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Evaluation and Analysis of Non-Intrusive Techniques for Detecting Illicit Substances

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ABSTRACT

Argonne National Laboratory (ANL) and the Houston Advanced Research Center (HARC) have been tasked by the Counterdrug Technology Assessment Center of the Office of National Drug Control Policy to conduct evaluations and analyses of technologies for the non-intrusive inspection of containers for illicit substances. These technologies span the range of nuclear, x-ray, and chemical techniques used in nondestructive sample analysis. ANL has performed assessments of nuclear and x-ray inspection concepts and undertaken site visits with developers to understand the capabilities and the range of applicability of candidate systems. ANL and HARC have provided support to law enforcement agencies (LEAs), including participation in numerous field studies. Both labs have provided staff to assist in the Narcotics Detection Technology Assessment (NDTA) program for evaluating drug detection systems. Also, the two labs are performing studies of drug contamination of currency. HARC has directed technical evaluations of automated ballistics imaging and identification systems under consideration by law enforcement agencies. ANL and HARC have sponsored workshops and a symposium, and are participating in a Non-Intrusive Inspection Study being led by Dynamics Technology, Incorporated.

1. Introduction

The Counterdrug Technology Assessment Center (CTAC) was established by Congress within the Office of National Drug Control Policy (ONDCP) to serve as the central counterdrug enforcement research and development organization of the United States Government. In order to fulfill this mandate CTAC must identify, evaluate and promote specific technologies to meet the needs of front-line drug enforcement agencies. Technologies of interest may be grouped into three general areas: wide-area surveillance, tactical technologies, and nonintrusive inspection. In the area of nonintrusive inspection, CTAC's goal is to develop rapid, modern, automatic systems to inspect shipment and cargo containers without physically removing the contents for manual inspection. This goal has led to the development of prototype systems for inspecting the contents of tankers, drums and other enclosures. Prototype instruments are then evaluated in the field and at operational technology test beds by scientists, engineers and operational personnel working together to evaluate and identify specific improvements in the inspection process. CTAC has also sponsored efforts to improve existing narcotics detection instruments and field test kits.

Argonne National Laboratory (ANL) and Houston Advanced Research Center (HARC) are under contract

to CTAC to provide infrastructure support to evaluate non-intrusive technologies used for illicit substance detection. The technologies under review include nuclear and chemical techniques used for nondestructive sample analysis. The main areas of activity include phenomenology, theory, basic data collection, target signature identification, field support, data analysis, and laboratory feasibility demonstration experiments in nuclear, x-ray, and chemical detection technologies.

2. Nuclear & X-Ray Technologies

Nuclear-based technologies offer great promise for interrogating large volume enclosures without opening the container. These technologies rely on x-rays and neutrons to penetrate deep into the subject enclosure. Numerous nuclear-based interrogation techniques have been proposed, and a number of prototype systems have been developed. ANL is performing simulation studies to determine the signatures of illicit substances from nuclear and x-ray based systems. These studies are intended to determine the sensitivities of the systems and the dependence of the results on the environment in which the illicit substances are contained. ANL has been performing studies on the Pulsed Fast Neutron Analysis (PFNA) systems from Science Applications International Corporation (SAIC) [1] and Gamma-Metrics [2]. A workshop on PFNA inspection systems, at which the attributes of the various systems were discussed, was held at Argonne in January 1994. ANL is also participating in system studies to determine the costs and risks in deploying such systems.

The PFNA technique provides a non-intrusive method of detecting the relative abundance of various elements located within a small volume inside a sealed container. The volume size interrogated is typically about one liter. Container sizes vary from those used in air transport (~ 5 m^3) to ocean shipping containers (~ 75 m^3). The PFNA technique uses a collimated beam of monoenergetic neutrons to interrogate a sealed container. The neutrons interact in the target volume to produce a gamma-ray signature that is characteristic of the elements of interest. PFNA systems are capable of detecting carbon, nitrogen, and oxygen by observing gamma rays created in inelastic scattering reactions. Hydrogen and chlorine can be detected by observing prompt activation gammas. This volumetric information on the relative concentrations of each of these elements can then be used to detect narcotics or explosives inside the container. For example, narcotics have higher concentrations of carbon and lower concentrations of nitrogen and oxygen compared to materials normally found in cargo containers. Similarly, explosives have higher concentrations of nitrogen and oxygen and lower concentrations of carbon and hydrogen than most benign materials.

Among the simulation studies undertaken is the use of the radiation transport code MCNP [3] to model PFNA neutron interrogation systems that examine shipping containers holding cocaine. An example of these studies is the estimation of the ^{12}C and ^{16}O gamma signals from a cargo container loaded with sugar at a density of 0.5 g/cm^3 with a 25-cm sphere of cocaine centered 75 cm from the front face [4]. The MCNP results give the gamma rays reaching a given detector per source neutron. Actual count rates are obtained by multiplying these data by the estimated neutron source rates and detector efficiencies. For a gamma-ray detector at the top center of the container, the count rates are 85 and 45 cps for the C and O lines with the cocaine sphere present, and 124 and 22 cps for the C and O lines with a pure sugar background.

Also of interest is the length of time required to interrogate a container to determine if illicit narcotics are present [4]. The number of counts required to detect the difference in the C/O ratios in sugar (1.0) and cocaine (4.25) will depend on the background and on the accuracy to which we need to know the C/O ratio. If one assumes a signal-to-background ratio of 1, and a 20% accuracy in determining the C/O ratio, then approximately 300 counts are needed in the $^{16}O(n,n2)$ peak for the case of the cocaine sphere in sugar. This implies a counting time of 300/22 = 14 s per voxel. Simulations such as these help to understand the operating characteristics of proposed systems prior to building and deploying the actual hardware.

Computer simulations are also used to compare alternative designs or different techniques. For the previous example of cocaine in a sugar background, the signal due to the presence of the background material

only was estimated by employing an analytic signal model that has been used for previous analyses [5]. Agreement was found between the analytic model prediction and the signal due to gammas created in front of the incident neutron beam. It was observed that using the total gamma signal as a contraband indicator overestimates carbon and oxygen densities because of the contribution of gamma rays that are created by neutrons which have scattered out of the beam.

The same analytic model was used to estimate the gamma-ray signal from 14-MeV neutron interrogation concepts such as that proposed by GammaMetrics. The penetration of 14-MeV neutrons is not significantly greater than that of 8.5-MeV neutrons (4% higher flux at the front of the cocaine sphere). The inelastic scattering cross sections are lower at 14 MeV than for 8-8.5 MeV, especially for oxygen, which would result in a smaller signal [6]. The count rate results from these models are used to examine the accelerator parameters required for neutron interrogation of cargo containers.

Another method of nondestructive inspection being considered for contraband inspection is Fast-Neutron Transmission Spectroscopy (FNTS). This method, being studied primarily for explosive detection, uses standard time-of-flight techniques to measure the energy spectrum of neutrons emitted from a collimated continuum source before and after transmission through an interrogated sample. The physics of this technique is similar to that of x-ray transmission systems used to obtain radiographic images in luggage inspection or medical diagnostics.

The energy spectrum of the transmitted neutrons depends on the integrated density of the elements present in the line-of-sight from the neutron source to the detector and on the total cross sections of those elements. Since each element has a unique total cross section, one can determine the integrated densities for individual elements by analysis of the transmission spectrum [7]. This yields a series of radiographic images, one for each element of interest at each projection angle. Radiographic images for one element at several projection angles can be combined to produce a tomographic reconstruction of the element's distribution inside the object. These elemental distributions are then combined into a signature that indicates the presence of narcotics or explosives. Results [8] from FNTS studies show that bulk shapes of narcotics or explosives can be detected with as few as three projections and modest (2-cm) pixel resolution inside the object.

ANL has witnessed testing of the high-energy x-ray system at the Tacoma test bed. Argonne is also performing simulations to determine the signatures of drugs using various x-ray approaches including direct transmission, multiple view, dual energy, and backscatter. ANL is also investigating imaging technologies for both x-ray and nuclear inspection systems to determine parameters such as resolution and number of views required for substance detection. ANL is discussing with the U. S. Customs Service (USCS) the development of an assessment program for cabinet x-ray instruments to inspect airline cargo.

ANL is supporting Dynamics Technology, Inc. in conducting an engineering tradeoff study of various types of commercially available nonintrusive inspection systems. ANL is helping to determine nominal performance and cost parameters for x-ray and nuclear interrogation systems for use at ports of entry to detect illicit drugs and other contraband.

3. Chemical Technologies

A chemical technologies laboratory, dedicated to testing and evaluating chemical technologies for applicability to detection of illicit narcotics, has been established at HARC. Among the techniques utilized in this laboratory are ion mobility spectrometry (IMS), gas chromatography - mass spectrometry (GC-MS), and a number of biochemical systems. This lab is focusing on evaluating those technologies that show near-term promise for developing fieldable instruments. HARC is also undertaking the development of standards analysis, preparation, and laboratory verification studies for chemical detection technologies.

ANL and HARC are consulting with LEAs to identify areas in which technology support could be focused on pressing legal issues. This effort has grown out of a workshop called by CTAC, held on May 5 and 6, 1994, which focused on "User Needs in Chemical

Detection Technologies." Both labs have participated in field tests to examine issues of interest to LEAs, such as drug contamination of U.S. currency. HARC and ANL are collaborating in a study of cocaine contamination of currency.

HARC is undertaking a study of the effects of environmental conditions on cocaine detectability. This includes an analysis of cocaine degradation products and a search for possible new signatures. Studies of the catalytic decomposition of cocaine on various substrates with the GC/MS have begun. HARC is also collaborating with United States Coast Guard (USCG) scientists regarding cocaine vapor detection. Possibilities for detecting cocaine or cocaine derivatives in air samples taken directly from cargo containers are being examined. HARC has performed calculations investigating the feasibility of this application. This potential method of air sampling could drastically reduce the time required to perform chemical testing on large cargo containers.

HARC has begun a study of the apparent masking of cocaine IMS signatures by various oils found in the marine environment. During field studies conducted with the USCS at the Port of Houston, HARC verified that oils commonly found in the engine rooms and bilges of cargo ships corrupt cocaine signals on an IMS instrument. A sample of bilge oil from the Peruvian container ship *Corain I* was obtained, and is being used to study this phenomenon. Approaches for overcoming this apparent difficulty are being explored.

ANL is undertaking a study to investigate the morphology of cocaine particles on paper currency. The goal of this study is to improve the understanding of the properties of cocaine transfer from currency to people. In recent field tests, experimenters reproduced earlier work which showed that individuals coming in contact with money contaminated with high levels of cocaine did NOT necessarily become contaminated. This result was not readily explained. To better understand the results of the in-field experiments, ANL began a study of money obtained in Miami using a scanning electron microscope (SEM). The preliminary results of the SEM study showed that the "newly contaminated" money was coated with large plates of cocaine sitting on the surface of the bill. These plates could easily be transferred to an individual. The structure of the currency consists of coarse fibers that are composed of smaller fiber bundles. These smaller bundles will contain cocaine after surface plates have been removed. Thus, when an individual handles money that has been contaminated in the past, their skin will not come into contact with the cocaine in the fibers. However, if the bill is rubbed vigorously as when sampling for an IMS test, the fiber is compressed and one can make contact with the cocaine. This data indicates that it may be possible to determine if money was newly contaminated by the presence of plates or crystals on the surface. Money that was contaminated at an earlier date could test positive after an IMS wipe but not show the same surface structure of the contaminating narcotic.

4. Field Tests

ANL and HARC personnel have supported numerous field tests during the past year. These field tests have been organized by various LEAs including the USCG, the USCS, and Canadian Customs (RCET). Tests have been conducted at sites in El Paso, TX, Houston, TX, Miami, FL, New York, NY, as well as in Canada.

A number of field tests held in Miami during 1994 and 1995 were aimed at conducting drug transfer and contamination studies. Staff from both HARC and ANL have participated in these tests. During one of these tests cargo from a targeted container ship was examined in a real-time operational scenario. The entire living quarters of a foreign ship were tested for contamination. Cocaine residue was detected in several containers that were subsequently tagged for further inspection at the USCS inspection warehouse. An electrical transformer was examined using a thermal neutron scanner and inconsistencies were discovered in the transformer interior. Subsequent disassembly of the transformer by USCS personnel revealed significant quantities of cocaine.

The El Paso field tests were conducted at the Bridge of the Americas (BOTA) and Ysleta border crossings in El Paso, Texas. This test was organized by

the USCS and held in March 1995. Examinations concentrated on truck cargo containers and automobiles. Several drug users were found at both locations, but no large amounts of illicit substances were discovered.

HARC personnel are conducting a series of field tests in the Houston area. Recent examples include work performed with the USCS at Houston's Intercontinental Airport, Houston, Texas, and at the Port of Houston, Houston, Texas. The purpose of the Houston Intercontinental Airport study was to evaluate the utility of ion mobility spectrometry at the Mickey Leland International Terminal (IAB), a Port of Entry into the United States. An IMS was deployed at the secondary baggage inspection area inside the terminal and at the outdoor luggage conveyer belts. In one instance, the IMS failed to recognize hashish, when a solid block of the material was sampled by wiping. In another instance, material was discovered which produced an IMS peak having the same drift time as cocaine. However, in several instances, the IMS successfully singled out cocaine users, and identified the presence of cocaine. The ion mobility spectrometer appears to be an effective tool for identifying users of cocaine, although no large amounts of contraband were discovered. These and other "real-world" tests of the instrumentation show the difficulties encountered in moving technology from the lab to the field.

At the invitation of the USCS, HARC participated in the search of the *Yacu Puma*, a large Peruvian container ship with a Panamanian crew, inbound from Colombia. Approximately twenty-five individuals participated in the search, including members of the Drug Enforcement Administration (DEA), Federal Bureau of Investigation (FBI), USCS, National Guard, HARC, and the British Consulate in Miami. Search team members were briefed at the start of the operation that reliable intelligence indicated the *Yacu Puma* was carrying cocaine. An IMS was deployed at the site in the back of a USCS van, and powered by a generator. National Guard and USCS personnel performed the majority of the wipe sampling of the ship and its cargo, and shuttled samples back and forth to the IMS. HARC personnel operated the instrument. Over 600 IMS samples were analyzed during this exercise. No contraband was discovered.

On May 15, 1995, US Customs at the Port of Houston, Houston, Texas, again invited HARC to participate in the search of the *Corain I*, a large container ship inbound from Colombia. During a previous inspection of this ship, canines indicated the presence of cocaine, but were unable to determine its exact location. It was hoped that the IMS would help locate any possible contraband. Participants included members of USCS, USCG, HARC, and the National Guard. An IMS was deployed in the back of a USCS van, and powered by a generator. Mild cocaine residue was detected from wipe sampling of the ship's gangway, and the cabin and hallway in front of the cabin of one of the crew. This was in the same vicinity where canines had previously indicated for narcotics, although no canine responses were observed during this inspection. Further wipe-sampling and analysis with the IMS produced strong cocaine signals in the ceiling, both in the same cabin and in the hallway outside the cabin. Portions of the ceiling were removed and the ceiling inspected. No contraband was discovered. It was postulated that contraband may have been smuggled in this location during the ship's previous trip to Houston.

HARC has been involved in numerous other field tests utilizing IMS technology at the Ports of Houston and Galveston. Similar results to those outlined above were obtained. In all these field tests, the participating LEAs were receptive to new technology aimed at detecting concealed narcotics.

5. Information Systems

HARC has developed a database to organize narcotics detection data and literature references. Microsoft Access is the relational data base manager. The software package now exists as a standalone information system. An operator's manual for the system has been written and the program is being offered to other scientists in the field. Literature searches and data input are expected to be an on-going effort throughout the life of this program.

Additionally, a *field test results database* has been constructed. This data base mainly contains the field test results generated from the IMS instruments. To greatly reduce time spent performing data reduction

following field tests, a software routine to automatically log data from the IMS data files has been developed. Database manipulation routines have been developed, and the completed package exists as a stand-alone information system. This system is a useful tool in analyzing field study results.

HARC, under guidance from ONDCP/CTAC, has organized and conducted an independent evaluation of computer-based ballistic imaging and identification systems. The main objective of this project was to perform an independent evaluation of the ballistics systems consisting of overall system performance and life cycle cost analyses. The independent evaluation team consisted of a team leader, a systems engineer and cost analyst, a computer and image analyst, an optics engineer, and two Firearms Examiners. The performance of the sophisticated image acquisition system, correlation algorithms, and network communications, and the system design were evaluated using a standard series of computer image analysis and system evaluation criteria. These criteria included: overall system accuracy, overall processing capability, system processing speed, complexity, computer requirements, database size and restrictions, interface compatibility, network compatibility, human factors, reliability, environmental limitations, facilities requirements, and expandability. Additionally, a Life Cycle Cost analysis was performed on each system based on a *national scale systems deployment plan* over a five-year time frame.

For each ballistic imaging system, the evaluation team spent approximately one week (five working days) on-site. These on-site evaluations consisted of demonstrations, real time *stress tests*, hands-on operational experience, and question and answer sessions. The system stress tests were utilized by the evaluation team to gain a better understanding of how each system worked and to determine possible operator bias in data input and sample matching.

The final results of the evaluation team are contained in a report entitled *"Benchmark Evaluation Studies of the Bulletproof and Drugfire Ballistic Imaging Systems,"* dated November 1995. A separate paper presented at this conference contains additional information on ballistics imaging and identification.

6. References

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