STTR Project
Phase 1

Sensor Fusion for Nuclear Proliferation Activity Monitoring

Final Report

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A Executive Summary

One of our most important national security missions is to detect and monitor nuclear proliferation activities at critically sensitive sites over extended periods of time. In general neither individual remote or *in situ* measurements alone are adequate to characterize the proliferation activities of interest – new methodologies that utilize all available information should be developed.

The objective of Phase 1 of this STTR project is to demonstrate a Proof-of-Concept (PoC) of the Geo-Rad system that integrates a location-aware SmartTag (made by ZonTrak) and a radiation detector (developed by LLNL). It also includes the ability to transmit the collected radiation data and location information to the ZonTrak server (ZonService). The collected data is further transmitted to a central server at LLNL (the Fusion Server) to be processed in conjunction with overhead imagery to generate location estimates of nuclear proliferation and radiation sources.

The project team has successfully completed all the objectives of the Phase 1. The Geo-Rad Proof-of-Concept system was developed and demonstrated. The ZonTrak SmartTag was integrated with a radiation detector prototype developed by LLNL. A radiation detector emulator board was also developed to possibly substitute for the radiation detector. Radiation was detected directly or simulated using the emulator board. Radiation data and geo-location references were gathered and transmitted to the ZonService server and communicated to the LLNL Fusion server.

The Geo-Rad proof-of-concept system clearly demonstrated the feasibility of the integration of a Geo-aware (GPS-based) tag like the SmartTag with a radiation detector. The combined functionalities of both systems; coupled with the LLNL's Fusion algorithms based on Baysian estimation that would translate these measurements to source location, would bring about the needed tools to detect proliferation inside and around facilities. This combined with overhead imagery will result in more accurate assessment of any threat.

Phase 1 efforts were instrumental in increasing our understanding of the requirements of a commercial Geo-Rad system. The analysis of the Geo-Rad proof-of-concept system showed the feasibility of achieving further enhancements from the system design point of view in preparation for commercialization of this system. These enhancements will optimize the GPS, radiation detector, and local wireless subsystems and will increase the efficiency of the resulting Geo-Rad tag from a functional, operational, cost, size, and power consumption points of views. Further, the Phase 2 efforts may also consider other radiation detectors technologies in concert with LLNL efforts and developments. In specific, the following directions for Phase 2 are recommended: (1) Optimize Geo-Rad System Design, (2) Increase Integration of SmartTag and Detector's Electronics, (3) Develop Detector's Power and Functional Management Schemes, (4) Increase Available Memory, and (5) Develop Operation Processes and Methodologies for the Geo-Rad system.

Section C of this report covers the proposed approach and applications scenarios of the Geo-Rad systems. It also covers the technical objectives of this research which is proposing a new process and methodology for the monitoring and detection of nuclear proliferation activities. The process links radiating objects to specific radiation sources through the measurement of radiation levels using detectors that come as close as possible to the radiation source. Each radiation measurement is associated with an exact geo-location coordinates. This will enable the close association between these measurements and overhead imagery. Some of the main benefits resulting from this coupling of in-Situ measurements and overhead imagery include:

(a) Enhancing the simulation process of overhead imagery to refine the detection algorithms.

(b) Development and discovery of patterns of activities to pinpoint sites of proliferation activities

(c) Detection of changes in specific sites of interest.

(d) Reduction of false positives by improving the ability to distinguish between normal and abnormal activities.

(e) Prediction of possible future activities based on past analysis.

Section D lists the Phase 1 work plan covering the proof-of-concept engineering prototype integrating a compact low power detector system developed at LLNL with the SmartTag technology developed by ZonTrak. It also highlights some of the related efforts at LLNL focusing on radiation measurement and overhead imagery. This section also includes the phase 1 performance schedule.

The SmartTag system description is included in Section E. The discussion includes a general overview of the SmartTag system design, technical specifications, and target applications. It includes block diagrams of the SmartTag, the TagDetector, and the service platform (ZonService). It also includes a description of the Local Wireless Link (ZonLAN) linking the SmartTag to TagDetectors.

Section F lists the LLNL Radiation Detector system description. It covers some of the related research on radiation sensor networks, extracting content from remotely sensed images, and activity modeling and query at LLNL. The section includes description of the LLNL radiation detector used in this research.

The proof-of-concept project overview is covered in section G including the tasks, schedule, and deliverables as stipulated in the ZonTrak proposal for this STTR project. Section H highlights some of the challenges that were resolved in this project.

The Phase 1 accomplishments are detailed in Section I. A description of the proof of concept system, aided by photos of the actual hardware used to implement the system, is included. The different enhancements that ZonTrak introduced to its SmartTag system are covered including adaptation to the radiation detector interface, modifications to the ZonLAN communications scheme, and needed changes to the ZonService to enable the communications to the Fusion server. Section I also includes a description of an emulator board developed by ZonTrak to emulate the functionality of the radiation detector since the project team encountered some issues with the robustness of the LLNL radiation detector hardware.

The Geo-Rad proof-of-concept prototype was tested in Oakland, CA and Pacifica, CA with excellent results. Screen shots of the ZonService platform highlighting the location and behavior histories of these tags, the detected (and reported) radiation levels, and the location mapping of these tags are all included in Section I. In addition, screen shots of popup windows for specific tags that are in alerts with their associated radiation data are included. Finally, screen shots from the Fusion server capturing the record logs for the tags, details of each record, and cumulative spectrum collected during the testing are included.

Section J includes a discussion on technology direction and availability of radiation detectors. This study was conducted for the purpose of identifying the commercial availability of other radiation detectors.

Based on the successful completion of this Phase 1 project, it is recommended that Phase 2 efforts be supported. These recommended next steps and phase 2 directions are highlighted in Section K. These directions include:

(1) Optimization of the Geo-Rad System Design

(2) Increase the integration of SmartTag ad Detector's electronics

(3) Develop Detector's power and functional management schemes

(4) Increase available memory

(5) Complete system development for wearable Geo-Rad device and system

(6) Develop usage process and methodologies for monitoring critical sites

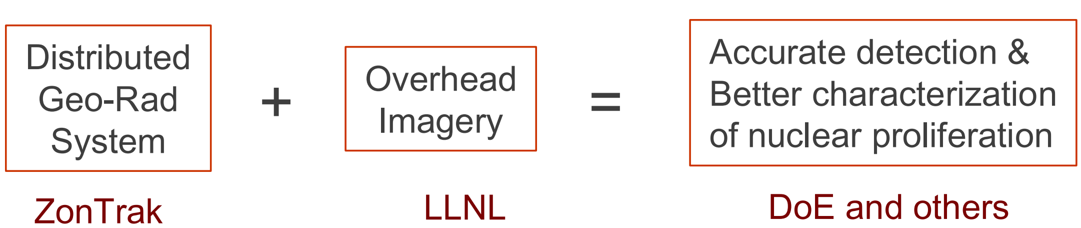
B OBJECTIVES

This STTR project is being conducted by Zontrak Inc. in collaboration with the Lawrence Livermore National Laboratories (LLNL). The objective of Phase 1 of this STTR project is to demonstrate a Proof-of-Concept (PoC) of the integration between a location-aware SmartTag and a radiation sensor and the ability to transmit the collected radiation data and location information to a central server. The radiation data and location information is used by the central server to generate location estimates of radiation sources.

C INTRODUCTION AND BACKGROUND

C.1 Proposed Approach and Application Scenarios

For nonproliferation detection, DoE needs ConOps and scenarios where radiation sensors are used. This mandates the development of a new class of activity detection and analysis methodology that incorporates remote sensing, in-Situ sensors, and Geo-location data.



The new Geo-Tad tags will combine the functionalities of GPS, radiation detection, and wireless links to communicate radiation and location reading to monitoring sites. This new class of tags should be compact, power efficient and light weight. It should also be cost effective with a target price of $250-$300 plus the cost of packaging (compared to existing detectors costing in excess of $1000.

Potential application scenarios include:

- Carried by inspectors while touring facilities
- Carried by public employees working around sensitive facilities (e.g. Airports)
- Distributed inside facilities under agreement
- Short-term clandestine emplacement
- Long-term clandestine emplacement
- Mobile clandestine emplacements

C.2 Identification and Significance of the Problem or Opportunity, and Technical Approach

One of our most important national security missions is to detect and monitor nuclear proliferation activities at sites over extended periods of time. In general neither individual remote or *in situ* measurements alone are adequate to characterize the proliferation activities of interest – we must develop methodologies that utilize all available information. Our goal in this project is to develop a new class of activity detection and analysis methods that incorporate both remote sensing information and *in situ* sensor data. Here we will focus specifically on demonstrating a state-of-the-art GPS-enabled radiation sensor network and coupling measurements from that network with overhead imagery to detect and characterize activity patterns that indicate nuclear proliferation. This will involve developing software tools for the system and autonomous networked radiation sensors. Field measurements, simulations and overhead imagery will be used to develop algorithms that establish and search for relationships between objects and/or radiation sources, discover patterns of activity, detect changes in the site, distinguish normal from abnormal activities, and predict future activities.

Detecting the radiation sources of concern is a difficult problem. In general, we are trying to detect weak sources buried in spatially and temporally varying backgrounds. For proliferation detection in limited access regions, the problem is further complicated by a limited ability to control the time and location of sensor placement. To achieve maximum performance in these detection systems, we will develop tools to combine the radiation measurements and geolocation data from the distributed sensors with the object-level information extracted from high-resolution overhead images. This will help us to associate sources with objects and to understand the context of the varying backgrounds.

The small detectors we propose are clearly not as sensitive as the large detectors used, for example, at portals; however, they can be still be quite powerful. For example a nominal 1 milliCurie source produces a flux of 3 photons/cm^2/s at a distance of 10 m, or 4 times that, 12 photons/cm^2/s at a distance of 5 m. Typical background in this class of detector is a few tenths of a photons/cm^2/s. At a few to 10 m separation distance, something much more readily achieved by these small detector (typically with a few cm^2 of projected area), we achieve significant detections in a matter of seconds from milliCurie class sources.

The radiation sensors required for this project must be deployable to suspected sites of nuclear proliferation activity. Access to such sites may be limited or restricted. Therefore, the sensors must be compatible with a range of deployment options including attaching to vehicles, carried cooperatively or covertly by personnel in pockets, briefcases etc., scattered at the site by people or by airdrop, or even flown over the site in a small, low-speed, low-altitude UAV. In addition to being compact, the sensor must also operate under a wide range of environmental parameters including temperature, humidity and vibration. They must remain operational for extended periods without servicing, and they must autonomously transmit their findings back to the agency collecting the data without depending on retrieval. LLNL has already engineered many of the sensor building blocks to be robust, low-power and compact. The sensor development effort proposed here represents the first step toward meeting these requirements.

Extracting signatures of proliferation activity from distributed sensors is also a technical challenge. We will develop algorithms that are compatible with a wide range of deployment types and densities. When only small numbers of sensors are available, our algorithms will compensate by using longer integration periods to increase the coverage and reliability of the measurements. We anticipate large gains in sensitivity by combining surveillance imagery with radiation sensor measurements. For example, we will use correlations of mover activity in surveillance imagery with larger apparent variations in the measured background radiation to extrapolate the expected characteristics of these fluctuations from regions with large numbers of sensors, to those with only very few sensors.

C.3 Anticipated Public Benefits

The primary application of the proposed project is monitoring of sites of interest for nuclear proliferation activity. Human analysts often manually construct site models and activity models by analyzing time sequences of overhead images of limited access sites. This time consuming manual process produces models of only limited complexity and scope of use.

Our ability to monitor nuclear proliferation activity at these sites can be significantly improved by combining data from *in situ* sensors infiltrated into the site with remote sensing images. We intended to demonstrate these methods by focusing on radiation sensors. It will be essential to establish relationships and discover patterns of activity by analyzing overhead images and radiation measurements collected over time. The users of the capabilities developed in this proposal will include site-monitoring programs in DOE and NGA.

C.4 Technical Objectives

The tools for computer-assisted and automated monitoring of limited access sites to be developed under this proposal will dramatically increase analysis efficiency and the amount that can be learned about a site. The capabilities developed will include:

- Autonomous radiation sensors, tagging and tracking system for clandestine operations
- The ability to detect suspected radiation sources from compact *in situ* radiation sensors.
- The ability to search for relationships between objects and/or radiation sources, identify related activities, distinguish normal from abnormal activities, and predict future activities.

C.5 Proposed Process and Methodology

This research project is proposing a new process and methodology for the monitoring and detection of nuclear proliferation activities. The process is centered around the linking of radiating objects to specific radiation sources through the measurement of radiation levels using detectors that come as close as possible to the radiation source. Each radiation measurement is associated with an exact geo-location coordinates. This will enable the close association between these measurements and overhead imagery. Some of the main benefits resulting from this coupling of in-Situ measurements and overhead imagery include:

(a) Enhancing the simulation process of overhead imagery to refine the detection algorithms.

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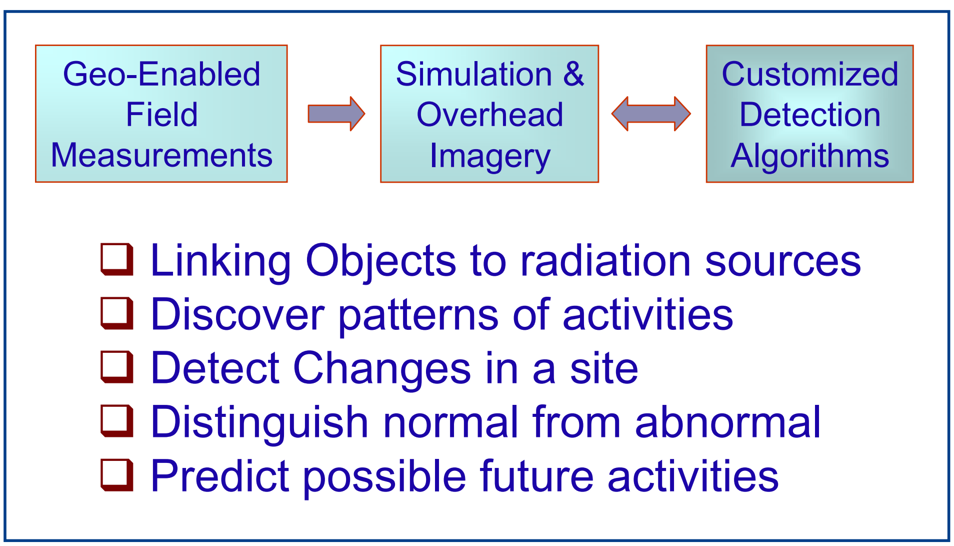


Figure C-1 Proposed Process and Methodology

D PHASE I WORK PLAN

D.1 Compact Autonomous Location-Aware Networked Radiation Sensors

It has been suggested that the revolution in micro-sensor technology, often referred to as "smart dust" or "sensor motes", could be applied to radiation detection. The general concept is to build a low-cost, low-power autonomous detector system with on-board communication capability. Large numbers of these radiation sensor motes can then be deployed to unobtrusively detect or monitor activities involving radioactive materials. Until now, the limiting factors for building such a system were the competing cost, size and power requirements of the radiation detector element. To be effective in a mote, the radiation sensor must provide the largest possible ratio of detector volume to total volume. Spectral resolution is important to help compensate for limitations in size. A mote also needs a low-power communication system and a geolocation measurement capability, in case they could be moved. Geolocation measurement also allows the mote to be used as a radiation sensor "tag" that can be attached to an object, person or other carrier that will be in an area where the transport or handling of radioactive material is to be investigated.

In the Phase I effort we will combine compact low power detector systems developed at LLNL with the "SmartTag" technology developed by ZonTrak. The ZonTrak system uses a low-cost, compact, advanced GPS system combined with motion and thermal sensors and a low-power communication system that can operate independently with a fixed or mobile access point, or as part of a mesh network system. We will begin by building an engineering prototype about the size of a pocket pager. These will include gamma-ray sensors with modest spectral resolution. Ten of these units will be built for testing, analysis, verifying and refining simulations and for demonstrations.

In Phase II we intend to design a second-generation sensor system using gamma-ray detectors with improved spectral resolution that will be integrated with a next-generation "SmartTag." The sensors will be based on pixilated CdZnTe modules being developed at LLNL with integrated ASIC readout. These advanced sensors will provide improved resolution and low power and low cost. Design modifications to be considered for the SmartTag include miniaturization, improved low-signal GPS system, improved power management and a communication network system optimized for deployment in remote locations. The system could be quite compact (about 1 cubic inch in volume) with the exact shape of this unit (cube, sphere, disk etc.) to be determined in consultation with the end-users that would deploy it. The system will be produced in a ruggedized package designed to minimize the impact from environmental conditions including humidity, vibration and shock. Thermal sensors will be used to compensate for the wide-range of expected operating conditions.

D.2 Analysis of Radiation Sensor Measurements and Overhead Imagery

To analyze the data from radiation sensors, LLNL will expand its distributed radiation sensor server architecture, and develop algorithms to extract probabilities of detection for radiation sources of interest. The analysis architecture will be coded in a C++/QT framework interfacing with a PostgreSQL database. Radiation data from measurements and simulation is fed into the database through an "input engine" that rationalizes the data into a common form.

To develop effective analysis algorithms, we will deploy sensor tags and obtain overhead imagery from two sites that represent different settings for potential proliferation facilities. The first site will be an industrial complex located with a high-density urban environment in the Pleasanton, CA metropolitan area near ZonTrak. The second site will be an industrial complex in a more isolated low-density environment in the Livermore, CA area near LLNL.

The sensor tags will be deployed using two techniques to simulated different deployment options at remote sites. Experiments will be conducted with tags carried through the site to represent carriers who have official business at the site. Experiments will also be conducted with tags in fixed location at the sites.

These data will be used to build a real background map. In addition to the background radiation, radiation from discrete sources will be included. We will include sources that are indicative of potential proliferation activity (SNM, nuclear fuel material, unusual quantities of natural and depleted uranium etc.) and "nuisance" sources (such as medical isotopes, naturally occurring radioactive material). These sources can be either stationary or in motion. Simulated sources will be placed at strategic location and its radiation field added to that of the background. The fusion algorithms will then be used to relate source detections to specific image objects.

In Phase I, our sensor fusion analysis will be based on direct overlays of radiation data, map features and overhead imagery. In Phase II, our approach to joint analysis of imagery and radiation measurements will be centered on the development of activity models. The activities are represented by spatio-temporal series of features values derived from detected image objects and radiation measurement analysis. These activity models will provide several levels of information to a user:

- Joint visualization of radiation measurements with overhead imagery, placing the radiation levels in a physical and temporal context
- Association of peaks in the probability of anomalous radiation sources with physical objects in images – important for both source detection and understanding background peaks, thus mitigating false alarm rates.
- Development of time-varying radiation maps and associations with patterns of activity detected in image sequences. One example is association of a source with a moving vehicle. A sparse set of weak, sub-threshold detections can be associated with a moving target in a track-before-detect architecture.

D.3 Phase I Performance Schedule

The objective of this phase is to demonstrate a proof-of-concept of the integration between the SmartTag and radiation sensors and the ability to collect radiation data using a network of sensors and detectors. The tasks are as follows:

Task 1: LLNL will define a low-power (target less than 40 mW continuous), low-cost radiation sensor design optimized for use with the existing SmartTag architecture. (LLNL) Duration: 1 Month

Task 2: The LLNL sensor interface will be changed to conform to the existing ZonTrak power, control and communication interfaces. (LLNL) Duration: 2 Months

Task 3: ZonTrak will define a method for reporting sensor data from the SmartTag to the TagDetector and from the TagDetector to a temporary network service. The existing ZonService is not required to support the LLNL sensor in this phase. (ZonTrak and LLNL) Duration: 4 Months

Task 4: ZonTrak will deliver 10 SmartTags and at least one TagDetector (with base) to LLNL for integration. (ZonTrak) Duration: 4 months

Task 5: LLNL will upgrade its existing sensor fusion server to accept SmartTag data, and develop overhead image overlay and analysis algorithms. (LLNL) Duration: 4 Months.

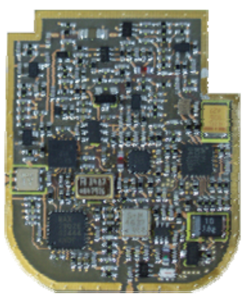
Task 6: The sensors tags will be tested, characterized, and deployed in different environments to simulate different types of potential proliferation site locations. Industrial facilities in both isolated and congested regions will be characterized, and sensor fusion techniques demonstrated. (ZonTrak and LLNL) Duration: 4 months

E THE SMARTAG SYSTEM DESCRIPTION

E.1 ZonTrak – Company Overview

ZonTrak has developed an innovative new solution to monitor the location and conditions of tagged objects or subjects. The ZonTrak SmartTag solution combines the performance of GPS and functionality of RFID technologies into affordable systems and modules that meet the requirements of significant opportunities in multiple markets. The ZonTrak solution provides an easy-to-use tool to monitor, follow, and determine the status (and history) of tags attached to individuals and objects. Alerts are generated when specific location/environmental -based conditions are violated. These alerts are communicated to a web-based service platform which relays these alerts to end users via SMS messages, e-mails, and phone calls.

The SmartTag system pioneers the next generation in tagging technologies, reporting critical details including positioning information and ambient environment conditions. The result of fusing the power of Global Position System (GPS) with the affordability and reliability of secure local wireless communication, the ZonTrak SmartTag platform makes for an intelligent monitoring and tracking solution at unprecedented size, power consumption, and cost levels. SmartTags continually monitor their location and surroundings. This information is passed to nearby readers, called TagDetectors, and then uploaded to the online ZonService where users can view SmartTag locations and conditions and configure behaviors. When a SmartTag is not where it should be or other monitored conditions are unusual (e.g. temperature is too high) the ZonService dispatches alert notifications to the owners of guardians of the violating SmartTag.



The SmartTag

ZonTrak SmartTags outsmart other technologies such as Radio Frequency Identification (RFID) and Real-Time Location System (RTLS) that can only offer short-range communication. These technologies require higher infrastructure costs rendering uneconomical implementations, and neither technology has provisions to cover tagged assets outside a covered area. Satellite-communication tags are cumbersome in size, have higher power consumption, and are only suitable for monitoring very large assets. Tags that communicate via the cellular network have limited battery life with unpredictable coverage since the cellular network is easily compromised indoors, through intentional jamming, or network congestion.

E.2 One Technology - Multiple Applications

ZonTrak's SmartTag solution is a common platform easily adaptable for numerous applications. ZonTrak continues to partner and discuss collaboration efforts with leading systems integrators, defense contractors, and government agencies. The ZonTrak can meet today's location and monitoring challenges in the following markets:

- **Efficiently Track and manage the behaviors of offenders on parole.** ZonTrak provides parole officers with the tools to customize, monitor, and modify the behavior of individuals on parole remotely through a secure web interface. The communications on alert feature streamlines the information flow and enhances the efficiency of parole officers in managing a large number of offenders.

- **Increase the safety and improve the efficiency of the mobile workforce.** ZonTrak provides the mobile force with an affordable means to communicate their locations and conditions when they are away form their service vehicles.
- **Efficiently Track and Manage Assets through a Supply Chain.** ZonTrak fills the gap between low-range RFID scanning solutions, and expensive long-range cellular and paging networks used in many GPS applications.
- **Enhance Security in Trucking and Shipping Industries.** The ZonTrak platform is capable of meeting the needs of the shipping and trucking industries, as well as the published requirements of the Department of Homeland Security.
- **Support our National Defense.** ZonTrak technologies have multiple applications in the defense sector ranging from ensuring the safety of soldiers and other personnel in battlefields, to monitoring and tracking equipment.

E.3 SmartTag System Overview

The ZonTrak Solution consists of the following three primary components:

1. **SmartTag** – a GPS-enabled device placed on an individual or item; equipped with the intelligence to identify its own location as well as monitor its surroundings through external sensors.
2. **TagDetector** – a handheld device that monitors it's associated SmartTags (as well as other tags roaming in its zone) and communicates with a server-based platform: ZonService.
3. **ZonService** – a customizable, network-based service that communicates with the TagDetector, acts as a user interface to input behaviors, and dispatches alerts to users through multiple communications channels.

E.4 The SmartTag

E.4.1 Overview

The SmartTag is a device which is installed, attached or integrated either permanently or temporarily on a mobile object or subject. Its main function is to sense its own position, condition (e.g. motion), or the conditions of external sensors attached to it and, according to a defined (programmed) logic, react in different manners. The SmartTag can activate local outputs based on either a remote command, or again on a preprogrammed logic. The SmartTag is further defined by its communication channels – a transceiver using the local wireless (LW) network, and the ability to continually monitor its location/condition and send a notification if it deviates from a predetermined set of permissible actions.

E.4.2 Block Diagram

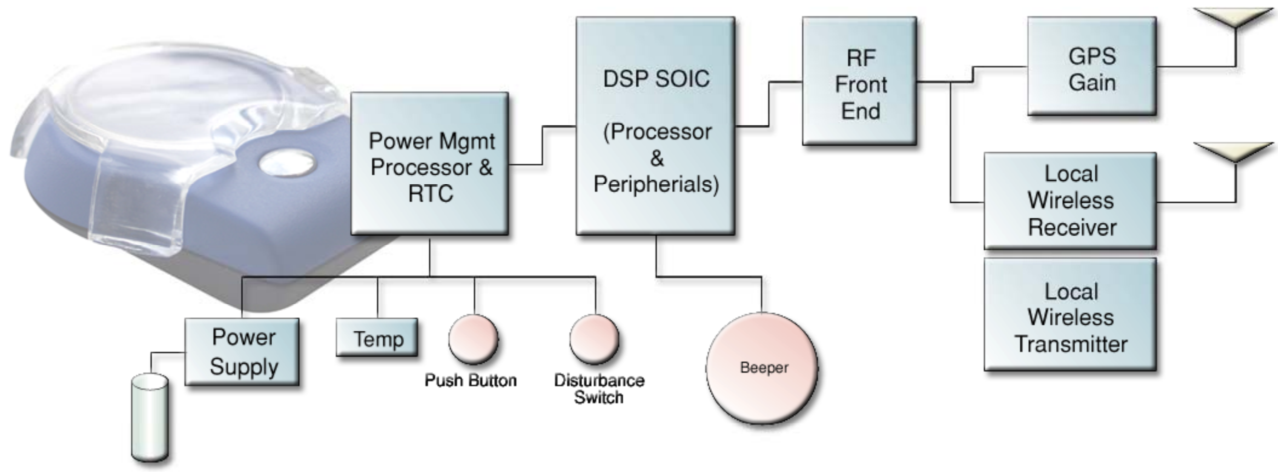


Figure E-1 - SmartTag Block Diagram

E.4.3 Selected SmartTag Features

E.4.3.1.1 SmartTag User Interface

The SmartTag has a very simple user interface in that it only has a single button and no display.

- **Power**

Pressing the button on the SmartTag turns on power.

- **Panic alert**

An extended button press on the SmartTag will generate a panic alert page on the TagDetector. The page alert is queued in the SmartTag in case it is out of range with the Tag Detector. When it is in range again, it will send the page.

E.4.3.1.2 Security

- **Electronic Serial Numbers (ESN)**

Each SmartTag and TagDetector contains a unique 10-digit (50 bit) serial number that is permanently stored by the factory into the product. There are approximately 8.2×10^{14} combinations within this numbering scheme based on each of the digits being reduced to 5 bits per ESN digit.

- **Encryption**

Communications between the SmartTag to the TagDetector may be encrypted with encryption algorithm. An owner code may also exist. The "owner code" protects the security of the SmartTag as it is used to generate the encryption key used for data exchange between the TagDetector and the SmartTag.

E.5 The Tag Detector

E.5.1 Overview

The "TagDetector" is a unique handheld device designed to locate SmartTag(s) that were previously paired with it. The TagDetector uses GPS and ZonLAN technology to provide location information and ZonLAN for communications. When the TagDetector is docked in its Base, it provides a stationary point for differential calculations from which SmartTag(s) are monitored. When the TagDetector is removed from the Base, the user can view the backlit LCD screen on the TagDetector, to determine the location, conditions, and direction and relative distance from the SmartTag. The TagDetector is also a mobile solution that can be taken to other locations without the Base to communicate with SmartTag(s).

TagDetectors could be connected together using any number of communications technologies including wireless mesh technologies.

E.5.2 Block Diagram

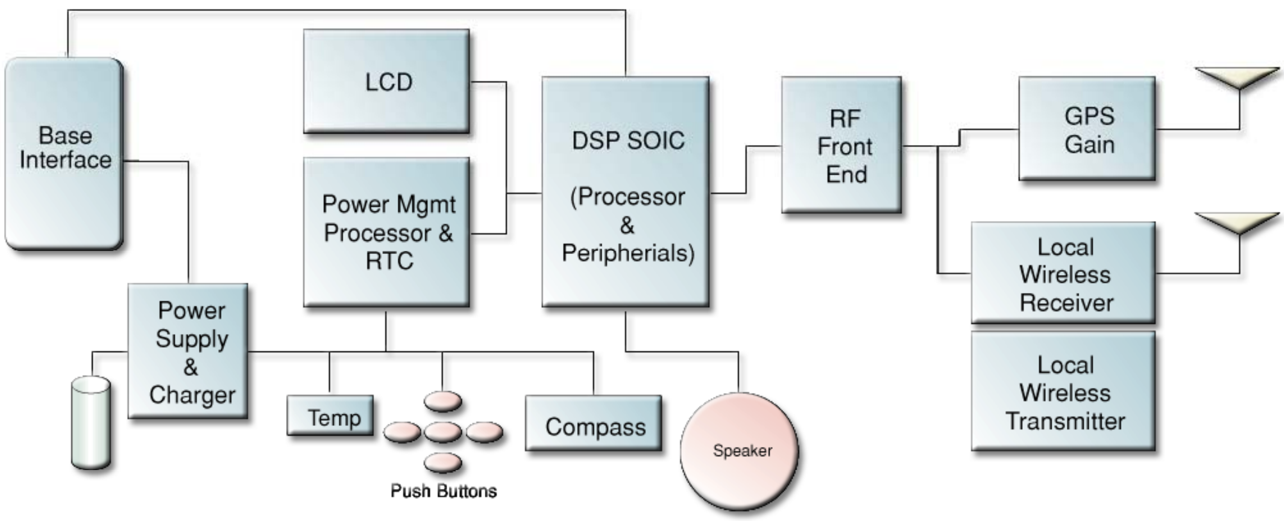


Figure E-2 – TagDetector Block Diagram

E.6 ZonService - Overview

The ZonService is a fully developed web-based/server-based service platform that provides users the ability to:

- Receive notifications of alerts. Notification methods include email, SMS and pager.
- Review item status and location history
- Enter and track multiple SmartTags with multiple Detector
- Securely synchronize information with Detectors
- Establish geographic "keep in" and "keep out" boundaries overlaid on street maps
- Create sophisticated alert rules, including time and day of week restrictions
- Customize notification preferences per item and per alert rule.

In addition to end-user benefits, the ZonService is designed to provide value to channel partners, including:

- Custom branding
- Secure remote administration of user accounts
- Integration with existing customer management and billing systems
- Reports of usage and system status.

E.6.1 Logical Architecture

The ZonService leverages a number of open source tools and technologies. At present, there is a wide array of robust, full-featured and commercial-quality tools available from open source initiatives. In fact, many of the leading technologies are open source projects, making it very cost-effective to build a robust system using off-the-shelf open source components. With this in mind, the overall architecture for the ZonService is presented in the diagram that follows.

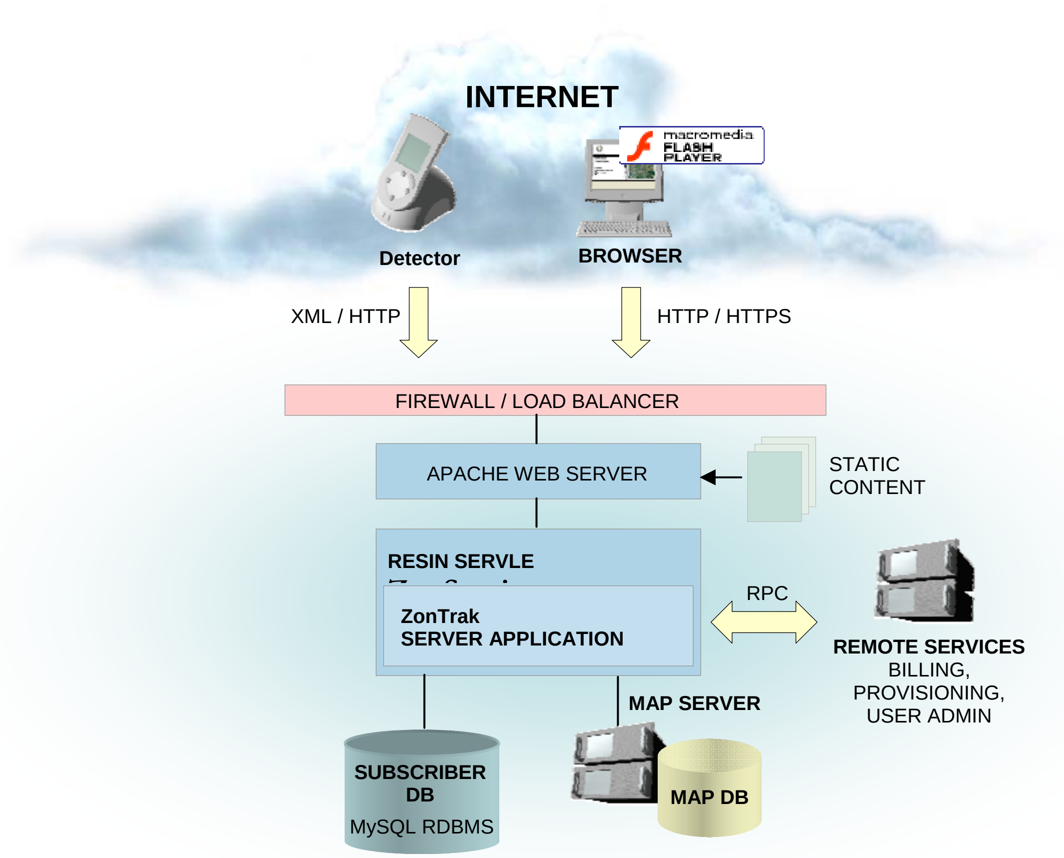


Figure E-3 ZonService Architecture

The ZonService is logically designed using the traditional three-tier web architecture where the tiers are comprised of: (1) the web tier, (2) the application or business logic tier, and (3) the data tier.

E.6.2 Subscriber Management and Billing

The ZonService subscriber management system is used to create and manage user accounts and billing information. The system has been designed to accommodate a number of methods of interaction, including:

- A subscriber may use their web browser to sign up for services and manage their account information.
- A partner's customer service representative may login to an administration web page to manage the subscriber accounts attached to that partner.
- A partner may programmatically exchange data with the web server to provision accounts and change subscriber settings.
- A ZonTrak company administrator may login to a dedicated page to manage partner administrator accounts.

The system is designed to accommodate various Billing arrangements. In one arrangement, wherein the partner maintains the customer support and billing relationship with the subscriber, ZonTrak will transact billing records to the partner, and the partner will charge the subscriber and collect payment. In another arrangement, ZonTrak will maintain the customer support and billing relationship with the subscriber. In this case, in addition to computing the bill amount, ZonTrak will process charges to the subscriber, collect payment, and manage charge-back reconciliation. Multiple billing plans and promotion types are supported.

E.6.3 Physical Implementation

The ZonTrak web service infrastructure is hosted at a commercial collocation facility in Oakland, California. The co-lo facility provides 24x7 Network Operations support, redundant internal communication network and high-speed Internet connectivity, backup power, and solid security systems. Load-balanced servers and multi-path network backbone provide scalability to hundreds of thousands of users with minimal unplanned downtime.

E.7 Local Wireless Link (ZonLAN)

E.7.1 Overview

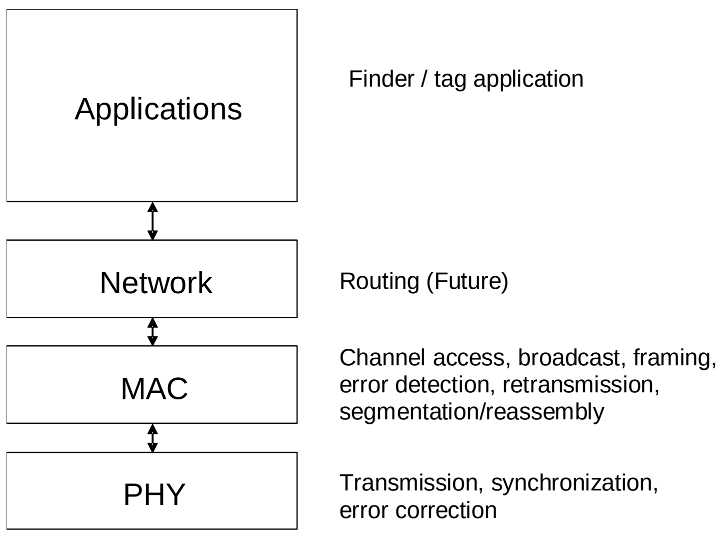
The local wireless (LW) link is referred to as ZonLAN. The ZonLAN defines wireless point to multipoint network operating in the public unlicensed spectrum. Some of the characteristics of ZonLAN are:

- Great Battery Life/Low Power
  - Months of life depending on applications - "set and forget" applications
- Low data rate
  - "Signaling" applications - 1K BPS
- Very Long Range
  - Up to 2 Miles Typical
- Network
  - 100's of mobile terminals communicating together
- Encryption
  - 96-bit symmetric key encryption

- Low infrastructure cost
  - 902-928 MHz unlicensed ISM band

Because ZonLAN can be used for many applications outside of the Detector and SmartTag described in this document, a more generic name is given to the wireless end-points for ZonLAN.

The functionality of ZonLAN is broken into layers shown below:

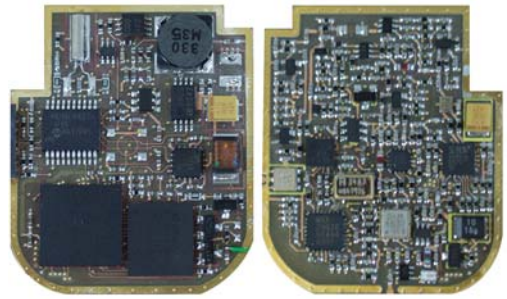


E.8 ZonTrak Hardware Common Technical Specifications

Common specifications of all hardware: SmartTag, Mobile TagDetector, and Fixed Access Point TagDetector.

- Operating range -20°C to +70°C.
- Communicate via the 902-928 MHz unlicensed band complying with ISM Part 15 specifications using direct sequence spread spectrum /frequency hopping on a non-interference basis.
  - Secure communications network.
  - Real-time, bi-directional local wireless network (ZonLAN).
  - Up to 2.0 mile range.
- Location, speed, direction, UTC time using GPS.
  - Accuracy 10m-30m (3m if WAAS is available).
  - Accuracy dependent on aiding and satellite visibility.
- Location, distance, UTC time using ZonLAN.
  - Leverage ZonLAN to identify SmartTag location even when the object is shadowed from GPS signals.

  - o Accuracy 3m.
- Real-time software on all components.
  - o Fully customizable.
  - o Remote software upgrades available for SmartTags and Mobile and FAP TagDetectors.



ZonTrak SmartTag (front and back), actual size

E.8.1 ZonTrak SmartTag Technical Specifications

- SmartTag board footprint: 1.25″ x 1.5″.
- Operating velocity up to 125mph
- Operating acceleration up to 1G.
- Battery life: weeks-months
  - o A function of selected battery and the ZonTrak power management features enabled for a specific application.
  - o TBT (time between touch) is same as battery life because of remote programming capabilities.

E.8.1.1 Power Supply Specifications

Specification	*Min*	*Nominal*	*Max*	*Note*
Battery Voltage Range	1.6V		3.25V	Input voltage is stepped up to 3.3V (87% efficiency), and linearly regulated to 3.0V to supply the product. Therefore, 3.3V*Iload=0.87*Vbat*Ibat. Ibat=3.8/Vbat*Iload.
GPS Receive Mode Current from Battery		67mA		At Vbat=2.7V
ZonLAN Receive Current from Battery		100mA		At Vbat=2.7V
ZonLAN Transmit Current from Battery		244mA		At Vbat=2.7V
uNAV Computation Current from Battery		33mA		At Vbat=2.7V
Sleep Current from Battery		50uA		At Vbat=2.7V
In-Rush Current from Battery		400mA		In ZonLAN Transmit mode.
Duration of Battery In-Rush Current		300msec		
Low Battery Detection Alert	10%		20%	Percent of Usable battery life remaining.

E.8.1.2 GPS Specifications

Specification	*Min*	*Nominal*	*Max*	*Note*
GPS Receiver Sensitivity for Position Fixes		-135dBm		At 3.0dB Noise Figure
GPS Receiver Noise Figure			3.0dB	
Input IP_3 at High GPS Gain	-103dBm			By Design
Input IP_3 at Low GPS Gain	-66dBm			
TTFF	2sec	5-10sec	40sec	Results depend on satellites & aiding
GPS Position Accuracy	3m	10m	30m	3m with WAAS; 10m without WAAS. Accuracy is dependent on satellite visibility. -130dBm signal level.
GPS Velocity Accuracy		0.2 m/s		Fastrax specs that 50% of fixes will have this accuracy.
GPS Antenna Port VSWR		1.5:1	2:1	In a 50Ohm System.

E.8.1.3 ZonLAN Specifications

Transmit Specifications	*Min*	*Nominal*	*Max*	*Note*
Transmit Output Power	+17dBm		+20dBm	
Transmit Bandwidth (-3dB)		1.7MHz		6 possible transmit channels.
Transmit 2nd Harmonic Interference Radiated Emissions			-35dBc	
Transmit 3rd Harmonic Interference Radiated Emissions			-70dBc	
Receive Specifications	*Min*	*Nominal*	*Max*	*Note*
Receiver Sensitivity at Antenna Port		-126dBm	-129dBm	Using FEC Correction
Noise Figure			5dB	
Input Dynamic Range	-129dBm		0dBm	

Input IP_3 at Maximum Rx Gain	-97dBm			By Design
Input IP_3 at Minimum Rx Gain	-58dBm			
Receiver Adjacent Channel Rejection (2.3MHz offset)		40dB		Measurement of Jam Immunity
Receiver Adjacent Channel Rejection (4.6MHz offset)		45dB		Measurement of Jam Immunity
PRN Sequence Rejection		23dB		PRN Sequence to PRN Sequence rejection.
General ZonLAN Specifications	*Min*	*Nominal*	*Max*	*Note*
Range			2 miles (3km)	direct-line-of-sight
Antenna Port VSWR		1.5:1	2:1	In a 50Ohm System
Antenna Gain	-5dBi	0dBi		Receiver Sensitivity numbers are based on this minimum Antenna Gain
Data Rate		1kbit/s		Burst rate
wOzdar Accuracy	-5m + (5% of Range)		+5m + (5% of Range)	wOzdar provides a radius from a fixed circle center at which the tag is located.

E.8.1.4 Environmental Ranges and Form Factor Specifications

Specification	*Min*	*Nominal*	*Max*	*Note*
Operating temperature	-20C		+70C	< 2ºC/minute change
Battery charging temp	0C		+45C	If temp moves outside range while charging, charging stops.
Storage temperature	-40C		+85C	Excluding battery.
Operating Velocity		35mph (57kmh)	125mph (200kmh)	Operating velocity means the range where GPS and LW will meet all ZonTrak specifications. NOTE: 57kmh is where Fastrax typically tests with no

Specification	*Min*	*Nominal*	*Max*	*Note*
				change in TTFF; Fastrax also states that <= 200kmh will show no significant degradation in GPS specs.
Operating Acceleration			1G	Operating acceleration means the range where GPS and LW will meet all ZonTrak specifications. NOTE: value is from Fastrax.
Board Area		1.25"x1.5"		excluding antenna and battery.
Weight		0.4lb(200g)		excluding battery.
Humidity	RH 10 to 85% (+5 to +45C); see waterproof packaging options.			
Vibration[1]	5 to 500Hz @ 0.95 G rms Non-Operating			
Shock[1]	10 impacts per face of 15G peak acceleration for 2ms Non-Operating			
ESD (ElectroStatic Discharge)	8KV through air and 4KV through contact			

E.9 Compliance, Standards, and Regulations

ZonTrak system is designed to comply with the following:

EMC/Immunity

EN61000-4-2 Electrostatic Discharge

EN61000-4-3 Electromagnetic Susceptibility

EN61000-4-4 Electro Fast Burst and Transient

EMI

FCC Class B USA EMI requirements, ICES 11-003 Class B Canadian EMI requirements

Safety

UL1950 (US), UL950(Canada)

[1] Unit will operate within specification <10 seconds after ending of exposure.

FCC

United States Federal Communications Commission (FCC) Part 15.247, Industry Canada RSS210

F THE LLNL DETECTOR SYSTEM DESCRIPTION

F.1 Radiation Sensor Networks at LLNL

This work began more than ten years ago with the Wide Area Nuclear Detection (WAND) project. The WAND project used Bayesian inference algorithms to combine data from large fixed-location roadside radiation detection systems. The system was recently deployed in a DTRA-funded exercise where vehicles with radioactive source on board were tracked moving through the network. LLNL has also been developing smaller hand-held networked radiation sensors systems based on cell phone/personal digital assistant (smart phone) units. The detector in these cell phone units (referred to as RadNet) use pixelated CdZnTe detectors coupled to low-power application-specific integrated circuit (ASIC) readouts to provide good spectral resolution (3 5%) in a compact, rugged, low-power, low-cost lightweight package. Each unit has spectral analysis software so it can operate independently using the smart phone display. Using the data communications capability of the cell phone, each unit can autonomously send continuous measurements of the location, radiation field intensity and spectral distribution to a central processing system that coordinates measurements for an entire network of these sensors.

The sensor that will be coupled to the ZonTrak SmartTag system uses a rugged CsI(Tl) scintillator crystal coupled to a Si PIN photodiode (see photo below). The complete detector system operates on less than 30 mW and has a resolution of about 10%.

F.1.1 Extracting Content from Remotely Sensed Images at LLNL

This capability is related to work that has been ongoing in the DOD targeting and the broader computer vision communities for years. We will address the content extraction problem by extending a new approach known as phase sensitive matching or PSM developed over the past three years at LLNL on the ICE project (Paglieroni2005A, Paglieroni2005B, Eppler2000). The PSM approach has proven robust against variations in illumination, sensor look angle, and sensor type. The ICE project has also developed configurable image processing pipelines and several processing libraries which will be applied to content extraction (Weinert2004, Brase2005).

F.1.2 Activity Modeling and Query at LLNL

Existing work is strongly focused in the video surveillance area, while some work in remotely sensed image sequence analysis is being pursued for environmental monitoring. Neither of these bears directly on the task at hand, though the fundamental statistical tools do apply. The Laboratory is currently funding R&D in dynamic data-driven decision support systems for atmospheric releases (Kosovic2005) and has supported work in stochastic Bayesian methods (Glaser2004). Bayesian belief networks have been developed for internal use in identifying chem.-bio manufacturing sites. This project will leverage expertise developed by these projects.

F.2 LLNL Radiation Detector

F.2.1 Detector assembly

The gamma-ray detector developed at LLNL is based on a scintillating crystal coupled to a photodiode. The crystal is a cylinder of 20 mm in length and 18 mm diameter, providing a good compromise between efficiency (ability to stop gamma-rays) and small size. The material is CsI(Tl), a robust, inexpensive and good performance scintillator. The photodiode is a 10 mm x 10 mm Hamamatsu S3590, a large and low noise photodetector well matched to CsI(Tl). The scintillator + photodiode assembly was manufactured by Scionix according to LLNL specifications.

F.2.2 Electronic readout

Since the final instrument is required to be small, the electronic readout was custom designed in order to achieve high performance and low power consumption, all in a small footprint. The design was fully simulated and found to perform as expected. The readout requires different stages: a preamplifier which provides an interface between the detector and the pulse processing electronic, a pulse shaping and amplification stage which enables precise amplitude measurements and the analog-to-digital (ADC) converter which provides the detector data in digital form to the Zontrak SmartTag unit.

- The preamplifier is based on a low noise JFET as the input element and a very low power commercial operational amplifier to generate the necessary open loop gain required for gain stability reasons.

- Pulse shaping is done with a delay line technique which produces both a signal that minimizes ballistic deficit (common with slower scintillators such as CsI (Tl)) and simultaneously creates a nearly ideal signal for analog-to-digital conversion. The delay line, for this application, was realized with a lumped constant technique that is both compact and inexpensive.

- The ADC is the Analog Device 7457, a 12 bit ADC with low power consumption. A fast channel derived from the detector signal triggers the digital conversion of the detector pulses. Its SPI interface is implemented to communicate with the SmartTag hardware.

F.2.3 Performance

The scintillator + photodiode assembly was tested with bulky but very low noise electronics. The performance was very good: the energy resolution was ~8% and the low energy threshold was ~100 keV (useful for detecting Uranium). This proved the validity of the photodiode approach to build a compact, high performance gamma-ray detector (see Figure F-1).

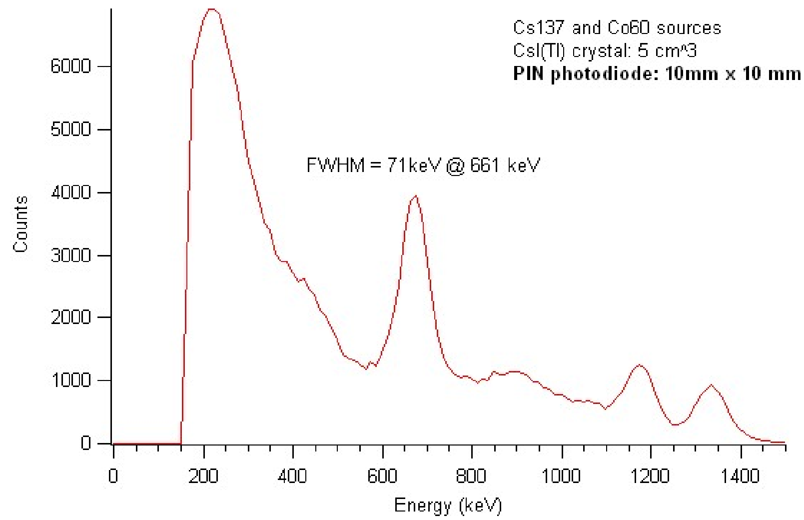


Figure F-1 Spectrum of ^{137}Cs and ^{60}Co sources using the scintillator + photodiode assembly

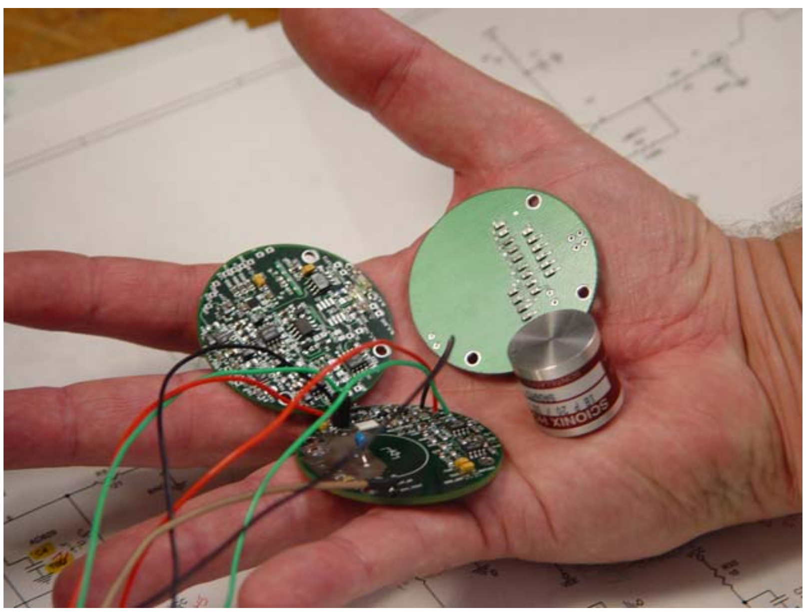


Figure F-2 LLNL prototype detector

A very compact readout electronics package consisting of three stacked circular printed circuit boards was developed, as shown in Figure F-2. The three round circular boards contain the custom low noise, low power electronics. The aluminum cylinder is the scintillator + photodiode assembly No larger prototype circuit preceded this as funding was limited and it was decided to directly build the smallest possible instrument. The lumped constant delay line was tested (externally) and found to be acceptable. The electronics was assembled with the scintillator + photodetector assembly and tested with a ^{60}Co and ^{137}Cs gamma-ray source. The performance was not satisfactory: the energy threshold was found to be very high and the energy resolution could not be measured. Numerous modifications were made but the overall performance did not improve. Evaluation of the circuit boards was complicated by the small circuit board layout. However, it is clear that there is excess noise from the power and photodiode bias supplies and some inadvertent errors were made on the high density circuit boards.

The gamma-ray detector with the compact electronics was tested with the Zontrak SmartTag unit in order to validate the communications interface. Radiation pulses were recorded at the SmartTag in accordance with the detector performance and communications interface, as shown in the Figure F-3 below. However, due to the issues with the board identified above, subsequent system testing was done with emulator boards.

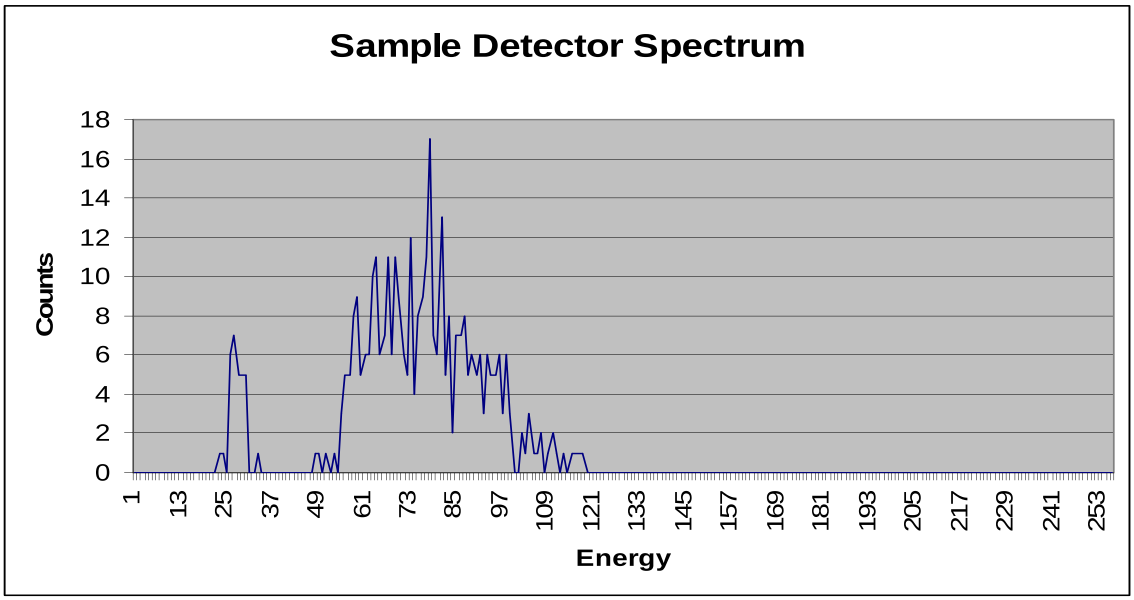
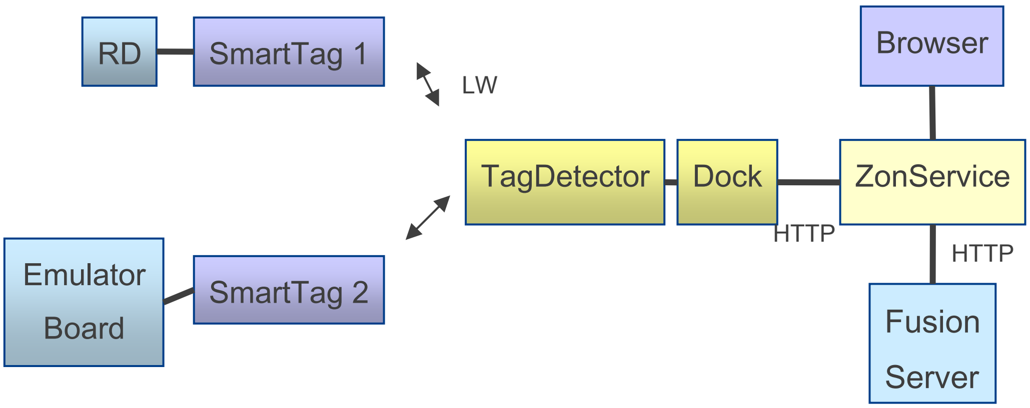


Figure F-3 Sample spectrum from radiation detector recorded by the SmartTag unit.

G PHASE 1 – PROOF OF CONCEPT (POC) PROJECT OVE RVIEW

G.1 Overview



The PoC System consists of a Radiation Detector (RD) developed by LLNL that includes a radiation sensor and an interface circuit to send the detected radiation events to the Zontrak SmartTags (ST). The ST collects this radiation data and appends location coordinates and a timestamp from the GPS module integrated with the ST. This information is transmitted over the Local Wireless (LW) link to the TagDetector. The TagDetector transmits the information to the Dock and over the Internet via an HTTP connection to the ZonService server. The ZonService server forwards the information to the Fusion Server via a HTTP connection. The Fusion Server includes inference algorithms developed by LLNL that process the received radiation and location data from a network of RD/ST units to detect and locate radiation sources.

G.2 Tasks

The following are the implementation tasks for this project.

Task 1: LLNL will define and fabricate a low-power (target less than 40 mW continuous), low-cost radiation sensor design optimized for use with the existing SmartTag architecture. (LLNL)

Task 2: The SmartTag interface will be changed to conform to the existing LLNL sensor power, control and communication interface. (Zontrak)

Task 3: Zontrak will define and develop a method for reporting sensor data from the SmartTag to the TagDetector and from the TagDetector to the ZonService. (Zontrak)

Task 4: Zontrak will integrate the radiation sensors with SmartTags; transmit the sensor data with the location and timestamp information over the LW link to the TagDetector to the ZonService. (Zontrak)

Task 5: LLNL will upgrade its existing sensor Fusion server to accept SmartTag data, and develop overhead image overlay and analysis algorithms. (LLNL)

Task 6: The PoC system will be tested, characterized, and deployed in simulated radiation proliferation site locations and sensor fusion estimation techniques demonstrated. (LLNL)

G.3 Schedule and Deliverables

The anticipated schedule for these tasks is shown in the table below.

#	Task	Resource	Deliverable	Date
1	Radiation Sensor Design and Fab	LLNL	Two(2) sensor boards	1/12/07
2	Sensor-Tag Interface	Zontrak	Integration of two (2) sensor boards and SmartTags	1/19/07
3	ZonService Enhancements	Zontrak	SmartTag, TagDetector, ZonService with PoC enhancements	2/2/07
4	System Integration	Zontrak	Radiation, location and timestamp data reported to the ZonService server	2/9/07
5	Fusion Server Enhancements	LLNL	Processing enhancements for Fusion server algorithms and integration	2/16/07
6	Field Testing and Demo	LLNL	Field test and DoE demo in simulated radiation sites.	2/23/07

H PHASE 1 CHALLENGES

In this section we highlight the challenges faced during the STTR Phase 1 POC system. These challenges will need to be further addressed during the STTR Phase 2 system requirements and design.

H.1 LW Bandwidth and Latency

The POC system has a reporting period of 100 sec and a spectral resolution of the radiation energy of 224 levels. For an estimated radiation count rate of 1 KHz, this represents a LW throughput requirement of 36 bps per SmartTag for the radiation data, without considering the other information (e.g., location, timestamp, etc.) and the LW overhead for packet headers, trailers, and error correction. The total number of SmartTags in range of a single TagDetector will determine the overall bandwidth requirements for the LW link.

For mobile applications, the reporting period will have to be decreased. For types of radiation sources and detectors, the spectral resolution will need to be increased. Both these factors will increase the bandwidth requirements for the LW link.

The random access MAC protocol has been replaced in the POC system with an assigned slotted MAC protocol. The slotted MAC protocol will be extended to support the total number of SmartTags in range of a single TagDetector.

H.2 Robustness and Integration of Detector

The challenges for achieving high quantum efficiency and low energy resolution in the design and implementation of the radiation detectors were described in Section F. The POC system validated the radiation detector scintillator and photodiode assembly design but the implementation of the compact electronics circuitry will have to be revisited.

Further, the integration of the Radiation Detector and SmartTag into a compact wearable device will need to be carefully designed. The high-voltage analog signals from the Radiation Detector circuitry will need to be isolated from the high-frequency GPS and LW communication signals from the SmartTag unit.

H.3 Integration with the Fusion Server

The ZonService platform is used (i) to provide a easy-to-use Web-based interface to configure the SmartTags and TagDetectors and (ii) to monitor and track the alerts generated by the SmartTag units. These functions can be secured and integrated with the Fusion Server to provide a single server platform for radiation detection.

I PHASE 1 ACCOMPLISHMENT

I.1 Proof of Concept System Description

In this section we address the Geo-Rad Proof-of-Concept System hardware units, software, mapping services, and the integration with the LLNL Fusion Server.

Figure I-1 shows a SmartTag prototype unit connected by a flex cable to an Emulator Board. The dimensions of the SmartTag unit are 3.6 x 2.6 x 1.12". The patch antenna is for GPS reception and the stub antenna is for the ZonLAN communications. The reverse side of the SmartTag unit includes a CRV3 battery compartment and a belt clip. The flexible cable physical and electrical interface is identical to that for the Radiation Detector.

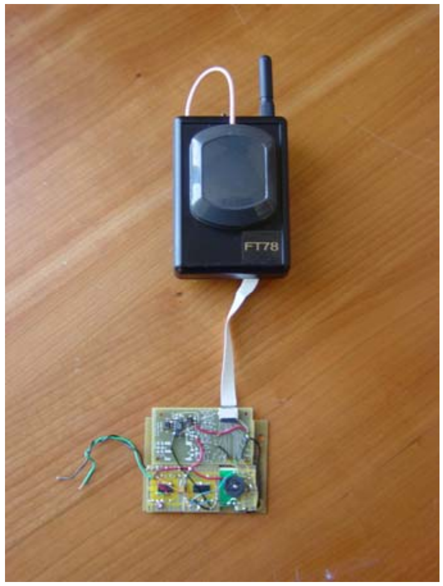


Figure I-1: SmartTag with Emulator Board

Figure I-2 shows the TagDetector prototype unit above the Dock prototype unit with an Ethernet connection to the Internet. The dimensions of the TagDetector units are 7.2 x 3.3 x 1.3". The TagDetector stub antenna is for ZonLAN communications. The User Interface (UI) displays the configuration information of the TagDetector for the SmartTags and their behaviors and zones. The UI also includes a System Log and Debug interface. The TagDetector has a serial cable interface to the Dock unit that provides the communication and power interface.

The dimensions of the Dock units are 7.3 x 7 x 1.5". The Dock unit is connected to any LAN/WAN infrastructure for access to the Internet. The Dock unit requires access to a DHCP server to provide an IP address.

Figure I-2: TagDetector and Dock units

Figure I-3 shows the ZonService Login page. ZonService is a web-based application that allows users to configure the SmartTags and TagDetectors in the system, define behaviors and alerts, identify notifications methods, and monitor and track individual SmartTags. The ZonService is integrated with MicroSoft MapPoint services to translate the GPS location information into physical geocode locations that can be displayed in a map.

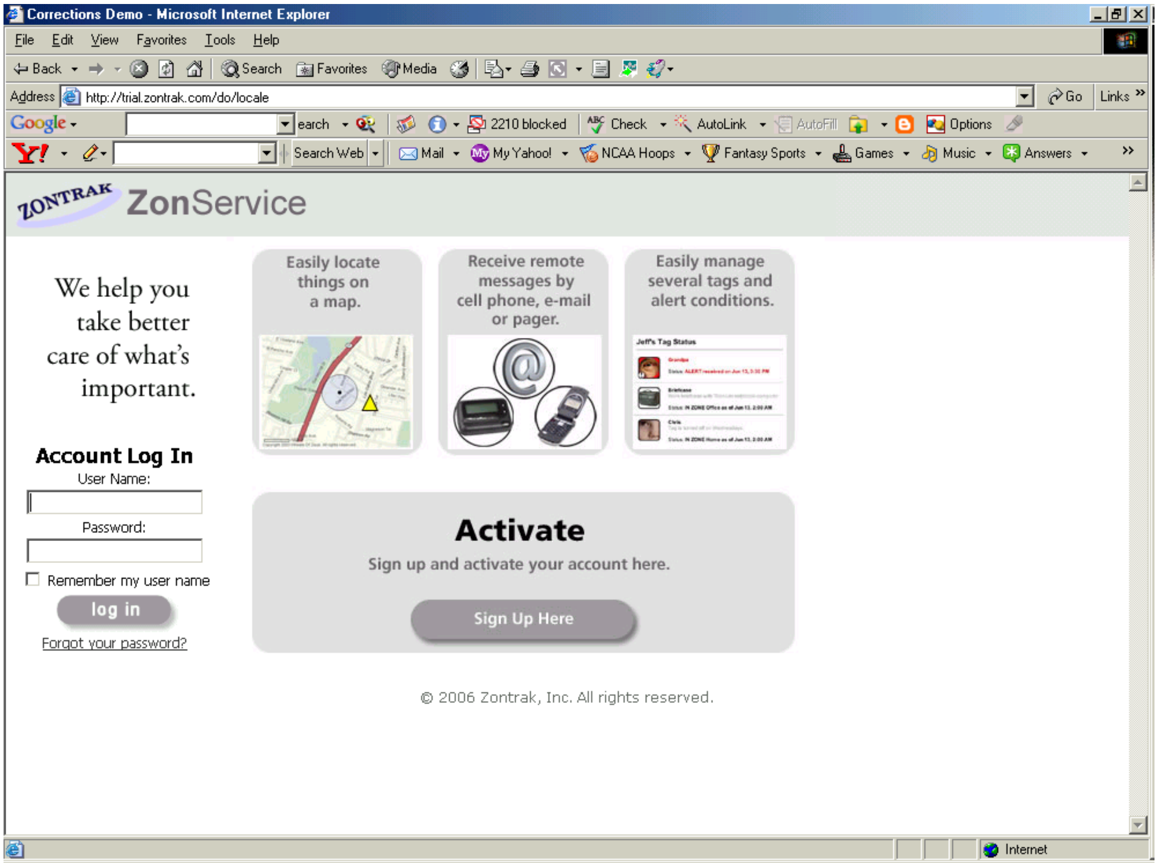


Figure I-3 ZonService Login Page

I.2 Enhancements for POC System

For the POC System the SmartTag system was enhanced in a number of areas. In this section, we describe the different enhancements and modifications implemented to complete the Phase 1 work.

I.2.1 Radiation Detector Interface

The first enhancement was to develop an interface between the SmartTag and the LLNL Radiation Detector to read the radiation energy provided by the A/D converter in the detector electronics for each detection event.

The hardware interface between the SmartTag and the Radiation Detector consists of Vbat, LLNL Vcc, Ground, SDATA, SCLK, and /INIT_CS. The electrical physical interface is a 14 conductor Flex Printed Circuit (FPC). Zontrak fabricated 1.25" square PC boards to which a 14 circuit FPC connector is mounted. The FPC PCB has 14 mounting holes so that jumper wires can be soldered. Other test circuits are defined for this PCB for both the SmartTag and the Radiation Detector. Figure I-4 shows the FPC layout with power and signal configuration.

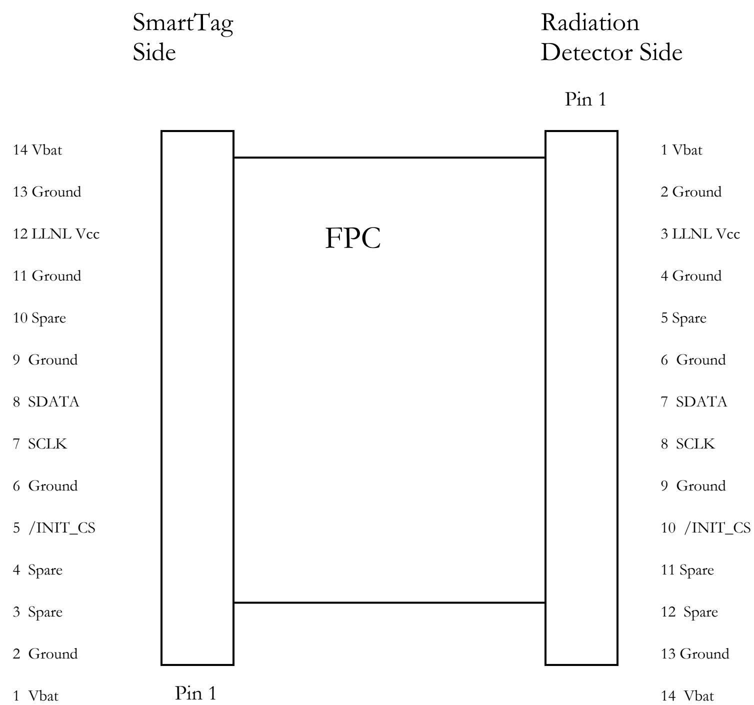


Figure I-4: SmartTag <-> Radiation Detector Interface

The FPC is routed out the back of SmartTag. The radiation detector can mounted on the back of the SmartTag. The SmartTag and radiation detector can be taped together.

The power is raw battery voltage from a 3.0V CRV3 Li battery located in the SmartTag enclosure. LLNL Vcc is used to power the high-side level translators. /INIT_CS signal comes from the LLNL circuit and equates to a radiation count which starts the measurement of the voltage applied to the ADC. The voltage applied to the ADC is proportional to the energy level of the gamma radiation of the count. The SDATA signal is the output of the ADC and is clocked out by the supplied SCLK from the SmartTag's PIC I/O pin. The frequency of the SCLK will be set at 78 KHz. The falling edge of the /INIT_CS starts the tracking of the input voltage to the ADC and the rising edge indicates when the input conversion starts and data can be clocked out. The time between the falling edge and the rising edge of /INIT_CS is 1us. If LLNL uses 5.0V as VCC on the ADC and flip flop, 3 level translators will be required because the uNav/PIC can only accept 3.3V max on its pins.

I.2.2 ZonLAN (LW) Communications

The SmartTag system was originally designed to support a large number of SmartTags with minimal data rate requirements per SmartTag, to report violations to the service. The SmartTag system was enhanced to report the GPS location, timestamp, and radiation data from the SmartTag and Radiation Detector combination on a periodic basis.

A period of 100 secs was selected for the POC system. For an estimated maximum radiation count rate of 1 KHz, this translates to a maximum of 100K radiation counts per period. The spectral resolution for the radiation energy was selected to be 224 to meet the LLNL radiation analysis requirements. Hence, 224 bins of radiation data were collected and transmitted by each SmartTag unit every 100 sec. Each bin is represented by 16 bits allowing for up to 65K radiation counts per bin.

The LW communications between the SmartTags and the TagDetector was based on timeslots with a random MAC protocol, with SmartTag transmissions restricted to a single slot. The LW communications was modified to continue with the slotted time structure but implement an assigned MAC protocol, with the SmartTag transmissions spread over multiple slots to accommodate the increased data due to the radiation information.

I.2.3 ZonService Enhancements

The XML messages from the TagDetector to the ZonService were augmented to include the radiation data in addition to the GPS location and timestamp information. On receipt of an XML message with the radiation data tag, the ZonService was enhanced to provide the following functionality:

- Reformat the XML message into appropriate format and fields and forward to the LLNL Fusion server.
- Store the radiation data associated with the XML message in a database table for viewing through the Find command and location pop-up window.

I.3 Development of Emulator Board

Zontrak developed an emulator board for the Radiation Detector. The emulator board includes the same A/D output stage as the Radiation Detector and supports the same physical FPC interface to the SmartTag. The emulator board includes two potentiometers to (i) adjust the value of the A/D output to represent different radiation count energy levels, and (ii) adjust the rate of the /INIT_CS chip select to represent different radiation count rates.

The emulator board was an effective tool for the testing and integration of the SmartTag system enhancements for the POC setup. Depending on the potentiometer settings, each emulator board generated a series of radiation counts at a fixed value. This corresponds to a single line in the radiation spectrum.

In the absence of a robust radiation detector, the emulator boards were also used in the POC system testing.

I.4 POC System Testing

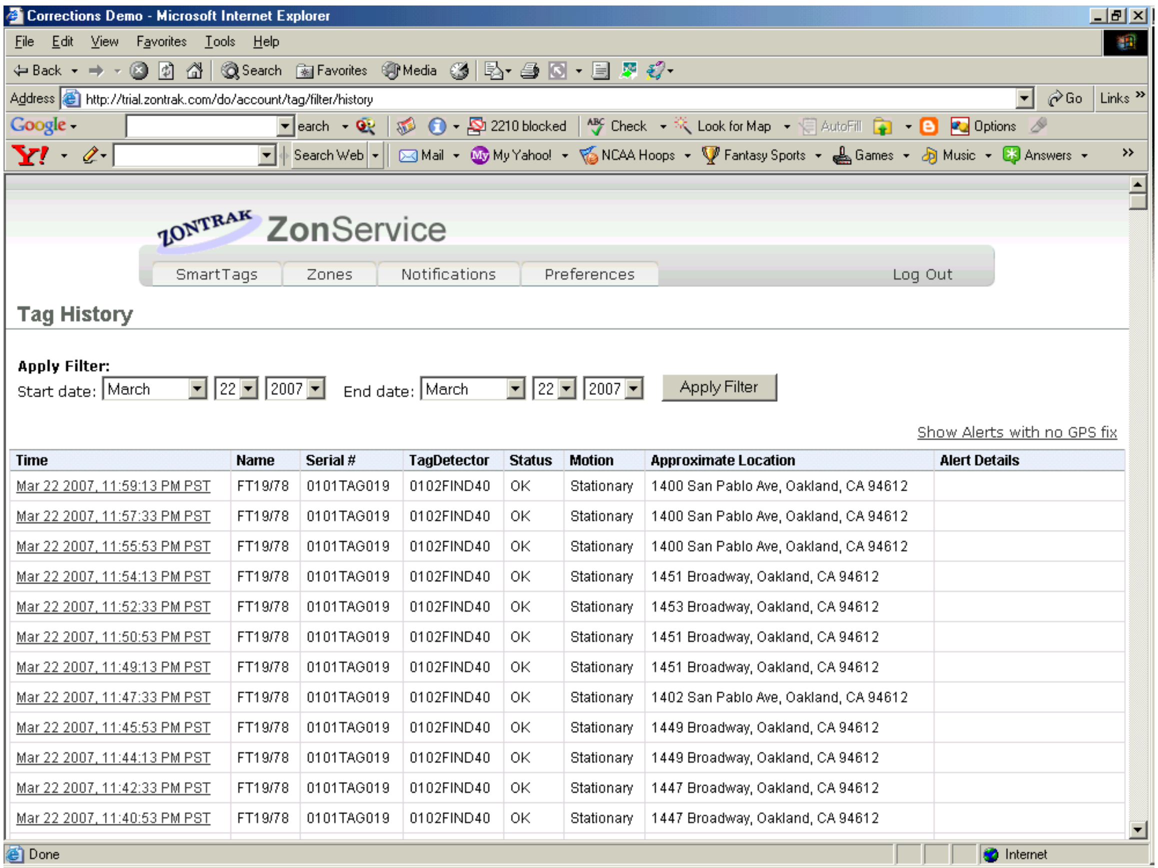
The POC system consisted of two geographically dispersed SmartTag/Radiation Detector combinations, one located in Oakland, CA and the other located in Pacifica, CA. As noted before, the Radiation Detectors were replaced by the emulator boards. The SmartTags reported the GPS location, the timestamp, and accumulated radiation data every 100 seconds to the ZonService via the TagDetector and Dock units in each location. The ZonService forwarded the GPS location, geocodes, timestamp, and radiation data to the Fusion server.

I.5 Results

This section will cover the recorded results of the POC system testing.

I.5.1 Oakland SmartTag

Figure I-5 shows the History of the alerts from the SmartTag Name FT19/78 located in Oakland. The alert details include, in the order shown in the screenshot below, the timestamp (alerts are generated every 100 sec), the SmartTag Name and Serial #, the corresponding TagDetector, behavior status, motion status, and approximate location based on the GPS coordinates.

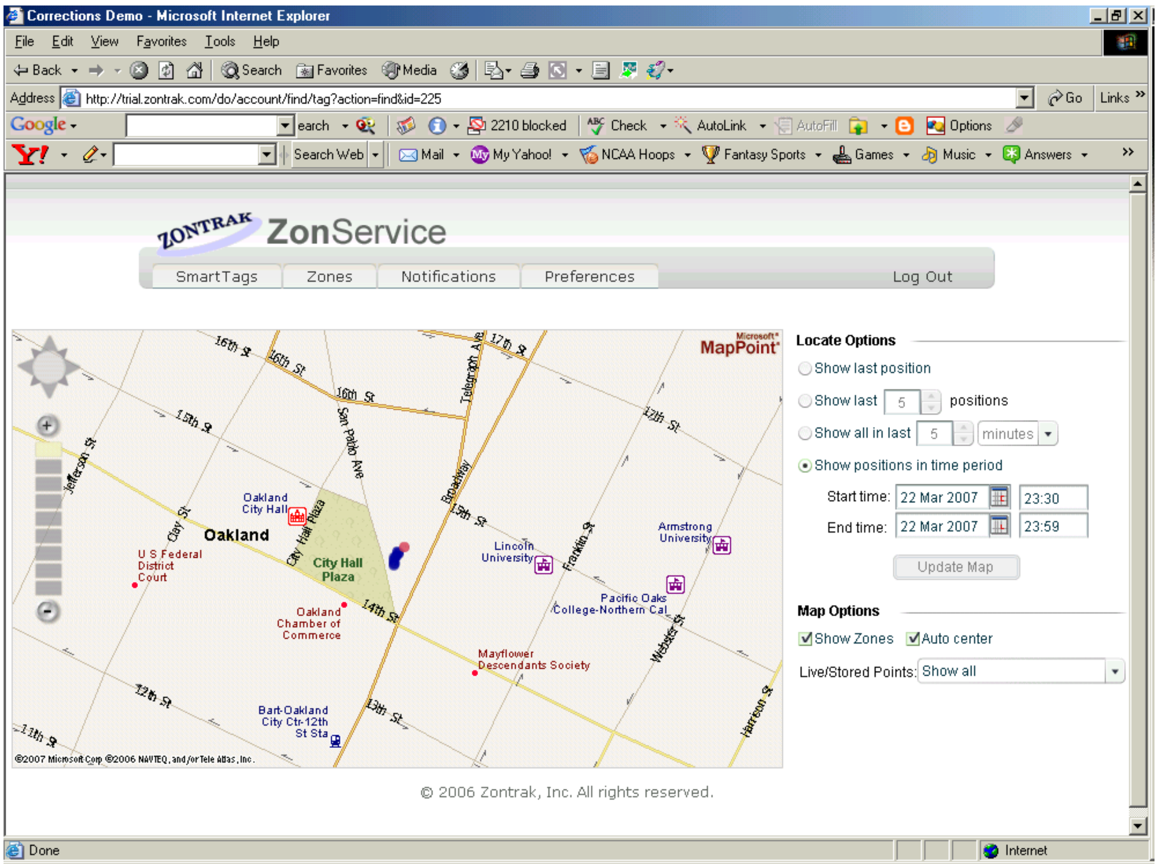


Time	Name	Serial #	TagDetector	Status	Motion	Approximate Location	Alert Details
Mar 22 2007, 11:59:13 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1400 San Pablo Ave, Oakland, CA 94612	
Mar 22 2007, 11:57:33 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1400 San Pablo Ave, Oakland, CA 94612	
Mar 22 2007, 11:55:53 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1400 San Pablo Ave, Oakland, CA 94612	
Mar 22 2007, 11:54:13 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1451 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:52:33 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1453 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:50:53 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1451 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:49:13 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1451 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:47:33 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1402 San Pablo Ave, Oakland, CA 94612	
Mar 22 2007, 11:45:53 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1449 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:44:13 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1449 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:42:33 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1447 Broadway, Oakland, CA 94612	
Mar 22 2007, 11:40:53 PM PST	FT19/78	0101TAG019	0102FIND40	OK	Stationary	1447 Broadway, Oakland, CA 94612	

Figure I-5 SmartTag FT19/78 History

Using the Find command, any alert or group of alerts can be located on a physical map as shown in Figure I-6 (see blue and red dots). A number of Locate Options are provided to select the displayed alerts. The red dot represents the most recent alert selected.

Figure I-6 SmartTag FT19/78 Location Mapping



The radiation data associated with each alert may be displayed by double clicking on the appropriate dot. This will create a popup window with the radiation data in addition to the other information stored by the ZonService for the alert.

A sample of the popup window for an alert from the Oakland SmartTag is shown in Figure I-7. Note that the radiation data consists of 224 bins with all 0s except for the bin corresponding to the potentiometer setting on the connected emulator board. The 224 bins correspond to the energy levels spanning the middle of an 8 bit A/D range from 17 through 240. In this example, the radiation counts have an energy level of 194 and a frequency of 331 Hz (30064/100). The other data displayed includes the timestamp, the latitude and longitude, and the location.

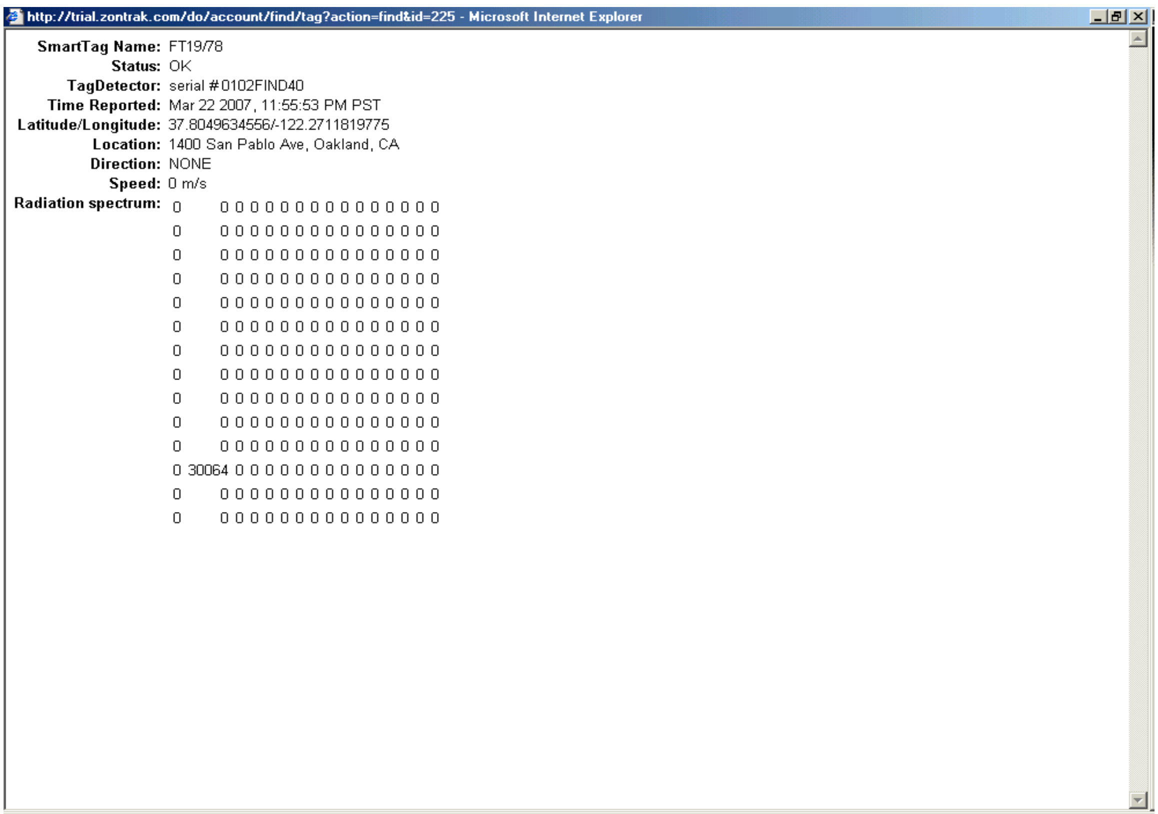
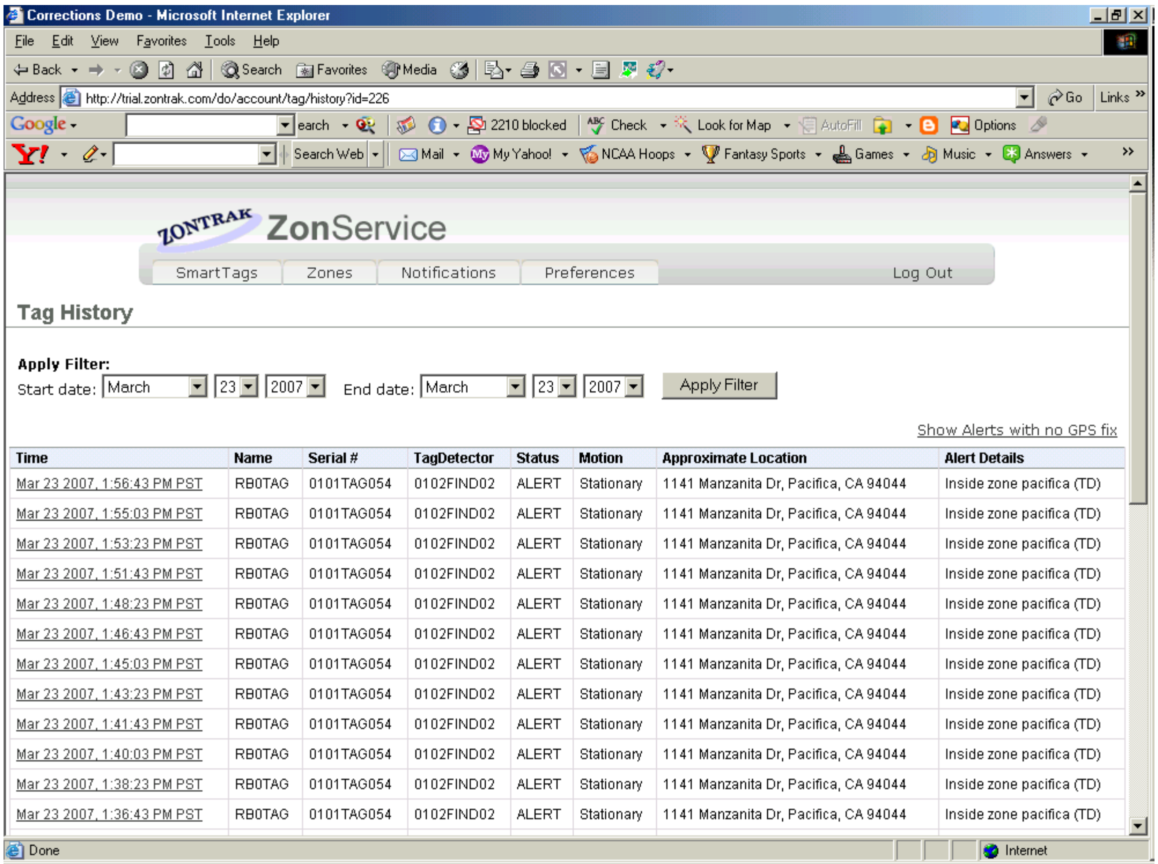


Figure I-7 SmartTag FT17/98 in Alert with Radiation Data

I.5.2 Pacifica SmartTag

Figure I-8 shows the History of the alerts from the SmartTag Name RB0TAG located in Pacifica. The alert details include, in the order shown in the screenshot below, the timestamp (alerts are generated every 100 sec), the SmartTag Name and Serial #, the corresponding TagDetector, behavior status, motion status, and approximate location based on the GPS coordinates.



Corrections Demo - Microsoft Internet Explorer

Address http://trial.zontrak.com/do/account/tag/history?id=226

ZONTRAK ZonService

SmartTags | Zones | Notifications | Preferences | Log Out

Tag History

Apply Filter:
Start date: March 23 2007 End date: March 23 2007 Apply Filter

Show Alerts with no GPS fix

Time	Name	Serial #	TagDetector	Status	Motion	Approximate Location	Alert Details
Mar 23 2007, 1:56:43 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:55:03 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:53:23 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:51:43 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:48:23 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:46:43 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:45:03 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:43:23 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:41:43 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:40:03 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:38:23 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)
Mar 23 2007, 1:36:43 PM PST	RB0TAG	0101TAG054	0102FIND02	ALERT	Stationary	1141 Manzanita Dr, Pacifica, CA 94044	Inside zone pacifica (TD)

Figure I-8: SmartTag RB0TAG History

Using the Find command, any alert or group of alerts can be located on a physical map as shown in Figure I-9 (see blue and red dots). A number of Locate Options are provided to select the displayed alerts. The red dot represents the most recent alert selected.

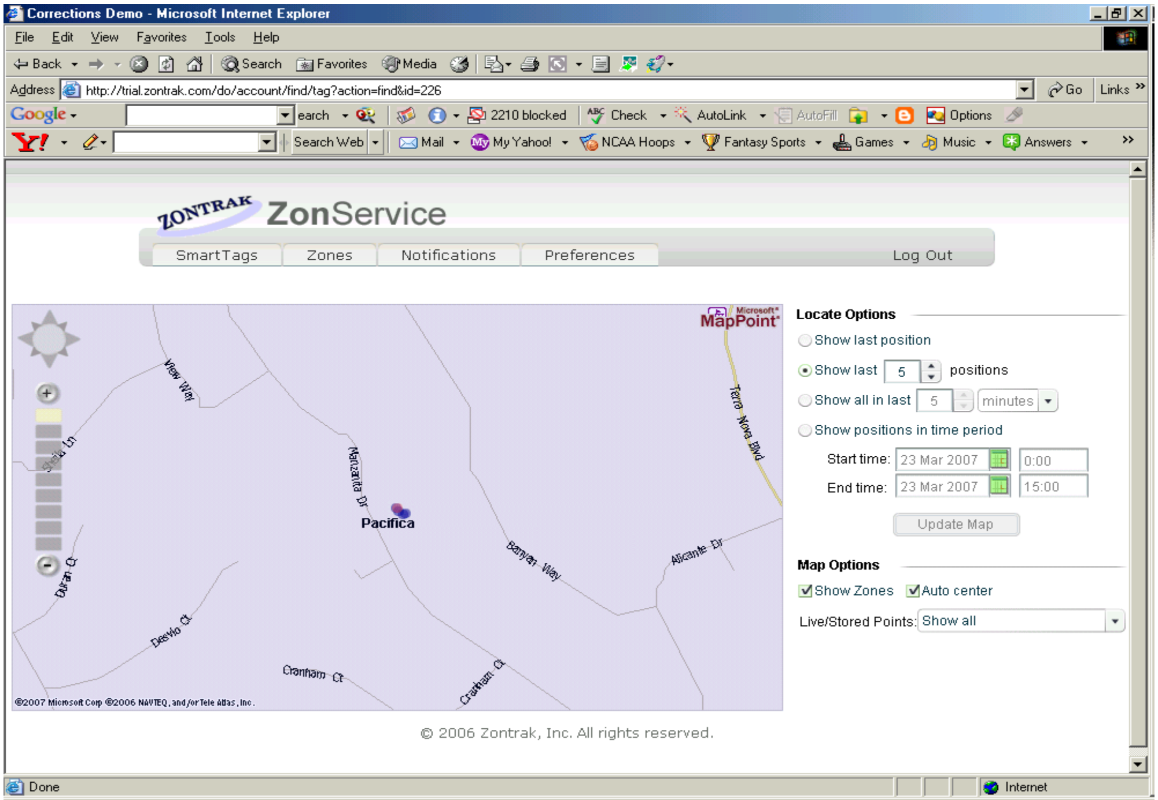


Figure I-9 SmartTag RB0TAG Location

The radiation data associated with each alert may be displayed by double clicking on the appropriate dot. This will create a popup window with the radiation data in addition to the other information stored by the ZonService for the alert.

A sample of the popup window for an alert from the Pacifica SmartTag is shown in Figure I-10. Note that the radiation data consists of 224 bins with all 0s except for the bin corresponding to the potentiometer setting on the connected emulator board. The 224 bins correspond to the energy levels spanning the middle of an 8 bit A/D range from 17 through 240. In this example, the radiation counts have an energy level of 163 and a frequency of 165 Hz (16549/100).

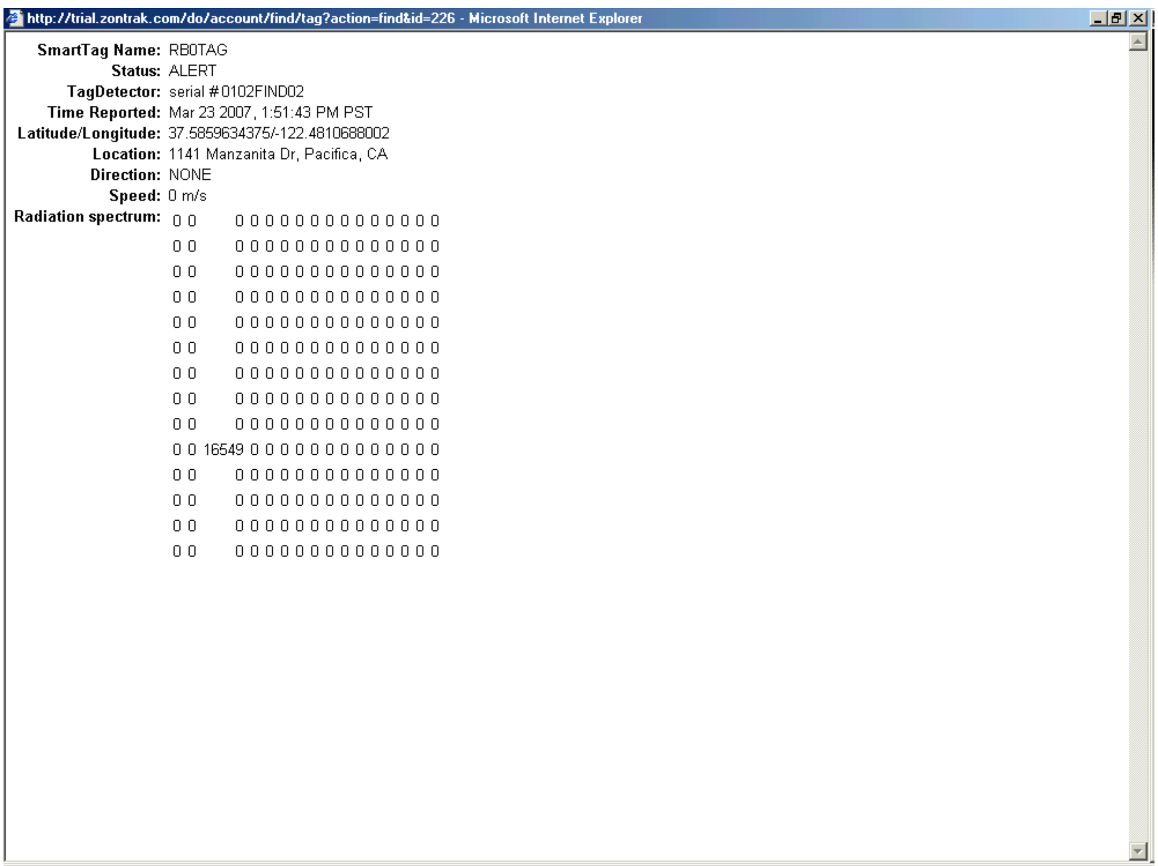


Figure I-10 SmartTag RB0TAG Collected Radiation Data

I.5.3 Fusion Server Record Log for Tags:

Figure I-11 shows the results from the LLNL Fusion server log for records from the SmartTags FT19/78 (SN: 0101TAG019) and RB0TAG (SN: 0101TAG054) collected between 23:00:20 and 23:59:00 on March 22, 2007. Note that 67 records were selected.

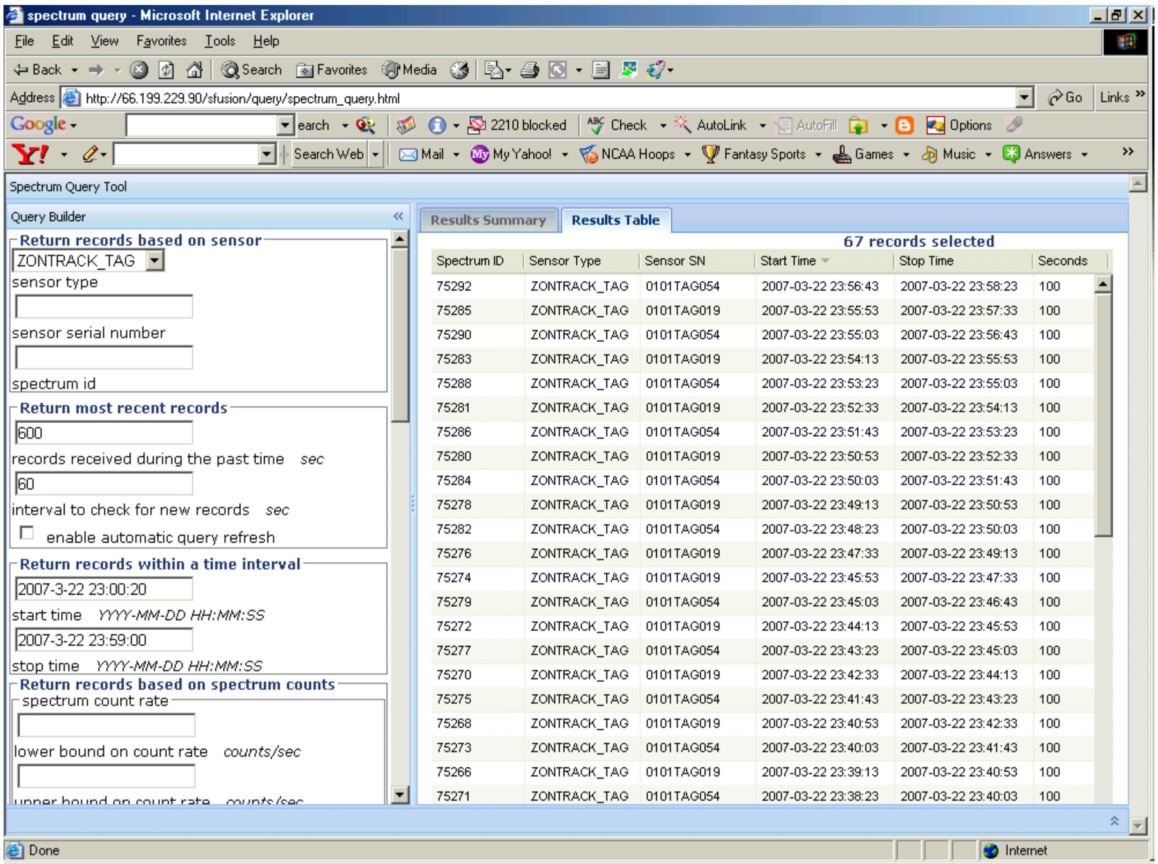


Figure I-11 FT19/78 and RB0TAG Captured on Fusion Server

Similar to the ZonService, the Fusion server is able to display details about the individual records received from the SmartTag system, as shown in Figure I-12.

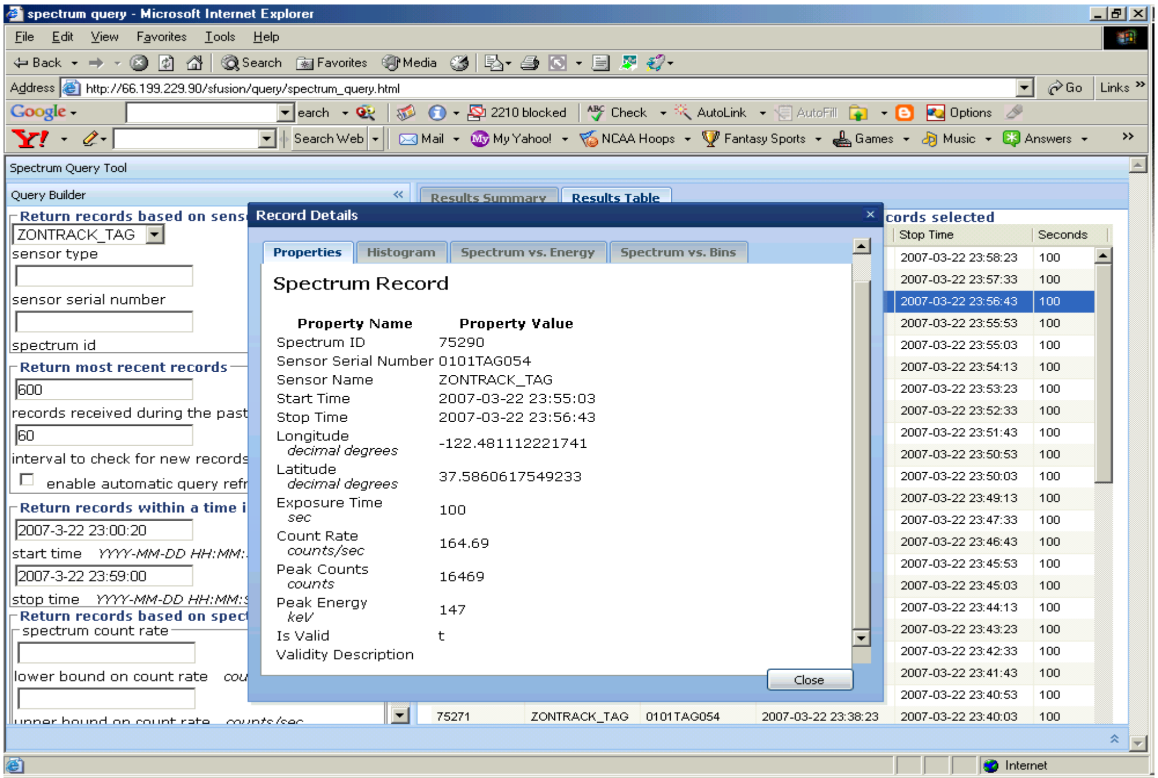


Figure I-12 Details of Records on Fusion Server

Finally, Figure I-13 shows the cumulative spectrum collected during a specified time window (between 17:01:43 and 20:05:53 on March 22, 2007) over the duration of the POC testing. The individual lines correspond to various settings of the emulator boards during the test period.

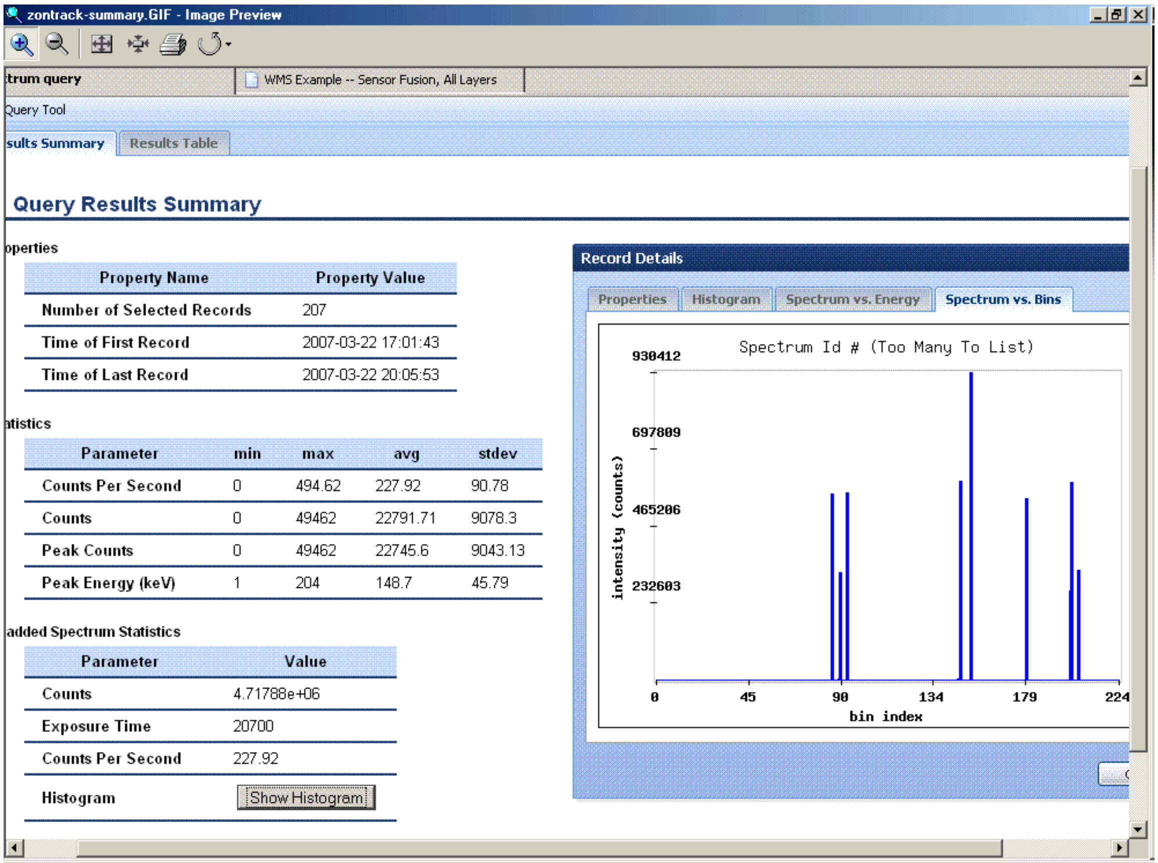


Figure I-13 Results Summary

J Radiation Detectors Technologies and Availability

J.1 Introduction

Most of the evolving technology intended for the detection and interception of nuclear materials relies on detecting gamma-rays emitted during the radioactive decay intrinsic to these materials. The energy of these gamma-rays provides a unique signature of the nuclear material. In order to uniquely identify the radioactive sources of interest in a sea of radioactive background, a detector with the capability to resolve between different gamma-ray energies is necessary. This feature is called "energy resolution" and is an important characteristic of a radiation detector. It is quantified by dividing the noise of the measurement to the signal height and varies between ~20% (poor) to <1% (excellent).

J.2 Scintillator-based detectors

A widely used method for the detection of gamma-rays involves the use of crystal scintillators. A scintillator is a material that emits low-energy (usually in the visible range) photons when struck by a gamma-ray. These lower energy photons are collected by a light sensitive detector, usually a photomultiplier tubes (PMTs). The amount of light collected is a measure of the energy of the gamma-ray. The advantage of scintillator-based gamma-ray detectors is their simplicity (no cooling required), their good performance (good energy resolution: 3-10%) and flexibility (inexpensive and robust materials available).

J.3 Light readout

In scintillator-based systems, the conversion of light into an amplified electrical signal is usually accomplished with a PMT. PMTs only absorb a small fraction of the emitted light (low quantum efficiency). In addition, the power requirements of PMTs are significant due to the large voltages (~kV) and currents (~µA) required, which also translates into larger instruments. An alternative to PMTs is using photodiodes for the light readout. Photodiodes can absorb a large fraction of the emitted light (large quantum efficiency), offer low-power consumption, are small and mechanically robust but they tend to be limited in terms of energy resolution when used at room temperature. They are an attractive alternative for handheld detectors which require good performance with low power consumption.

J.4 Commercially available technology

A wide range of scintillator-based gamma-ray detectors are currently commercially available. They are based both on PMT and photodiode readout and are optimized for specific applications. In terms of small, high performance detectors, the choice is more limited. There is a variety of products for sale for measuring the amount of radiation (dosimetry) [1], detecting high radiation fields (high-threshold alarming) [2,3,4] and, in some cases, rudimentary nuclear material identification [5]. Their performance in terms of energy resolution and low power consumption is limited. The best energy resolution in commercially available scintillator based miniature instruments is 9% with small CsI(Tl) crystals [5]. The power consumption is strongly dependent on the features but is on the order of hours on a single AA battery when high performance is required.

K RECOMMENDED NEXT STEPS

K.1 Analysis of Phase 1 Results

Phase 1 efforts were instrumental in increasing our understanding of the challenges faced in developing the Geo-Rad system. The proof-of-concept system allowed the research team to conduct detailed analysis of the functional and operational requirements of the Geo-Rad system and to develop a clear plan take this effort to the next phase.

K.1.1 Integration of location-aware tag and radiation detector is feasible

The proof-of-concept system clearly demonstrates the feasibility of the integration of a Geo-aware (GPS-based) tag like the SmartTag with a radiation detector. The combined functionalities of both systems would bring about the needed tools to detect proliferation inside and around facilities. This combined with overhead imagery will result in more accurate assessment of any threat.

K.1.2 Power Consumption must to be carefully optimized

The proof-of-concept system allowed the research team to assess the power consumption of the SmartTag and the radiation detector systems separately and as combined. For example, while the SmartTag system consumes approximately 80mW when it is on, power management techniques allows the system to have an extended battery life and longer operational time. In contrast, the radiation detector consumes 40mW but has no power management techniques available to it. This would have a drastic effect on reducing the operational life and will increase the size of the bused batteries.

The result of our analysis is that power consumption of the combined Geo-Rad must be carefully optimized to extend the operational effectiveness of the system. Power management techniques need to be implemented on the entire system. Furthermore, new operation and management processes must be developed for the radiation detection side of the Geo-Rad system.

K.1.3 Wireless Data Transport Requires Careful Management

The SmartTag system, like most geo-location systems, was optimized for communicating geolocation data and alert conditions (10-16 bytes) for a large number of potential users within close proximity. The proof-of-concept system clearly shows different modes of operation where a smaller number of radiation detectors will be present in close proximity of each other. However, each of the detectors will communicate up to 256 bins of 2-bytes each.

This result indicates that the wireless data transport for the Geo-Rad system must be optimized for these new requirements. In Phase-1, ZonTrak has begun the process by restructuring the data link and its payload to accommodate the needed higher data rates. In Phase 2, ZonTrak is planning to continue this effort with the objective of streamlining the data communications process to reduce latency.

K.1.4 Size and Cost of the Geo/Rad tag could be reduced

The proof-of-concept system allowed the research team to carefully examine the architecture and implementation possibilities of the radiation detector in relationship with the geo-location tag (The SmartTag system). This analysis clearly shows that the size of the Geo-Rad tag will be influenced by the size of the radiation sensor used (which depends on the technology used for detection). It further showed that there are some common control electronic subsystems between the two systems. When these subsystems are further integrated, the resulting size of the Geo-Rad tag will be further reduced. This reduction in size will also results in reduction in cost since it eliminates some of the duplicate subsystems.

K.1.5 System design of the Geo-Rad tag can be further optimized

As a result of the previous point, the analysis of the proof-of-concept system shows (as expected) that the Geo-Rad system could be further enhanced from the system design point of view. This optimization will optimize the GPS, radiation detector, and local wireless subsystems and will increase the efficiency of the resulting Geo-Rad tag from a functional, operational, cost, size, and power consumption points of views.

K.2 Phase 2 Directions

The results obtained in the course of completing Phase 1 set the path forward for Phase 2 implementation plan. After careful considerations of all possible options, the following directions for Phase 2 are recommended.

K.2.1 Optimize Geo-Rad System Design

As previously mentioned, one of the most important findings of Phase 1 is that the system design of he Geo-Rad system can be further optimized to further reduce size, power consumption, and cost. The Phase 1 proof-of-concept system integrates two independent systems as shown in Figure K-1 below. Each system has its own functional, control, interface, and power subsystems. This creates duplication in some of the required subsystems.

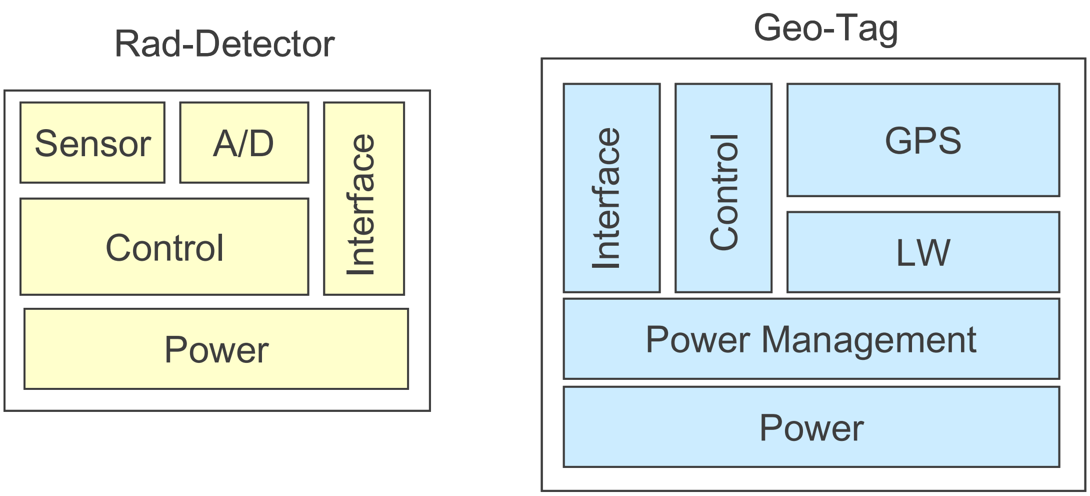


Figure K-1 Geo-Tag and Radiation Detector High Level Systems

A more efficient system design will optimize the use of the common subsystems and will extend the functionalities of these subsystems to service the main functional blocks. By carefully structuring the system design, it would be possible to eliminate this duplication and to reduce the cost and size of the resultant design. Further, a more power-efficient system will be developed. This is illustrated in the Figure K-2 below.

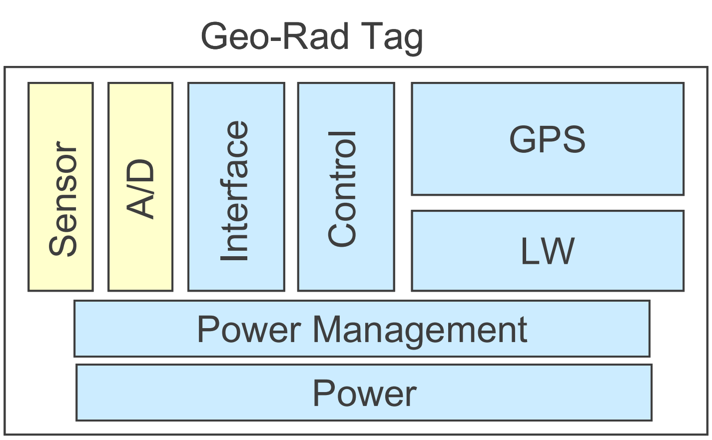


Figure K-2 Integrated System Design for Geo-Rad

K.2.2 Increased Integration of SmartTag and Detector's Electronics

One of the main results of the new system design is to reduce the size of the Geo-Rad system. The Phase 1 analysis of the proof-of-concept system shows an opportunity to further integrate the electronics of the SmartTag system to free up more board space. This available space would be used to include some of the electronics of the radiation detector and to create a common interface suitable for multiple types of radiation sensors.

K.2.3 Develop Detector's Power and Functional Management Schemes

The SmartTag system has successfully implemented power management techniques to reduce the total power consumption and increase the battery life. This power management methodology was carefully incorporated in the system design of the SmartTag system.

Radiation detectors, on the other hand, do not have such power management approaches implemented. The system design, and subsequently the hardware and software implementation, does not lend itself to such power consumption optimization. This significant drawback could be easily overcome by extending the power and functional management methodologies of the SmartTag system to the radiation detector blocks as previously shown in Figure K-2.

K.2.4 Increase Available Memory

Another enhancement to the Geo-Rad system is to increase the on-board memory to accommodate the higher volume of gathered data when the Geo-Rad is away from the communicating Base Station. Given the advancement of memory chips, this enhancement could be easily achieved by replacing the existing memory on the SmartTag with a higher capacity memory chip. It will have minimal or no impact on size or power consumption.

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[3] Mini rad-D, http://www.laurussystems.com

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