



NIOSH PHASE I SBIR:

# FIREFIGHTER LOCATION AND RESCUE EQUIPMENT (FLARE)

Q-TRACK CORPORATION

Grant Number: 1R43OH010007-01A1

Contract Period: September 1, 2011 - May 29, 2012

**FINAL REPORT**

March 8, 2013

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## **LIST OF TERMS AND ABBREVIATIONS**

AM - Amplitude Modulation

dB - decibel

E911 - Emergency 911

FF - Firefighter

FLARE - Firefighter Location and Rescue Equipment

GPS - Global Positioning System

GUI - Graphical User Interface

MAC - Media Access Control

NFER - Near-Field Electromagnetic Ranging

RF - Radio Frequency

RSSI - Received Signal Strength Indicator

RTLS - Real-Time Location System

SOLD - Signal-of-Opportunity Location Device

UHF - Ultra High Frequency

UWB - Ultra-Wideband

WPI PPL - Worcester Polytechnic Institute Precision Personnel Location

## ABSTRACT

**Title:** Firefighter Location and Rescue Equipment (FLARE)

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**Start & End Dates:** 9/1/2011 - 5/29/2012

**Program Area:** NIOSH/CDC

Our aim was to implement and commercialize a Firefighter Location and Rescue Equipment (FLARE) system: an effective, practical, and affordable personal location and tracking system for use by first responders. By improving situational awareness at incident response scenes, our system may avoid some of the annual 100 firefighter deaths and enhance occupational safety for firefighters and other emergency responders. The FLARE system collects sequential ambient AM band signal data from broadcast stations along the route taken by a firefighter. This data provides a robust and repeatable RF fingerprint of the path. By correlating live data against the stored path data, one can tell not only if the current location is on the path, but also determine how far along the path one has progressed. An individual firefighter can employ the data for self-rescue, evacuating a building along the ingress path, or a team member can use the data to follow the path of a lost or disabled firefighter. If a pre-calibration of an indoor environment is possible, FLARE will be able to deliver absolute location data with foot-level (i.e. 30cm rms or better) accuracy. Even if calibration data are not available, FLARE will enable path routing to guide firefighters out on their entry paths or to enable rescuers to be routed to the location of a lost firefighter with foot-level accuracy.

## 1 EXECUTIVE SUMMARY

This section summarizes the key findings, translation of findings, and outcomes and impacts of the Phase I effort.

### 1.1 SIGNIFICANT (KEY) FINDINGS

Our Phase I effort investigated Firefighter Location and Rescue Equipment (FLARE) using an AM broadcast band Signals-of-Opportunity Location Device (SOLD) to provide precise geo-location capability in an indoor environment. We discovered SOLD accuracy using an individual AM beacon was just under 1m. Having nine uncorrelated stations available improved rms accuracy by about a factor of three to 26cm with respect to the 1.3m spaced points to which it was calibrated. Between calibration points, the rms accuracy was 45cm. Only one point in the entire test exceeded 1m location error. We also deployed the system in a cave, a multi-story residential living facility, and in our office to evaluate tracking capability. This proof-of-concept testing demonstrated the feasibility of SOLD to provide precision location data in a variety of operational settings.

Absolute location accuracy depends on pre-calibrating the tracking environment, a luxury not available in most emergency incident scenes. Q-Track devised a “path calibration” system to overcome this lack of pre-calibration. The RF breadcrumb algorithm collects and compares sequential RF data from the FLARE tag to identify when one tag is following the path of another and where, relative to the path, the tag is located. This innovative approach enables a rescuer to be vectored to the precise location of a disabled firefighter ***along the same path originally taken by the firefighter in distress***, thus avoiding the conventional problem of homing in on a firefighter from the wrong side of a wall. Then a rescuer can be vectored along the same path by correlating the rescuer’s signal characteristics to those collected along the lost firefighter’s path.<sup>1</sup> The accuracy of the path correlation is comparable to the 26cm rms accuracy demonstrated by SOLD. Another key feature is the ability to detect and bypass “dead ends” and follow the most direct path. In the 2010 testing, Q-Track’s prototype system found a simulated lost firefighter in seven minutes. By way of comparison, two state-of-the-art inertial systems yielded rescue times of nine and twelve minutes, respectively. A video is available of the simulated rescue exercise.<sup>2</sup> We updated and improved upon the GUI. We also collaborated with Prof. Bruce Walker of Georgia Tech to develop concepts for sonification – an auditory user interface that could be used by firefighters in a low visibility smoke-filled environment. Further details on these significant findings are in Section 2.

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1) Hans Schantz et al, “Testing a Novel Firefighter Location System Using Near-Field Electromagnetic Ranging,” Submitted to 5th Annual IEEE International Conference on RFID, 12-14 April, 2011. See: <http://bit.ly/cKIuhU>.

2) H. Schantz, “NFER® FLARE Rescue Video Now Available,” *ÆtherCzar Blog*, 23 August, 2010. See: <http://bit.ly/aAOWEC>.

## 1.2 TRANSLATION OF FINDINGS.

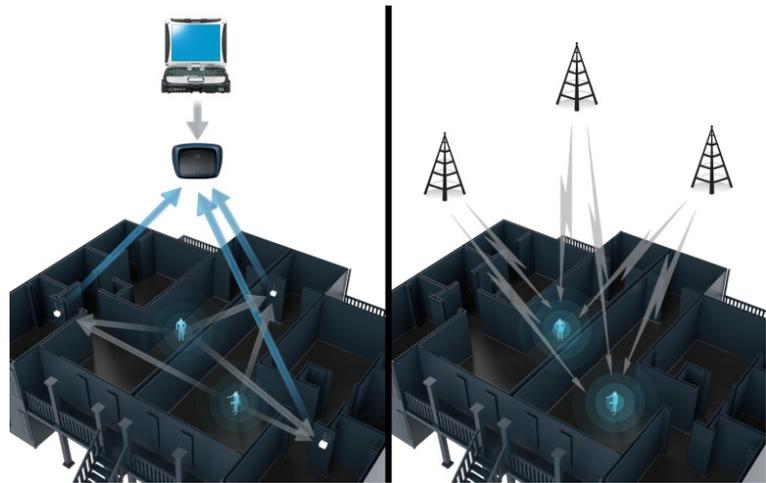
Fire Fighter Location and Rescue Equipment (FLARE) has the potential to provide enhanced location awareness in support of emergency responder operations. Our goal is to enable firefighters to guide themselves out of a building, avoiding the need for a rescue. If a rescue becomes necessary, rescuers can use the RF breadcrumb data from the lost firefighter to guide them to the lost firefighter's location. Work is underway through a funded effort from Homeland Security to extend the results of this proof-of-concept effort into a prototype capable of being tested by first responders in operational settings.

SOLD has the potential to provide precise indoor location data in the service of a variety of worker safety missions beyond location awareness for first responders. Knowing the location of workers in dangerous industrial environments enhances their safety. Q-Track's existing Near-Field Electromagnetic Ranging (NFER®) Real-Time Location Systems (RTLS) already enhance worker safety in a variety of applications including nuclear worker training and proximity detection and collision avoidance systems that help keep workers safe from their robotic co-workers.

The advantage of SOLD over NFER and other conventional RTLS is dramatically lower infrastructure cost. This advantage becomes clear in discussing Outcomes and Impacts of the present research.

## 1.3 OUTCOMES/IMPACT.

Conventional RTLS requires an expensive infrastructure ranging from about \$5-\$10/sqft for UWB RTLS solutions to about \$1/sqft for NFER RTLS. Because SOLD relies on AM broadcast band signals-of-opportunity, there is no infrastructure to install, and thus no infrastructure cost. This lower infrastructure cost promises to make location awareness more available in the service of worker safety and other applications. The present effort made significant progress toward this goal by more rigorous testing and evaluation of SOLD performance in a variety of operational environments of interest.



**Fig. 1:** A classic RTLS infrastructure employs a fixed infrastructure of receivers (left). By employing signals-of-opportunity, an effectively infrastructure-free location system becomes possible (right).

## 2 SCIENTIFIC REPORT

This section presents background for the project, specific aims, methodology, results and discussion, and conclusions

### 2.1 BACKGROUND FOR THE PROJECT

Each year approximately 100 firefighters die in the line of duty, and over 30,000 suffer from fireground injuries.<sup>3</sup> While many of these injuries are unavoidable due to the hazardous and stressful conditions under which firefighters must labor, the incident response scene becomes safer with better situational awareness. A particular goal is the ability to navigate within chaotic and potentially smoke-filled incident scenes. The most critical navigation needs are first for firefighters to navigate their own way safely out of danger, and second, for rescuers to be able to navigate their way to a comrade in distress. This section will discuss significance of the proposed effort, the innovative location technology developed by Q-Track, and our approach to completing and commercializing a Firefighter Location and Rescue Equipment (FLARE) product.

#### 2.1.1 LOW-FREQUENCY RF LOCATION SYSTEMS

The critical barrier to progress is the use of high frequency and wireless hardware optimized for high data rate communications yet applied to geo-location in indoor environments. Most commercial wireless systems exploit the leading edge of RF electronics in the microwave realm. The large bandwidths available at gigahertz frequencies are ideal for communications and data network applications. The high tech allure of high frequency RF electronics has led many vendors to develop systems using this spectrum, including UHF (typically 433MHz), 2.4GHz, and ultra-wideband (UWB) systems. High frequencies, though well-suited for data and communications applications, are not a good choice for wireless tracking. “In general, given typical wood or reinforced concrete buildings, attenuation is an increasing function of frequency. The higher the frequency, the worse the attenuation”.<sup>4</sup> High frequencies have wavelengths significantly smaller than typical indoor obstructions, thus, high frequency systems are prone to confusion by multi-path. “Deploying a positioning system that works well indoors is a challenge, because signals are reflected off walls, floors, and ceilings, which tend to confuse sensors.”<sup>5</sup>

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3) See <http://www.usfa.fema.gov/fireservice/fatalities/statistics/casualties.shtm>

4) Krzysztof W. Kolodziej and Johan Hjelm, *Local Positioning Systems: LBS Applications and Services*, (Boca Raton, CRC/Taylor&Francis, 2006), p. 95.

5) *Ibid.*, p. 76.

### 2.1.2 NEAR-FIELD ELECTROMAGNETIC RANGING

Q-Track's proposed FLARE system relies on SOLD technology. Since SOLD shares many characteristics with Q-Track's already commercialized Near-Field Electromagnetic Ranging or NFER® RTLS. This section will briefly describe NFER® RTLS and Q-Track's development track record. NFER is an emerging RTLS technology that exploits near-field RF characteristics, such as the phase relations between the electric and magnetic field components of an



*Fig. 2: Q-Track's product line-up (from left to right), a QT-550 Locator Receiver, QT-654 Cradle Charger, QT-500 Tag, Q-XL Interactive Location Device, QT-600 Tag, QDose, QT-640 Tag.*

electromagnetic field. Q-Track's founders invented and developed NFER technology with location in mind, choosing a low-frequency approach to the problem instead of the standard high frequency or microwave approach.<sup>6</sup> NFER® RTLS operates within about a quarter-wavelength of a transmitter, in the vicinity of the transition point at  $\lambda/2\pi$  between the near-field and the far-field zones.<sup>7, 8</sup> Using low frequency (~1MHz), long wavelength (~300m) signals, NFER systems are more penetrating, longer range, more multipath resistant, and more robust than alternatives.<sup>9, 10</sup>

Figure 2 shows Q-Track's product line-up. Q-Track's NFER technology is the basis of a simulated dosimetry system piloted at Southern Company's Plant Vogtle nuclear facility.<sup>11</sup> RFID Journal recognized the breakthrough nature of Q-Track's innovative NFER RTLS offering with a "Best-In-Show, Finalist," designation at the third annual RFID Journal Awards.<sup>12</sup> The Nuclear Energy Institute awarded Southern Company the 2010 Top Industry Practice (TIP) Award for Training for their use of Q-Track's NFER RTLS-based "Dosimulation™" system. The system is currently deployed at seventeen plants with more installations in progress.<sup>13</sup> Q-Track's NFER RTLS is also employed in a proximity detection system and other

6) H. Schantz and R. DePierre, "System and Method for Near Field Electromagnetic Ranging," U.S. Patent 6,963,301, November 8, 2005. <http://bit.ly/s5jGfp>

7) C. Capps "Near Field or Far Field," EDN, August 16, 2001. <http://bit.ly/voHKdz>

8) Hans Schantz, "Near Field Phase Relationships," IEEE APS Conference July 2005. <http://bit.ly/edzH82>

9) Kazimierz Siwiak, "Near-Field Versus UWB Ranging," 2009 IEEE RFID Symposium, 27 April 2009. <http://bit.ly/rUOjoB>

10) Krzysztof W. Kolodziej and Johan Hjelm, *Local Positioning Systems: LBS Applications and Services*, (Boca Raton, CRC/Taylor & Francis, 2006), p. 95. See: <http://bit.ly/tzMUvJ>

11) C. Swedberg, "Nuclear Plant Operator Uses RFID to Promote Safety," *RFID Journal*, May 18, 2009. <http://bit.ly/df90oj>

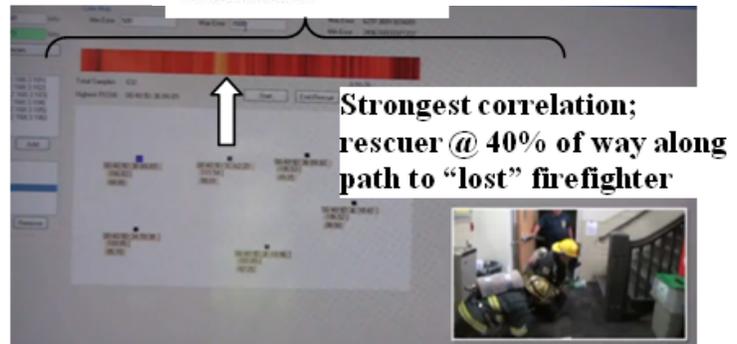
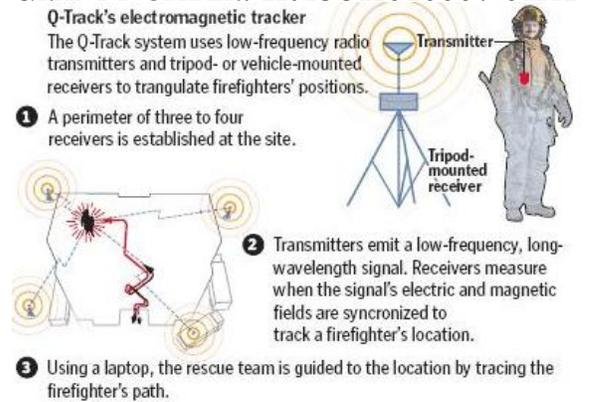
12) "Finalists Unveiled for the Third Annual RFID Journal Awards," *RFID Journal*, March 16, 2009. See: <http://bit.ly/c5dPjA>

[13] Staff, "Virtual Radiation," *Nuclear Engineering International*, 20 April 2012. See: <http://bit.ly/I9E7VL>

location awareness products.<sup>14</sup> Strong sales over the last six months have pushed cumulative commercial revenue from NFER® RTLS products to over \$1.2M.

**2.1.3 NFER FLARE PROOF-OF-CONCEPT**

Q-Track deployed a proof-of-concept system evaluated at the 2010 WPI PPL Workshop (see Fig. 3).<sup>15</sup> Q-Track’s Firefighter Location and Rescue Equipment (FLARE) approach captures the near-field signal characteristics of firefighters’ tracking tags to characterize and calibrate the system to their paths. The RF breadcrumb algorithm collects and compares sequential RF data from the FLARE tag to identify when one tag is following the path of another and where, relative to the path, the tag is located. This innovative approach enables a rescuer to be vectored to the precise location of a disabled firefighter **along the same path originally taken by the firefighter in distress**, thus avoiding the conventional problem of homing in on a firefighter from the wrong side of a wall. Then a rescuer can be vectored along the same path by correlating the rescuer’s signal characteristics to those collected along the lost firefighter’s path.<sup>16</sup> Another key feature is the ability to detect and bypass path “loops” or “dead ends” to follow the most direct path. In the 2010 testing, Q-Track’s prototype system found a simulated lost firefighter in seven minutes (see Fig. 3). By way of comparison, two state-of-the-art inertial systems yielded rescue times of nine and twelve minutes, respectively. A video is available of the simulated rescue exercise.<sup>17</sup>



*Fig. 3: A Boston Globe graphic (top, Ref. 15) describes Q-Track’s prototype FLARE system that yielded the fastest rescue in testing by the Worcester Fire Department at the 2010 WPI PPL Workshop. A screenshot showing the GUI and inset video are below.*

14) C. Swedberg, “RFID Helps Halt Collisions Between People and Robots,” *RFID Journal*, May 25, 2012. See: <http://bit.ly/KUFFCv>

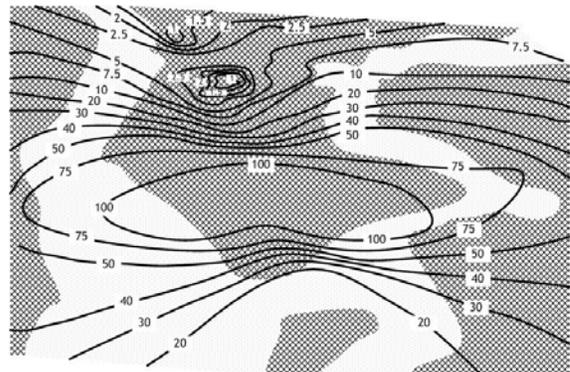
15) Hiawatha Bray, “When rescuers need rescuing,” *The Boston Globe*, August 30, 2010. See: <http://bit.ly/aLivB6>.

16) Hans Schantz et al, “Testing a Novel Firefighter Location System Using Near-Field Electromagnetic Ranging,” Submitted to 5th Annual IEEE International Conference on RFID, 12-14 April, 2011. See: <http://bit.ly/cKIuhU>.

17) H. Schantz, “NFER® FLARE Rescue Video Now Available,” *ÆtherCzar Blog*, 23 August, 2010. See: <http://bit.ly/aAOWEC>.

**2.1.4 AM BROADCAST BAND SIGNALS-OF-OPPORTUNITY**

In an Air Force project, we characterized how urban terrain couples to and distorts low frequency signals. Substantial amplitude variations due to urban terrain are well known, as seen in Figure 4.<sup>18</sup> We went further, examining phase behavior and determining field impedance. Urban terrain couples to and reradiates signals in ways that defy simple localization schemes. As AM broadcast band signals propagate through urban environments, they couple to power lines and buildings causing them to perturb signals. These perturbations introduce near-field components that are detectable by Q-Track’s Locator-Receiver. Because these perturbations result from interactions with fixed objects like electrical lines, buildings, and geological features, a tracking system that maps these perturbations and uses them as an RF-fingerprint for geo-location has the potential to achieve remarkably good accuracy and repeatability.<sup>19</sup> Figure 5 illustrates this behavior and shows the field impedance on a dB scale (-20dB = 3.8ohm; 0dB = 377 ohm; +20dB = 38kohm, etc.) for an AM broadcast station as measured within a four acre industrial facility. Substantial near-field content is present. These distortions provide the basis for a highly accurate geo-location system based on RF-fingerprinting to support first responder location.



*Fig. 4: Signal strength contours (E-field in mV/m) for an AM station in Manhattan (1927) [Ref. 14].*



*Fig. 5: AM signals couple to the urban environment, generating distinctive near-field fingerprints (far left). We gathered data at “blue” points in a four acre industrial facility (left). Field impedance scaled in dB with respect to 377ohm (right) shows substantial variation in the surface plot surface plot (far right). These variations enable precise localization.*

18) John H. Morecroft, *Principles of Radio Communication, 2nd ed.*, New York: John Wiley and Sons, 1927 (frontispiece).

19) H. Schantz, et al, “Method and apparatus for determining location using signals-of-opportunity, U.S. Patent 8,018,383, September 13, 2011. See: <http://bit.ly/yjVG72>

The most successful RF-based location systems: LORAN and GPS, employ an architecture involving an infrastructure of transmitters and a mobile receiver capable of locating itself relative to the infrastructure. We offer a third approach with comparable potential: Signal-of-Opportunity Location Devices (SOLD). By taking the tested and proven architecture of GPS, and applying it to the indoor environment where we spend much of our time, SOLD has the potential to provide pervasive location and navigation in GPS-denied environments, using an RF-fingerprinting approach. Q-Track's SOLD technology has the potential to provide pervasive precision indoor location data in support of emergency responders and other applications.

## 2.2 SPECIFIC AIMS

In 2009, the National Occupational Research Agenda (NORA) Public Safety Sub Council laid out strategic goals for occupational safety and health research and practice in the U.S. public safety sub-sector:

**Strategic Goal 2:** Reduce injuries and fatalities associated with structural firefighting operations by 30% by 2015.<sup>20</sup>

**Intermediate Goal 2.4:** Enhance firefighter safety by development of effective, practical and affordable personal location and tracking technologies and systems by 2013 through collaborative efforts of equipment manufacturers and fire service management, labor and consensus organizations.<sup>21</sup>

Q-Track's proposal for a Firefighter Location and Rescue Equipment (FLARE) system supports these goals. In addition, we will continue to be guided by the firefighter tracking concepts and requirements identified by John Orr and David Cyganski in 2001,<sup>22</sup>

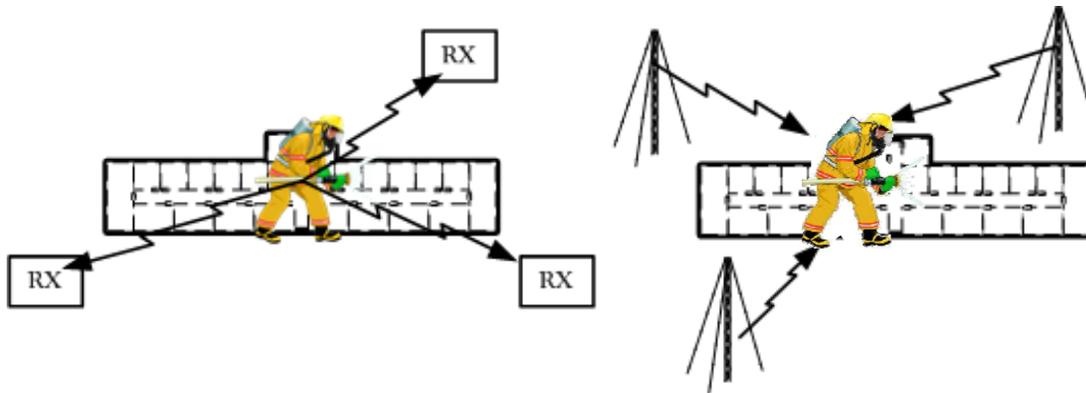
- Identify the current location of each rescue team member (in 3D) to the incident command post outside the building,
- Provide status (health and motion) information on each team member, and on conditions in the exit path,
- Provide emergency exit guidance (back-tracking) to each team member (perhaps via synthesized voice commands), and to the incident command post,
- Provide location precision of +/- 1 ft, (necessitated to prosecute rescue operations in which the question "on which side of the wall are they?" can be crucial), and
- Provide full integration with communications and incident management operations.

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20) *National Occupational Research Agenda (NORA): National Public Safety Agenda, April 2009, p. 9.*

21) *Ibid., p. 10.*

22) *John A. Orr and David Cyganski, "Firefighter and other Emergency Personnel Tracking and Location Technology for Incident Response: Concepts and Requirements," Worcester Polytechnic Institute, July 11, 2001. See: <http://www.wpi.edu/Images/CMS/PPL/jaowhite2.pdf>*



**Fig. 6:** The specific aim of this project was to demonstrate the feasibility of replacing the NFER pathfinding receiver infrastructure with the SOLD signal-of-opportunity architecture.

Firefighter location is a significant challenge, so we have narrowed our focus to a system meeting the final three of these five requirements. Our specific objective is to implement and commercialize a FLARE system: an effective, practical, and affordable personal location and tracking system for use by first responders. The proposed effort has the potential to exert considerable influence on the localization research community by overcoming a significant barrier to progress: the use of high frequency and wireless hardware optimized for high data rate communications yet applied to geo-location in indoor environments. Q-Track has already demonstrated the merits of our comparatively low-frequency approach whose signals propagate much better in cluttered indoor environments.

Our specific aims include answering the following questions:

- What accuracy can SOLD achieve under day and night time conditions?
- Can SOLD provide accurate location data in a variety of realistic environments?
- What improvements can be made to the FLARE path following routine?

The following sections discuss our methodology and results.

## 2.3 METHODOLOGY

Our work involved several distinct projects.

- To determine accuracy, we laid out a 4ft (1.3m) grid in our office space. We characterized variations in AM signal behavior in this area and evaluated location accuracy.
- We also performed four qualitative tracking tests: tracking in our office during daytime hours, tracking in our office at night, tracking in a multi-story assisted living facility, and tracking in a cave.
- A third aspect of our work was an evaluation and improvement to our FLARE path-following algorithms and the Graphical User Interface (GUI).
- Finally, we collaborated with Prof. Bruce Walker of Georgia Tech to investigate the possibility of devising an auditory interface to the pathfinding data.

The following section discusses the results from each of these efforts.

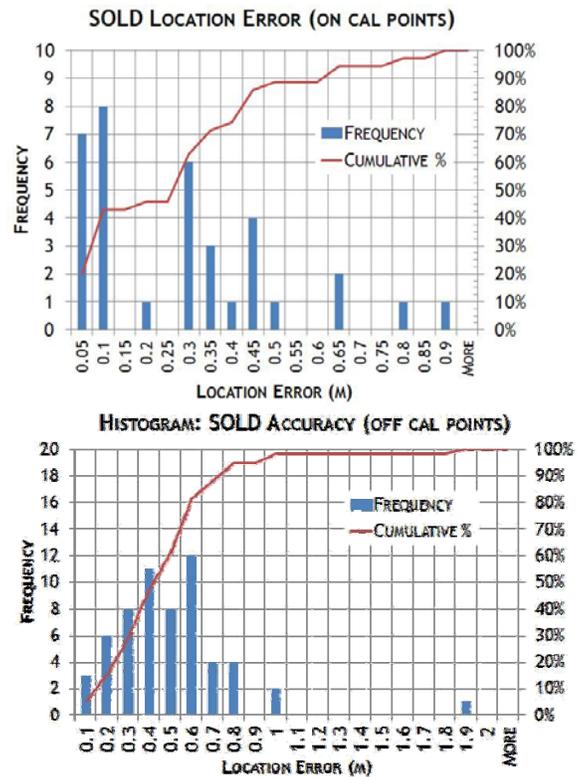
## 2.4 RESULTS AND DISCUSSION

This section discusses our results in accuracy testing, tracking in various environments, updating the FLARE GUI, and development of concepts for an auditory interface.

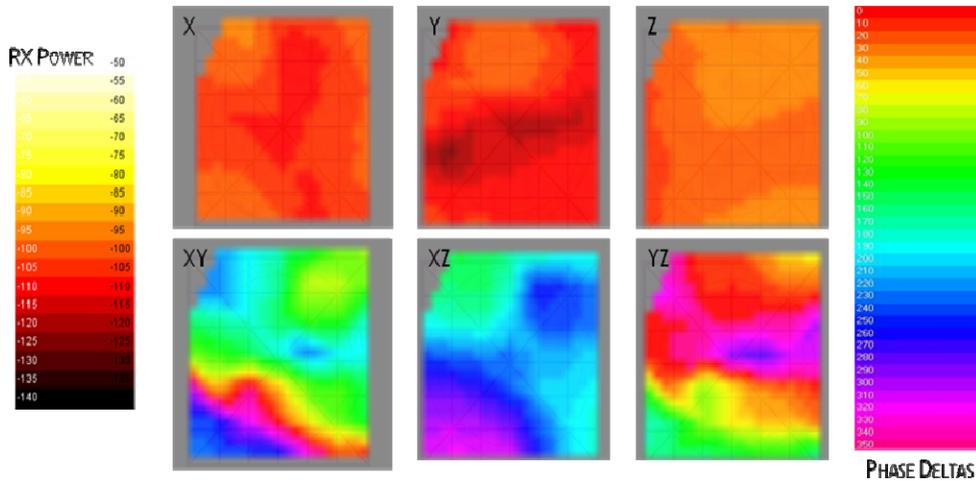
### 2.4.1 SOLD ACCURACY

We discovered SOLD accuracy using an individual AM beacon was just under 1m. Having nine uncorrelated stations available improved rms accuracy by about a factor of three to 26cm with respect to the 1.3m spaced points to which it was calibrated. Between calibration points, the rms accuracy was 45cm. Only one point in the entire test exceeded 1m location error. Figure 7 shows histograms of the results. Our commercial tag transmitter architecture achieves about 55cm rms accuracy using data from four receivers nominally, demonstrating that the architectures yield similar performance. Furthermore, the proof-of-concept system worked well tracking during day-time and night-time hours in our office. At night, we were able to track on four local stations, bypassing any difficulties with ionospheric propagation modes. Accuracy was slightly degraded to about 50cm rms due to the lower number of trackable signals. In a particularly challenging test environment with limited signals-of-opportunity, one can always add additional low-power transmitter beacons to improve tracking accuracy.

Figure 8 shows the RSSI and phase measurements for one of the nine AM band stations used in the location exercise. We took calibration data points on a 6 x 6 grid spaced 1.3m (4ft) measuring three orthogonal magnetic field amplitudes and three phase differences between channels. This gave us 54 separate data points (9 stations x 6 data points/station) to compare in the RF fingerprinting algorithm. This wealth of data makes the system both robust and accurate. From the results of Figure 8, we see that 4ft spaced samples are probably more dense than necessary to capture subtle variations in signal behavior.



*Figure 7: The proof-of-concept system obtained 26cm rms accuracy with respect to calibration points (top) and 45 cm rms between calibration points (center) in an indoor test with calibration points spaced in a 1.3m (4ft) grid (bottom).*



**Figure 8:** The RX power (scale to left) for three orthogonal magnetic antennas (x, y, z, top), and the phase deltas (scale to right) for each of the three pairwise measurements. A similar set of six data surfaces from each of nine local AM band signals yielded 26cm rms tracking.

### 2.4.2 QUALITATIVE TRACKING TEST

In an abandoned limestone mine, the SOLD proof-of-concept accurately tracked a user along a loop as far as 100m from the entrance of the cave. In a twelve story apartment building, the SOLD proof-of-concept correctly determined floor and location most of the time. The principal error mode of the SOLD proof-of-concept is an occasional erroneous location solution far from the current location. These errors are amenable to relatively simple filtering algorithms. Typical accuracy was within 1m. Figure 9 shows screenshots from the four tracking tests captured in a video of system performance.



**Figure 9:** Four screenshots from a video of tracking results.

### ***2.4.3 FLARE GUI UPDATES***

In the current Phase I effort we revised and updated the WPI GUI. Key improvements included:

- Ability to correlate multiple tag responses simultaneously,
- Ability to add maps or aerial photography for enhanced situational awareness,
- Time scaled correlation bars,
- Improved connectivity diagnostics, and
- Ability to support multiple users simultaneously across a distributed network.

Figure 10 presents screenshots of the GUI in “tracking mode” (left) and “rescue mode” (right). The “Start Tracking” button enables tracking mode. In tracking mode, the FLARE Client collects RF breadcrumb data from a collection of tags. The GUI displays elapsed time. Selecting any individual tag allows a user to monitor the general zone or location of the tag by noting which receiver detects the strongest signal, as denoted by the blue icon.

The “Rescue” button enables rescue mode. Rescue mode begins with a pop-up menu allowing the user to select any one of the tags to rescue. Once the user makes the selection, the GUI generates time-scaled correlation bar charts for each of the remaining tags relative to the “lost” tag. The correlation bar uses a color scale to denote the degree of correlation between the current location of any particular tag and the path of the lost tag.

In the example of Figure 8, at time 10min 15sec into the tracking, Tag 3 was declared lost. The bar charts correlate the live data from the current locations of the two remaining tags with the 10min 15sec RF-breadcrumb path of the lost tag. In the Figure, the top bar shows Tag 5 has reached the final location of the lost tag. The bottom bar shows that tag 1 is in the vicinity, approximately one minute behind. Some weak correlations show up on the early part of the top bar, because the final location of the lost tag was actually in the vicinity of its starting point. The video (<http://bit.ly/aAOWEC>) shows how this correlation bar is used in a realistic rescue scenario.

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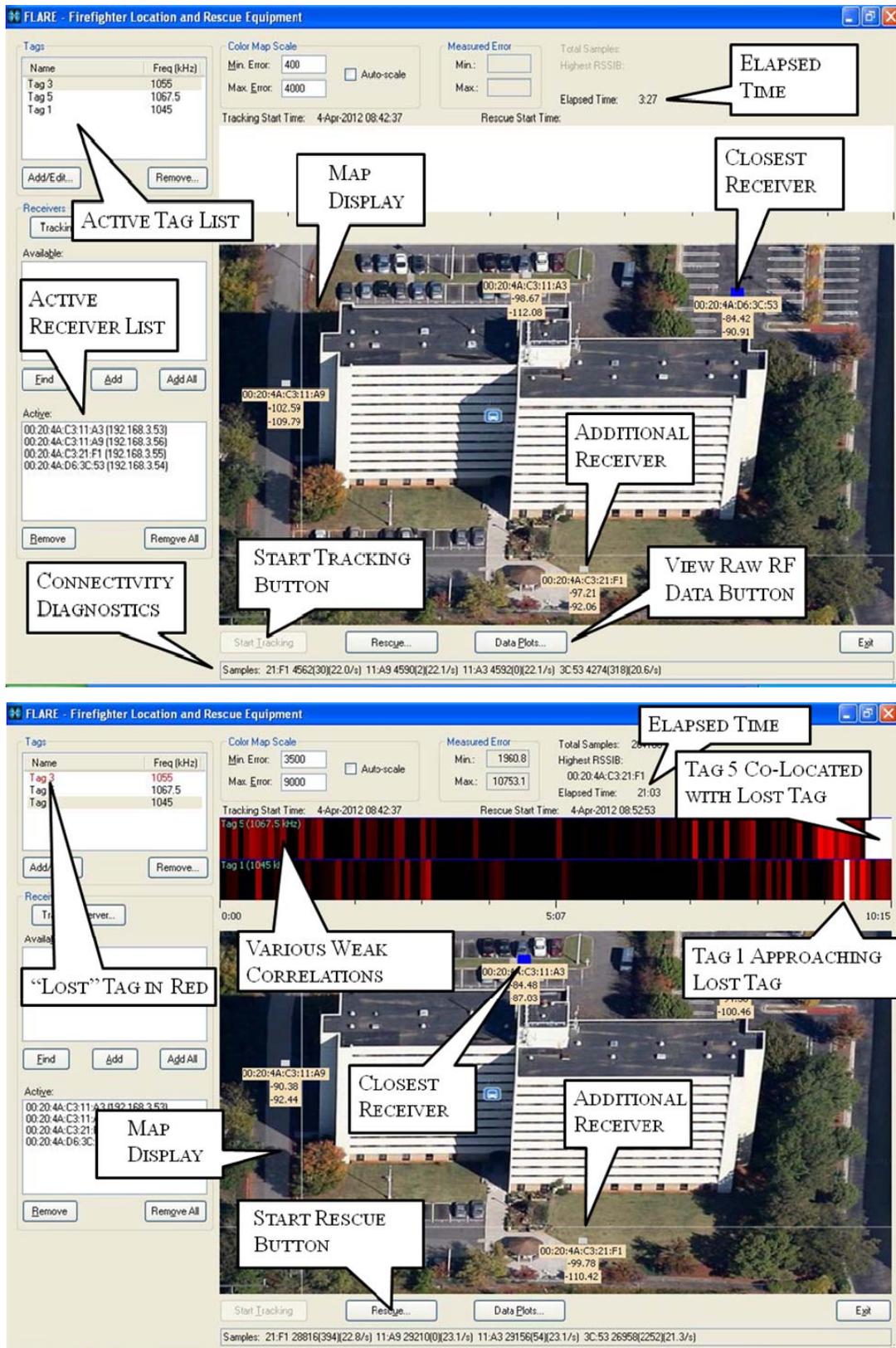


Figure 10: FLARE Client in tracking mode (top), and FLARE Client in rescue mode (bottom).

#### **2.4.4 SONIFICATION CONCEPT DEVELOPMENT**

Although the visual display is quite effective, it is likely to be impractical for implementation by an individual firefighter in a smoke filled environment. Q-Track collaborated with Prof. Bruce Walker of Georgia Tech to develop three auditory display design options.

**DESIGN A – Basic Proximity Monitor (Sonification):** In this concept, we monitor and provide feedback on proximity and progress. This minimalistic approach is the most intuitive just mapping a single measure of proximity or progress into sound. We employ a single, intermittent "system tracking" beep to indicate that the system is tracking and operational. We put the tracking sound in one ear, leaving the other free for voice communication and listening to the immediate environment. We change to a double "beep-beep" when the path is encountered based on (a threshold/notification). The "beep-beep" would probably start louder to capture attention and make the threshold super-salient, then settle in to a moderate level until next threshold. As rescuers proceed the beep-beep changes to either a "boo-beep" or a "bee-boop." The "boo-beep" (ie. ascending two-tone pattern) indicates increasing match, getting "warmer," or further along the path. The "bee-boop" (ie. decending two-tone pattern) indicates decreasing match getting "colder" or regressing along the path. A triple "beep-beep-beep" sounds when a certain proximity threshold (close to target) is reached, continuing with boo-beep or bee-boop sounds until the lost firefighter is found.

Prof. Walker recommends using broad spectrum or multi-component tones to avoid masking, designed appropriately for the typical/expected noise profile of the fire scenario. Design A is very simple to use, probably very robust to noise, and would support simultaneous speech/radio communication. Users could be quickly trained in scavenger hunt type exercises. Design A would require code to identify threshold crossings and logic to manage audio. Each tag would generate its own unique audio feedback based on the tags current status with respect to the path. This allows each user to interactively probe, for instance, to move a couple feet one way or the other to see if they are on the right path.

**DESIGN B – Spectral Display (Audification):** In this concept, we create an auditory histogram of the correlation display, and let the rescuers listen to the actual data. For each bin in the vector (each thin colored line, from left to right in the visual color bar), map onto a frequency band or note in the sound (like mapping the color bar onto the keys of a piano). Use musical notes or 1/3 octave bands to even spacing and equal power potential. Map vector strength to loudness of that auditory component (currently strength mapped to color and brightness on a black-red-yellow-white color scale). Poor matches would sound quieter, with random notes. As rescuer approaches the track, the "sound" would evolve into a chord. Chord would be predominantly low pitched for matches to the earlier or older trace (like brighter colors in left part of the color bar), and predominantly higher pitched for the newer trace (like brighter colors in right part of color bar). Multiple centers (low notes plus higher notes) would indicate the lost firefighter had been there

multiple times. Rescuers search, and as they move, the auditory display would evolve and update with their movements; they could quickly hear whether they are getting closer or farther from the FF, as the pitches would evolve to a higher pitch, and louder tones with a tighter grouping.

Design B provides a more detailed real-time display, rather than a processed, threshold-driven auditory interface. No extra logic or threshold-calculation logic/code is needed, so Design B is the fastest and easiest to build auditory display at the prototype stage. This option will be harder to integrate with the full tracking system, however. While Design B probably gives more precise info, it will likely also require more training and practice to achieve proficiency. Until tested under realistic conditions, it will be difficult to determine whether Design B will be more fragile due to its complexity, or more robust due to its sophistication. In Design B, the audification display-generation system on the tag needs to be able to generate multiple audio events/notes (using PureData or maybe a basic multichannel MIDI note generator). Thus, Design B requires more power to run high-level programs on the tag. Broadcasting Design B over the radio is not really an option – it would clog the channel and be degraded by the radio bandpass. Each tag would need to generate its own audio.

**DESIGN C – Hybrid Design A+B:** This concept combines the real-time audification of the data (Design B) running in the background, and overlays the notifications from the sonification (Design A). Rescuers could track their movements in real time using the auditory histogram, but also benefit from the computer-generated notifications (the beep-beeps, etc.) to help them identify threshold crossings (intersecting a path, reaching a 10-foot radius, moving away from the lost firefighter, etc.).

Design C requires the most sophisticated/powerful tag/mobile system, and has all the pros and cons of the two separate designs. Hopefully the sum of the pros would dramatically outweigh the sum of the cons. This would require considerable effort to build and integrate.

## 2.5 CONCLUSIONS

Our Phase I effort investigated Firefighter Location and Rescue Equipment (FLARE) using an AM broadcast band Signals-of-Opportunity Location Device (SOLD) to provide precise geo-location capability in an indoor environment. We discovered SOLD accuracy using an individual AM beacon was just under 1m. Having nine uncorrelated stations available improved rms accuracy by about a factor of three to 26cm with respect to the 1.3m spaced points to which it was calibrated. Between calibration points, the rms accuracy was 45cm. Only one point in the entire test exceeded 1m location error. We also deployed the system in a cave, a multi-story residential living facility, and in our office to evaluate tracking capability. This proof-of-concept testing demonstrated the feasibility of SOLD to provide precision location data in a variety of operational settings. In addition, we

made improvements to the FLARE pathfinding algorithm and GUI and collaborated with Prof. Bruce Walker to develop concepts for an auditory interface well-suited for emergency responders in low visibility environments.

Q-Track's corporate vision is to enable "knowing where, anywhere." The proposed project aligns closely with this goal. Q-Track's proposed Locator-Receiver tags use AM broadcast band signals to determine location. Thus, like GPS, the proposed indoor navigation technology requires no user-supplied infrastructure. Employing concepts pioneered in Q-Track's patented and award-winning Near-Field Electromagnetic Ranging (NFER®) products, the proposed "Signal-of-Opportunity Location Device" (SOLD) system can deliver sub-meter accuracy in complicated indoor settings. Q-Track estimates the ultimate cost of the SOLD system at \$50 for a stand-alone tag to as little as \$20 for a module that leverages the battery and enclosure of a smart phone or similar device. The future of location awareness divides into three tiers:

- Outdoor Location: using GPS,
- Address Level Location: via GPS, WiFi MAC address recognition, or cellular [E911] approaches, and
- Indoor Location: using SOLD RTLS.

The SOLD approach, which underlies the FLARE concept described in this proposal truly has the potential to fundamentally transform location science and technology by making sub-meter location accuracy indoors as pervasive as GPS location is outdoors.

### 3 REFERENCES

- 1) H. Schantz et al, [2011] "Testing a Novel Firefighter Location System Using Near-Field Electromagnetic Ranging," Submitted to 5th Annual IEEE International Conference on RFID, 12-14 April, 2011. See: <http://bit.ly/cKIuhU>.
- 2) H. Schantz, [2010] "NFER® FLARE Rescue Video Now Available," *ÆtherCzar Blog*, 23 August, 2010. See: <http://bit.ly/aAOWEC>.
- 3) See <http://www.usfa.fema.gov/fireservice/fatalities/statistics/casualties.shtm>
- 4) Krzysztof W. Kolodziej and Johan Hjelm, [2006] *Local Positioning Systems: LBS Applications and Services*, (Boca Raton, CRC/Taylor&Francis, 2006), p. 95.
- 5) *Ibid.*, p. 76.
- 6) H. Schantz and R. DePierre, [2005] "System and Method for Near Field Electromagnetic Ranging," U.S. Patent 6,963,301, November 8, 2005. <http://bit.ly/s5jGfp>
- 7) C. Capps [2001] "Near Field or Far Field," *EDN*, August 16, 2001. <http://bit.ly/voHKdz>
- 8) H. Schantz, [2005] "Near Field Phase Relationships," *IEEE APS Conference July 2005*. <http://bit.ly/edzH82>
- 9) Kazimierz Siwiak, [2009] "Near-Field Versus UWB Ranging," *2009 IEEE RFID Symposium*, 27 April 2009. <http://bit.ly/rUOjoB>
- 10) Kolodziej [2006], p. 95. See: <http://bit.ly/tzMUvJ>
- 11) C. Swedberg, [2009] "Nuclear Plant Operator Uses RFID to Promote Safety," *RFID Journal*, May 18, 2009. <http://bit.ly/df90oj>
- 12) "Finalists Unveiled for the Third Annual RFID Journal Awards," *RFID Journal*, March 16, 2009. See: <http://bit.ly/c5dPjA>
- 13) Staff, [2012] "Virtual Radiation," *Nuclear Engineering International*, 20 April 2012. See: <http://bit.ly/19E7VL>
- 14) C. Swedberg, [2012] "RFID Helps Halt Collisions Between People and Robots," *RFID Journal*, May 25, 2012. See: <http://bit.ly/KUFFCv>
- 15) Hiawatha Bray, [2010] "When rescuers need rescuing," *The Boston Globe*, August 30, 2010. See: <http://bit.ly/aLivB6>.
- 16) H. Schantz et al, [2011] "Testing a Novel Firefighter Location System Using Near-Field Electromagnetic Ranging," Submitted to 5th Annual IEEE International Conference on RFID, 12-14 April, 2011. See: <http://bit.ly/cKIuhU>.
- 17) H. Schantz, [2010] "NFER® FLARE Rescue Video Now Available," *ÆtherCzar Blog*, 23 August, 2010. See: <http://bit.ly/aAOWEC>.
- 18) John H. Morecroft, [1927] *Principles of Radio Communication*, 2nd ed., New York: John Wiley and Sons, 1927 (frontispiece).
- 19) H. Schantz, et al, [2011] "Method and apparatus for determining location using signals-of-opportunity," U.S. Patent 8,018,383, September 13, 2011. See: <http://bit.ly/yjVG72>
- 20) National Occupational Research Agenda (NORA): National Public Safety Agenda, April 2009, p. 9.
- 21) *Ibid.*, p. 10.
- 22) John A. Orr and David Cyganski, [2001] "Firefighter and other Emergency Personnel Tracking and Location Technology for Incident Response: Concepts and Requirements," *Worcester Polytechnic Institute*, July 11, 2001. See: <http://www.wpi.edu/Images/CMS/PPL/jaowhite2.pdf>
- 23) RNCOS Industry Research Solutions, "Global Positioning Systems Market Forecast (2006-2008)." See: <http://bit.ly/lGBYR4>
- 24) See <http://www.kiplinger.com/money/bestcities/> for details.
- 25) See [http://money.cnn.com/smallbusiness/best\\_places\\_launch/2009/snapshot/151.html](http://money.cnn.com/smallbusiness/best_places_launch/2009/snapshot/151.html) for details.

#### 4 INCLUSION ENROLLMENT REPORT

N/A – No human subjects research was performed

#### 5 PUBLICATIONS

Schantz, H.G., “Theory and Practice of Near-Field Electromagnetic Ranging,” *Proceedings of the 2012 International Technical Meeting of The Institute of Navigation*, Newport Beach, CA, January 2012, pp. 978-1013.

**Abstract:** This paper illustrates the divergence of phase, signal, and energy velocities in the near field by employing space-time diagrams of the evolution of near-fields. In addition this paper describes near-field link and impedance relations a near-field phase diagram for electrically small quadrature transmitters. Near-field physics enables near-field electromagnetic ranging systems in a variety of modes for a diverse range of applications. This paper summarizes recent results applying near-field electromagnetic ranging to a Signal-of-Opportunity Location Device (SOLD) implementation. Q-Track tested this system in realistic environments including a multi-story building and underground. SOLD yielded an rms accuracy of 26cm when returning to a calibration point and 46cm rms between calibration points.

This paper described the theoretical background of the SOLD concept and shared some of the results of the present effort.

#### 6 INCLUSION OF GENDER AND MINORITY SUBJECTS

N/A – No human subjects research was performed

#### 7 INCLUSION OF CHILDREN

N/A – No human subjects research was performed

#### 8 MATERIALS AVAILABLE FOR OTHER INVESTIGATORS

We have additional related materials and publications available for other investigators include reprints of the paper cited above and other work. Many are available at <http://www.q-track.com/index.php/location-innovation/technical-papers>. The most recent work is available on request by sending an e-mail to [info@q-track.com](mailto:info@q-track.com).