IDEA

Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Detection of Radioactivity in Transit Stations – Phase 2

Final Report for
Transit IDEA Project 54

Prepared by:
Dr.Eric P. Rubenstein and
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East Hartford, CT

October 2009

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

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- Dr. Peter Zimmerman, of the Homeland Security Institute
- Connecticut Department of Transportation (CT DOT): Mr. Jim Sime, P.E., Director of Research Department
- Mr. Gilad N. Cohen, MS, DABMP, Radiotherapy Physicist, Memorial Sloan-Kettering Cancer Center
- Prof. Charles D. Bailyn, Yale University, Astronomy Department
- TRB, Transit IDEA Program: Mr. Harvey Berlin, Senior Program Officer

Detection of Radioactivity in Transit Stations – Phase 2

Transit IDEA Project 54

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EXECUTIVE SUMMARY

The purpose of this Transit IDEA project was to test and evaluate a prototype system to detect dangerous levels of radioactivity in rail transit stations. A prototype system was installed into the Medical Center Metrorail station of the Washington Metropolitan Area Transit Authority (WMATA); it has been running since its installation on 13 January 2009. The data collection allowed us to measure the achieved sensitivity and to evaluate it against various concepts of operations (CONOPS) we have discussed with representatives from WMATA. Use of the preexisting security cameras and network infrastructure will greatly reduce cost and facilitate broad coverage.

When the test was begun, we were restricted to using digital cameras on digital networks only. A contract from the Domestic Nuclear Detection Office (DNDO) of the Department of Homeland Security (DHS) has provided the support needed to evaluate the likely degree of success we would have in modifying the algorithms to work with analog network connections. The result suggests that such an adaptation should be straightforward to implement. Nonetheless, the work performed under this project was with the digital cameras that we installed, operated and tested against a radioactive source in the WMATA Metrorail station, and the algorithms work with digital cameras.

Transit stations are potential targets for terrorist attacks because they serve large numbers of people daily. To protect against that threat, pervasive radiation detection is needed at all times. Transit systems pose special detection problems due to limited line-of-sight areas in transit stations arising from radiation blocking obstructions, e.g. concrete, steel, and earthen walls and supports. In this report, we discuss the results achieved by Advanced Fuel Research, Inc. (AFR) to address these concerns. The work was performed in collaboration with representatives from the Communications Division of WMATA and the Metro Transit Police of WMATA. We have worked with experts from these organizations and elsewhere in order to elicit feedback to make the technology more applicable to users, and this report includes our collective conclusions.

The system has reached operational capability. In addition to the algorithm work, we made progress on the user interface to ensure that an operations supervisor would have easy access to all key information should the system be deployed and at some point produce an alert.

The conditions of the test were controlled so that we were able to estimate the effective sensitivity of the detection system. An alarm was produced when the camera was exposed to a radiation field of about 17 milliroentgen (mR) per hour, a field approximately equal to what would be expected about two feet from a patient treated with nuclear medicine. As another comparison point, the Nuclear Regulatory Commission (NRC) and DHS have agreed that a "threat-level" source of the radioactive isotope Cesium-137 is 27 Curies, which the system can detect out to ~75 feet now, and eventually out to 150 feet or more. Such a powerful source is smaller than a pea and could very easily be mixed with putty or gum and stuck on the underside of a train seat. The system would easily detect such a weapon within seconds of a train pulling into a station.

The Radiation Event Detection System: Tracking And Recognition™ (RedStar™) technology is based upon the innovation of using existing digital cameras with Charge Coupled Device (CCD) or other solid-state light detectors for radiation measuring sensors (Patent 7391028 [1]). Modern security cameras in transit stations are already connected to an operations center. The addition of our software running on standard computers allows the security cameras to be transformed into radiation detectors, while still able to perform their primary mission of optical image capture for safety and security purposes. These sensors have sufficient sensitivity to detect dangerous levels of radioactivity, as measured in our laboratory experiments and in the WMATA Metrorail station.

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[1] Dr. Eric Rubenstein, AFR, Inc., "Apparatus and method for detection of radiation" - Patent 7391028, which can be found here: http://www.freepatentsonline.com/7391028.html, patent filed February 2005; last accessed on 16 October 2008.

1. IDEA PRODUCT

The fully developed product will be a software/hardware product that will allow dirty bombs to be detected using modern digital security cameras as the radiation detector. This product will augment other radiation sensors and enable high-level coordination by transit and law-enforcement authorities. Network-enabled software, using common communication interfaces (e.g. TCP/IP, XML, SHTTP, etc.), will facilitate the dissemination of alerts to key stakeholders in transit and government activities. The ubiquitous distribution of existing security cameras ensures that dangerous amounts of radioactive material will have to pass within detection range, as demonstrated during this project, and shown in Figure 1. Unlike portal detection scanners that require individuals to file past one at a time, this product would not slow down passenger flow. Since its sensitivity can be set to the level desired by operators, its use can mirror the expectations and goals of local law enforcement. For example, at locations where patients who have been treated with nuclear medicine are expected, lower sensitivity settings are called for.

2. CONCEPT AND INNOVATION

The objective of this Transit IDEA project was to test a working prototype system based upon the innovation identified above. Briefly, the prototype implements a proprietary method of analysis to use digital imagery data to search for the telltale artifacts caused by radioactivity that hits and interacts with the Charge Coupled Device (CCD) detector within the digital camera. Most transit security cameras are connected to a Network Operations Center (NOC). Therefore, the envisioned system, described in the next section, allows for extremely efficient use of resources. The system makes use of existing detectors, data acquisition systems, communication networks, and centralized security staffing. The RedStar algorithms run on standard PC's, which minimizes the cost of "buy-in."

This Transit IDEA Project 54 is a Phase 2 project that builds on the results of previous Transit IDEA Project 42, which was completed in October 2006.

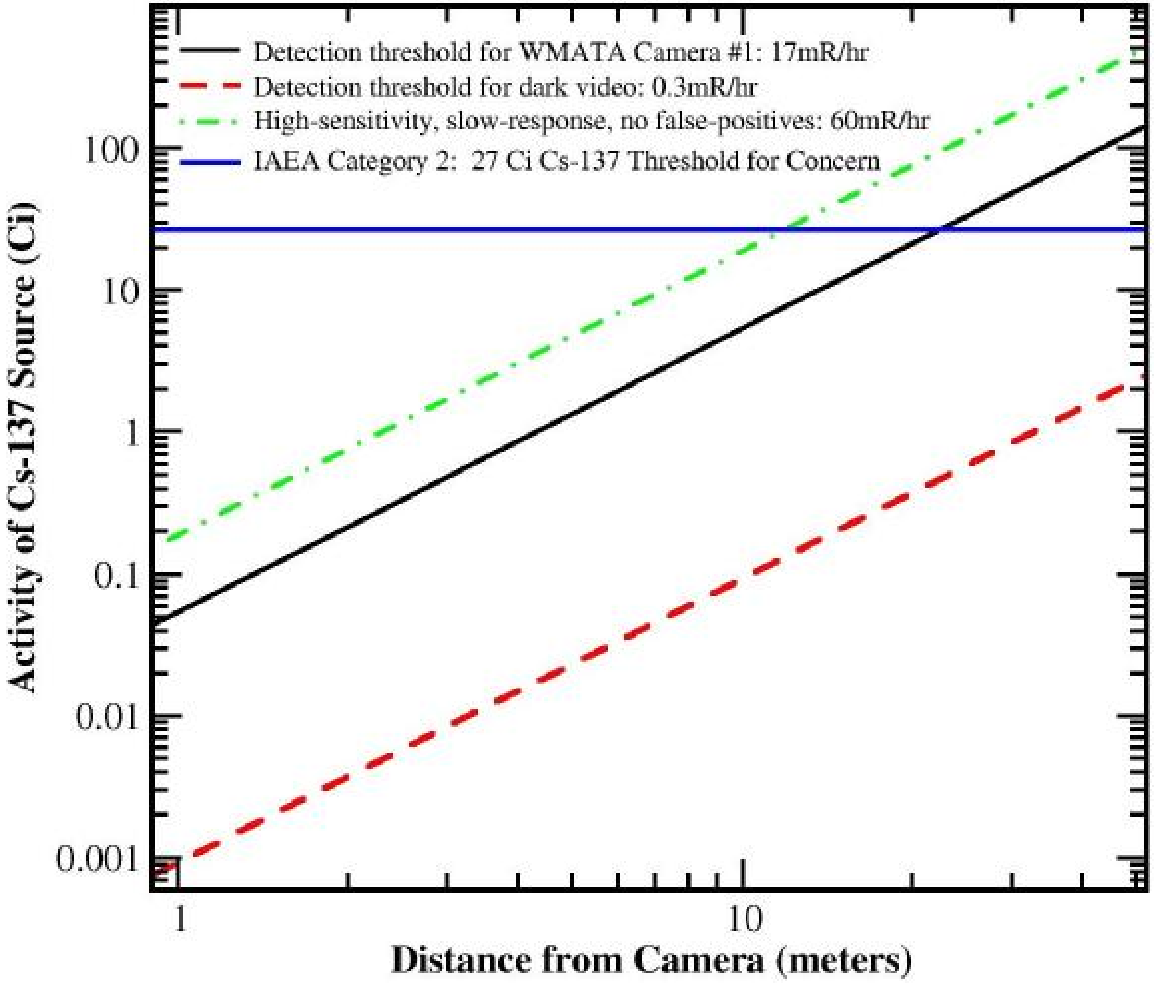


Figure 1: Plot showing sensitivity of Camera #1, from the deployed system in the Washington, D.C. area Metrorail station. The solid black line shows the sensitivity curve derived from the actual alert achieved during the field test on March 16-18, 2009, in which the system alerted based on a radiation field of ~17 mR/hr. At this sensitivity setting, there are several false-alarms per hour during non-rush hour conditions in the station, and typically no false alarms occur at night. However, alarms are very frequent during peak travel times. The green, dash-dot line shows the sensitivity of the same algorithms, but set to a sensitivity of 60 mR/hr; at that level of sensitivity the system produced no false alarms during the period of the test, as described in the text. The red, dashed line shows the ultimate sensitivity of the system, 0.3 mR/hr, estimated from our laboratory tests with covered cameras, i.e., dark video. The horizontal, blue line shows the activity level that the International Atomic Energy Agency (IAEA) and Nuclear Regulatory Commission (NRC) deem the "Threshold for Concern" for Cs-137, 27 Ci. The black line (17 mR/hr sensitivity) shows overall system sensitivity consistent with detecting the IAEA Threshold for Concern for Cs-137 out to a distance of 22.5 meters distance. We expect that by mid-2009, the RedStar algorithms should be able to detect 15 to 20 mR/hr radiation fields with an extremely low false-positive rate, at least comparable to the current high-sensitivity/slow-detection version of the algorithms (i.e., no false-positives in a given 24 hour period).

3. INVESTIGATION

4.1 TASK 1 – Develop Concept of Operations (CONOPS) with WMATA

The Principal Investigator (PI), Dr. Eric P Rubenstein, of Advanced Fuel Research, Inc. (AFR), and Senior Scientist, Dr. Gordon Drukier, worked with the Metro Transit Police of WMATA to establish requirements for the operational testing of RedStar at a Metrorail station. CONOPS and standard operating procedures (SOPs) were evaluated for the testing protocol.

4.1.1 Meetings:

Three formal meetings were held during the performance of this contract. The first meeting was held at the headquarters of the Domestic Nuclear Detection Organization (DNDO) at the Department of Homeland Security (DHS), the other two at WMATA headquarters. These meetings and a series of telephone and email conversations have allowed us to determine the system requirements, CONOPS and SOPs for the test and evaluation program, and set the plans for executing the tests. The first meeting at WMATA, on October 2, 2008, was held with Deputy Chief Michael Daly of the Metro Transit Police, and with Harvey Berlin, Senior Program Officer for the Transit IDEA Program.

The third meeting was of particular note. At that meeting, representatives from the Metropolitan Transit Police, the Communications division, the individual responsible for camera selection, and the WMATA Environmental division were present. Chaired by Mr. Geoff Hunter, PROTECT Projects Manager and Chem-Bio Emergency Coordinator for WMATA, the meeting allowed the various stakeholders to evaluate our proposed project. The decision to not integrate with the WMATA data networks ensured that there would be no unintended conflicts or excess bandwidth consumption during an early-stage technology evaluation. By minimizing the impact on people’s schedules, we were able to move into the project execution phase rapidly.

In addition, during the course of the deployment, we met with Michael Powley of WMATA a few additional times and had very lengthy conversations concerning the way sensor data is used by WMATA, and additional details on CONOPS. These conversations, meetings, and emails have all had an impact on the nature of how we plan to provide alerts and other operational reports. The involvement of WMATA and the Metro Transit Police has helped shape our mode of operations.

4.1.2 CONOPS decisions and implementation:

The statement of work for this contract specified several questions that would need to be addressed in order for us to perform the field test at a WMATA Metrorail station. Since some of this information pertains to security decisions and in some instances security policy, we will just provide a summary of the field test plan.

In summary, the field test and evaluation program was performed with a single AFR computer accessing three cameras. We implemented Deputy Chief Michael Daly's preference that during the test alerts and data analysis be accessed remotely and not depend upon Metropolitan Transit Police personnel. In subsequent discussions with WMATA personnel, it became clear that should a RedStar system be permanently installed and tied in to the Metro Transit Police security framework, the SOP for any radiation alarm would be for the data to be reviewed by senior operations and/or security staff, similar to what is currently done for fire alarms. As with the latter case, we would provide training in evaluating the data underlying a potential alert. We anticipate providing an optional alert monitoring service should it be deemed desirable to have an expert available on demand. These steps lower the barrier to implementation since a false alarm rate of once or twice a month system wide, as with fire alarms, is tolerable and achievable in the very near term. Lower false alarm rates are expected as development continues.

In order to comply with this test requirement, we contracted with Verizon to obtain an internet connection in the station. Since the system uses standard protocols, such as http and XML, we were able to contact the computer from AFR and also able to transfer results to our off-site web-server. For the purposes of the test, alert information was collected and analyzed by AFR. Summary results are reported below and in Figure 1.

4.2 TASK 2 – Integrate CONOPS with RedStar Prototype Software

4.2.1 The Prototype System:

RedStar detection software was run on a standard Dell laptop computer, making use of three modern digital cameras. Our proprietary software detects the interaction between high-energy particles from radioactive material and the camera's semi-conductor detector (e.g. CCD). This technology may be deployed in many ways, but the most relevant CONOPS for transit applications involve the centralized processing of transit security video images at either a station-level or system-wide NOC. For the testing procedure we used, data was collected from three cameras in the "Medical Center" station and were routed to the utility closet where the computer and internet access point were kept securely locked (Figure 2).

These data were then made available to the RedStar software. The software searches each image for the presence of static-like spots that result from high-energy radiation. The data processing happens very quickly, allowing detection to be made in near real time. The cameras typically acquire images at about six frames per second (fps). In brighter locations as many as 30 fps are achieved, but 6-10 fps is typical indoors and especially underground.

Since many image frames are analyzed, the probability of generating a false-positive alert can be tremendously reduced. In operation, an alert would only be considered a candidate if the level of radioactivity remains elevated for some extended period of time, perhaps 10 seconds or so and satisfies the additional tests posed by our expert system. The amount of time it takes for an alert to be issued depends on a number of factors including the source strength and distance to the cameras, the amount of intervening material (e.g. walls, shielding, floors, etc.), and the number of frames per second collected and evaluated.

As described above, the CONOPS for the test called for a computer analyzing the video from three cameras in a Metrorail station, with the output of these calculations being sent to our web server for detailed analysis by AFR scientists. The system that we ultimately installed was based on the following operational goals. We wanted to ensure that if a radioactive source were carried into a transit station, it would pass in close proximity to the entryway camera at the bottom of the escalator, followed by (possibly) the camera over the fare machine, before moving to the camera near the "turnstile." Once in the station, the relative amount of radiation received by cameras would provide a clue as to the approximate location of the source, if the source were strong enough to be detectable by multiple cameras at once. Additional, more advanced techniques to further refine the location determination are under study. The layout of cameras is discussed further in the next section and in Figure 3.

The goal of the Stage 1 development efforts were to create the required software infrastructure to support the requirements for this field-test so that the test CONOPS could be employed. Figure 4 shows some of the program interfaces. Our review of alerts used local storage and both encrypted computer-to-computer connections back to AFR and to the website. Local storage was always available and allowed for retrospective looks at more data than could be handled across the internet. The ability to connect to the laptop, and for the laptop to connect to the internet proved essential as we upgraded the deployed software, performed system maintenance, and even recovered from dynamic changes to the Verizon network. It turned out that having redundant techniques for tracking down the computer when Verizon changed its network topography was very important; we successfully used IPMonitor software and a homebrewed background job to connect to Twitter.

Figure 2: The Dell laptop computer and network equipment were stored in the labeled cart inside of the locked telephony closet. For security, the cart was padlocked and chained to the wall. In addition, multiple layers of network security were utilized to protect both the equipment and the privacy of WMATA's riders.

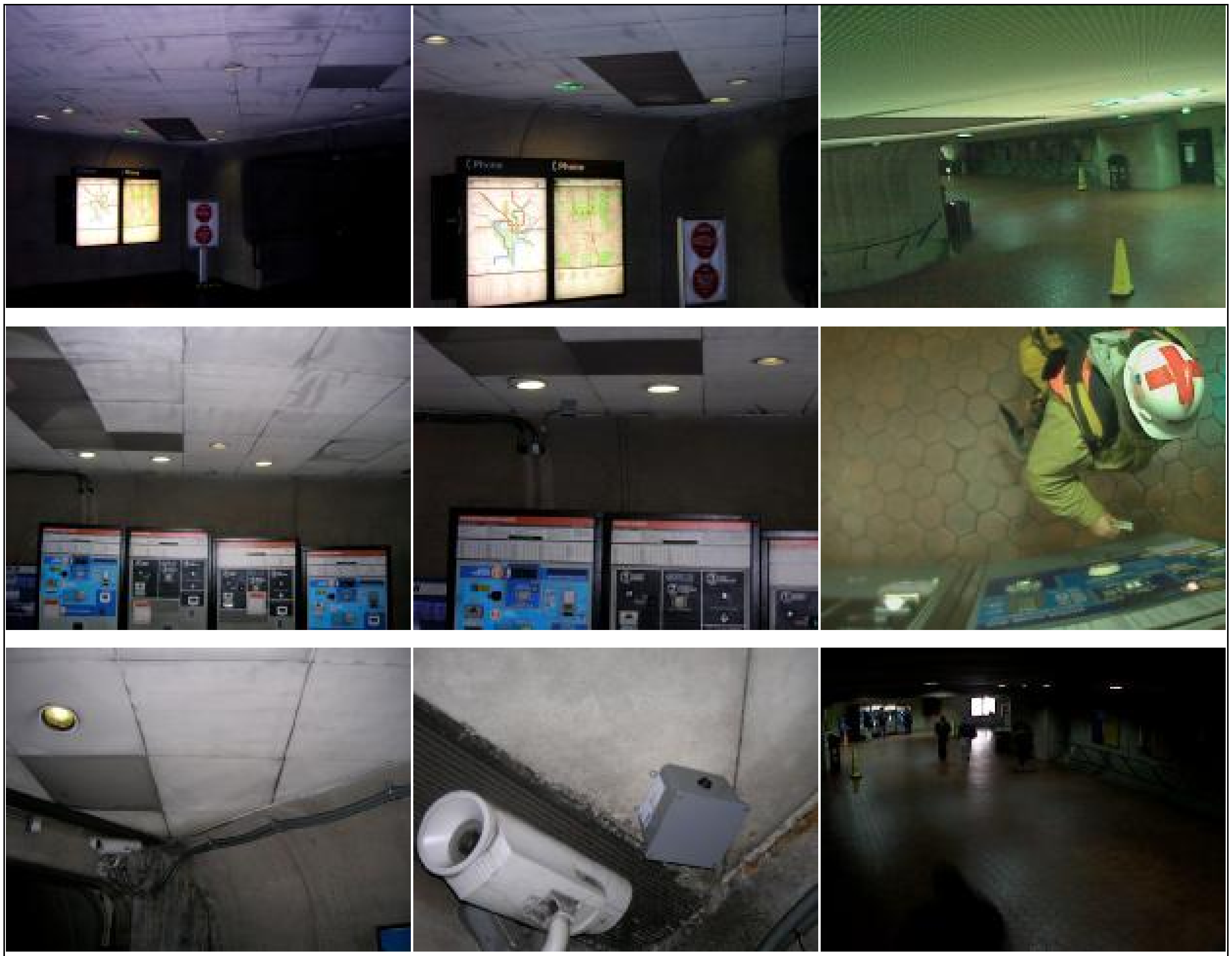
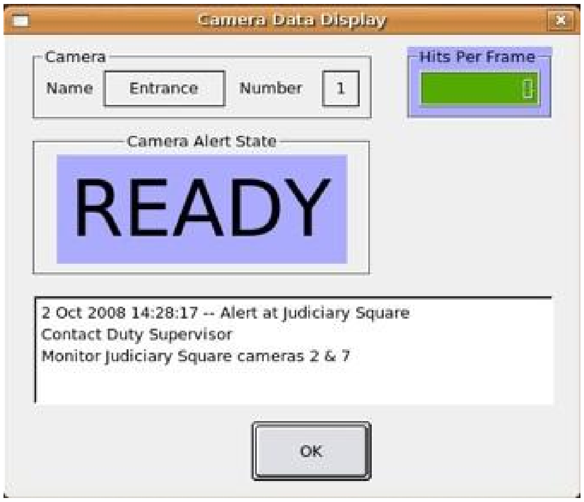


Figure 3: The three camera installations were done with professional equipment by Mr. Don Ziegler, who routinely installs such equipment for WMATA. The pictures in the left column show a wide view of the installation locations. The middle column shows the installed cameras. The right column shows the field of view of each camera. The location over the telephone booths where Camera 1 was to be installed (top left panel) was selected for its proximity to the turnstiles, just to the right of the edge of the image. The top, center panel shows that Camera 1 is very unobtrusive. It looks back towards the escalators and includes Camera 3 in its field of view. The location for Camera 2 (middle panels) was selected since people using the fare machines must loiter briefly, which provides time to pick up less powerful radiation signals that might emanate from an attacker. Camera 2 looks straight down over the left-most fare machine. The bottom panels show Camera 3 nestled next to one of WMATA's security cameras, near where the escalators enter the station concourse. Its field of view is away from the escalators and includes both of the other cameras.

Figure 4: The screen shot to the right shows the RedStar application as it appears during a calibration phase of operation. In addition to the current state of the system, there are fields to display the current count rate in hits per image, alert messages, error messages, and other associated system information. Other screens are available for configuration of cameras (below, left), sensitivity settings (not shown), and alert configurations (below, right). Alerts modes include: alert window pop-ups, email, SMS text messaging, and website alerts. The American National Standards Institute (ANSI) 42.42 standard for radiation monitoring equipment is utilized to ensure interoperability with other detection systems.

Alert State: READY

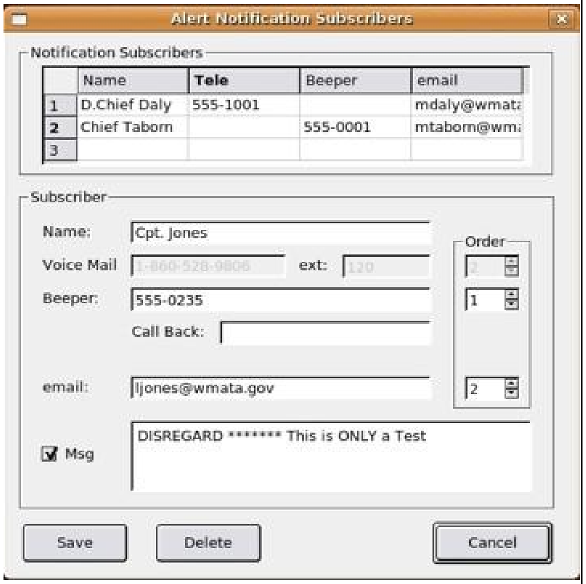
Mode: ● Calib ○ Detect



Name: Entrance Number: 1

Camera Alert State: READY

2 Oct 2008 14:28:17 -- Alert at Judiciary Square
Contact Duty Supervisor
Monitor Judiciary Square cameras 2 & 7



Notification Subscribers

	Name	Tele	Beeper	email
1	D.Chief Daly	555-1001		mdaly@wmata
2	Chief Taborn		555-0001	mtaborn@wm
3				

Subscriber

Name: Cpt. Jones
Voice Mail 1-860-528-9806 ext: 120 Order 2
Beeper: 555-0235 Order 1
Call Back:
email: ljones@wmata.gov Order 2
☑ Msg DISREGARD ******* This is ONLY a Test

4.3 TASK 3 - DEPLOY THE REDSTAR PROTOTYPE TO A WMATA STATION

On the night of 12 Jan 2009, we installed the three-camera prototype in the concourse of the Medical Center station of the Red line of the Washington Metropolitan Area Transit Authority (WMATA) Metrorail system. Two Axis 207 (referred to as Camera 1 and Camera 2, near the turnstiles and over the fare machine, respectively) and one Axis 210 camera ("camera 3" on the ceiling near the bottom of the escalator) were fastened to the ceiling of the concourse area. Camera placements are shown in Figure 3. Network and power cables were run from them, through a convenient conduit near the fare machines (visible to the left of Camera 2), and into a secure closet (see Figure 2) giving access to a Verizon DSL network connection. A single, dual-processor computer was left there running the RedStar system on network feeds coming from the three cameras. We remotely access this machine via the Verizon DSL line using encrypted communications tools. As algorithmic improvements are made, new versions of the software are uploaded to the deployed machine.

4.4 TASK 4 - TEST & EVALUATION OF REDSTAR PROTOTYPE AT WMATA STATION

On the nights of 16-17 and 17-18 March 2009, we returned to the deployed system with some small, unregulated (^{137}Cs) sources to perform live tests of the system with radiation. The sources had to be placed very close to the detectors for the radiation to be observable. We estimate they were roughly 5 cm away, with the resulting radiation field, ~17 mR/hr. This work was done after revenue hours in order not to pose any hazard to the public, our team, and the WMATA support personnel, who served as stand-ins for the passengers. Data was taken both with and without our presence in the field of view of the cameras. We also employed various props and changes of clothing to mimic the sorts of dynamic situations our system may have to confront and deal with. In addition, video was collected from all three cameras nearly continuously over a 57-hour span from 17 to 19 March 2009. We have prepared a video explaining these activities and put them on our website athttp://RedStarDetect.com/

4.5 TASKS 5 - PROCESS AND PRODUCT ASSESSMENT

In Figure 5 we show 12 hours of data from one of the Axis 207 cameras deployed in WMATA. The top panel shows the mean light level in the frame, while the bottom shows the reference radiation background measured in units of counts per megapixel (Mp^{-1}). The middle two panels show two measures of the detected signal above background, again in Mp^{-1}. The lower measure is a local temporal average over a series of consecutive frames. The upper measure is a longer, rolling average. As a first stage cut, our algorithms set thresholds for both measures which must be surpassed for a sufficient length of time before a possible radiation alert will be considered. Note that we did not do a live test of the camera during this period. This particular series gives an example of a low-sensitivity, fast-response setting suitable for finding strong sources quickly. These data come from the second half of our collection and the proceeding 24 hours have been used to establish the initial set of reference backgrounds.

There are several features to note about this time series. The mean light level in the scene is fairly uniform; the major exception being the step-wise drop between 4 and 5 A.M., likely due to a change in the camera's gain settings, and a more gradual drop around 11 A.M. In terms of movement on the concourse, the overnight period is fairly quiet except for shortly after 4 A.M. The station opens at about 5:30 A.M., after which time the series of sharp spikes in the second panel reflect waves of passengers traveling through the concourse during the morning rush hour. This activity dies down after 10 A.M., although the arrival of trains can still be seen in the individual spikes thereafter. There are clear correlations between the light level and the spikes in the estimate signal as regions of the images with passengers are temporarily excluded from consideration. The background level is at around 0.35 counts Mp^{-1}.

In order to prevent false positives, we must set the thresholds higher than the estimated signal coming from the observed passengers. Assuming the data shown is representative, we can estimate the required threshold from the measured detection rates. Our actual radiation tests at this light level give an observed radiation signal of about 0.5 Mp^{-1} for an estimated dose rate of ~15 mR/hr.

The threshold requirement for these low-sensitivity setting are such that a dose rate of ~200 mR/hr would be required to surpass them, i.e., to prevent any false-positive alerts in the data under discussion. This high threshold will fall significantly as we improve the algorithms—essentially reducing the background noise-level, allowing the signal to be more statistically significant for lower radiation fields. This threshold requirement has already dropped considerably because of improvements to our algorithms under the DHS contract. These improvements would not have been possible without the data from the WMATA prototype deployment in this Transit IDEA project.

Figure 6 shows the same time series, but in this case filtered with a high-sensitivity, slow-response setting suitable for weak sources. With the longer effective dwell time, the large fluctuations are suppressed and the background level is also lower. In this case, a radiation dose rate some 4 times that of our test source, or ~60 mR/hr would rise above the thresholds and be detected. That is, with the algorithms in their current state, a threshold of ~60 mR/hr would avoid false-positive alerts using the high-sensitivity, slow-response setting. These values are not at the optimum threshold yet, but suggest both the progress (from 200 mR/hr in previous work) made in terms of data utilization and the value of further work, which should permit us to get to our target sensitivity of 15 – 20 mR/hr.

Our ability to refine and improve our algorithms has been greatly enhanced by the access and live data provided by WMATA in this Transit IDEA project. It has resulted in rapid improvement and a clear demonstration of the efficacy of our technique and its capability to successfully work in a transit environment. As a result of this project, the RedStar system is very close to the optimum detection threshold for deployment to provide radiation detection in transit systems. We expect completion of the algorithm refinement work during the final months of 2009. Fine tuning of parameter settings to a particular locale would take place during installation and initial calibrations, to be completed by on-site technicians upon future deployment..

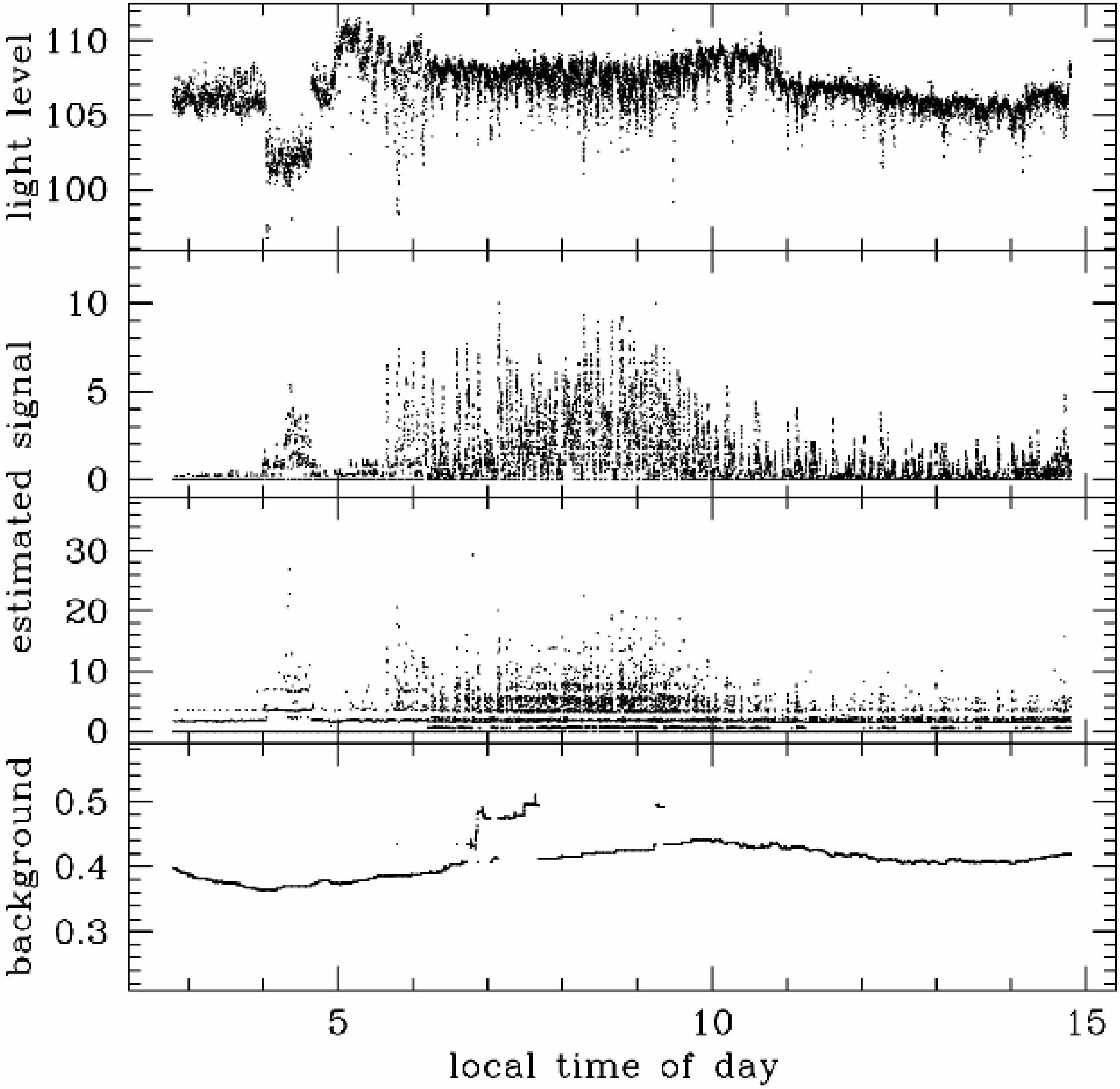


Figure 5: Time series for the Axis 207 camera deployed to the Washington Metrorail station for the low-sensitivity setting. The time series starts at 2:48 A.M. and runs through 2:48 P.M. the next day. The station opens at about 5:30 A.M. The top panel shows the mean light level in the frames of the video stream. Pure white is represented by 255 counts. The lowest panel shows the reference detection background against which we are trying to detect the radioactive sources. The step functions come as the system adjusts to changes in the properties of the visual image. The two middle panels show two, time-averaged, estimates of the radiation signal. The lower one is a local time-average, while the upper is a rolling, longer, time average. The sharp spikes come from waves of passengers transiting the concourse as trains arrive at the station. The A.M. rush period is clearly evident between 7:00 and 10:00 AM.

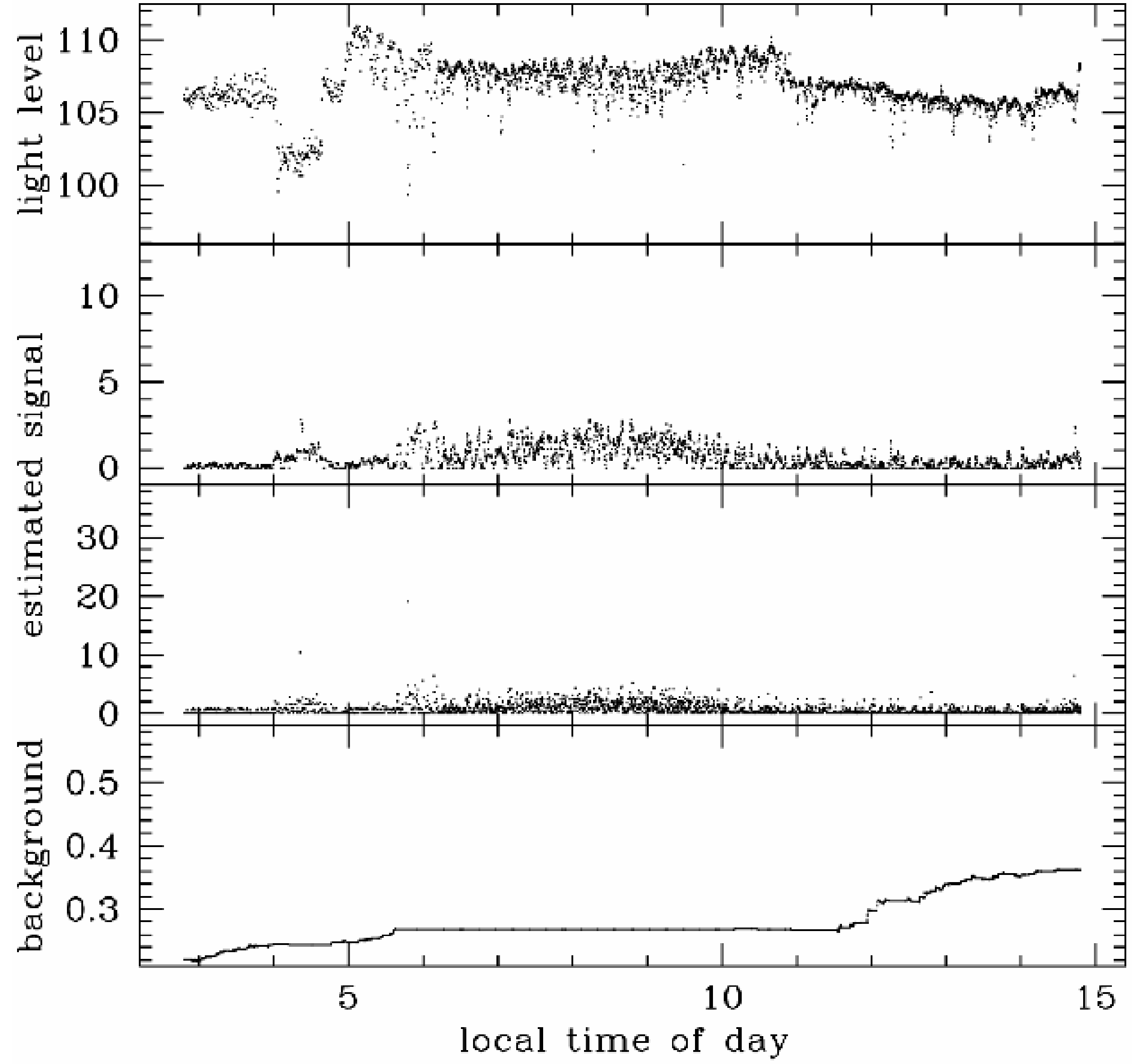


Figure 6: As Figure 5, but for the high sensitivity settings. Note the reduced background and the much lower amplitude of the variations in the estimated signal as passengers transit the field of view.

5. CONCLUSIONS

All activities for this Transit IDEA project have been successfully completed. Productive meetings were held, and their lessons positively impacted CONOPS development and prototype deployment. The field test was conducted, and radiation was detected in live video at the WMATA Metrorail station.

These sensors have sufficient sensitivity to detect dangerous levels of radioactivity, as measured in our laboratory experiments and in the WMATA Metrorail station. The system is still deployed in the Metrorail station and continues to provide a critical test bed for ongoing algorithm refinement. Progress was rapid both in technical algorithm work and in our understanding and adaptation of the detection system to the transit station operational environment. We look forward to continuing to work with WMATA and to keeping the Transit IDEA Program office updated on our future developments.

6. PRINCIPAL INVESTIGATOR CONTACT INFORMATION:

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