tag ③	Tag ④
2.5m (RMSE)	5.31m	4.65m	23.68m	62.05m
3.5m (RMSE)	3.39m	1.86m	23.23m	19.13m

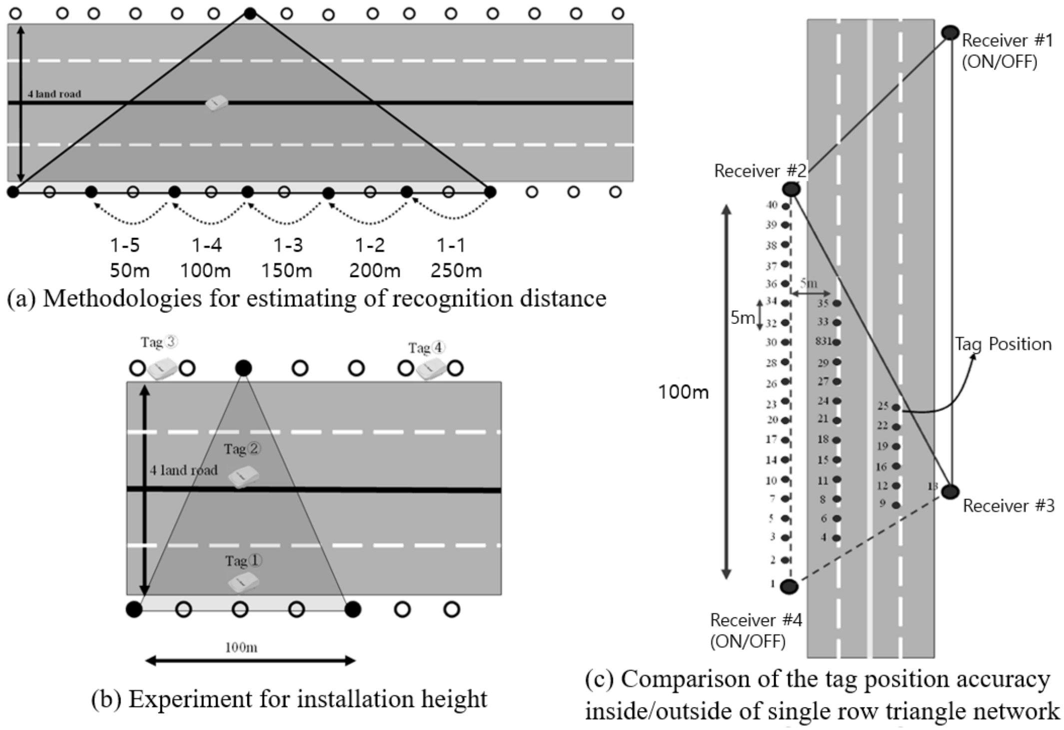

Figure 2. Choice of installation alignment

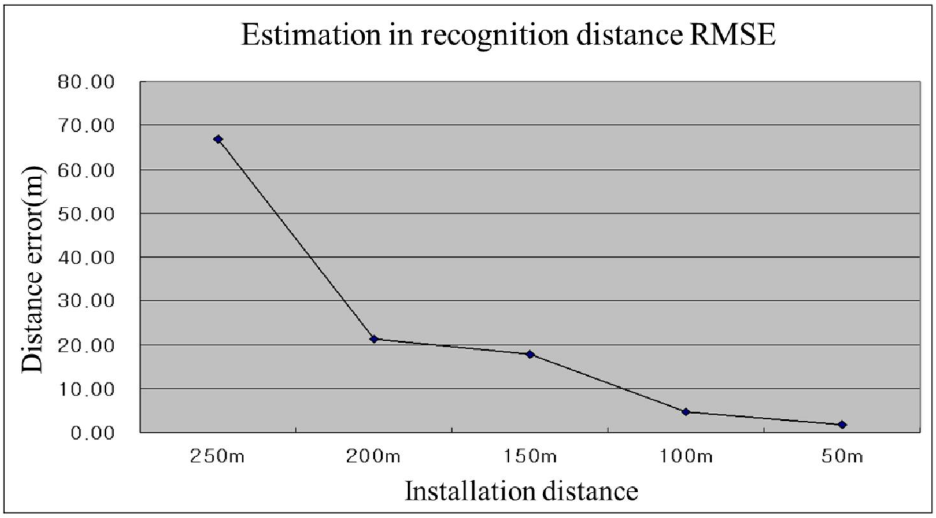

Figure 3. RMSE graph of recognition distance by installation distance

4.3 Experiment of the installation height

To determine a suitable height of RFID receiver to be installed, the distance between RFID tag and RFID receiver is set to be 100m as the result of the former experiment, and position analysis according to height of RFID receivers is performed at the height of 3.5 m and 2.5 m respectively. The height value of 3.5 m is determined, taking into account that the height of a normal bus is 3.4 m. In the experiment space, the road adjacent to the main athletic field at Seoul National University, the signal transmission is interfered by shuttle buses operated at a five-minute interval and two regular urban buses. Therefore, the experiment of RFID height has the meaning that this is one of the practical simulations when the RFID SLiF is used in the city. As shown in Fig. 2(b) RFID receivers are installed on SLiFs to form a single row triangle and two tags are attached in and out of the triangle network. The accuracy tests are performed at the height of both 2.5 m and 3.5 m, respectively.

The position accuracy at 3.5 m high is shown to be more accurate than that that at 2.5m high. Especially at the height of 3.5 m, the position accuracy of tag 3 and 4 installed outside of the triangle network rapidly increased as well as the accuracy of tag 1 and 2 which are installed inside of the triangle network as Fig. 4.

4.4 Comparison of the tag position accuracy between receivers inside and outside of triangle network

RFID receivers are formed as a single row triangle network generally used to measure a narrow and long area. It is verified that the position error is remarkably reduced when RFID tags are located inside of the network. 40 points with a distance interval of 5 m from the centre line of the road are examined to confirm whether the position error is a significant difference or a difference due to chance. A tag is attached at each point, and tag positions are calculated while the RFID receivers are turned on and off. In this case the distance interval of 5m reflects the fact that the equipment located outside of a building is accurate within 3m and 5m (Fig. 2(c)). Each point is selected from the digital topographic map and each point position is verified using the total station which is able to measure distances to an accuracy of 2-3 millimetres per kilometre, and angles to 1-second accuracy.

The ideal distance of RFID receivers, 100m distance, is applied to accuracy estimation between receivers inside and outside of the single row triangle network. As illustrated in Fig. 2(c), the

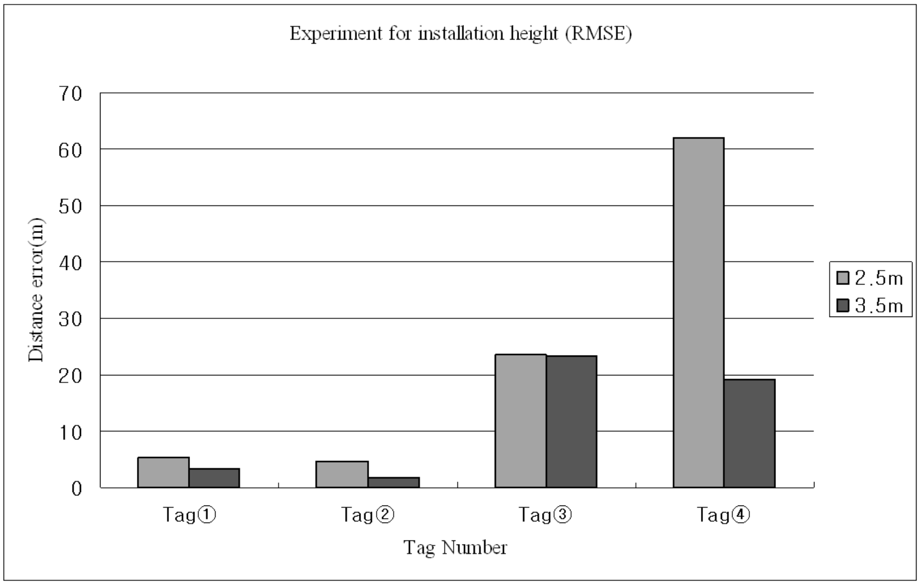

Figure 4. Result of experiment for tag installation height

RFID receivers from 1 to 4 are installed, and the accuracy tests are performed for a tag located inside and outside of the network, respectively, while the first and the fourth receivers are being turned on and off. In the first case where the first, the second and the third receivers are turned on and a tag is located outside of the network the position error is calculated. And in the second case where the second, the third, and forth receivers are on and a tag is located inside of the network, the position error is also calculated. When the tag is located outside of the network, a position error is diverse from 3.48 m to 44.45 m, which is relatively large. However, in the case of placing a tag inside of the network the result showed to be similarly distributed with an average of 3.48m.

5. Mobile object tracking

5.1 Experiment purpose

Application of the RFID SLiF to the various road situations after above experiments is described in this section. Roads where the RFID SLiFs are applied are divided into two areas: a curved road and an intersection. Experiments for an intersection are performed both on intersection of three roads and an intersection of four roads. Experiments for a curved road and a three road intersection are performed in the circulation road at Seoul National University, and experiment for an intersection of an intersection of four roads is tested on Teheran Road in Seoul. Five RFID receivers which are the necessary numbers for quantitative installation are used to track mobile object tag positioning in the triangle network.

5.2 Experiment method

Mobile objects are restricted to a human and a car. The moving speed is set to 4km/h at human's walking and set to 40km/h at car driving, which 40km/h is the speed limit in circulation road at Seoul National University. The result is overlapped on the route passage and received data using Post Map in Surfer program as Fig. 5. The solid line represents the routes of the mobile object and the dotted line represents the experiment result route for a man's and car's movement.

5.3 Analysis of mobile object tracking

Position accuracy is examined by checking the area difference between the real moving distance and the estimated values. The method of coordinates is a method which measures the area of a polygon when the coordinates of each point are known. The accuracy examination which uses the method of coordinates is as follows (Fig. 6).

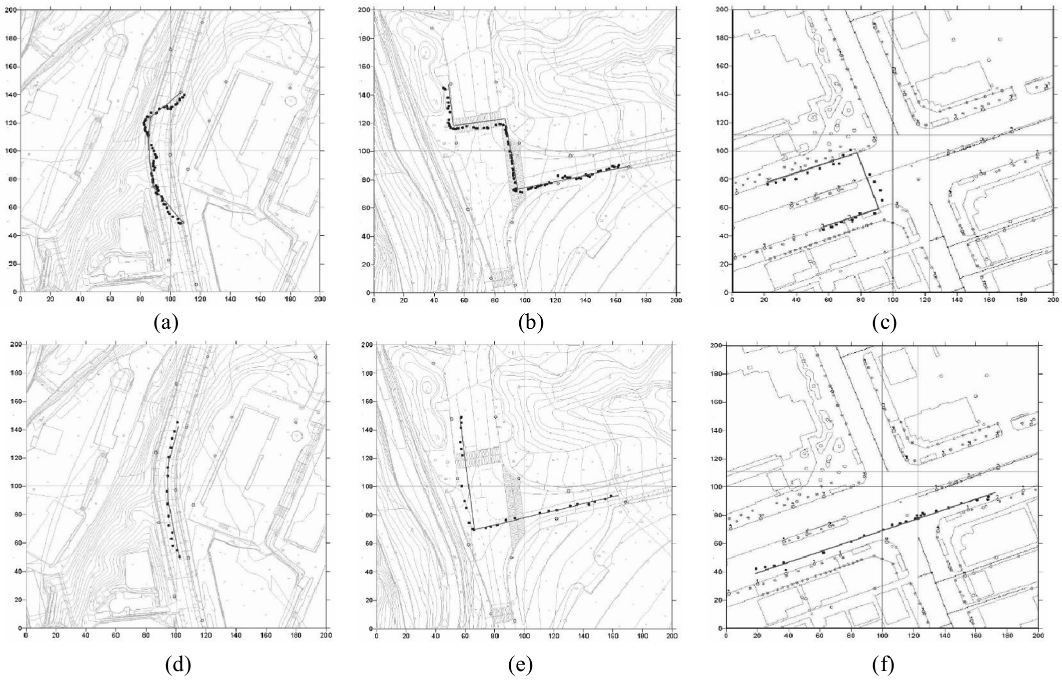

Figure 5. Result of overlapped route passage experiment (Man: (a)(b)(c) / Car: (d)(e)(f))

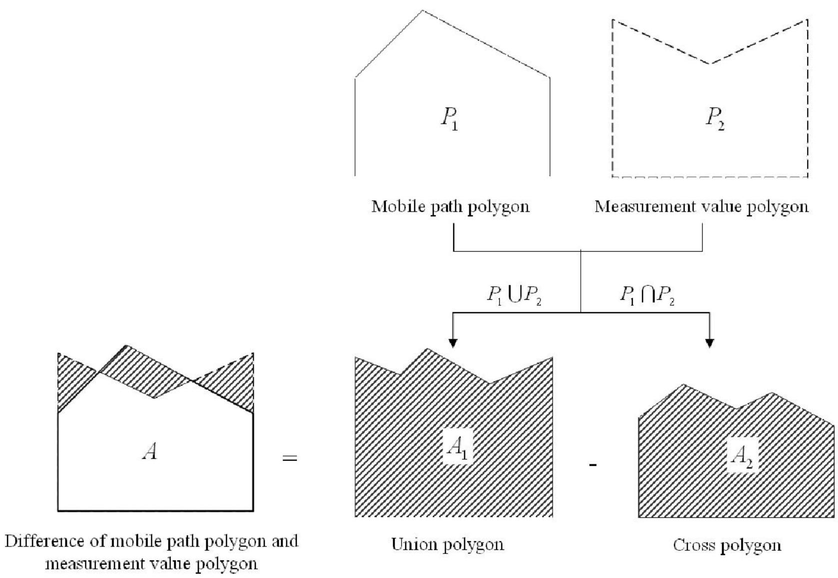

Figure 6. Accuracy assessment

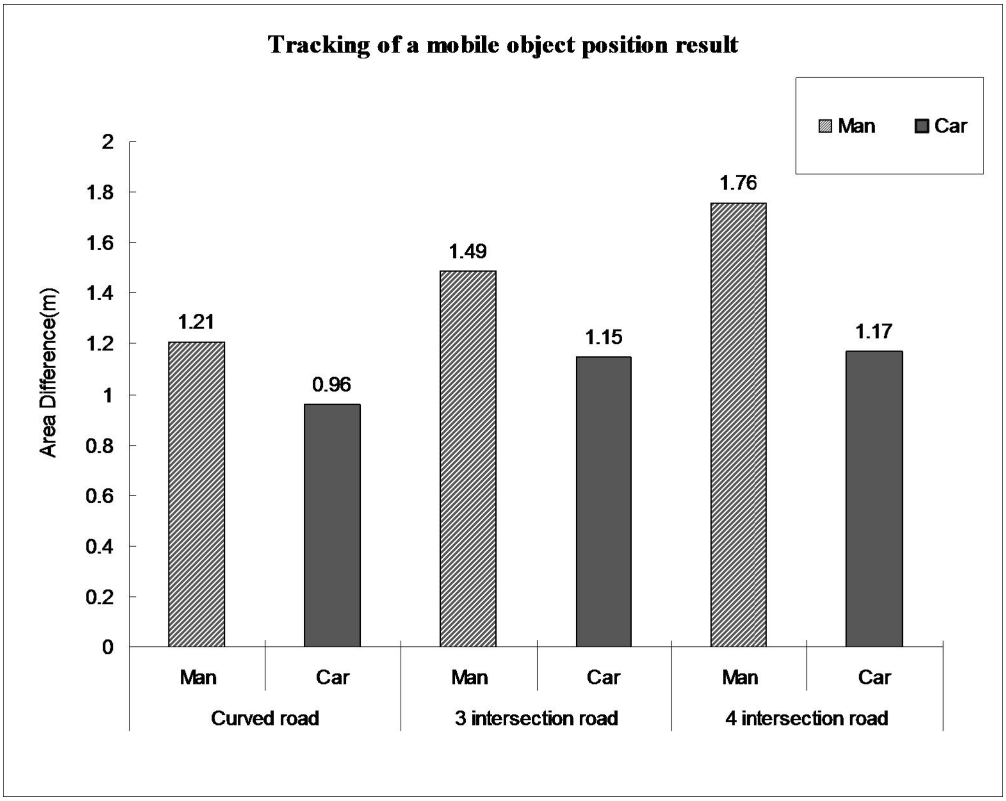

Figure 7. Tracking results of a mobile object position with various conditions

The result of measurement value accuracy is shown in Table 4 and Fig. 7. In general, the errors of the mobile object position tracking are 1.49 m and 1.02 m on an average for the man and the car, respectively. The error of the moving car is lower than that of the moving person on both the curved road and the intersection. The result is lower than 3.48m calculated for a stationary tag in the single

Table 4. Result of Accuracy assessment

	Curved road		Three intersection		Four intersection	
	Man	Car	Man	Car	Man	Car
Calculate area of a union polygon ($A_1 = P_1 \cup P_2$)	8457.32 m^2	9047.44 m^2	18112.26 m^2	17494.79 m^2	5887.81 m^2	11043.79 m^2
Calculate area of a cross polygon ($A_2 = P_1 \cap P_2$)	8324.45 m^2	8956.60 m^2	17819.56 m^2	17287.34 m^2	5645.14 m^2	10891.81 m^2
Calculate an area difference (A) ($A = \| A_1 - A_2 \|$)	132.87 m^2	90.84 m^2	292.70 m^2	207.45 m^2	242.67 m^2	151.98 m^2
Assume an error ($E = \frac{D}{A}(m)$)	1.21 m^2	0.96 m^2	1.49 m^2	1.15 m^2	1.76 m^2	1.17 m^2

row triangle network. In particular, taking into account that a lane width is between 2.5m and 3m, the fact that the error for the moving car is 1.02m can be utilized in analyzing movement pattern of vehicles and providing traffic situation.

6. Conclusions

In this study a mobile object tracking scheme with RFID tags on the SLiF is implemented as a reference stations. Street light textures installed at a certain distance interval are employed as reference points for the RFID tag establishment. Some experiments such as the evaluation of the recognition distance of the signal using the principle of the triangulation network which provided suitable installing height and accuracy comparison of RFID tag location between receivers inside and outside of the triangle network. The mobile tracking scheme is evaluated with two different speeds: a man walking at 4km/h and a car moving at 40km/h and the experiments are performed on curved road and intersections.

The results showed that RFID receivers are best installed at 3.5 m height in the SLiF with the distance interval of 100 m. The triangulation network is proved to be effective with an average accuracy of 3.48 m in the network and the position errors of the mobile object tracking are 1.49 m and 1.02 m at 4km/h and 40km/h, respectively. In conclusion, the RFID SLiF is effective and this can be adapted in many applications such as the traffic information, searching for missing child and business assistance management.

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