BEACHCOMB Program Overview: History, Status, and Directions (U)

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(U) The development of new tools and techniques to perform technical security inspections in the information processing environment, known as the BEACHCOMB program, is discussed.

SUMMARY

~~(FOUO)~~ This report discusses the past, present, and future of the BEACHCOMB program. This program was started in order to develop new ways to inspect communications security (COMSEC) equipment but has expanded to include the development of technology and techniques used for technical security inspections of the information processing environment.

~~(S)~~ As incidents of insecurities increase and as technology continues to provide the means to launch sophisticated attacks, this program is becoming ever more important. The current methods of manual inspections are prone to operator error and fatigue. By developing tools to aid or replace the human inspector, we can reduce the chance of error as well as increase the rate of inspections while lowering the overall cost. The cost savings result from reduced labor requirements and less need for staple items such as film and developer.

~~(S)~~ The scope of the program covers many disciplines, including physics, electronics, and mathematics. Computers play a major role as analytical tools, for data manipulation, and as controllers for use in automation of inspection systems. Research in the field of nondestructive testing is conducted for the program in-house as well as by contractors and the national labs. Results of these studies are used to assemble prototype inspection systems. Technologies that are addressed include radiography, electromagnetic imaging, infrared imaging, image processing and data analysis, and computer software design.

~~(S)~~ Future directions of the program include automating present inspection systems, improving current inspection methods, and finding new techniques that can be developed into practical systems. These projects are part of the quest for the ultimate system, one that would connect to a device and say "This is bugged!" or assure us that everything is fine. Various groups in the Agency, as well as other government offices, benefit from the projects contained in the BEACHCOMB program. By providing the means to protect the security of the information processing environment, we ensure that the value of the equipment or facility in that environment is retained.

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BACKGROUND

Importance of Inspections

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~~(S)~~ This particular scenario of compromised equipment is speculation, but there have been several incidents in the past that show that our adversaries have the capability and the willingness to conduct physical attacks. One of the most notorious attacks was discovered during project GUNMAN, [redacted]

~~(C)~~ The BEACHCOMB program was established to develop new techniques and technologies for nondestructive inspection of information processing equipment. Further, the program seeks to automate these methods by creating systems of sensors, controllers, and computers. The tools developed in this program are the next generation beyond the [redacted] To ensure that when nothing is found it is because nothing is there, the systems must be as effective as we can make them.

~~(S)~~ In the wake of compromises such as GUNMAN, the finds at the new U.S. embassy in Moscow and the probable hostile access to the facilities at the old U.S. embassy, the importance of equipment inspection is indisputable. There is a movement in the United States to encrypt more of our communications. This means that an adversary has to become more aggressive in order to obtain the same information. On his side are electronics technologies that are helping make circuits ever smaller and easier to conceal. We must develop the means to ensure the integrity of our information processing environments by being able to detect this kind of attack.

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Inspection Techniques

~~(S)~~ A basic, often-used method of inspection is a visual check of a piece of equipment. An inspector will at least partially disassemble the device and visually scan the parts looking for anything unusual. Drawbacks to this method include the large amount of time required for a thorough inspection and the fact that modifications can easily be disguised. Also, if a large number of devices are inspected, the time available may allow only a sampling of the parts in a device. This is a problem at depots and distribution facilities, such as the one used in [redacted]

~~(S)~~ Radiographic inspections are carried out by the [redacted] The workhorse of these inspections is the [redacted] pulsed X-ray source. To perform an equipment inspection with the [redacted] source requires placing the device, or subassemblies of the device, on a film plate and using the X-ray source to shoot through the device, exposing the film. With [redacted] radiographic film, the X-ray can be developed in just one minute. An inspector then takes this hard copy X-ray and studies it on a light table looking for possible anomalies. He may also visually compare the X-ray to one taken from a device known to be good.

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Automation of Inspections

~~(C)~~ In addition to improved inspection techniques, BEACHCOMB projects seek the means to automate inspection procedures. The task of comparing two images, such as two X-rays, is more accurately accomplished with the aid of a computer. The ultimate analysis system would be able to take an image and indicate positively that there is or is not a tamper. Until then, computers are still invaluable for managing archives of images, aiding in human comparison of images, and doing elementary image analysis, such as pointing out an area where something is wrong so that a human can take a better look.

~~(C)~~ Throughput of equipment being inspected can be increased considerably using automated procedures. This is especially important where a large number of devices must be processed, such as at a distribution facility or on a production line. By letting computers do initial analysis, for example, the human analysts need to spend time only on regions the computer indicates differ from the standard. As the computer analysis software becomes more sophisticated, assembly line inspections involving very little human intervention will be possible.

BEACHCOMB Systems

~~(FOUO)~~ The BEACHCOMB program first began with a project to design an automated inspection system. The front end of the system was to be an X-ray source in a shielded enclosure that would send digitized signals to an image processing system. The X-ray unit had specifications written up by [redacted] was also responsible for negotiating the contract to have the machine built. (See CURRENT EFFORTS.)

~~(FOUO)~~ The original image processing system consisted of a [redacted] image processing computer with built-in software. While this system was very good at image processing, it was not a general purpose computer system; therefore, custom algorithm and general software development were very difficult to perform with it. The [redacted] system, however, did provide valuable knowledge in image processing techniques.

~~(FOUO)~~ The computer system selected to replace the [redacted] system consisted of a pair of Sun-2 workstations. These were general purpose computers using the UNIX operating system and were programmable in the C programming language. A basic image processing package was developed on the Sun-2s for use with BEACHCOMB systems. The Sun-2s were later upgraded to more powerful Sun-3 computers. Currently, Sun SPARC stations are used as software development and image processing workstations.

~~(FOUO)~~ When this program started, [redacted] was responsible for acquisition of the hardware and for development of the primary software packages. To enable parallel development efforts at [redacted] and at the Agency, [redacted] maintained an identical system of computers. In this way, software could be shared and exchanged, and software development could occur at both locations.

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CURRENT EFFORTS

Radiographic Inspection Systems

~~(C)~~ Much of the recent work in inspection technology has been in the field of radiography using X-ray systems. This is because radiography is a proven method that is fairly easy to implement and has the potential to become even more effective as new radiographic techniques are developed.

~~(S)~~ The BEACHCOMB program has several X-ray systems under development and in operation. The most notable of these is the microfocus X-ray inspection system (MIXIS) designed and built for the program [redacted]

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~~(S)~~ The MIXIS consists of a [redacted] microfocus X-ray source, which differs from other sources in that the small spot size of the source allows geometric magnification of the objects being inspected; a custom-built flat-field scintillator screen to convert the X-rays to a visible image; a silicon-intensified target (SIT) camera; a manipulator, or robot, used to manipulate the equipment being tested over the X-ray source; and a pair of Sun computers to operate the source and the robot. The computer system contains at least one imaging board for digitizing images from the camera and for basic image processing and image display and a serial port for communications with the robot controller.

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~~(S)~~ The system has been designed to accommodate several printed circuit boards at one time and to be able to scan the boards and store the digitized X-ray images at a rapid rate. These images are analyzed either immediately or at a later time by analysts using the computers to aid in the inspection. The analysts have sets of image processing tools available to them, as well as a custom-designed inspection interface to help guide them through the analysis process.

~~(S)~~ The system is capable of acquiring images of up to seventy times magnification, with enough resolution to easily distinguish parallel marks at a separation of down to ten microns. The robot is accurate in its motion to one thousandth of an inch, including repeatability of motions. The enclosure that is used to shield the system has been shown to be effective at attenuating radiation from the source well below the maximum allowable level.

~~(FOUO)~~ Many software packages have been written to support the inspections systems. These range from image processing routines to menu display programs and additional operating system utilities. The largest of these packages is the operational software for the MIXIS. This consists of a window-oriented and mouse-operated user interface, machine control software, basic data storage functions, and image processing tools.

Portable Inspection Systems

~~(FOUO)~~ In addition to the X-ray inspection systems described above, there are BEACHCOMB projects to develop smaller, portable systems to perform automated inspections in the field. Constraints on these systems include low weight, few separate pieces of equipment, standard power requirements, and little or no need for radiation shielding.

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~~(S)~~ New systems are currently being designed that will be easier to use and more efficient than the current models. These will use X-ray sources that provide a wider field of view or line-scanning detectors that give extra-high-resolution images. A wider field of view will allow more of a circuit board to be displayed than is possible now with portable systems. Line-scanning systems use a collimated source that directs a line of X-rays through the object to a linear array of detectors. To acquire an image, the object is moved across this detector array while image data are stored and formatted, allowing later display of the entire image. [redacted]

Data Analysis

~~(FOUO)~~ Another project in the BEACHCOMB program involves development of computer analysis techniques to process the digitized data obtained from the new inspection systems. These techniques include image processing, statistical image measures, and artifact analysis. Computer analysis is used to extract information from acquired data and to distill large amounts of data for use by an analyst.

~~(S)~~ Currently, most computer analysis is accomplished with image processing tools. Images are obtained from video sources, X-ray units, and other systems that use video displays. The image processing routines allow the analyst to perform filtering, contrast adjustment, magnification, translation and rotation, and many other image manipulation functions. One of the more basic, yet effective, techniques involves subtracting two similar images to produce a picture of just the difference of the two. [redacted]

~~(FOUO)~~ A number of other analysis methods have been proposed. Among them are statistical image analysis, histogram equalization, histogram matching, and hyperbolization. The benefits of these methods include the ability to ignore irrelevant changes, make accurate comparisons more quickly, and allow for contrast differences in images being compared. Studies using these methods with test images must be undertaken to determine their effectiveness and efficiency.

Equipment Characterization

~~(C)~~ An equipment characterization project was initiated to investigate the feasibility of uniquely identifying a piece of equipment electrically. A tester would be connected to the equipment under test (EUT) and would produce a reading for that piece of equipment. At a later time, another test could be made with the test results compared to the original results. If the readings differ, then a possible compromise of the equipment is indicated.

~~(S)~~ The initial work in this field has shown promise. Ford Aerospace used a spectrum analyzer and a time-domain reflectometer in feasibility tests. A study performed in X31 showed that changes in circuitry can be detected with the use of a network analyzer. Further research will be undertaken to determine the sensitivity of this method. For instance, tests will be made to see whether small changes in impedance can be detected. Also up for investigation will be different test setups, such as connecting the analyzer to just the I/O ports and using a bed-of-nails approach to test printed circuit boards.

DIRECTIONS

Programs Using BEACHCOMB

~~(FOUO)~~ The BEACHCOMB program includes research into a number of different fields. No single direction can be taken if we are to keep abreast of current technology and continue to develop state-of-the-art inspection techniques. However, as research progresses we must keep in mind the implementation of these methods.

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~~(C)~~ To guide our research and development projects, we keep in touch with the people and organizations who will ultimately be responsible for implementation of BEACHCOMB systems. In the Agency, this includes

Supercomputer Modeling and Simulation

~~(FOUO)~~ As the sophistication of our adversaries increases, our countermeasures must be improved accordingly. While we do not always know the precise methods used by an adversary, we can assume that he will keep pace with current technology. The same

technology that allows ever smaller circuits to be used in attacks also provides us with inspection tools not possible before.

~~(C)~~ One problem with the great variety of possible inspection techniques is the enormous effort required to evaluate these systems. This will be at least partially alleviated by the use of simulation and modeling on supercomputers. For instance, we will be able to model an ideal X-ray source and test its capabilities at different energy levels. This would be extended to tomography and laminography experiments, where we could change parameters of the systems not normally adjustable by an operator.

~~(C)~~ A computer workstation connected across a network to a supercomputer could become an inspection system tool providing the means to analyze large amounts of data in a short amount of time. This would be important for systems with multiple sensors or for techniques that depend on analysis of many data sets, such as X-ray tomography. Another use would be for analysis of data collected in the field, which could be shipped to the computer site on magnetic media or entered into the system over a secure computer network.

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Radiographic Techniques

~~(FOUO)~~ A parallel effort to the development of improved radiographic systems is research into advanced radiographic techniques. The goal here is to go beyond the physical limits we currently have to deal with. The result will be the ability to see ever smaller features, to penetrate denser materials than now possible, and to greatly improve resolution, allowing us to discriminate between similar materials.

~~(C)~~ Two similar methods that show promise are radiographic laminography and tomography. They both are used to display a specific plane inside an object. Laminography isolates a plane by moving the X-ray source and the detector so that blurring of the object occurs everywhere except in the plane of interest, which is kept the same distance from the source and detector. Tomography also uses a moving source and detector but obtains multiple images by rotating around the object. An image of the plane can be derived by processing the acquired images. Tomography requires a great deal of computer processing but results in an image free of the blurred areas found in laminography. Initial work in laminography has been performed by SAIC at their own

expense. Tomography is very similar to a CAT scan, but more research is needed for equipment inspection applications.

~~(FOUO)~~ Multiple wavelength radiography, also known as dual energy radiography and multispectral imaging, is a technique used to detect different types of material. By changing the wavelength of the X-ray source (by changing the voltage), the penetration abilities of the X-rays can be reduced or increased. Images taken at different energy levels are then processed by a computer to identify features not visible in a single image radiograph. Since no physical motion of the source is required – only changes in the voltage level – this method would be easier to implement than tomography once the processing software was written.

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~~(S)~~ Another X-ray technique being developed will allow us to see the circuit tracks inside an integrated circuit without opening the package. This project is currently under way at [redacted] is determining the physical limits of microfocus radiography to determine the smallest feature size that can be detected this way. His current tests involve obtaining images from X-rays shot directly through the object. Other proposed tests include determining the effectiveness of reflective and refractive radiography. The most recent experiments have been performed at Brookhaven National Laboratories in Long Island, New York. Brookhaven is home to the world's brightest white light (i.e., wide frequency spectrum) X-ray source.

~~(FOUO)~~ Neutron radiography, or N-rays, may become a future inspection tool as well. N-rays differ from X-rays in that they pass easily through dense materials, such as metals, while organic materials show up readily in the resulting radiographs. A number of drawbacks prevent immediate use of neutron radiation sources. N-ray sources require a substantial amount of shielding for safe operation. Also, the sources are very large, so finding adequate space can be difficult. The sources are also expensive, with a single unit costing in the neighborhood of $1 million. These machines have recently been in the news as more and more airports install them for inspecting luggage for explosives.

Other Sensor Technologies

~~(FOUO)~~ The BEACHCOMB program also includes projects investigating other types of sensors that could be used for inspection systems. These sensors are meant to augment each other since there is no single sensor yet conceived that can definitively indicate a tamper or other compromise in a piece of equipment or a facility. While use of a particular sensor may not be feasible at present, developments in that field are monitored for breakthroughs that could enable implementation of the sensor.

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~~(FOUO)~~ A recent development at [redacted] is the metglas sensor. This uses a special metal-glass material that is sensitive to magnetic fields, an effect called magnetic striction. High resolution is achieved by bonding the metglas to a loop of optical fiber set up as a Mach-Zehnder fiber sensor interferometer. The metglas responds to magnetic fields by changing size, which in turn stretches or compresses a portion of the optical fiber.

Deviations in the optical fiber are monitored by the interferometer. Variations of the sensor will be tested for suitability as wall inspection tools as well as for inspection of printed circuit boards.

~~(FOUO)~~ There are several other types of nondestructive testing that bear investigation. Acoustic and ultrasonic microscopy are methods that use high frequency sound as a source. Reflections from the sound waves are measured and timed to give a picture of the different densities of material in the object. Infrared and high resolution thermal imaging use heat detection to create an image. Optical and holographic interferometry record light interference patterns, and nuclear magnetic resonance imaging detects the magnetic moment of hydrogen, which is often found with carbon and is thus a good means to evaluate organic material.

The Ultimate System

~~(FOUO)~~ The ultimate system would be one we could attach to the object we would like to inspect and after a few seconds a green light would indicate "good" or a red light would warn of a problem. While we do not foresee even approaching this ideal anytime soon, it does give us a direction in which to head our efforts. Features of the ultimate system can be incorporated into the inspection systems we develop. Also, it is much more efficient to break up the problem by developing simpler systems.

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~~(C)~~ In putting together a system, we seek sensors that have as few limitations as possible. We would like our sensors not only to be able to look at the smallest details of our test objects but also to give us a good overall view. Moreover, we would like our sensors to be able to evaluate every kind of object we may want to test. For now, however, this means a variety of systems to cover the gamut from rooms to ROMs. Also, we would like the systems designed for field use to be nonalerting, so we do not announce our inspections or inspection methods to our adversaries. Of course, we would like the sensors to be as economical as possible.

(~~FOUO~~) Another requirement is for the system to be able to gather data quickly and efficiently. There is usually a compromise made in the time allotted to making an inspection, either because the equipment or facilities to be inspected cannot be spared for

very long or because the items to be inspected are too numerous for proper inspections to be completed before the usefulness of the objects expires. We would, therefore, like to have sources powerful enough and detectors sensitive enough and computers fast enough to acquire and process the data in a relatively short period of time. This is very desirable economically as well.

~~(FOUO)~~ As a cost savings feature, inspection systems would ideally be portable. This would allow the system to be taken to where it was needed and save having to ship large or numerous items. Somewhat related to portability is the concern for safety. In assembling an X-ray system, for example, the lead shielding necessary for some systems would preclude portability while a system small enough not to need shielding would tend to be very portable. The reality of portability is dealing with the trade-offs that must be made. A goal, then, is to minimize these trade-offs and take advantage of state-of-the-art technology to continue making the systems as small as possible.

~~(FOUO)~~ Perhaps the most important requirement of all is for the sensors and the systems they are incorporated into to be easy to use. This is true for any kind of test equipment, and care must be taken to design systems for use by people with limited or no technical knowledge. Ease of use also implies reliability of the system. Even the most sophisticated user will fail to provide adequate results if the system operates improperly or not at all.

~~(FOUO)~~ Until we can build our ultimate system, we will continue to seek out and develop state-of-the-art systems and techniques for technical security inspections. If we succeed, we may be able to deter tampering, but we need to develop enough confidence to know that we have succeeded.

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