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Bomb Detection Using Backscattered X-rays*

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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. This procedure eliminates the use of film behind the target. All of the detection is done from the same side as the source. When an object is subjected to x-rays, some of them are scattered back towards the source. The backscattering of x-rays is proportional to the atomic number (Z) of the material raised to the 4.1 power. This $Z^{4.1}$ dependence allows us to easily distinguish between explosives, wires, timer, batteries, and other bomb components.

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.

Keywords: bomb detection, x-rays, explosives, radiography

1. INTRODUCTION

Using transmission radiography to image the contents of an unknown package poses some undesirable risks. The object must have an x-ray film placed on the side opposite the x-ray source; this cannot be done without moving the package if it has been placed firmly against a wall or pillar. Therefore it would be extremely useful to be able to image the contents of a package from only one side, without ever having to disturb the package itself.

Sandia National Laboratories has done extensive work under a program funded by the Army in the detection of buried nonmetallic landmines.[1] This program was very successful in obtaining detailed images of both metal and plastic landmines, buried up to several inches below the surface of the ground. This system was tested in the lab as well as in field conditions.[2] With the same backscattered x-ray technology, we performed several experiments on identifying the contents of a closed package.

Using industrial x-ray machines with a collimated beam and a scanning technique developed for landmine detection, we have taken images with sufficient resolution to identify the components and wiring of a mock bomb hidden in a case. We also took a preliminary image using a pinhole camera with results that are encouraging toward development of the use of a charge coupled device (CCD camera) as a detector rather than the plastic scintillating detector.

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DISCLAIMER

2. APPARATUS AND PROCEDURES

At the average energies used for this experiment, the predominant mode of x-ray interaction is the photoelectric effect. The photoelectric coefficient is dependent on the effective atomic number (Z) of the material being irradiated:

$$_a\tau = (\text{constant})\ Z^{4.1} / E^3,$$

where E is the energy of the incoming x-ray. The volume of x-rays absorbed is important because it is, of course, directly correlated to the intensity of x-rays that will be scattered. Most of the x-rays that scatter will do so in a generally forward direction; however, a small percentage do scatter in a backward direction. Figure 1 shows a diagram of the various fates of x-rays directed into an object.

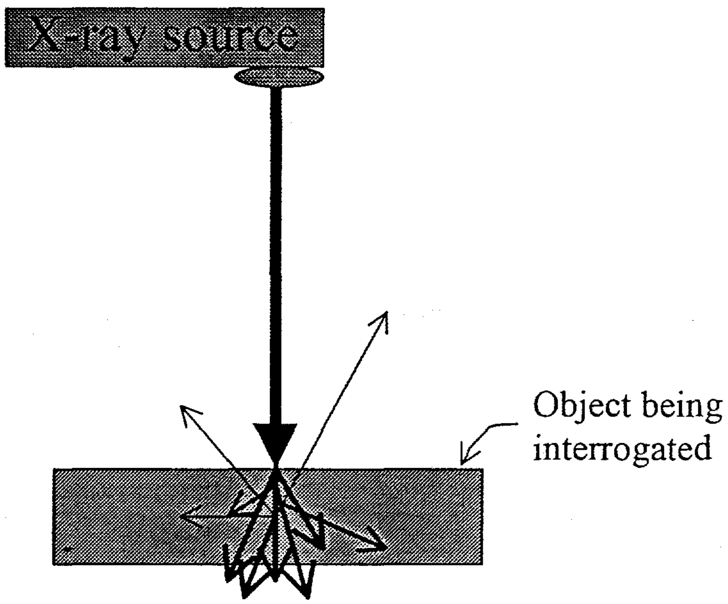

Figure 1. Scattering and absorption of x-rays in an irradiated object

If the original intensity of x-rays is large enough, the detection of these backward scattered x-rays becomes sufficient to generate an image of the material being irradiated. Variances in the intensity of the image are created by the varying effective atomic numbers as the composition of the irradiated object changes. These differences can be exploited to great benefit in distinguishing objects hidden or obscured by other objects.

The x-ray generator that was used for the experiment was an industrial x-ray machine. It was operated at 150 kV and 5 mA. The output beam was collimated to produce a 0.6 cm diameter spot size. The spot was scanned across the package being interrogated in 0.64 cm steps. The detector used for the first part of this experiment was 244 cm long by 7.6 cm wide by 5 cm thick. It used a photomultiplier tube as the light sensing element and plastic scintillating material. Figure 2 shows a schematic diagram of the initial experimental setup.

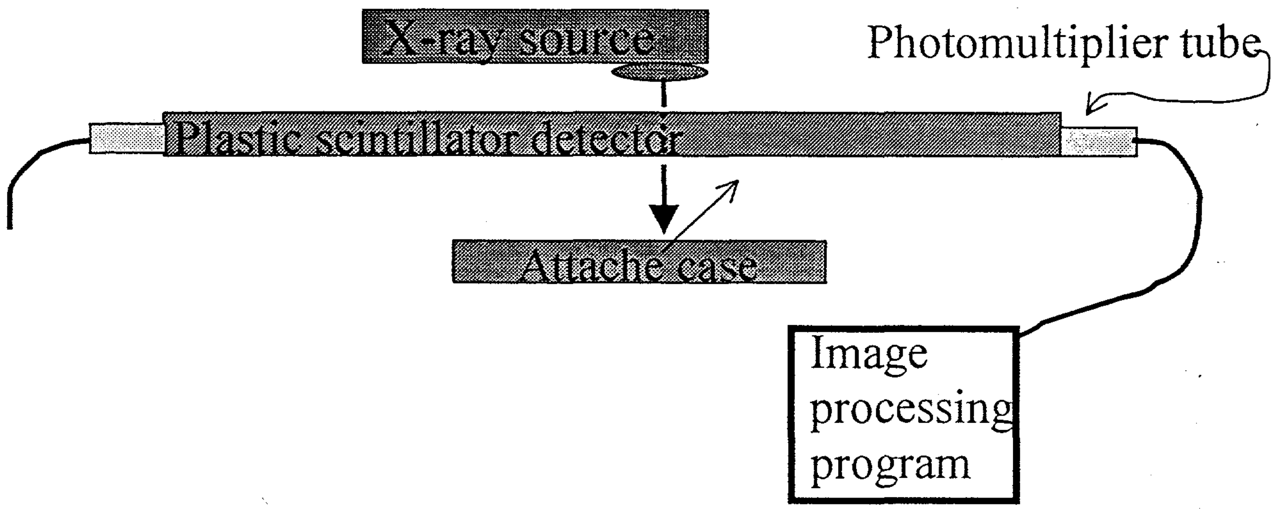

Figure 2. Setup for first imaging experiment.

The package that was examined in this experiment was an attache case made of pressed fiberboard with a vinyl covering. It was approximately 36 cm wide by 51 cm long by 13 cm deep. The case was placed on an aluminum sheet under the x-ray source. Because of the laboratory setup, the attache case was rastered in the y-coordinate direction, while the x-ray source rastered in the x-coordinate direction. However, for field use, the x-ray source would of course raster in both the x- and y-coordinate directions, while the object under interrogation would remain stationary and undisturbed.

The information gathered by the plastic scintillating detector was transmitted through the photomultiplier to an image processing program on a computer. The image can be produced in real time as the x-ray beam scans the package.

A secondary experiment was conducted to check the feasibility of using a CCD camera to record the backscattered x-ray data rather than using the plastic scintillating material. This involved creating a crude pinhole camera. A schematic diagram of the setup for this part of the experiment is shown in Figure 3.

Polaroid film was placed in the pinhole camera to record the image rather than using the computer image processing program for this initial test of this system. The x-ray source setting for this experiment was 100 kV and 15 mA. The pinhole aperture was 0.16 cm.

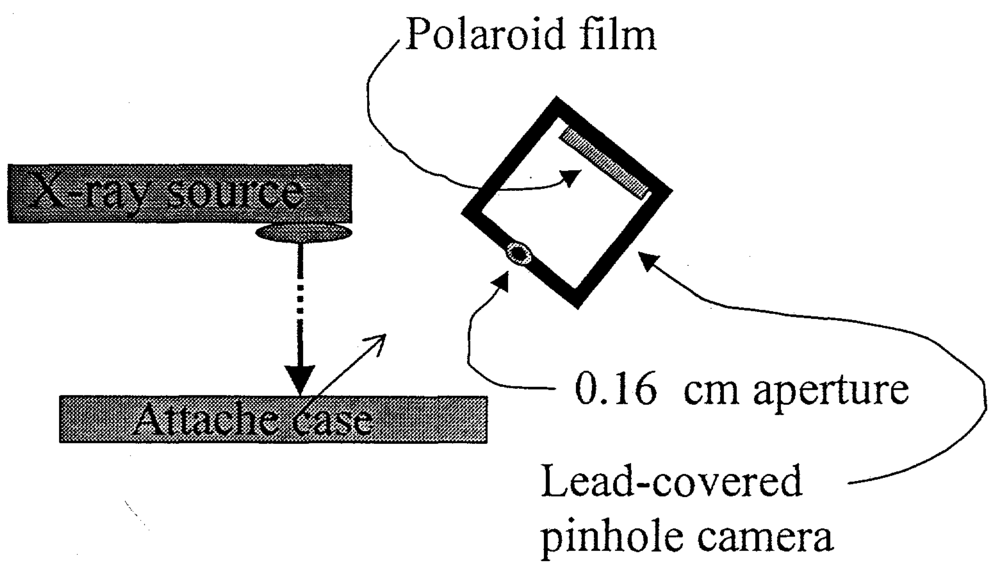

Figure 3. Setup of pinhole camera imaging experiment.

A photograph of the experimental setup for the experiment using the pinhole camera with Polaroid film is shown in Figure 4.

Figure 4. Photograph of the pinhole camera experimental setup.

3. RESULTS

The images produced from the first part of the experiment are shown in Figures 5 and 6.

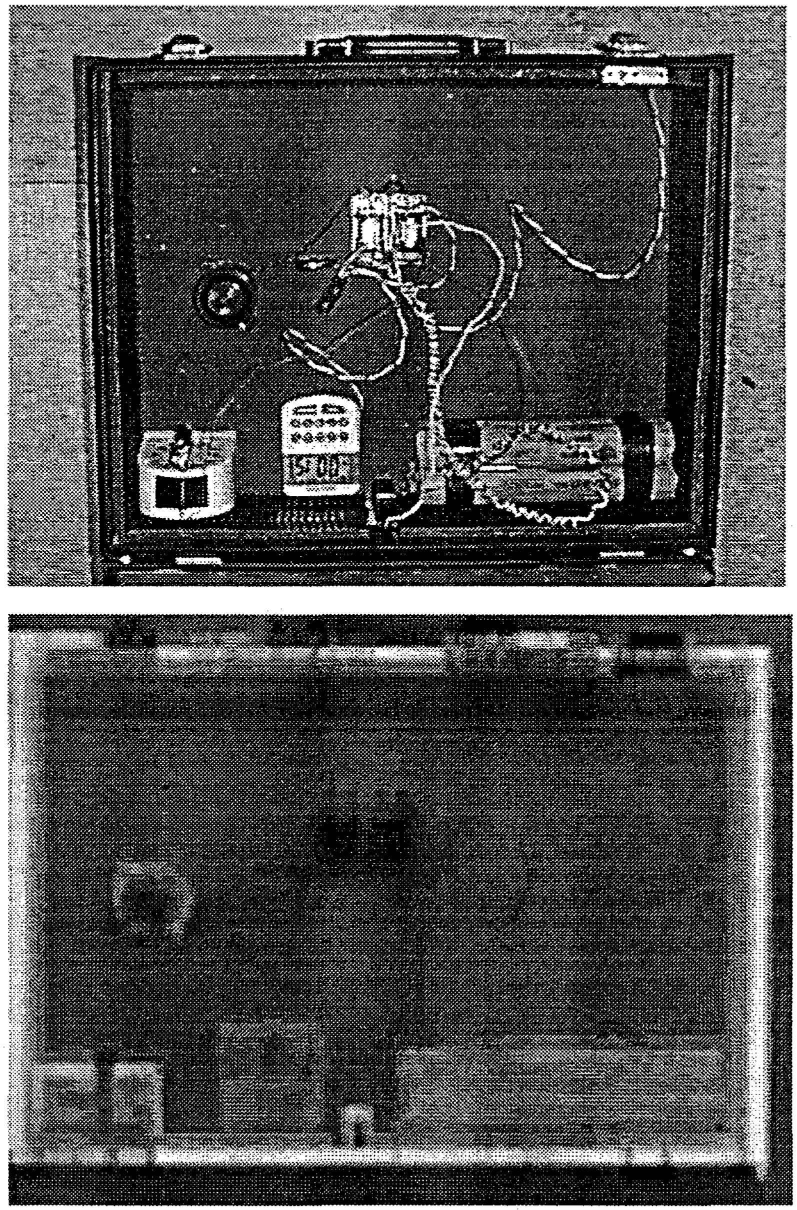

Figure 5. Photograph (top) of the mock bomb in an attache case and the image (bottom) produced from the backscattered x-rays.

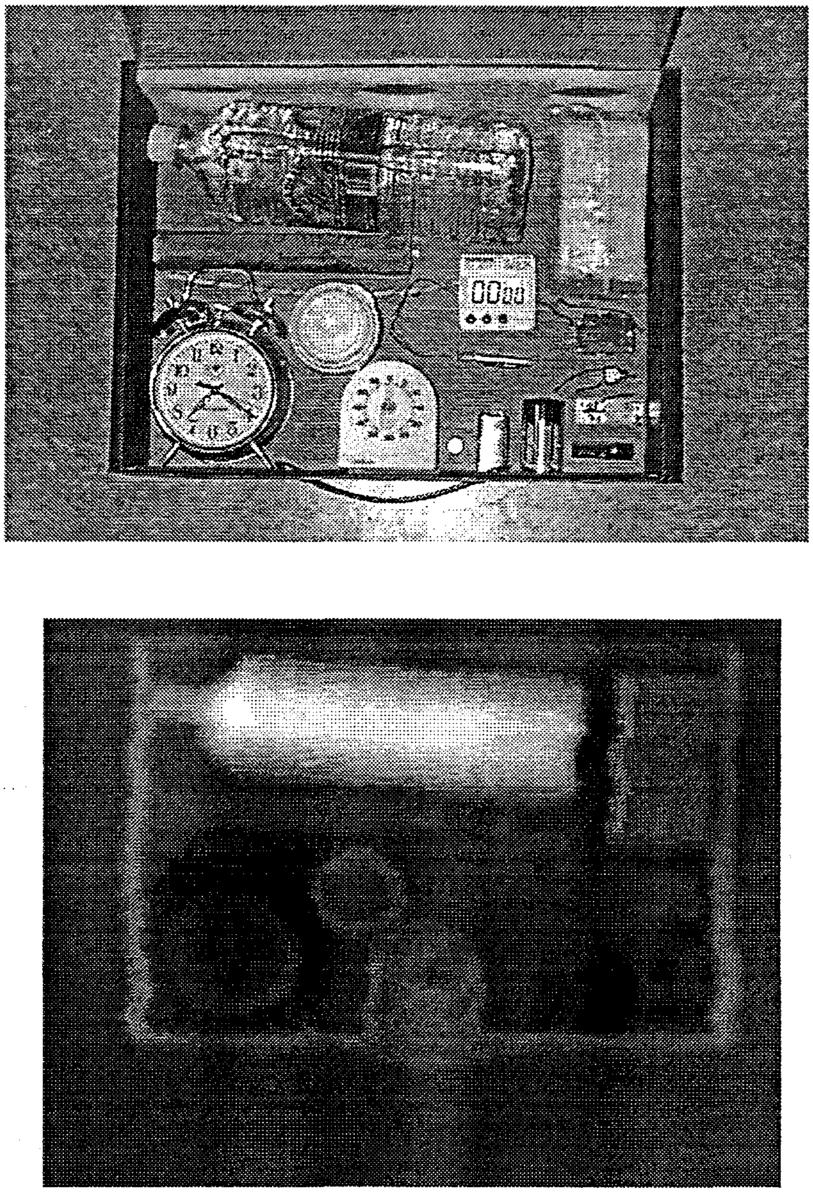

Figure 6. Photograph (top) and image (bottom) of another mock bomb in an attache case.

These images show not only the bomb components and timing elements, but also the connecting wiring. The time required to produce each image was approximately 45 minutes. A 1.3 cm step size would allow for the image to be produced in half the time and would show all the components except the wiring.

The image produced from the second part of the experiment, using the Polaroid film inside the pinhole camera, is shown in Figure 7.

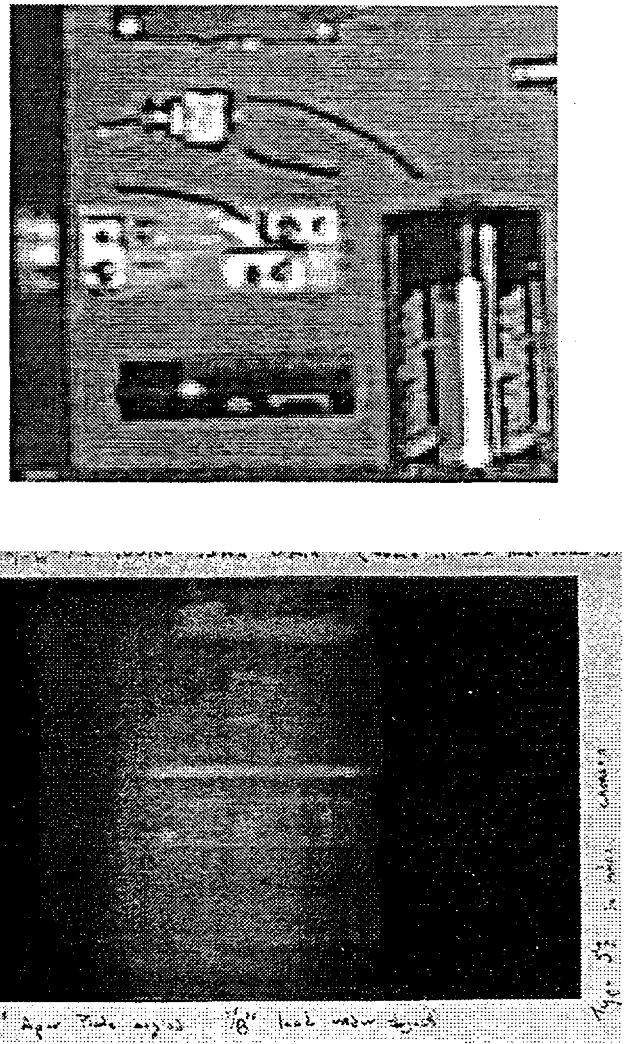

Figure 7. Photograph (top) and Polaroid film image (bottom) of a corner of a mock bomb system produced by a pinhole camera.

This image was generated 5 minutes. Several images of this size would be required to cover the entire case, but could be produced simultaneously by multiple systems.

4. DISCUSSION

While this system has provided useful images in the laboratory to demonstrate proof-of-principle, a simpler portable system is desirable for field work. A system based on the scanning technique used in the first part of the experiment could be engineered for field use but it would have bulk and speed limitations. These limitations could be improved if a distributed source that covered all or a large fraction of the object were used. The source would be an uncollimated industrial x-ray machine, but this requires a new detector arrangement. The detector arrangement that would lend itself to this system would be a pinhole camera.

The image shown in Figure 7 is a rough initial pinhole camera image that was created in order to test the possibility of using the CCD camera. Further development of this method, as well as the use of an actual

CCD camera rather than the simple pinhole camera that was constructed for this experiment, will allow for much more detailed resulting images. A resolution of 1 mm should be possible using this method. This would allow the identification of bomb components, including wires. Improvement in detection efficiency using either multiple pinholes or coded apertures should allow imaging times of five minutes or less. The image would be real time and could be displayed on a laptop computer.

A mobile system for use by law enforcement agencies or bomb disposal squads needs to be portable and somewhat durable. A 300 kV x-ray source should be sufficient for the task requirements and can be mounted on a mobile system. A robotic carriage could be used to transport the x-ray source and the CCD camera to the proximity of the suspect package. The controlling and data analyzing elements of the system could then be maintained at a safe distance from the possible explosive. Figure 8 shows a diagram of a conceptual design of a possible system for this type of use.

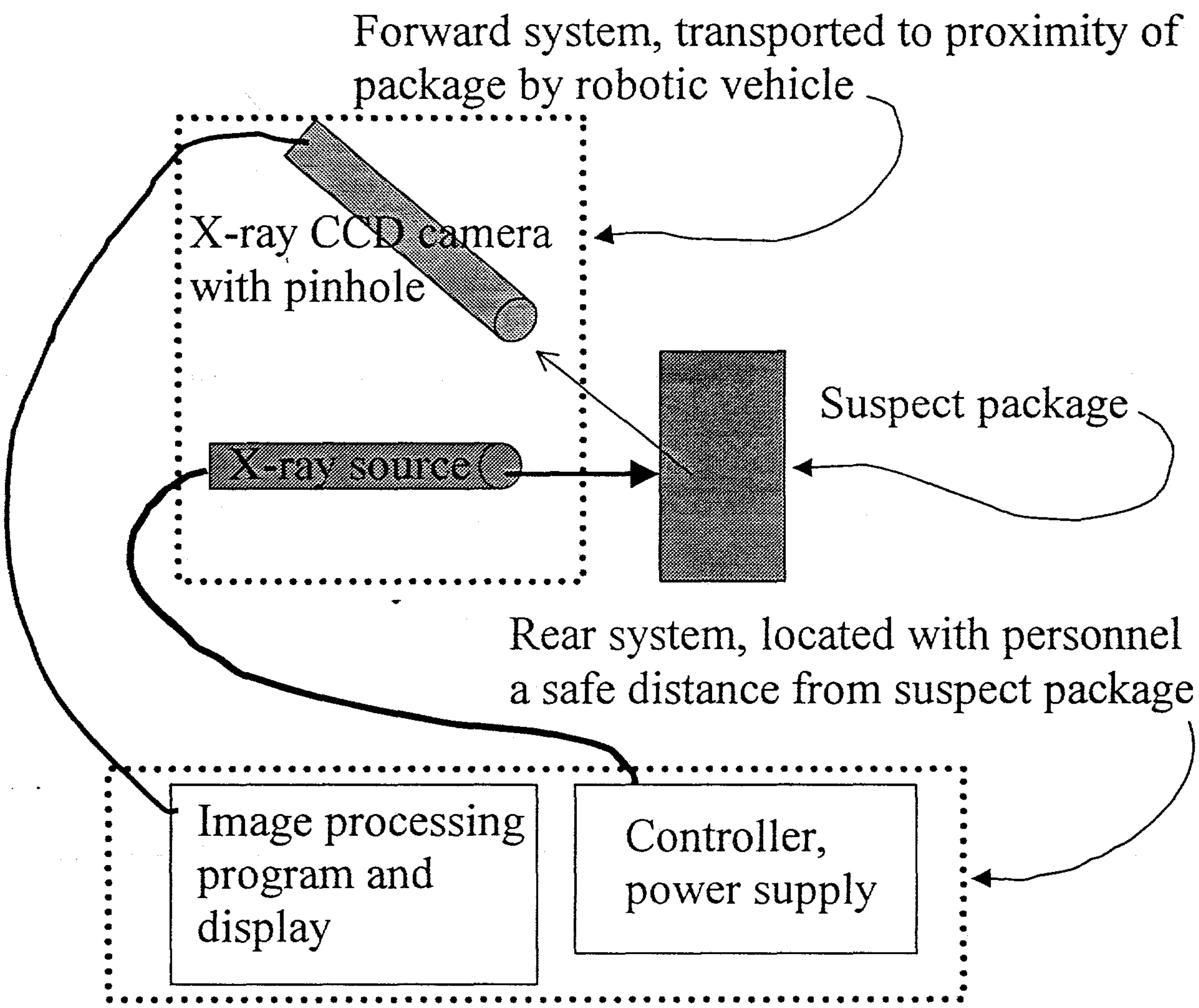

Figure 8. Conceptual design of a mobile system for package interrogation.

5. CONCLUSIONS

The use of backscattered x-rays for interrogation of packages that may contain explosive devices has been shown to be feasible in the laboratory. Using a 150 kV x-ray source and detectors consisting of plastic scintillating material, all bomb components including the wiring were detectable. However, at this time the process requires more time than is desirable for the situations in which it will most likely be needed. Further development of the technology using CCD cameras, rather than the plastic scintillator detectors, shows promise of leading to a much faster system, as well as one with better resolution. Mounting the x-ray source and the CCD camera on a robotic vehicle while keeping the controlling and analyzing components and the operating personnel a safe distance away from the suspect package will allow such a package to be examined at low risk to human life.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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