RFID-ASSISTED INDOOR LOCALIZATION AND COMMUNICATION FOR FIRST RESPONDERS*

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ABSTRACT

An indoor localization and communication project is described that proposes to use RFID (radio-frequency identification) tags, placed in the building beforehand, as navigation waypoints for an inertial navigation system carried by a first responder. RFID devices commonly are attached to persons or to moveable objects so that the objects can be tracked by using fixed readers (special-purpose radio receivers) at different locations. In this project, we explore the "flip side" of this practice. Our concept is that detection of RFID devices in known, fixed locations by a moving reader provides a precise indication of location for tracking the person or moving object that is carrying the reader. This information can then be used to correct for any errors of an inertial tracking system.

1. INTRODUCTION

RFID (radio-frequency identification) devices commonly are attached to persons or to moveable objects so that the objects can be tracked using fixed readers (special-purpose radio receivers) at different locations. In this project we are exploring a novel application of the "flip side" of this practice based on the concept that detection of an RFID device in a known, fixed location by a moving reader provides a precise indication of location for tracking the person or moving object that is carrying the reader. The research aims to evaluate this concept in order to implement a low-cost, reliable means for tracking firefighters and other first responders inside buildings, where navigation using GPS (global postioning system) is not reliable, and the GPS signal may even have been disabled temporarily to prevent its exploitation by terrorists [1].

The reception of RF signals is not reliable inside most buildings. Inertial tracking systems inherently drift over time and produce errors in position, especially for inexpensive and lightweight systems. Corrections, in the form of the insertion of known locations that have been reached, can be developed automatically using an RFID device, either by correlating the identity of the device with a table of locations or by reading the device's location from data stored on it. Based on which tags the reader detects, the reader can be located as being within a certain region.

The research will also consider the use of building-related information stored in RFID devices placed at fixed on-site locations to aid the responders in their mission, as well as to describe the room layout or other context of the device, thereby minimizing the need for accessing remote databases through the communication system.

This project, supported by the NIST Advanced Technology Program (ATP), is a joint effort by components of three NIST laboratories: the Wireless Communication Technologies Group of the Information Technology Laboratory (ITL) and the Fire Fighting Technology Group of the Building and Fire Research Laboratory (BFRL), both in Gaithersburg, Maryland; and the Electromagnetics Division of the Electronics and Electrical Engineering Laboratory (EEEL) in Boulder, Colorado.

1.1 Concepts Motivating the Study

Indoor Navigation Cannot Depend on GPS. It is difficult to use GPS indoors or in urban canyons because line of site is obscured or severely attenuated. Even if the GPS signals are not blocked or obscured, the reception of GPS signals inside most buildings is not reliable.

Inertial Sensors Can Track Location, Motion. In addition to, or in place of GPS, the position of a first responder inside a building can be tracked by using inertial sensors such as accelerometers and gyroscopes or noninertial sensors such as magnetometers and barometers.

RFID Fixes Can Enhance the Accuracy of Inertial Tracking Systems. Inertial tracking systems inherently drift over time and produce errors in position. Corrections, in the form of the insertion of known locations that have been reached, can be developed automatically by detecting the presence of an RFID device (Figure 1), either by correlating the identity of the device with a table of locations or by reading the device's location from data stored on it.

1.2. Approach to the Study

The overall approach can be described as follows: In addition to the RF propagation environment of buildings in emergency situations, the research will consider several operational scenarios consisting of (1) the strategy for RFID deployment, (2) the tracking method, and (3) the options for presenting location information to the user and communicating this information to a monitoring station. The RFID deployment and tracking aspects of the scenarios to be studied will include:

- The tradeoffs involved in the choice of RFID devices for this application, including cost, ease of programming, suitability for emergency environments, and data capacity.
- Use of relatively few RFID location reference points to correct or calibrate an inertial navigation or other localization system to maintain sufficient accuracy during a first responder incident.
- Use of multiple RFID location reference points to furnish data for tracking without the use of inertial sensors.
- Informing the user (only) of position (stand-alone mode), assuming any person-to-person communication is provided by a separate system.
- Informing the user, other team members, and an incident commander of their positions via an ad hoc network of radio terminals that combine RFID reading and radio communication.
- Providing the user with directions for safe exit from the building.

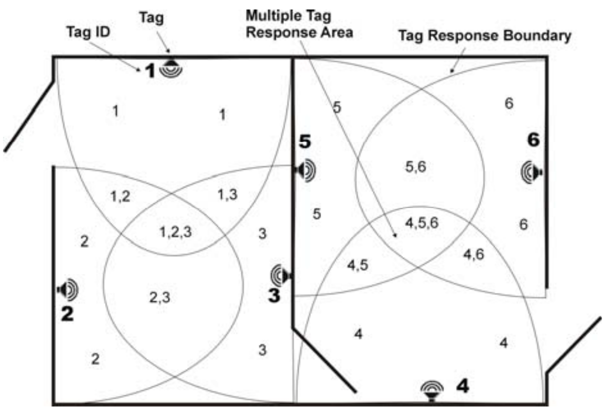

Figure 1. Building with simple RFID tag layout.

2. FIREFIGHTER LOCATION PARAMETERS

Firefighter location and in-building information requirements have been developed, as representing perhaps the most demanding environment for an RFID-assisted localization and communication system. The important criterion for placement of tags is the continued functioning of the tag in the environment. The number of RFID tags is still an open question, depending on a tradeoff between practicality and the desired localization resolution—in many first responder scenarios, we need to be able to identify in which room in a building a given first responder is located. This question will continue to be considered in later phases of the project.

Firefighter location and in-building information requirements may be grouped in terms of (a) building type, (b) temperature environment, (c) radio signal attenuation factors, and (d) desired location resolution.

Building type refers both to the building's construction, which relates to its resistance to fire, and to factors affecting communications in the building. The building type, along with classification of the building use (e.g., residential or industrial), is the primary parameter in the description of the fire event scenario. Building and fire codes classify buildings according to the type of construction and the fire resistance. There are five types of building construction identified in the various codes [2, 3]:

Type I Buildings are classified as Fire-Resistive. Most of these buildings include high-rise office buildings, shopping centers, or residential units. They are of either reinforced concrete or structural steel. Structural members are of approved noncombustible or limited-combustible materials with specified fire resistance ratings.

Type II Buildings are classified as Noncombustible. These buildings can be used for example as office buildings, warehouses, or automobile repair shops. There are three basic types of non-combustible buildings: metal frame covered by metal exterior walls (Butler Buildings), metal frame enclosed by masonry as non-bearing exterior walls, and masonry bearing walls supporting a metal roof. The structural members are noncombustible or limited-combustible materials.

Type III Buildings are classified as Ordinary. Type III buildings are often called ordinary buildings or combustible/noncombustible. The majority of buildings probably fall into the Type III category. These buildings can be office buildings, retail stores, mixed occupancy, dwellings, or apartment buildings. These buildings usually have non-combustible bearing walls and combustible roofs. Usually, the exterior walls are concrete, concrete block, or brick.

Type IV Buildings are classified as Heavy Timber. The exterior and interior walls and structural members that are portions of walls must be of approved noncombustible or limited combustible materials. The exterior walls are typically masonry.

Type V Buildings are classified as Wood Frame. Wood frame buildings generally are constructed in one of five methods: log, post and beam, balloon, platform, and plank and beam. A wood frame building can be used for many different purposes, such as single-family dwellings, multiple-family dwellings, restaurants, or retail stores. The major structural members are typically composed of wood and the exterior walls are combustible.

The communications factors associated with the building type include whether the building has a pre-wired communication system and whether the construction of the building (*e.g.*, steel or metal) is such that radio signals may not penetrate the building adequately.

The temperature environment of a building during a first responder event is described in terms of zones that correspond to degrees of exposure to heat flux and therefore to risk of injury [4]. An in-depth description of the four zones can be studied in [5-9].

Radio signal attenuation factors are those affecting the transmission of radio signals into and out of a burning building. These factors include

- Presence of water in the air, due either to combustion products or the fire suppression water. 100% relative humidity can be expected.
- Smoke particulates in the air, usually carbon. Typically the concentration is one gram per cubic meter.
- Charged particles in the air; these are ions from combustion processes.
- Thermal layers that can reflect or refract radio waves.
- Construction materials and their various attenuation properties. Adverse effects originate from the metal facing on insulation, metal rebar in concrete, metal siding, and solar window treatments.

The desired resolution of indoor location information during a first responder event varies according to the scenario.

3. NAVIGATION TECHNIQUES AND DEVICES

The surveys and evaluations of navigation techniques and inertial navigation sensor technologies have been completed, with the major findings summarized below. On the basis of the surveys, a particular dead-reckoning module (DRM) has been selected for testing. A report containing survey details and tutorial materials on navigation has been drafted; its completion awaits testing of the selected DRM so that the test results may be included.

The most widely used navigation system is the GPS, which enables position determination through the measurement of time delays of signals from multiple satellites in known (moving) positions. The difficulty in using GPS indoors and in urban "canyons" is that the line of sight to the GPS satellites is obscured or severely attenuated, and multiple reflections can cause erroneous timing data. Without four good satellite signals, the GPS position solution is inaccurate. Also, with weak signals, the GPS receiver continually loses lock and must spend an inordinate amount of time in attempting to acquire the signals.

Prior to the establishment of GPS, of course, many techniques and devices for navigation have been used. Today's navigation devices implement some very old navigation techniques, such as dead reckoning and waypoint navigation. Dead Reckoning (DR) is the process of estimating position by advancing a known position using course, speed, time and distance to be traveled—in other words, figuring out where one will be at a certain time if one holds the planned speed, time and course [10]. The usefulness of the technique depends upon how accurately speed and course can be maintained on a given "tack;" in the air and on the sea, the selection of fixed speed and course for relatively long periods of time are feasible, while on land or inside buildings the duration of the tack may need to be relatively short due to maneuvers that are required by the terrain or building layout. The uncertainty of the DR position grows with time, so that it is necessary to check the position regularly with a "fix" of some kind (perhaps an RFID tag, as envisioned by this project).

Various systems are being proposed for "pedestrian navigation" utilizing DR techniques in combination with other devices such as compasses and gyrometers [11-14]. The performance of one such system is compared to GPS in Figure 2.

Although in our studies the DR positions were generally in agreement with those developed by GPS, they were often significantly different, due in part to unknown magnetic effects along the path, probably from the presence of an underground electric utility substation along the path. The standard deviation of the position area for the test was about 20 m.

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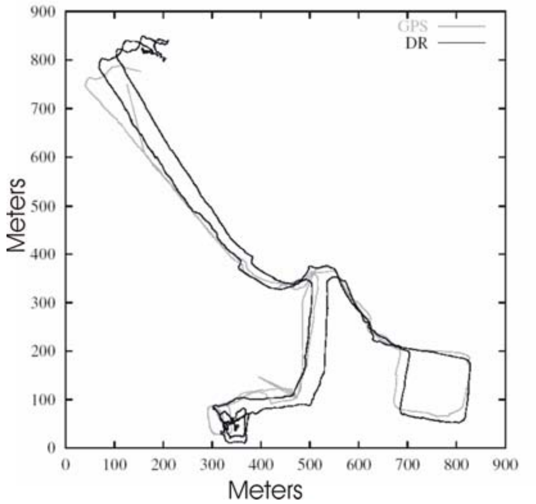

Figure 2. Positions developed by a DR system vs. GPS over a 4 km urban trail (from [11]).

For improved stability and accuracy, a version of the DRM can be obtained that includes a gyroscope. Figure 3 from [13] shows an example of the improvement in DRM performance using a gyroscope.

Figure 3. Manufacturer's demo of gyro-stabilized dead reckoning module improvement (from [13]).

There is some question as to whether the step-counting algorithms in current personal navigation devices are sufficiently sophisticated to adapt to the irregular stepping patterns of firefighters while doing their work. Even if they are not very accurate, they may be good enough to preserve a useful track if they are periodically updated by accurate position information (see below). For the purposes of this study, ITL has placed an order for the DRM described above so that it can be tested under various conditions relevant to first responder scenarios, and eventually integrated with an RFID reader for obtaining position fixes from RFID tags.

4. NUMBER AND PLACEMENT OF TAGS

Determining the number and placement of RFID tags assumes respectively that a required localization accuracy or range of accuracies has been stated and that the accuracies of various navigation techniques have been formulated in terms of the spatial density of waypoints and/or frequency of navigation fixes.

Although general information on the accuracy of potential navigation techniques for use indoors was developed, we realized during the project that analyzing the final accuracy of an RFID-assisted inertial system was premature at this time.

One factor involved is that the accuracy of the dead reckoning module to be tested is unknown under the conditions to be expected in a first responder scenario, particularly the effect of irregular walking on the step-counting algorithm.

Another factor involved is that there is no single device available to first responders at this time that provides indoor location with any reliable degree of accuracy. The firefighting community would consider the ability just to identify the floor of the building on which a firefighter is located as a step forward. Therefore, we will not focus on an analysis of the potential accuracy of a sophisticated system yet.

However, the project team did agree that it would be useful to evaluate the requirements for placement of RFID tags in order to indicate location from the tags alone. Using just RFID tags to derive the indoor location of a first responder has certain advantages that are known in advance. The "you are here" event of detecting a particular RFID tag in a building provides a positive indication of not only which floor of the building the first responder is on, but also which room or work area he or she is nearest to, assuming the ability to correlate the data on the RFID tag with building information or the existence of this information on the tag itself. That is, this result can be expected if there is no ambiguity in the case of the detection of more than one RFID tag.

In the industrial and supply chain applications of RFID technology, the expectation is that many tags will be within the range of the RFID reader, so that the standards for RFID devices provide protocols and procedures for resolving the signals from multiple tags. However, no attempt is made to determine the locations of the multiple tags, other than that they are all within the range of the reader.

Since the "read range" of RFID tags is very dependent on the specific RFID technology that is being used, some RFID tags and readers were procured and testing was performed to determine the read range and related parameters.

5. OPTIONS FOR RFID TECHNOLOGIES

Discovery of a technique for deducing the orientation of a person at the time of detecting a device in a known location would be a significant accomplishment for the study. For system studies, the evaluation of RFID technologies should include availability, cost, portability, and power consumption in addition to the functional parameters of read range and data capability.

We have evaluated the commercially available 13.56 MHz passive tags. The tags and readers communicate via magnetic coupling, which limits the read range to less than 10 cm for typical readers (simple loop antenna). More complex loop systems can be used to extend this range, but the practicality of such systems for first responder navigation remains under investigation. The key challenge is that because of the large wavelength, of approximately 22 m, these systems operate in the near field with the magnetic field strength dropping as one over the distance cubed.

For higher frequencies, such as 400 MHz and 900 MHz, wavelengths are about 0.3 – 0.8 m. These systems operate in the far field. Coupling is via the electric field, and the field drops more slowly (as one over the distance). This results in an anticipated read range of several meters for passive tags. We have noted [15] that 600 MHz to 2 GHz is the best frequency band for propagation in buildings.

6. FIRST RESPONDER SIMULATION

NIST purchased a RFID developer's kit that operates nominally at 900 MHz, and that includes the reader, software and various passive tags. A demonstration program was developed to test the basic RFID localization concept for first responders in a straight hallway. It shows the location of the reader and the location of the tags graphically, as shown in Figure 4, and updates in real time as the responder moves through the hallway.

The program incorporates a database containing a series of tag ID's. The reader was attached to a cart, as shown in Figure 5, to facilitate smooth travel through the hallway. As the reader moves through the hallway, the tags enter the read field of the reader and are detected. When a tag is detected, the tag ID is entered as an index into a lookup table that contains the tag's position coordinates.

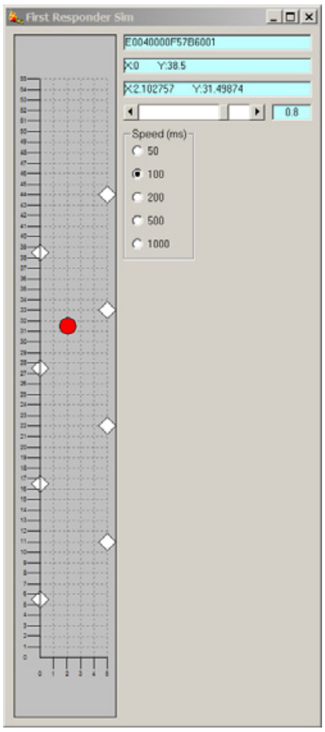

Figure 4. Graphical display of reader and tags.

In order to provide the best possible read performance the tag reader was programmed to identify only tags of the type used in the hallway. The frequency was fixed at 907 MHz, and the reader power was set to maximum (500 mW). The tags used in the demonstration were

Figure 5. RFID reader and laptop on cart.

modified slightly by placing them in front of conductive reflectors, as shown in Figure 6. This improves the read distance (an increase from 2 m to 3.3 m). We are in the process of obtaining commercial tags that can be mounted on any surface (metal, plastic, wood, glass, etc.) and still maintain a read distance of more than 3 m.

Since this first version of the system had no other position tracking capability (such as inertial sensors or GPS signals) except for the tag information, a simple weighting scheme was used to average the new position data as they were acquired. The current position was given more emphasis (0.8 to 0.9), and the new position datum was given less (0.2 to 0.1) in order to provide a smooth transition as new tags were read. Since the tags were read, on average, several times per second, this scheme worked well for tags spaced about 244 cm apart.

Figure 6. RFID tag and metallic backing placed on hallway wall.

7. CONCLUSION

This paper has suggested the use of RFID technology along with other technologies such as gyrometers, dead reckoning, and GPS as a navigation tool for first responders. It explained conceptually how RFID technologies would work and discussed the strengths and weakness of the different technologies. It has demonstrated how the RFID technology will provide fixed position waypoints as the first responder moves through a hallway.

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