Appendix B
X-Ray-Based Detection Systems

Standard X-Ray Scanners

Sponsor: Commercially developed and available from several vendors, such as EG&G Astrophysics, Siemens-Heimann, and American Science & Engineering (AS&E).

Status: In serial production, both domestically and abroad.

Funding: Developed through private funding. Unit cost approximately $20,000 to $40,000.

Basic Operating Principles

The standard airport hand-baggage scanner has a fan-shaped or scanning x-ray beam that is transmitted through the object to be inspected. The absorption of x-rays is usually measured by a line of detectors, and a high-resolution image, derived from the degree of absorption of the beam, is produced. The image depends primarily on the density of objects located in the bag along the beam of the x-ray. These devices cannot distinguish between a thin sheet of a strong absorber, such as a metal, and a thick slab of a weak absorber. Simple x-ray systems rely on humans to serve as pattern recognition devices; in the absence of advanced computer pattern recognition techniques, they are very dependent on human factors, i.e., the training and quality of the observer.

X-ray scanners come in single- or two-view versions, with the two views being orthogonal. X-ray scanners present their images in shades of gray (as many as 80 shades depending on the degree of absorption), or in "pseudo-color," where colors are used to produce an artificially enhanced visual presentation.

Dual- or Multi-energy Scanners

Sponsor: Commercially developed by several vendors.

Status: Commercially available. Several vendors make such equipment, such as Siemens-Heimann, and EG&G Astrophysics.

Funding: Commercially developed, unit cost less than $100,000.

Basic Operating Principles

Dual-energy systems are really two x-ray systems, whose beams are generated by sources that peak at different energies, producing two independent pictures. The higher energy view suffers less absorption. While areas of heavy elements are dark in both views, areas of light elements are darker in the lower energy view. By comparing both images, light elements such as carbon, nitrogen, and oxygen may be emphasized. In this way, it is possible to determine whether a given object is made of a light or a heavy element.

Multi-energy systems are essentially the same except that they have a single x-ray tube that transmits a broad spectrum of energies. Detectors are used to select specific energy regions. Both systems produce effectively the same result.

Technical Description

This technique cannot distinguish among the light elements (e.g., tell nitrogen from oxygen from carbon). However, it can overcome the countermeasure of hiding explosives behind an object made of a heavy element (unless enough material is present to absorb the entire beam-corresponding to approximately 8 to 10 mm of steel), which standard x-ray scanners cannot.

These devices are technically identical to simple x-ray scanners, except for the dual energy and image feature. The systems use color to separate the image into organic (light elements), inorganic (usually heavy elements), and opaque materials (a lot of heavy element matter). For instance, the EG&G E-Scan system assigns the color orange to organic materials, which might include explosives. Some proponents believe that this use of color is a big help to an operator's ability to detect explosives.

Backscatter X-Rays

Sponsor: Commercially developed by AS&E.

Status: Commercially available from AS&E. Computer algorithm currently under development for automatic detection of explosives.

Funding: The Model 1012/10122 systems are available for $60,000 to $100,000 per unit either as a single (101Z) or dual (101ZZ) view system.

Basic Operating Principle

The AS&E backscatter system scans a pencil beam of x-rays across the object and makes two images: the normal transmission image, created by a single detector on the opposite side, and a backcatter image, created by a large area detector on the side of the entering beam. A single energy x-ray beam is utilized. A two-sided version of this system with two identical x-ray beam systems makes backscatter measurements from opposite sides of the object to enhance the backscatter penetration capability of the system.

The transmitted beam provides a typical x-ray image showing primarily the absorption by heavy elements. The backscatter signal intensity depends on how much of the transmitted beam has been absorbed, how much is backscattered, and how many of the backscattered x-rays reach the backscatter detectors. The backscatter signal depends on the competition between photoelectric absorption and Compton scattering. The photoelectric cross section increases with the atomic number of the object z, while the Compton cross section is relatively independent of atomic number. Therefore, the resulting backscatter signal favors the low Z elements, with particular emphasis on low Z elements of high density, such as plastic explosives. Backscatter imaging provides a direct measure of the density of elements with low atomic number.

Technical Description

The AS&E system produces two independent x-ray images: an x-ray transmission image emphasizing the high Z elements, and an x-ray backscatter image emphasizing the low Z elements. The system utilizes a proprietary Flying Spot technique, which sweeps a small pencil beam of x rays across the object to generate each line of image data.

A single large solid-state. transmission detector measures the x-ray absorption by integrating the detected x-ray flux over time. The Flying Spot scanning beam technology is required for efficient scatter imaging. Because only one small area is illuminated by the pencil beam at any instant of time, all detectable backscatter must come from that pixel. A large solid-state detector measures the backscattered x-ray signal, again with time integration of the detected backscattered flux. By comparing the two images, the operator can make judgments about the composition of regions of high density, which may help detect and identify threatening contents of a bag.

Currently, AS&E is implementing a computer algorithm for automatic detection of explosives with the aim of achieving a high probability of detection and a low false alarm rate for explosives. The automatic detection scheme is based on an algorithm that compares properties of object bag images against acceptable thresholds. The system builds a database of acceptable histograms by observing and "learning" the characteristics of a large variety of bags. An algorithm sorts and combines the data for online comparison with acceptable values. The AS&E system "learns" the characteristics of bags in a manner similar to the learning part of the TNA system.

Potential and Shortcomings

Implementation of the automatic detection algorithm has proceeded slowly in the past, supported only by company funding. However, the FAA has recently funded the completion of development and initial field testing of this system. Field testing is scheduled to begin within a few months. Although the automatic detection of simulated explosives has been demonstrated, to date there have been no definitive field tests of the effectiveness of the system. If this scheme is successful, it will be easy to retrofit to existing AS&E systems. The company states it can produce these systems at a rate of about 200 to 300 per year.

Computerized Tomography (CT) X-Ray Scanners

Sponsor: Commercial development with some support from the Army and FAA

Status: Pre-prototype system demonstrated by Imatron, Inc. to FAA in June 1989; Imatron claims a prototype is being readied for airport testing in the near future.

Funding: The cost of these systems will probably be of the order of $500,000 to $600,000.

Basic Operating Principles

This system is an adaptation of a compact, fast, mobile medical CT scanner, which Imatron has developed for the U.S. Amy. This concept utilizes a conventional x-ray scan projection to locate areas with sufficient density to represent a threat. In addition, multiple detectors, placed on a rotating circumferential element around the object, measure the transmitted signal from a fan beam that traverses it (as in standard CT devices). The density at each location along the path of the beam can be determined, with the rotating action giving the information to provide a complete two-dimensional slice. The inspected object is moved through the detector/beam station by means of a conveyor belt, providing the third dimension, i.e., multiple slices, for an image that then can be viewed from all angles by computer projection techniques. This technique also has very good spatial resolution (a few millimeters).

Technical Description

This system operates and looks very much like the medical CAT (computerized axial tomograpy) scanner from which it was developed. Imatron's niche in the medical CAT scan business is the field of very fast scanners, as well as portable systems designed for army field use. The explosive detection device was adapted from this work.

The system first produces an x-ray scan similar to the conventional airport x-ray scanner. An automated inspection algorithm determines the locations within the baggage where the absorption indicates a suspicious area; cross-section CT slices then need to be made to determine the density, texture, mass and shape of the object. Dual-energy CT, a theoretically possible, although not yet implemented option, would also provide information on atomic number. If no high-density areas are detected, a single slice through the bag is made to look for any sheet explosives that may not have been seen in the projection scan. Since the CT scan produces true cross section slices, it is able to identify objects that are surrounded by other materials or hidden by innocuous objects. When alarms are encountered, the CT Scan operator can make further slices to reveal size, shape, mass and make-up of the suspect object. Three dimensional rendering may also be applied.

The Imatron CTX 5000 uses color coding to highlight possible explosives. The spatial resolution may be good enough to locate wires, detonators, or related bomb components.

Potential and Shortcomings

The current claim for throughput is 360 bags/hour, which is too slow for current FAA requirements. This throughput is calculated assuming an average of 2.5 slices per bag. Only field experience can establish what the real requirements will be. Since this limit derives from limits on speed of computation, it is possible that future computer improvements (which are coming very rapidly) will sufficiently increase the speed of the system. The current aperture diameter is 63 cm, which is too small for some bags. Future versions will have an 80-cm diameter aperture, according to the vendor. The ability to resolve explosives using only density information was investigated at LAX by CT scans of 900 checked bags and 100 bags with simulated explosives in a FAA sponsored test in 1988. The results were encouraging to the vendor. However, more precise data, including detection probabilities, false alarm rates, and throughput will have to be determined through more extensive tests. Unit cost is estimated by the vendor to be around $500,000 to $600,000.