Electrical and Computer Engineering Department
100 Institute Road, Worcester, MA 01609-2280
Phone 508-831-5231 Fax 508-831-5491
http://www.ece.wpi.edu

Firefighter and other Emergency Personnel Tracking and Location Technology for Incident Response

Concepts and Requirements

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John A. Orr
Professor and Head
Electrical and Computer Engineering Dept.

David Cyganski
Professor
Electrical and Computer Engineering Dept.

Personnel Location Technology for Incident Response

John A. Orr, Ph.D. and David Cyganski, Ph.D.

orr@wpi.edu, cyganski@wpi.edu,

Worcester Polytechnic Institute

Electrical and Computer Engineering Department

Worcester, MA 01609

On December 3, 1999 six fire fighters lost their lives in a tragic cold storage warehouse fire in the City of Worcester, Massachusetts. Two fire fighters initially got lost and then two search teams also became lost in the maze and zero visibility from the dense smoke resulting in the six deaths. One of the recommendations of NIOSH and a separate internal review of the circumstances of the fire was:

- **Manufacturers and research organizations should conduct research into refining existing and developing new technology to track the movement of fire fighters on the fire ground.**

Problem Statement and Scope of Proposed System

The first and most important job of most emergency response situations is the location and rescue of persons. This is certainly true in structural fires and may be true in other situations such as natural disasters, airport emergencies, toxic release accidents, and terrorist events. To accomplish this task, a responder must often enter a structure with minimal equipment for personal safety, generally nothing more than a two-way radio and possibly an air pack of limited duration. The combination of limited air supply, increasing fire and smoke intensity, and destruction of escape paths, makes the likelihood of entrapment a very real threat. Annual statistics on the loss of firefighters and other emergency responders sadly validates these statements. Recent advances in RF and communications technology and integrated electronics make development of a personnel location system feasible. Several technologies and areas of expertise can be brought to bear on this problem, ultimately resulting in a wearable device, which will:

- Identify the current location of each rescue team member (in three dimensions) 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)
- Provide full integration with communications and incident management operations.

Problem Context

The role and utility of positioning, navigation, and geolocation systems has expanded greatly over the past decade. The principal driver for much of this expansion has been the availability of the Global Positioning System, a satellite-based system for outdoor positioning to an accuracy of 100 meters or less (without augmentation). Also critical in the growth of the technology has been the availability of low-cost, high-capacity, battery-powered processing, storage and display systems. Quite different from GPS, and filling a separate need, have been various forms of proximity control systems, which operate by sensing the proximity of a tag to a sensor. Traditional uses include inventory control and tracking of persons within a controlled environment (as in a home for the elderly). Enhancement of proximity technology has led to systems, which can determine range of the tag with respect to one or more sensors, and hence can determine position of the tag. These systems determine 2-D tag floor-position with either range-range or range-angle location sensor units in a pre-wired infrastructure located in virtually every compartment of the coverage space. In summary, enhanced capabilities have been emerging at the two ends of the application spectrum: large-area, outdoor-only systems with a single, common, extraterrestrial infrastructure and low position resolution (10-30 meter accuracy), and small-area, high resolution indoor systems constrained by pre-installed, site-specific and site-calibrated infrastructure. We will refer to these two kinds of systems below as global-scale and compartment-scale solutions.

This situation has left a substantial gap in an important application area: a system for rapidly deployable position determination and tracking of personnel, particularly emergency service personnel over relatively short ranges of emergency response operations (between that of global- and compartment-scales), but with high precision and reliability in an unprepared and radio unfriendly environment. Development of a deployable operations-scale capability is important for at least two reasons: (1) it will greatly increase emergency response efficiency, improving results with limited human resources, and (2) it will provide a quantum step increase in personal safety and recovery of responders. Finally, cost of new technology is often a factor impeding its adoption in budget-constrained environments. Thus a system must be developed that minimizes the cost of the mobile personnel tags. The dual-use opportunities of the personnel location system considered here promise to also lead to significantly reduced costs.

System Requirements

The overall system characteristics include:

- High-accuracy geolocation, parallel in concept to the Global Positioning System (GPS) but rapidly deployable with no site preparation or on-site calibration procedures, specialized for indoor applications and enhanced in accuracy,
- Rugged and miniature low-power user equipment with no controls (always on!),
- Portable, rugged, easy-to-use computerized system control unit,
- Self-configuring, fault-tolerant, distributed software systems.

More specifically, following is a draft set of operational specifications:

- Location precision: +/- 1 ft
- Maximum range: 2000 ft

- Simultaneous users: 100
- 3-D position information (multi-level emergencies being common)
- Guidance information available to rescue teams
- Self-rescue guidance (voice synthesis)
- Integration with stored databases: geographic and structural
- Backtracking information automatically generated
- Small, rugged and very low cost tag devices
- Requires no interaction with wearer during normal use
- Integrated with present turn-out equipment
- Optional basic physiologic/environmental information capture and transmission

Overview of the Technical Approach

A deployable operations-scale geolocation system must operate in indoor as well as outdoor environments. The indoor environment is much more problematic than outdoor; challenges in the indoor environment include multiple radio transmission paths, signal attenuation through walls, and the need to continuously capture "track information" to find a clear path to the person once he/she is located. Possible approaches to solutions may be partitioned in several ways. One such partition is "active" (where the wearer emits signals) vs. "passive" (where the wearer receives signals only).

Standard GPS is an example of a passive system wherein the speed of radio propagation is used to determine the distance between several transmitters and a mobile, multi-channel receiver. Recovery of multi-path free location information requires many operational channels, advanced signal processing and ultimately the results must also be transmitted back to the base station. Hence any passive system modeled on GPS must suffer the costs associated with a large number of mobile units of great complexity. There are also the associated problems of power consumption in an environment where operations may last many hours (either interruptions to operations for battery changes, or, the inconvenience of a bulky and heavy battery).

The alternative approach of an active system is better suited to this environment. In this approach the mobile unit can consist simply of a low cost, low complexity transmitter (of appropriate, uniquely identifiable signals) while the multi-channel reception, signal processing complexity, power consumption, etc. of the system is shifted to the small number of base stations.

The multipath signals introduced by operations indoor or outdoor/urban environments affect signal reliability and accuracy for either active and passive systems that use GPS like signals: signal reflectors in the environment may appear as false target positions, multipath signals can null out direct target signals causing position drop-outs and summation of direct and multipath signals introduce phase shifts that obstruct high-resolution position determination by means of carrier phase estimation and tracking.

One component of the solution to the multipath problem takes the form of the use of signals which are generically called “ultra-wide-band," or UWB. UWB systems may use either highly impulsive time domain signals or traditional pseudo-random, time-distributed, spread-spectrum code signals. The very wide RF bandwidth of UWB signals help mitigate multipath effects by elimination of frequency dependent signal nulls, and by allowing minimum arrival time (direct propagation path) determination for use with phase independent high resolution time difference of arrival estimation of target position.

A complete solution to multipath mitigation and high resolution location for operations-scale geolocation will necessitate incorporation of recently developed and also new signal processing and information fusion algorithms combined with emerging technology for UWB signal generation and acquisition. At WPI we have been investigating the application of "super-resolution" and "direction of arrival" based signal extraction technology developed by the radar and automatic target recognition communities in conjunction with COFDM technology developed by the mobile communications industry to form reliable (zero drop-out) and accurate (sub-meter) position estimates. Smart antenna systems (real-time adaptive beam-forming) at the base stations provide yet additional means to mitigate the effects of severe multipath conditions.

WPI is prepared to apply its expertise and undertake the UWB indoor propagation studies and end-to-end signal processing algorithm testing and optimization needed to develop a proof-of-concept prototype of a robust and cost non-prohibitive geolocation system for emergency operations.

Very broadly, the overall problem has another major aspect beyond deployable operations-scale geolocation: systems integration. While the geolocation aspect may appear more significant, a position-determination device which is not integrated into the operation of the emergency response system may not be used on a routine basis, and hence will not accomplish its objective.

There are three important components of the systems integration task:

- First, design and implementation of an autonomous, fault-tolerant, self-calibrating and referencing positioning system.
- Second, integration of the personnel position information provided above with whatever geographical and/or structural database is available, and presentation of the three-dimensional position information of multiple personnel in a usable manner.
- Third, integration of this information with the overall command, control, and communications system for the incident response; a decision support system is needed to enhance rescue operations during emergent situations.

WPI is prepared to finalize the development of a personal locator technology, with the active involvement and assistance of the firefighting community and the communities of other emergency response, military services and commercial partners to integrate the technology into a full system solution. Towards that goal we wish to design a research methodology and to test bed the deployment of the technology in the City of Worcester Fire Department.

WPI Expertise

WPI faculty have substantial demonstrated experience and expertise in all of the relevant areas of the proposed work:

- Firesafety, research expertise and collaboration with the firefighting community (The Center for Firesafety Studies: one of the world's leading laboratories for R&D in topics including combustion/explosion phenomena, fire and smoke performance of structures, and firesafety design. The Fire Protection Engineering Program: the first Fire Protection MS program in the US was established at WPI in 1979, and the first US Ph.D. program was added in 1991),

- Global positioning systems (Satellite Navigation Lab),
- Mobile communications and indoor geolocation (The Center for Wireless Information Network Studies),
- Radar/Sonar signal processing and Automatic Target Recognition (Machine Vision Lab),
- Networking and embedded systems,
- Distributed computing and fault tolerance (Convergent Technologies Center),
- RF/Microwave analog design (NECAMSID: The New England Center for Analog and Mixed Signal Integrated Circuit Design).