Urban Operational Experimentation hosted by the National Urban Security Technology Laboratory (NUSTL)

X-ray Scanning Rover Report

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Executive Summary

On July 29, 2015, Smart Imaging Systems Inc. demonstrated its X-ray Scanning Rover (XSR) at the New York City Police Department's Floyd Bennett Field in Brooklyn, New York, during the Department of Homeland Security (DHS) Science and Technology Directorate's (S&T) Urban Operational Experimentation (OpEx), hosted by the National Urban Security Technology Laboratory (NUSTL). Ten responders with experience in bomb response from New York, New Jersey, Washington D.C. and Massachusetts were present during the XSR demonstration.

The XSR is a prototype X-ray robot designed to rapidly screen bags left behind after an evacuation or emergency. This technology is being developed under a research and development agreement with DHS S&T. It is intended to bridge a technology gap between currently available handheld or robot-mounted X-ray scanners, which have a small imaging area, and larger vehicle-mounted mobile X-ray scanners, which are not nimble enough for indoor use.

Participating bomb technicians and observers first watched a presentation about the technology, then went outside to observe the XSR operate and view X-ray images produced and displayed on a monitor. Since this system is a developmental prototype, the vendor operated the unit from a laptop computer and system controls were not evaluated. The XSR scanned a suitcase laying on its side, two suitcases standing upright, and a car door. Feedback was collected from the observers during the experiment and in a debrief session.

The responders present at the OpEx believed the XSR could be used as another useful tool. However, at its current price point, they would be unlikely to buy one for the limited instances where they would need large scale, rapid-screening. Instead, the responders suggested that it could be a regional resource shared among a few states. They also suggested that it might be most suitable as a portable screening tool for customers such as the Transportation Security Administration or U.S. Customs and Border Protection. Responders noted that they would prefer to have the X-ray system as an attachment to their existing bomb robot rather than as an additional custom robot. They considered the raw image generated by the XSR adequate to meet their needs and supported the planned integration with X-Ray Toolkit™, a software tool for processing and enhancing X-ray images.

Figure 1 - X-ray Scanning Rover at OpEx

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1 Introduction

The X-ray Scanning Rover (XSR) is a prototype technology that is being developed by Smart Imaging Systems Inc. (SIS) under a cooperative research and development agreement with Department of Homeland Security (DHS) Science and Technology Directorate (S&T). The XSR consists of a custom robot with a fold-out arm that can X-ray packages of any length in a single scan while the operator remotely controls the unit (Figure 2). The XSR is intended to bridge a technology gap between currently-available handheld or robot-mounted X-ray scanners, which have a small imaging area, and larger vehicle-mounted mobile X-ray scanners, which are not nimble enough for indoor use. The design is geared toward rapid inspection of multiple bags left behind due to an evacuation or other emergency event.

Figure 2 - X-ray Scanning Rover (XSR)
Smart Imaging Systems Inc.

On July 29, 2015, SIS demonstrated the XSR during the DHS S&T Urban Operational Experimentation (OpEx), hosted by the National Urban Security Technology Laboratory (NUSTL). This event brought together first responders and product developers to experiment with emerging technologies in operational conditions. The OpEx was supported by the New York City Fire Department, New York City Emergency Management, New York City Police Department (NYPD) and Port Authority of New York and New Jersey. These subject matter experts selected the technologies and worked with NUSTL scientists to plan the experimentation scenarios and arrange test venues. Responders from these agencies and members of the First Responder Resource Group experimented with the technologies and provided feedback and observations. Table 1 lists all of the technologies that were included in this event. Technologies assessed during this event were selected for their potential to meet capability gaps as identified in the Project Responder 4 - 2014 National Technology Plan for Emergency Response to Catastrophic Incidents (1).

Table 1. Technologies included in OpEx 2015

Product Name Manufacturer	**Description**
Situational Head Up Display Avon Protection Systems	Micro liquid crystal display with full color widescreen layout built into face shield
Tridion™-9 PerkinElmer	Portable Gas Chromatography/Mass Spectrometry (GC/MS) system that provides identification of volatile and semi-volatile organic hazards in the field in less than three minutes
BioFlash-E Biological Identifier PathSensors	Portable and rapid aerosol sample collection and identification of up to 16 biological threat agents

Product Name Manufacturer	**Description**
Fido B2 IBAC FLIR	Networked array of portable biosensors
Internet of Things Networks for First Responders BAE Systems	Networked sensors that use a long-range wireless protocol capable of concrete penetration to send signals through a network aggregator
Knight Robot/HAZPROBE WM Robots	All-terrain robot with a manipulator arm, cameras and a boring and inspecting device that can drill through walls for bomb tech personnel to inspect suspect abandoned vehicles or objects
RepKnight ADI Technologies	Software that monitors and analyzes social media with geolocation feature
X-ray Scanning Rover Smart Imaging Systems Inc.	X-ray scanner integrated into a custom-built robot that is designed to rapidly screen suspicious bags left behind or parcels on the ground

1.1 Purpose

The purpose of this event was to provide feedback on the XSR prototype technology for bomb squad use. By bringing together emergency responders and product developers during technology development, design changes can be effected early, responders can learn about emerging technologies to enhance mission capabilities, and S&T can gain a better understanding of responder needs and gaps to guide future homeland security investments.

1.2 Objective

This experimentation allowed responders to observe the use of the XSR in operational settings to offer feedback and suggestions to the developers that could enhance the product capabilities and usability for responder operations.

1.3 Responder Capability Need

The ability to detect and analyze passive and active threats at incident scenes in real time is one of the capability needs consistently identified by first responders participating in the Project Responder studies (1). The XSR system offers a technology solution that could address this capability need during bomb threat incidents.

1.4 Prototype Description

The XSR consists of a custom robot with a fold out detector arm and a control unit (Figure 3). It uses an X-ray source mounted on one side of the robot to generate a fan-shaped beam which is received by the detectors built into the top and sides of the fold out arm. The arm spans approximately 36 inches in the horizontal direction and 30 inches in the vertical direction. The X-ray source can be set to run continuously for maximum penetration or maximum resolution options. Penetration depths of 2.5 inches of concrete and 1 inch of steel are possible. It is operated remotely using its own wireless system, allowing an operator standoff distance of 300 feet. The current model weighs 245 pounds and operates on a rechargeable battery. Real-time images are displayed on a laptop screen during the scanning operation.

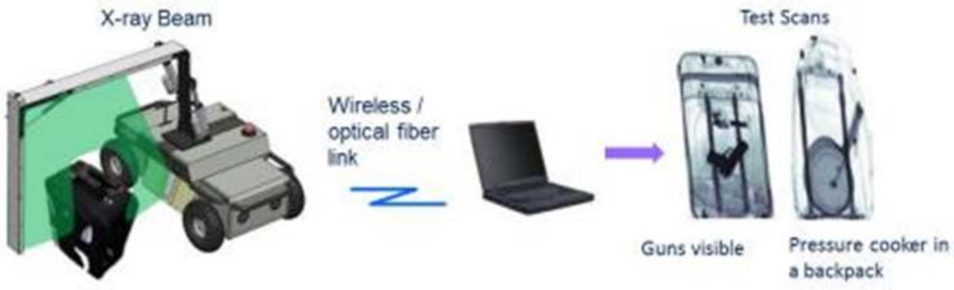

Figure 3 - X-ray Scanning Rover System

Miniaturized electronics (Figure 4) are a unique element of this technology which enables the detectors in a lightweight arm to span past the object being scanned. The robot drives alongside the package at a rate of 4 inches per second and scans packages of any length in a continuous pass. This eliminates the need for placement of an imaging plate or multiple scans for larger objects.

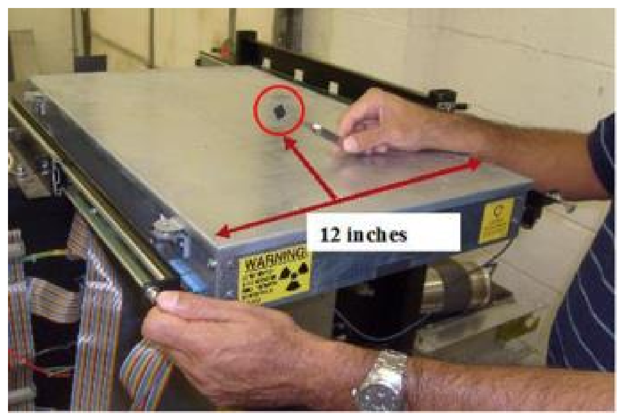

Figure 4 - Miniaturized Electronics
The X-ray detector used in conventional cabinet scanners is shown in comparison to the chip developed by SIS. The conventional detector is the 12-inch wide rectangular box. The new application-specific integrated circuit is marked by the red circle in the photo; it is intended to enable compact, lightweight X-ray detection systems for scalable, customizable formats.

Based on prior feedback from bomb technicians in the Washington, D.C. metropolitan area, the next version of the XSR will be integrated onto a Northrop Grumman F6A robotic platform, currently in use by civilian bomb squads. SIS is working to incorporate responder feedback into designs for the next generation of prototypes anticipated to be released in spring 2016. Several design options are being considered based on input from responder subject matter experts.

2 Experimentation Design

A detailed description of the experimentation design can be found in the Experimentation Plan for Knight Robot and X-ray Scanning Rover (2). The experimentation scenario was developed with input from responders, instrument designers and DHS program management to simulate bomb threat operational environments that would use available features of the XSR.

A group of experienced bomb technicians and first responders convened to experiment with this technology in a simulated operational field environment and provide feedback. The experimentation station consisted of an approximately 300 square foot paved, outdoor area marked off by traffic cones. Four objects were left on the ground for screening. X-ray images were displayed on a large screen. The features that were demonstrated included concept of operation, X-ray penetration and imaging performance. Data collectors recorded responder comments during the operation, and in subsequent group discussions.

2.1 Summary of OpEx

On July 29, 2015, ten responders with experience in bomb response from law enforcement and firefighting convened at the NYPD facility within Floyd Bennett Field, located in Brooklyn, New York, to participate in the XSR experimentation. This group included representatives from the NYPD, the Port Authority of New York and New Jersey Police Department, Montgomery County Fire and Rescue (Maryland) and the Boston Fire Department (Massachusetts). The meeting started in a training classroom and experimentation activities were performed in the adjacent paved lot.

The NUSTL experimentation director provided participants with information on the OpEx program and the goals, as well as the purpose and overview of the XSR experiment. A representative from SIS gave an introduction of the XSR and explained plans for its future development. The responders and observers then went outside where the robot, controls, and experimentation articles were stationed. Because the control technology is developmental, the vendor operated the XSR with responders observing and directing actions they wished to see. The robot scanned a suitcase laying on its side, two suitcases standing upright, and a car door. For safety reasons, the XSR was operated so that the X-ray beam always faced away from observers, and the area was secured to prevent anyone from being exposed when the beam was on.

All the activities went well with no major deviations from the experimentation plan. Participants were attentive and asked questions about system capabilities and specifications. They observed the operation of the robot and the X-ray images produced, and asked to see the folding of the robotic arm. Data collectors recorded questions and commentary.

After completion of all activities, the experimentation director led the participants in a debrief meeting to provide feedback about the XSR. The S&T project manager described future plans.

Figure 5 - XSR Scanning a Suitcase

3 User Feedback

All recorded questions and comments are captured in Table A in the Appendix. Basic questions about capabilities and specifications are included, as they may cover items of priority to the responder that were not discussed in the briefing.

The comments show that the participants recognized the XSR as a prototype. Their comments mostly focused on potential use cases, development plans and recommendations. Observers expressed interest in the robot's cost, weight, battery life and arm reach. They also discussed a modification for inspecting under vehicles, and the robot's communication link over Wi-Fi and fiber optic cable. The group questioned whether the data over Wi-Fi was encrypted, whether the unit works with electronic countermeasures, or whether the software could store and compare images of previous scans of the same object. Although this prototype does not have these features, the vendor noted that these can be incorporated into future versions.

The X-ray image projected on the large external screen for observers was somewhat degraded by outdoor lighting conditions. However, responders considered the image adequate for their needs and noted that they did not require a perfect picture for their application. Rather, they would use the image to determine the need for additional tools in order to further investigate the parcel. The vendor also pointed out that the images produced are currently in raw form. The XSR will be integrated with X-ray Toolkit™ (XTK), a software tool for processing and enhancing X-ray images. Responders agreed that XTK would be useful and noted that XTK typically stitches multiple images together in a mosaic grid, rather than using the continuous image produced by XSR.

A feature of the XSR is its ability to survey a long object in a continuous pass, eliminating the need for multiple X-rays and repositioning detector plates. Responders stated that, using their current systems, each X-ray image takes under a minute to process. For large objects such as vehicles, New York area responders use backscatter technology which creates an image from reflected X-rays. The consensus of this group of responders was that the XSR is another tool, but at a $250,000 price point they would be unlikely to buy one for the limited instances where they would need large scale, rapid screening. The responders felt that other tools they have, such as backscatter and explosive detecting canines, can perform comparable tasks. They suggested that the XSR could be a regional resource shared among a few states. The vendor noted that other X-ray systems can cost a million dollars and that the price of the XSR is expected to decrease.

These responders felt that the XSR may be better suited to applications with checkpoint or general screening, such as at airports or special events, rather than bomb squad use. They suggested the Transportation Security Administration or Federal Express as possible customers who might appreciate the XSR's portability. U.S. Customs and Border Protection (CBP) was also proposed as a potential customer if XSR filled a need that is not served by CBP's large truck scanners. Responders were not interested in a prior suggestion for a conveyor belt system integrated with the XSR, as parcels would have to be lifted before scanning.

Responders echoed prior feedback that, for bomb squad use, they would prefer to have the X-ray system as an attachment to their existing robot rather than an additional, custom robot. SIS is developing a modular version of the XSR to be integrated onto a Northrop Grumman F6A robot. Responders cautioned that in their experience, the robotic arm of the F6A does not always perform well with heavy loads (the quoted capacity of the F6A arm is 60 pounds, and the lead-lined and oil-cooled X-ray system of the XSR is approximately 50 pounds). Responders emphasized that the final version of the XSR should be as simple as possible for end users. They suggested color-coding connections and the use of standard (non-proprietary) connectors.

4 References

1. **U.S. Department of Homeland Security.** *Project Responder 4 - 2014 National Technology Plan for Emergency Response to Catastrophic Incidents.* s.l.: DHS Science and Technology, July 2014.

2. **NUSTL.** *Urban Operational Experimentation Plan for the Knight Robot and X-ray Scanning Rover, OpEx-T-PL-1.* July 2015.

5 Additional Information

To learn more about the X-Ray Scanning Rover, contact SandTFRG@hq.dhs.gov. For more information on NUSTL OpEx, contact NUSTL@hq.dhs.gov.

6 Acronym List

CBP	-	U.S. Customs and Border Protection
DHS	-	Department of Homeland Security
NUSTL	-	National Urban Security Technology Laboratory
OpEx	-	Operational Experimentation
S&T	-	Science and Technology Directorate
SIS	-	Smart Imaging Systems Inc.
TSA	-	Transportation Security Administration
XSR	-	X-ray Scanning Rover
XTK	-	X-ray Toolkit

Appendix

Table A. Questions and Comments, Grouped by Topic

Topic	Emergency Responder Question or Comment	Vendor Response; Notes
Specifications and operation	What is the unit weight?	225 - 235 pounds; the X-ray unit is 50 pounds with battery. The weight distribution of the robot would allow it to go upstairs with tracks.
	Are there plans to make the X-ray Scanning Rover (XSR) lighter?	Not at this time.
	Is the X-ray just on one side?	Yes
	Does the arm stretch further? Does the arm go higher?	Not in this prototype, but future designs could incorporate this.
	Can the arm be remotely controlled?	Yes
	Can the arm scan the underside of a car? (Responders noted that there are drive-over systems to scan undersides of vehicles. They also specified that X-ray technology was the way to screen under vehicles.)	No, but it could be adapted in future versions if needed.
	What is the battery life?	A small lead-acid battery would last 30 to 45 minutes with the X-ray scanning.
	Comments: The responders typically do not spend as long per X-ray as was suggested in the vendor presentation; each X-ray is typically 15 seconds to 60 seconds. If they were to try to X-ray an entire vehicle using panels, however, it would take a long time.	
Cost	What is the cost?	The price of the robot/X-ray is currently approximately $250,000. This compares to other X-ray systems at around $1 million.
Software and Data Transmission	Responders considered the raw X-ray image “not bad.” They also stated that they don’t need a perfect picture, only enough information to know whether they would need a tool (counter device) for further resolution. They are looking for specific bomb components.	Resolution with the system is a function of the speed of the robot.
	Does the software store and compare images? (A responder described a system with a license-plate archive and database that compares the X-ray scans of a vehicle to its previous scans and notes any anomalies or changes.)	Not at this time.
	How is data transmitted?	It currently operates over Wi-Fi, but there is an option for fiber optic cable.
	Is the data over Wi-Fi encrypted?	Not at this time.
	Does it work with electronic countermeasures?	Not at this time.

Topic	Emergency Responder Question or Comment	Vendor Response; Notes
	Comments: Responders agreed that X-ray Toolkit™ (XTK), the imaging software that Smart Imaging Systems Inc. (SIS) intends to utilize, is a great tool. Responders noted that the XTK has a grid system that stitches images together in a mosaic rather than a continuous image.	
Market and Customers	Responders would not find a (proposed) conveyor-belt system for left-behind bags useful, since the bags would have to be lifted up before scanning. It is a possibility for other customers such as the Transportation Security Administration (TSA) or U.S. Customs and Border Protection (CBP), however.	The conveyor-belt system was proposed at a former focus group event.
	Comments: Responders see the XSR as another possible tool, but said they would be unlikely to spend up to $300,000 on a tool that would only be used once or twice. • They suggested it could be a regional resource shared among a few states. • For vehicles, a large city bomb squad is more likely to use backscatter technology, but may have more resources than smaller city bomb squads. Responders noted that of the 4,000 bags left behind at the Boston Marathon bombing, only 25-30 bags were X-rayed. Bomb sniffing dogs were used to flag suspicious bags.	
	Comments: Responders felt that the XSR may be more useful for general screening of bags at airports or events as opposed to bomb squad response. CBP was suggested as a possible customer, but CBP has large truck scanners and XSR would have to serve a different need. TSA and FedEx were also suggested as possible customers because of the XSR's portability. A possible use could be check point screening for items at events.	
Recommendations	Responders echoed prior feedback that they do not want another robot; incorporating the XSR X-ray technology into an existing robot such as the Grumman F6A is preferred. Responders advised SIS to be cautious trusting the quoted 60 pound capacity of the F6A arm.	Department of Homeland Security is funding XSR system adaptation to a F6A Robot platform. SIS discussed how the X-ray system is lead-lined and oil-cooled. It weighs about 50 pounds.
	Comments: Make the XSR as simple as possible for end users. Use color-coded connectors. Use standard connections (not proprietary or mil-spec) because the responders take the units apart.	