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Improved Backscatter X-ray Detection for Anti-terrorist Applications

S. Shope, G. Lockwood, M. Selph, and J. Wehlburg

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Improved Backscatter X-ray Detection for Anti-terrorist Applications

S. Shope
Beam Applications and Initiatives Department

G. Lockwood, M. Selph
Materials Radiation Science Department

J. Wehlburg
Optics and Emerging Technologies Department

Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185-1182

Abstract

Currently the most common method to determine the contents of a package suspected of containing an explosive device is to use transmission radiography. This technique requires that an x-ray source and film be placed on opposite sides of the package. This poses a problem if the package is placed so that only one side is accessible, such as against a wall. There is also a threat to personnel and property since explosive devices may be "booby trapped."

We have developed a method to x-ray a package using backscattered x-rays based on similar work for landmine detection. This procedure eliminates the use of film behind the target. All of the detection is done from the same side as the source. Backscatter experiments at Sandia National Laboratories have been conducted on mock bombs in packages. We are able to readily identify the bomb components. The images that are obtained in this procedure are done in real time and the image is displayed on a computer screen. Preliminary experiments have also imaged objects within or behind a wall.

We are currently using a scanning x-ray source and scintillating plastic detectors. It can take several hours to image a briefcase size object. This time could be reduced if better x-ray detection methods could be used. We have looked at using pinhole photography and CCD cameras to reduce this time.

I. Introduction:

Realtime images of suspect packages that may contain bombs would benefit from improved detectors. Images of mock bombs have been taken with sufficient resolution to see critical components and wiring. We have developed a x-ray backscatter imaging system for the Army for landmine detection using scintillating plastic and photomultipliers as the x-ray detector.^{1,2} The scanning takes a considerable amount of time, which can be a critical issue if a bomb is involved. The speed and resolution would be improved if a large distributed source that covered all or a large fraction of the object were used. This requires a new detector arrangement. We studied new detection methods to improve image quality and reduce imaging time. We investigated the use of a pinhole camera with Polaroid film or using a CCD camera with an intensifier screen. We also used the standard detectors to image objects hidden in a wall. There are other applications for this detector technology in the emerging threats area. The current scintillating detectors are large and detection requires that the object be scanned to provide a grid of data points for image reconstruction.

II. Backscatter Imaging Technology:

In the mine detection work a collimated x-ray source projected a beam of x-rays on to the ground. There are two types backscatter x-rays, the first and predominant signal is from singly backscattered x-rays that come mainly from the surface and a lesser amount from a buried object. The other is from multiple backscattered x-rays. These two scattered signals can be distinguished by using a set of collimated and uncollimated detectors. The uncollimated detectors pick up both types of x-ray signals. The collimated detector is designed to detect only multiple backscattered x-rays. The detectors were Bicron scintillating plastic with optically coupled photomultipliers. This detector arrangement allows the imaging algorithms to identify surface features and remove them leaving the image of a buried object. A diagram of the technique is shown in Figure 1.

Figure 1. Diagram of a x-ray imaging setup for landmine detection.

The source and detectors are scanned from side to side and a point taken every 2 cm. Once the entire width is scanned the whole assembly, detectors and source, is moved forward 2 cm and the process repeated. This defined a 2 x 2 cm pixel array. The array size can be varied to any desired size depending on the desired resolution. Figures 2 and 3 show the setup and images of landmines.

Figure 2. Landmine field

Figure 3. Image of landmines

This technique was then used to image a mock bomb hidden in a briefcase. These results are shown in Figure 4.

Figure 4. Picture of the mock bomb and it's backscatter X-ray.

To get sufficient resolution to see the wires the image was taken at a grid size of 0.5 x 0.5 cm. This small of pixel size required two hours to get the image. For bomb detection the imaging time needs to be reduced to 10-15 minutes.

III. X-ray Images Through Wall:

There was interest in using this technique to image a wall to see if there were objects hidden in the wall. A section of standard type of 2x4 sheet-rocked wall was fabricated. A bag of powdered sugar to simulate drugs and a metal wrench to simulate a gun were among the objects hidden in the wall. The wall was imaged using the scintillating plastic detectors and scanning source. The wall construction and images are shown in Figure 5.

Figure 5. The upper pictures show the construction of the simulated wall and the placement of objects inside it. The images are shown in the lower pictures.

The lower left image clearly shows the stud, screws, electrical outlet and part of the metal wrench handle. The lower right shows the bag of powdered sugar directly below the electrical outlet.

IV. Pinhole Camera:

One approach to improving the detection time would be the use of a pinhole camera and instant Polaroid film with an intensifier screen. A large area of the suspect object could be exposed to an expanded x-ray source and an x-ray photograph taken. The image size and resolution is a simple geometric ratio of the object to pinhole distance and the pinhole to film plane distance. Film size can be from 4 inch x 5 inch to 8 inch by 10 inch. The present project designed and fabricated multipurpose pinhole camera for evaluation of the concept. The camera was constructed from brass and was 6.5 inches in diameter. It has a removable section so that the pinhole to film plane can be changed from 2 inches to 10 inches. It has replaceable tungsten pinholes with sizes of 1/32 inches to 5/32 inches. A photograph of the camera mounted on the Phillips 225 x-ray source is shown in Figure 6.

Figure 6. Brass pinhole camera mounted to the x-ray source.

To test the resolution and imaging time a target was made with $\frac{1}{4}$ inch steel and nylon screws, nuts and washers and arranged in a 6.3 cm diameter circle. Images were taken with energies from 100 to 175 kV and currents from 10 to 15 ma. The target and a x-ray pinhole image using Polaroid film with this setup are shown in Figure 7.

Figure 7. X-ray target and image taken at 150 kV and 15 ma. The imaging time for this image was 20 minutes.

Acceptable images were taken in 5 to 20 minutes depending on the pinhole size, x-ray source energy and geometric distances. Taking the best case of 5 minutes to image a 6.5 cm diameter circle (10.6 cm^2) the imaging time per cm^2 is 2.1 cm^2 per minute. An

average briefcase is approximately 2000 cm^2 so it would take about 1000 minutes to use this method of imaging. This time is considerably longer than imaging with the scintillating detectors (~120 minutes), and would be unacceptable for most applications.

V. CCD camera:

The use of a CCD camera instead of the Polaroid film may allow the imaging time to be reduced. There were insufficient funds to purchase an x-ray CCD camera (approximately \$60K required). We were able to borrow an inexpensive (~\$2K) Meade CCD camera that is used in astrophotography. While this camera was known to be insufficient for a complete demonstration, we proceeded with the experiment as a proof of principle and to identify problems inherent in this approach. The camera specifications are:³

Pictor 416XT Technical Specifications

- CCD chip : Kodak KAF-0400
- Size : 6.90 mm x 4.60 mm
- Pixels : 768 x 512
- Full well : 85,000 e-
- Dark current : < 1e- per 5sec @ -20C
- A/D conv. : 16 bit
- Brightness : 65536
- Temp control : thermoelectric, 2 stage
- Change deg. : (Δ)-40 C from ambient
- Temp accuracy: 0.1C
- Shutter : electro-mechanical
- Min exp. time : 10 millisec.
- Color capable : yes (with 616 color wheel)
- Power req. : 2.0 amp @ 12vDC

The camera was bench tested and characterized before using it to image. A standard Nikon 50 mm macro lens was mounted on the camera and used to photograph an object. The exposure times were compared to readings made with a Gossen Luna Pro light meter. It was determined that the camera was 5-10 times more light sensitive than the readings taken with the meter. The Polaroid film used for the pinhole imaging has an ASA of 3000. This would imply that the CCD camera would have an ASA of 15000-30000 for equivalent pinhole imaging.

To protect the camera from radiation damage, it was located a short distance away from the radiation field. A CRONEX Quanta Fast Detail intensifying screen was mounted on one end of a six foot coherent fiber optic bundle. This end was placed in the pinhole camera at a position that would give an image of a target that would fill the 2 x 2 cm fiber optic bundle. The CCD camera and 50 mm lens was used to photograph the other end at a 1:1 image ratio. Before using the CCD camera a standard pinhole photograph was taken of a target consisting of 1/4" steel washers, see Figure 8. The pinhole time suggested good exposures could be made with the CCD camera at ~5 minutes.

Figure 8. X-ray pinhole photograph of 1/4" steel washers used as target for CCD camera. The exposure time was 5 minutes at 150 kV and 15ma.

We were unable to obtain acceptable images at exposure times of 1 to 5 minutes. When longer times were tried the camera would malfunction even though it is supposed to be able to take 2 hour exposures. The reason for this problem could not be determined. It was tried with and without the x-ray source on, in total darkness and several other exposure situations. In order to get longer exposures, eight successive 5 minute exposures were taken. One of these eight images is shown in Figure 9. Several different techniques were used to combine these images with little or no improvement. Straight addition, averaging and median averaging were tried. These results are shown in Figure 10.

Figure 9. One of the five minute images.

Figure 10. A is the addition of the eight images, B is the average with enhancement, and C is the median average.

There is somewhat of a bright spot that could be the center of the washer, however, it is not conclusive. The intensifying screen that was used in these experiments was not a good match to the CCD camera.⁴ There was a mismatch in the spectral response between the two. Figure 11 gives the quantum efficiency for the camera and the spectral emission for the screen.

Figure 11. A is the spectral response of the CCD camera and B is the relative intensity of the intensifier screen.

The CCD camera has the highest quantum efficiency in the 700-800 nm wavelengths. The intensifier peaks at about 450nm. The gain is down about a factor 8 due to this mismatch. We were unable to find an intensifier that had a better wavelength match.

The imaging efficiency could also have been improved if the 50 mm lens could have been eliminated and the fiber optic bundle mounted directly to the CCD chip. This was not done since the camera has an electro-mechanical shutter just in front of the chip. It would have been a simple modification to do this; however, since the camera was on loan this was not an option. The best way to increase the sensitivity would be to mount the intensifier screen directly to the chip. This would mean operating the camera in a moderate x-ray field which would require a minimal amount of shielding and some lead glass. Again, since the camera was on loan this was not tried. This modification needs to be investigated. If it works it would be ideal for law enforcement applications where funds are limited.

VI. Summary:

Pinhole images have been made using backscatter x-rays. A less than ideal CCD imaging system was tried for proof of principle and problem identification, but did not give acceptable images. A better match of the intensifying screen and method of coupling would improve this system as would the use of a more capable x-ray CCD camera. The versatility of the backscatter imaging technique was demonstrated in the wall images. This technology has direct application to law enforcement applications and emerging threats.

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