RFID-Assisted Indoor Localization and Communication for First Responders

L. E. Miller, P. F. Wilson, N. P. Bryner, M. H. Francis, J. R. Guerrieri, D. W. Stroup, L. Klein-Berndt
National Institute of Standards and Technology (NIST)
Contact: L. E. Miller, 301-975-8018, 301-590-0932 (fax), lmiller@antd.nist.gov

An indoor localization and communication project is described that proposes to use RFID tags, placed in the building beforehand, as navigation waypoints for an inertial navigation system carried by a first responder. The findings from the first year of the planned three-year project are summarized.

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 radios) at different locations. In this project, supported by the NIST Advanced Technology Program (ATP), 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 the exploitation of this concept to implement a low-cost, reliable means for tracking firefighters and other first responders inside buildings, where navigation using GPS is not reliable—indeed, the GPS signal may have been disabled temporarily to prevent exploitation by terrorists [1]. 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.

Previous research and development for indoor localization includes that of a wireless network that integrates communications, precise tracking, and data telemetry, based on ultrawideband (UWB) technology, for use in hospital and manufacturing environments [2]. In contrast, the system envisioned by this new project is intended for an environment that is potentially much less "friendly" to RF propagation—the in-building environment of first responders that may contain smoke, dust, or flames—and is intended to leverage advances in ubiquitous RFID tag technology, in combination with recent advances in miniaturized inertial sensors, to develop a low-cost tracking system that does not depend upon the stability of the RF environment over relatively large distances to derive range from precision timing. The "philosophy" of the proposed RFID-assisted system also involves reducing the dependence on RF links to external data sources by exploiting the capability of RFID tags to store critical building information for retrieval when it is needed, where it is needed.

This project 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) in Gaithersburg, Maryland; and the Radio-Frequency Fields Group of the Electronics and Electrical Engineering Laboratory in Boulder, Colorado.

1.1 Concepts Motivating the Study

Indoor Navigation Cannot Depend on GPS. It cannot be assumed that GPS position solutions will be available to first responders in an indoor mission-critical situation. Even if the GPS signals are not blocked or obscured for tactical advantage, 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 using inertial sensors such as accelerometers and gyroscopes. Non-inertial sensors such as magnetometers and barometers can also be used in conjunction with dead reckoning to develop positions of a first responder in motion.

RFID Fixes Can Enhance the Accuracy of Inertial Tracking Systems. Inertial tracking systems inherently drift over time and produce errors in position, especially for inexpensive and lightweight systems. Corrections to the position solution at points along the path of the first responder can limit the maximum error to an acceptable level. Corrections, in the form of the insertion of known locations that have been reached, can be developed automatically by the detection of 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.

1.2 Approach to the Study

At the outset of the study, the overall approach was 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.
- The emphasis will be to make maximum use of information and to leverage software to simplify hardware implementations. The presentation and communication aspects of the scenarios to be studied will include:
- Informing the user (only) of position (stand-alone mode), assuming any 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 exiting of the building.

1.3 Project Milestones and Plans

The project goals are rather ambitious. But the milestones do serve to show how the work is intended to sequence and how the three groups collaborate.

1.3.1 FY 2005 Milestones

A. Define critical parameters of firefighter localization and in-building informational requirements in typical scenarios that relate to the building RF propagation environment and to the number and placement of RFID tags in buildings, as well as the type of data to be stored on the tags. (BFRL, EEEL)
B. Evaluate inertial and dead-reckoning navigation techniques and device options (including MEMS-based sensors) regarding their accuracy, availability, and suitability for integration with an RFID reader on a small platform for location updating. (ITL)
C. Analyze the requirements for the number of RFID tags and their placement to achieve desired localization accuracies, as a function of navigation techniques and device options. (BFRL, ITL)
D. Evaluate options for RFID technologies—including both tags and readers—to use for location updating of a navigation system implemented on a small, battery-powered device similar to a handheld computer or PDA (personal digital assistant). (EEEL, ITL)
E. Establish a project web page. (ITL)[1]
F. Document/publish interim results. (ITL, EEEL, BFRL)

1.3.2 FY 2006 Milestones

A. Select RFID tag and reader technologies and develop a prototype reader for use in this application. (EEEL)
B. Develop embedded software for acquisition of data from the RFID reader and use of that data to perform location updates and to display the location on a handheld computer as well as building information derived from RFID tag data. (ITL, EEEL)
C. Conduct preliminary experiments in NIST's Large Fire Facility to evaluate the performance of RFID-assisted localization devices in structures of simple geometry. (BFRL)
D. Evaluate options for interfacing the localization device with an ad hoc wireless communication network (ITL, BFRL)
E. Document/publish interim results. (ITL, EEEL, BFRL)

1.3.3 FY 2007 Milestones

A. Develop embedded software for interfacing an RFID-assisted localization device with an ad hoc wireless communication network. (ITL, BFRL)
B. Integrate RFID reader, navigation hardware and software, and ad hoc communication system for prototype testing. (EEEL, ITL)
C. Identify test sites/buildings and conduct tests to demonstrate the operation of the prototype localization and communication system in burning or smoke-filled building environments. (BFRL, ITL)
D. Develop embedded software for directing the user to the nearest RFID-tagged exit. (ITL)
E. Document/publish final results. (ITL, EEEL, BFRL)

[1] The project web page is found at http://www.antd.nist.gov/wctg/RFID/RFIDassist.htm

2. Summary of FY 2005 Accomplishments

2.1 Firefighter Localization 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 implications for placement of tags have been identified as the survival of the functioning of the tag in the environment.[2] 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, it would be a much-needed advancement to be able to identify 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 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 of the various load-bearing and non load-bearing elements, such as exterior and interior walls, columns, beams and girders, and floor construction. There are five types of building construction identified in the various codes [3, 4]:

Type I Buildings are classified as Fire-Resistive. Most of these buildings are used as high-rise office buildings, shopping centers, or residential units. They will be either reinforced concrete or structural steel. Structural members will be approved noncombustible or limited-combustible materials with specified fire resistance ratings. Any steel construction members must be protected to withstand prescribed test temperatures for fire resistance.

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. These metal roofs can be either solid steel girders and beams, or lightweight open-web bar joists or a combination of both with corrugated metal sheathing. 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. Interior, non-load bearing walls can be made of wood.

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 non-combustible or limited combustible materials. Interior structural members, including walls, columns, floors, and roofs, are large dimension solid or laminated wood timbers. The exterior walls are typically masonry. These buildings exist primarily in the New England area.

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 is such that radio signals may not penetrate the building adequately (*e.g.*, steel or metal).

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 [5]. Tables 1–4 give examples of fires in the different temperature and heat flux zones (Zone I to Zone IV).

Radio 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 one gram per cubic meter.
- Charged particles in the air that are ions from combustion processes.

[2] High temperature testing of the functionality of typical RFID tag systems will be conducted in FY 2006, using FY 2005 DHS funds that have been made available in part on an interest in this ATP project.

Table 1. Examples of Zone I environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA; 1992 [6]	None		
Abeles Project Fires, 1980 [7]	Class 1	Overhaul, up to 30 minutes	Temperature to 40 °C Flux to 0.5 kW/m^2
IAFF; Based on Abeles Project Fires 1980	Class1	Overhaul, up to 30 minutes	Temperature to 40 °C Flux to 0.5 kW/m^2
FRDG, FEU 1995 [8]	Routine	Elevated temperature, no direct thermal radiation, 25 minutes	Temperature to 100 °C Flux to 1.0 kW/m^2
Coletta, 1976 [5]	None		
Abbott, 1976 [9]	None		

Table 2. Examples of Zone II environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [6]	Routine	One or two objects burning	Temperature 20 C to 60 °C Flux 1.0 to 2.1 kW/m^2
Abeles Project Fires, 1980 [7]	Class 2	Small fire in a room, 15 minutes	Temperature 40 °C to 95 °C Flux 0.5 to 1.0 kW/m^2
IAFF; Based on Abeles Project Fires 1980	Class 2	Small fire in a room, 15 minutes	Temperature 40 °C to 93 °C Flux 0.5 to 1.0 kW/m^2
FRDG, FEU 1995 [8]	Hazardous	Elevated temperature and direct thermal radiation, 10 minutes	Temp. 100 °C to160 °C Flux 1.0 to 4.0 kW/m^2
Coletta 1976 [5]	Routine	Fighting fires from a distance	Temperature to 60 °C Flux 0.4 to 1.25 kW/m^2
Abbott 1976 [9]	Routine	Fighting fires from a distance	Temperature to 70 °C Flux 0.5 to 1.7 kW/m^2

Table 3. Examples of Zone III environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [6]	Ordinary	Serious fire, next to a room in flashover; 10 to 20 minutes maximum	Temp. 60 °C to 300 °C Flux 2.1 to 25 kW/m^2
Abeles Project Fires, 1980 [7]	Class 3	Totally involved fire, 5 minutes	Temp. 95 °C to 250 °C Flux 1.0 to 1.75 kW/m^2
IAFF; Based on Abeles Project Fires, 1980	Class 3	Totally involved fire, 5 minutes	Temp. 93 °C to 260 °C Flux 1.0 to 1.75 kW/m^2
FRDG, FEU 1995 [8]	Extreme	Rescue, retreat from flashover or backdraft	Temp. 160 °C to 235 °C Flux 4.0 to 10.0 kW/m^2
Coletta 1976 [5]	Hazardous	Outside burning room or small building	Temp. 60 °C to 300 °C Flux 1.25 to 8.3 kW/m^2
Abbott 1976 [9]	Ordinary	Outside burning room or small building	Temp. 70 °C to 300 °C Flux 1.7 to 12.5 kW/m^2

Table 2.4 Examples of Zone IV environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [6]	Emergency	Severe and unusual, 15 to 30 seconds for escape	Temp. 300 °C to 1000 °C Flux 25 to 125 kW/m^2
Abeles Project Fires, 1980 [7]	Class 4	Flashover or backdraft, up to 10 seconds	Temp. 250 °C to 815 °C Flux 1.75 to 42 kW/m^2
IAFF; Based on Abeles Project Fires, 1980	Class 4	Flashover or backdraft, up to 10 seconds	Temp. 260 °C to 815 °C Flux 1.75 to 42 kW/m^2
FRDG, FEU 1995 [8]	Critical	Could be encountered briefly	Temp. 235 °C to 1000 °C Flux 10 to 100 kW/m^2
Coletta 1976 [5]	Emergency	Not normally encountered, may be during flashover	Temp. 300 °C to 1000 °C Flux 8.3 to 105 kW/m^2
Abbott 1976 [9]	Emergency	Not normally encountered, may be during flashover	Temp. 300 °C to 1100 °C Flux 12.5 to 208 kW/m^2

- Thermal layers that could reflect or refract radio waves.
- Construction materials and their various attenuation properties. Adverse effects can be 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, that is, whether the building is residential or industrial. Tables 5 and 6 correlate the location resolution in meters to the accuracy in locating personnel and escape openings.

Table 5. Location parameters for residential scenarios.

Resolution in meters	Location		Escape	
	X-Y Direction	Z Direction	X-Y Direction	Z Direction
100	City Block +/-	10 floors +/-		
10	Front or rear of house	3 floors +/-	Structure +/- (Townhouse)	Floor +/-
1	Room	Floor +/-	Correct Wall	Window or Door
0.1	Location in Room	Correct Floor	Location on wall	Height of window or door

Table 6. Location parameters for industrial scenarios.

Resolution in meters	Location		Escape	
	X-Y Direction	Z Direction	X-Y Direction	Z Direction
100	Building +/-	10 floors +/-		
10	Section of Bldg	3 floors +/-	Section of Bldg	Floor +/-
1	Room	Floor +/-	Correct Wall	Window or Door
0.1	Location in Room	Correct Floor	Location on wall	Height of window or door

2.2. 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 today is the Global Positioning System (GPS), which enables position determination through the measurement of time delays of signals from multiple satellites in known (moving) positions; the time delay measurements are based on cross-correlating received satellite signals with local replicas to identify the signals' digital code position in time relative to the common reference. 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. 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 he 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. As illustrated in Figure 1, 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).

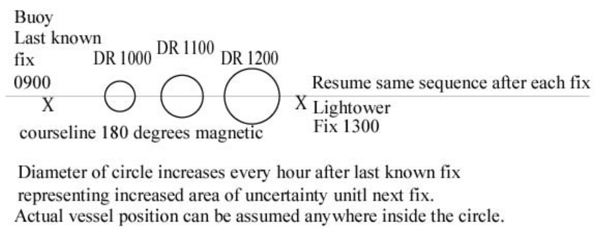

Figure 1 Dead reckoning in open ocean (from [11]).

Various systems are being proposed for "pedestrian navigation" utilizing DR techniques and small compasses. For example, [12] describes a small DR unit that utilizes a two-axis compass, a three-axis compass, or a rate gyroscope to track a walking person's heading. The heading produced by the 3-axis sensor is least affected by deviations in the person's orientation—very important in the case of first responders, who often do not walk "normally" in the course of their work. For computation of speed (actually, displacement as a function of time), the system in [12] uses an accelerometer to detect the person's steps; on average, the distance covered by a step was found to be quite consistent, even though the detection process can be rather subtle.

The outdoor performance of the system in [12] with a 2-axis magnetic compass and step detection using an accelerometer in an urban "tourist area" test is shown in Figure 2 in comparison to GPS. The scales in the figure are in meters. Although 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. The authors conclude, "This case illustrates the susceptibility of magnetic compasses to localized magnetic fields, particularly in an urban environment. In these circumstances a gyroscope solution is clearly advisable."

Another personal navigation product based on dead reckoning and step counting is a DRM that integrates a GPS receiver with a magnetic compass and other sensors [13–16] and is described as follows [14]:

> The Dead Reckoning Module (DRM®) is a miniature, self-contained, electronic navigation unit that provides the user's position relative to an initialization point. The DRM® is the first commercially available practical implementation of a drift-free dead reckoning navigation system for use by personnel on foot. It is specifically designed to supplement GPS receivers during signal outages. You still know where personnel are located even when GPS is blocked by nearby buildings, heavy foliage, or even inside many structures. The DRM contains a tilt-compensated magnetic compass, electronic pedometer and barometric altimeter to provide a continuous deduced position. A microprocessor performs dead reckoning calculations and includes a Kalman filter to combine the dead reckoning data with GPS data when it is available. The filter and other proprietary algorithms use GPS data to calibrate dead reckoning sensors for a typical dead reckoning accuracy of 2% to 5% of distance traveled, entirely without GPS. Options for the system integrator include a selection of voltage input ranges, CMOS or RS232 interface, data logging, and special software functions. In addition to horizontal position data, compass azimuth, tilt (pitch and roll), and barometric altitude are available.

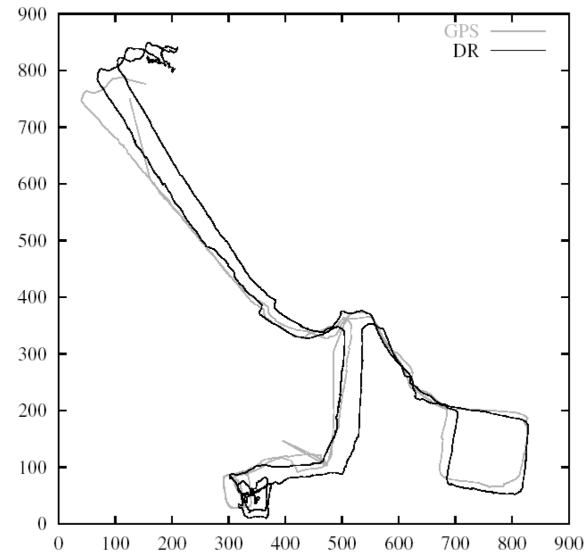

Figure 2 Positions developed by a DR system vs. GPS over a 4 km urban trail (from [12]).

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.

The relatively small size and cost of these personal navigation devices is made possible by the development in recent years of very small inertial and non-inertial sensors. For example, Micro-machined (MEMS) rate gyros based on vibration are available; a diagram of a semiconductor rate gyro based on a MEMS tuning fork is shown in Figure 4. The principle of a vibrating gyro is very simple: a vibrating object (such as a tuning fork) tends to keep vibrating in the same plane as its support is rotated. It is therefore much simpler and cheaper than is a conventional rotating gyroscope of similar accuracy. In the engineering literature, this type of device is also known as a *Coriolis vibratory gyro* because as the plane of oscillation is rotated, the response detected by the transducer (usually a piezo

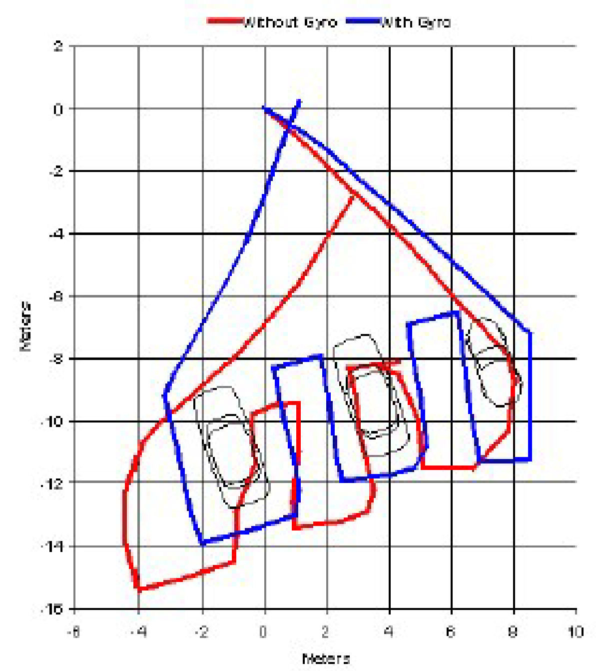

Figure 3. Manufacturer's demo of gyro-stabilized dead reckoning module improvement (from [14]).

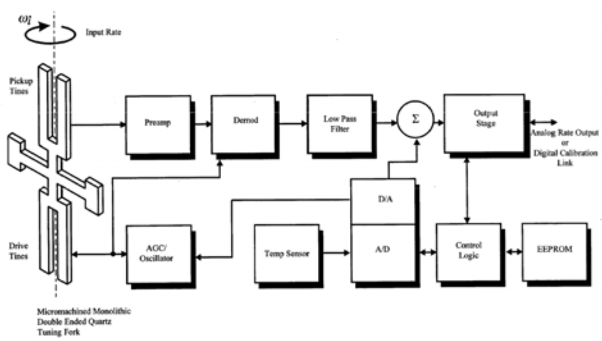

Figure 4. Block diagram of a semiconductor gyro based on MEMS technology (from [17]).

electric device) results from the coriolis term in its equations of motion. [16]

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, it is possible that they are 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.

2.3. Number and Placement of Tags

This milestone is predicated on the results of milestones A and B in that it 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, it was realized during the project that it was premature to analyze the final accuracy of an RFID-assisted inertial system 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 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 would be a step forward. Therefore, it is not appropriate to focus on 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.

2.4 Options for RFID Technologies

The RFID technologies referred to in this milestone include not only the currently available devices, standards, and frequencies, but also any technique by which a person in a building can automatically detect that he is in a known location.

Discovery of a technique for deducing the orientation of a person at the time of detecting a device in a known location would be significant information 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.

NIST-Boulder has developed an RFID test bed at 13.56 MHz that complies with the ISO 14443 and 10373-6 standards. We have evaluated the 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, as shown in Figure 5, 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.

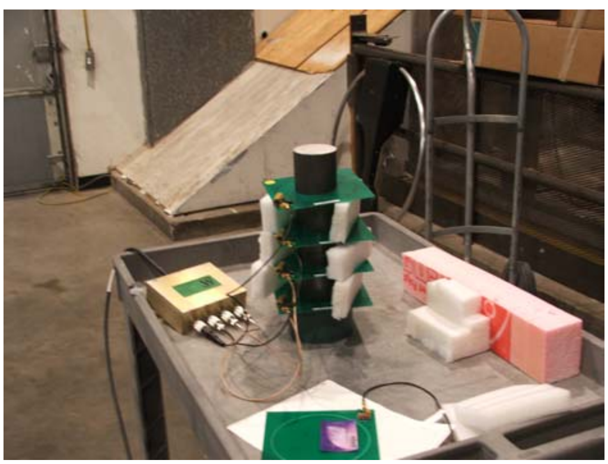

Figure 5. Loop antennas used to activate and read 13.56 MHz tags.

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. It has been noted [19] that 600 MHz – 2 GHz is the best frequency band for propagation in buildings.

We have also started to evaluate an active tag RFID system that operates at 433 MHz, shown in Figure 6. This system requires an additional computer and power supply. The tags are battery powered. The tag and reader communicate using an electric field and the read range is over 30 meters. The reader can be set to recognize the tag responding with most power. This should be the tag closest to the first responder unless the battery power is low.

We have ordered 900 MHz RFID systems with software development kits. Anticipated delivery is mid-November 2005. These are passive tag systems. One uses a hand held reader that weighs only 1 kg and has a read range of approximately 3 meters (see Figure 7).

There is on-going work in the industry to optimize the performance and reduce the costs of RFID antennas and readers [20–24].

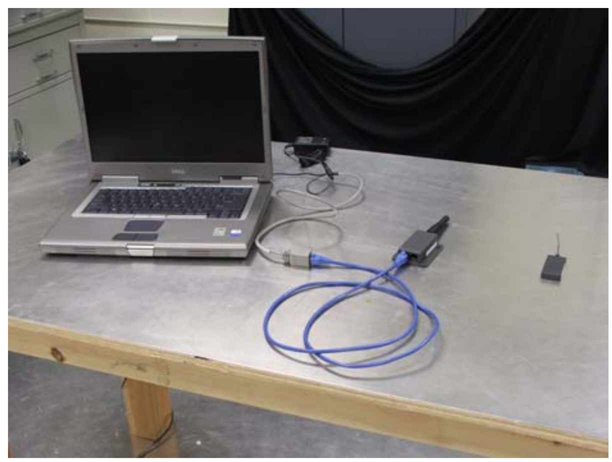

Figure 6. RFID system using active tags at 433 MHz.

Figure 7. Handheld 900 MHz reader.

3. References

[1] "Bush prepares for possible GPS shutdown," http://abcnews.go.com/Politics/wireStory?id=335054&CMP=OTC-RSSFeeds0312

[2] "Time Domain and GE Corporate R&D Announce Technology Partnership to Develop Ultra Wideband -UWB- Wireless Indoor Network," http://www.bbwexchange.com/news/archive/archived_broadband_wireless_files_2001/timedomain042401.htm

[3] NFPA A 220 Standard on Types of Building Construction, National Fire Protection Assoc., Quincy, MA 02269-9101, 2006.

[4] NFPA 5000 Building Construction and Safety Code, National Fire Protection Assoc., Quincy, MA 02269-9101, 2006.

[5] C. Coletta, I. J. Arons, L. E. Ashley, "Development of Criteria for Firefighters Gloves," NIOSH-77-134-A; GIDEP-E072-2273; Natl. Inst. for Occupational Safety and Health, Morgantown, WV, February 1976.

[6] ——, "Minimum Standards on Structural Fire Fighting Protective Clothing and Equipment: A Guide for Fire Service Education and Procurement," U.S. Fire Admin., Emmitsburg, MD, 1992.

[7] F. J. Abeles, "Project Fires, Volume 2: Protective Ensemble Performance Standards, Phase 1B," NASA CR-161530, National Aeronautics and Space Admin., Washington, DC, May 1980.

[8] J. A. Foster and G. V. Roberts, "Measurements of the Firefighting Environment – Summary Report," Central Fire Brigades Advisory Council Research Report number 61, 1994, Home Office Fire Research and Development Group, *Fire Engineers Journal*, United Kingdom, September 1995.

[9] N. J. Abbott, T. E. Lannefeld, and R. E. Erlandson, "Exploratory Development of Coated Fabric for Firefighters' Protective Clothing. Final Report. April 1974-March 1975," AFML-TR-75-72; Fabric Research Labs, Dedham, MA, July 1975.

[10] ——, http://www.deadreckoning.com/

[11] W. Newberry, "Dead Reckoning: A Skill All Navigators Should Master," Pilothouse Online at http://www.pilothouseonline.com/IS2V1_00/Lessons/main0001.htm

[12] C. Randell, et al., "Personal Position Measurement Using Dead Reckoning," *Proc. 2003 ISWC* at http://www1.cs.columbia.edu/~drexel/CandExam/Randell2003_ISWC_DeadReckoning.pdf

[13] C. T. Judd, "A Personal Dead Reckoning Module," *Proc. ION GPS '97*. Online at http://www1.cs.columbia.edu/~drexel/CandExam/DRM_ION97paper.pdf

[14] http://www.pointresearch.com/drm3_module.htm

[15] ——, "DRM-III OEM Dead Reckoning Module for Personnel Positioning," Point Research Corp. brochure. Online at http://www.pointresearch.com/PDFs/DRM3.pdf

[16] ——, "Vibrating structure gyroscope," Wikipedia article online at http://www.answers.com/topic/vibrating-structure-gyroscope

[17] A. M. Madni and L. E. Costlow, "A third generation, highly monitored, micromachined quartz rate sensor for safety-critical vehicle stability control," *Proc. IEEE 2001 Aerospace Conference*, Vol. 5, pp. 2523–2534.

[18] ——, "Waypoint," Wikipedia online article at http://en.wikipedia.org/wiki/Waypoint

[19] A. E. Fathy, discussion during "Through-Wall Imaging and Sensing" July 7, 2005, session 99, 2005 IEEE Antennas and Propag. Soc. Internatl. Symp. and USNC/URSI Natl. Radio Science Mtg.

[20] S. M. Weigand, "Compact Microstrip Antenna with Forward-Directed Radiation Pattern for RFID Reader Card," July 6, 2005, session 64, 2005 IEEE Antennas and Propag. Soc. Internatl. Symp. and USNC/URSI Natl. Radio Science Mtg.

[21] L. Ukkonen, D. Engels, L. Sydänheimo, M. Kivikoski, "Reliability of Passive RFID of Multiple Objects Using Folded Microstrip Patch-Type Tag Antenna," July 6, 2005, session 64, 2005 IEEE Antennas and Propag. Soc. Internatl. Symp. and USNC/URSI Natl. Radio Science Mtg.

[22] D. Bechevet, T.P. Vuong, S. Tedjini, "Design and Measurements of Antennas for RFID, Made by Conductive Ink on Plastics," July 6, 2005, session 64, 2005 IEEE Antennas and Propag. Soc. Internatl. Symp. and USNC/URSI Natl. Radio Science Mtg.

[23] C. Cho, H. Choo, "Design of UHF Small Passive Tag Antennas," July 6, 2005, session 64, 2005 IEEE Antennas and Propag. Soc. Internatl. Symp. and USNC/URSI Natl. Radio Science Mtg.

[24] P,V, Nikitin, K.V.S. Rao, S. Lam, "Low Cost Silver Ink RFID Tag Antennas," July 6, 2005, session 64, 2005 IEEE Antennas and Propag. Soc. Internatl. Symp. and USNC/URSI Natl. Radio Science Mtg.