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Defense CBRNE Threat-Detection Systems For Transportation Security

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Abstract-*New technology is needed to counter the growing threat of Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) terrorist attacks. Joint Department of Defense (DoD) CBRNE programs can support homeland-defense efforts in this area. This paper explains some DoD-developed technology involved in advancing and integrating hardware and software components into an advanced threat-detection system. This research has three thrusts: (1) new, next-generation individual and arrayed CBRNE sensors. (2) new deployment methods for lightweight, modular sensors, and (3) the integration of sensors into a network where intelligent software agents, data-fusion algorithms, and expert systems enhance the user's ability to retrieve and understand the data.*

1. INTRODUCTION

Lighter, smaller, accurate, low-power, and network-ready [7] CBRNE sensors are needed for homeland security as well as on the battlefields. One application will provide vehicles and pedestrians small, portable devices that use Commercial-Off-The-Shelf (COTS) compact, wireless technology. Vehicles will not need modifications to accommodate these detectors. Personnel on foot also can carry them easily in the equipment with which they already deploy. The technology that is the subject of this research is aimed at supporting the Department of Homeland Security (DHS) in vehicle, group, and individual safety in both U.S. urban and rural environments.

To enhance transportation security, vehicles need small, reliable, inexpensive, interoperable chemical and biological sensors along with expert processing capability to protect against terrorist threats. The following DoD-developed technologies offer contributions to DHS in enhanced vehicle security:

- Ultra-sensitive chemical detector based on the patented Micro-Electro-Mechanical Systems (MEMS) [15] Fabry-Perot Optical Interferometer integrated with a Surface Enhanced Raman Spectroscopy (SERS) [1] activated Molecularly Imprinted Polymers (MIP) coating.

- Biological detector. The detector and processing software, including ultraviolet microscopes and optical imaging developed originally for the detection of anthrax, (U.S. Patents 7,006,923 and 7,082,369) will be researched for potential detection of explosives.

- Data Fusion, feature extraction. The Knowledge Amplification by Structured Expert Randomization (KASER) expert system can be applied to biological and chemical sensors, and future "plug-and-play" sensors to discern features in sensor data.

- Wireless LAN, UAV sensor deployment [5] and intelligent agents [14] can be used to collect, fuse and process the sensor data.

- Joint Warning and Reporting Network (JWARN) Component Interface Device (JCID)-on-a-chip and Holster architecture [2] enables CBRNE sensors to "plug-and-play" in a modular [7], network-centric [8] environment.

- Open architecture and standardized I/O for nets will host sensors using JWARN infrastructure.

The paper is organized as follows. Section 2 explains SERS, MEMS, and MIP-based sensor hardware technology [1], [15]. Section 3 describes Geodesic Feature Synthesis and Mining and the KASER anthrax detector (U.S. Patents 7,006,923, 7,082,369 and 7,047,226). Sections 4 and 5 summarize the integration of CBRNE information in the Joint Warning and Reporting Network (JWARN) Component Interface Device (JCID)-on-a-chip firmware, and the Holster sensor-network infrastructure respectively. Section 6 covers wireless-sensor distribution and data fusion. Section 7 concludes with a discussion of the advantages of these technologies for transportation security.

2. SERS-MEMS

Current sensors are too large and heavy and require too much power. MEMS sensors can decrease the size and power consumption of existing sensors. MEMS based sensors, such as microcantilevers, rely on selective coatings for specificity. Consequently, these sensors cannot differentiate between a chemical agent and a dust particle. Although the MEMS sensor under development at SSCSD also uses selective coatings, false positives are eliminated because both binding of the chemical agent and optical detection must occur in order to identify the agent. The SSCSD MEMS sensor [15] uses a Fabry-Perot Interferometer (FPI) tunable filter to scan the wavelength. The fully assembled sensor is comprised of a photodiode that is monolithically integrated with the FPI-tunable filter, a Vertical Cavity Surface Emitting Laser (VCSEL) as an excitation source, and a surface-enhanced Raman spectroscopy (SERS) [1] substrate between the tunable filter and the VCSEL.

All polyatomic species will exhibit a characteristic SERS spectrum that can be used for identification purposes. Another advantage of SERS is sensitivity. Large enhancement factors have been observed for SERS and single molecule detection has been reported. Coatings on the SERS substrates are used to attract chemical agents of interest, Using sol-gel technology, SERS active molecularly imprinted polymers (MIPs) can be fabricated to increase selectively. The fully integrated sensor is a small (<0.5 in^3), low-cost, highly sensitive, reliable device capable of nearly real-time (<60 sec.). It can be arrayed to provide simultaneous detection of multiple CBRNE agents. Because the SERS-MEMS sensors produce data that can be sent anywhere, they will fit into the Holster standard-interface architecture [2], [7].

3. Geodesic Feature Synthesis and Mining

A fundamental component of ISR technologies pertains to all levels of data fusion and extrapolation. The greater need here is for more accurate predictive methods as well as methods that combine symbolic (e.g., textual) data with numeric sensor readings in a seamless heterogeneous architecture. Geodesic mining uses multiple distributions, imbued in the original data, to make more accurate predictions. "Geodesic" refers to the capture of this distribution in the knowledge derived for subsequent replay. Whereas this is a computationally intensive process, it has the advantage of being maximally amenable to execution on fine-grained processors.

Unlike the case for neural networks, the resulting knowledge can be explained to the user. Moreover, the KASER (U.S. Patents 7,006,923, 7,082,369 and 7,047,226) can generate analogous features from a feature set. Given that the geodesic miner can bias automatically the set of supplied features, the system will converge on ever-better sets of features and heterogeneous rules expressed in terms of those features for fusion and prediction. Features are evolved along geodesic lines to minimize evolutionary time, but are necessarily annealed to insure diversity. A quantum mechanical description of the KASER might serve both requirements. Finally, geodesic feature synthesis and mining can allow the system to evolve to play better chess, for example, starting with primitive game descriptions. Given this conceptualization, application domains include battle management, logistics, signal analysis, targeting and tracking, counter terrorism, as well as the development of intelligent auto pilots for UAV (swarms), among others, can be addressed better by the methodologies suggested in this paper than by any combination of conventional methodologies (e.g., case-based reasoning, expert systems, genetic algorithms, neural networks, support-vector machines, *et al.*). Some of the reasons underpinning this claim are provided below.

The war fighter must deal with a plethora of sensors and need to make sense of the ever-growing volume of data that they produce. The situation is complicated by the fact that we are not dealing with only numerical sensors, but rather heterogeneous sensing throughout the battle space. The information overload that the war fighter experiences in the battle space is similar to what personnel from DHS and from other federal agencies experience during times of crisis. One technical solution supports two others, as explained below.

- Novel data mining techniques to reduce data to a set of consistent, but evolving rules. Declarative information is reduced to procedural knowledge. The difficult part is that the response to novel situations needs to be adapted from successful responses to similar, but not identical, previous encounters. The challenge is to predict future events after collecting salient past data. The solution is to apply DoD-developed novel mining and fusion technology [11] that can utilize massively concurrent distributed processors for the on-going iterative reduction of sensory data to a consistent set of rules, or the equivalent.

• Situational awareness and threat assessment does not follow at once from the existence of a mined rule base. This is true because knowledge requires a contextual setting for its proper interpretation. Knowledge begets knowledge. The feature recognition capabilities of the miner/fuser using a Knowledge Amplification by Structured Expert Randomization (KASER) expert system [9] needs to be augmented. Domain-specific knowledge will be applied for the synthesis of features that best capture the operational situation. Feedback is provided by running the miner/fuser using the evolving feature sets – rejecting feature sets that are not found to be predictive, while saving those that are found to be more so. Over time, such feedback will facilitate the capture of causality and insure a high degree of predictive reliability in the overall data-management system.

• The KASER [13] (U.S. Patents 7,006,923, 7,082,369 and 7,047,226) is a patented operational expert system that is to conventional expert systems what fuzzy logic is to classical Boolean logic. KASERS can learn to induce qualitative rules, where the firing sequence fails to complete. Conventional expert systems rely on a square-wave like inference engine. Such engines are either 100 percent or 0 percent sure of their rule-based actions, depending on the context. KASERS embody the same capability, but also can form new rules that are not necessarily valid using computational analogy. In a sense, KASERS augment the square-wave behavior of conventional expert systems using qualitative sinusoidal waves [9].

• A KASER [13] can take a known domain-specific feature (e.g., a change in barometric pressure) and suggest computationally similar features (e.g., a change in relative humidity or temperature). These candidate features are input into the mining system to determine whether they are good predictors (i.e., in combination with other known or predicted features). A complex evolutionary loop can be established that can predict future events with ever-increasing (but never absolute) accuracy (Fig. 1). The results here can far outperform neural networks, genetic algorithms, case-based reasoners, and the like. For example the best predictor of an incoming storm might be 1) an observed decrease in barometric pressure; 2) an observed decrease in temperature; and 3) an observed increase in relative humidity.

Actual measurements of a KASER's capability for creating analogous knowledge (via the transformation of experiential knowledge) are given in Fig. 1 and are based on about 140 trials per vehicle – proceeding temporally in training from left to right [9]. The observed "dip" is due to the fact that the 1983 Plymouth Voyager is diagnostically random to a relative degree (i.e., when first encountered) in comparison with its two predecessors. The 70 percent asymptote seen here is domain dependent.

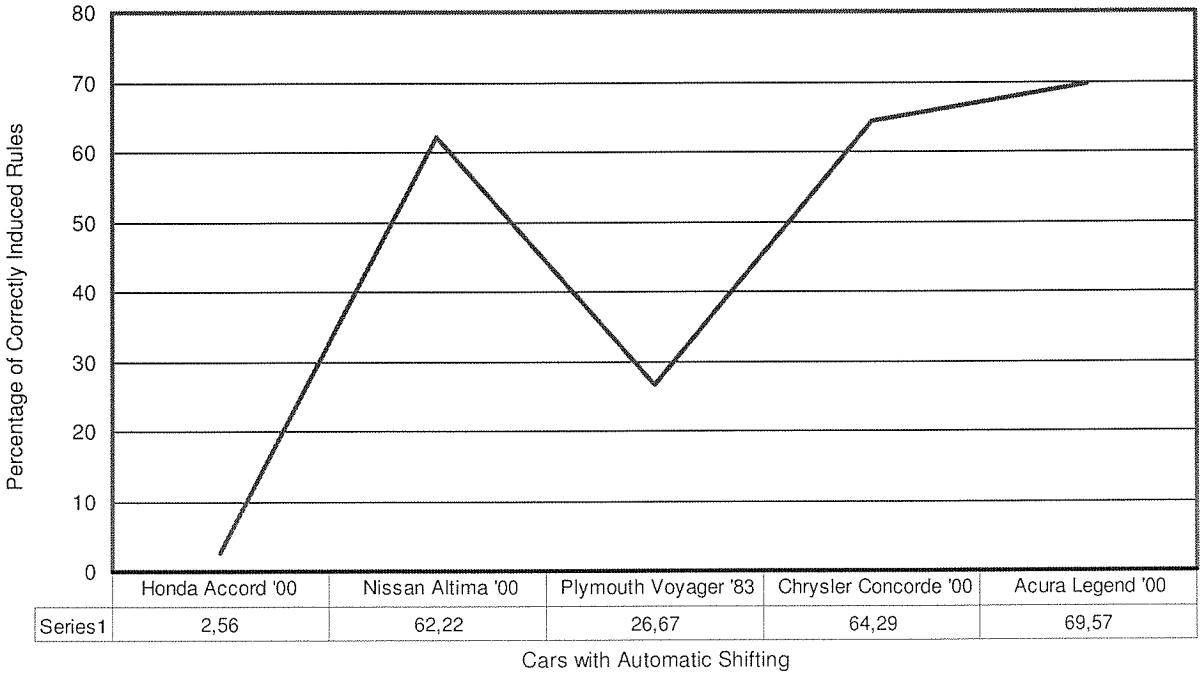


Figure 1. Knowledge transference and supra-linear learning in a KASER applied to an automotive diagnostic domain.

One of the major problems with other approaches to achieving the aforementioned goals is simply that they cannot be coordinated for execution on massively concurrent distributed processors. The approach of the KASER is predicated on randomization theory [3], [4], [6], [10], [12] and thus need not suffer this fate. Knowledge discovery and control algorithms that fully can utilize over a million concurrent processors have unrealized potential that far exceeds those that at best can run on super VonNeuman architectures.

The KASER-Based anthrax detector (U.S. Patents 7,006,923, 7,082,369 and 7,047,226) is a different type of next-generation sensor to detect biological threats using KASER technology. The increased sensitivity is due to amplified detections using innovative artificial-intelligence and data-fusion techniques. Automated feature extraction increases gain to outperform current technologies, as explained above. The evolutionary feature of the learning system enables detection of new threats. Signatures can be communicated via radio or cell phone.

The anthrax particulate detector based on the KASER expert system uses an ultra violet microscope to view the smallest bacterial samples present in the air. A flash optical source illuminates the samples and a high-resolution digital camera records the magnified image of the captured particles. KASER can input heterogeneous sensor data and find patterns that increase the sensitivity of the ensemble over that of any single sensor using innovative artificial-intelligence and data-fusion techniques. KASER's novel data-mining algorithm helps distinguish features and patterns in optical spectra as well as bacterial pathogens from innocuous particulates. KASER can learn the optical signatures of chemical and biological agents, thus adapting to emerging threats. The detection system can upload microscopic images to keep users in the decision-making loop and can download new threat signatures automatically. The system improves its capability in the same way that desktop virus-detection software retrieves updates. KASER's evolutionary learning supports detection of new explosives and prediction of events.

4. JCID-ON-A-CHIP

JCID-on-a-chip is a software-defined sensor concept, architecture, and approach to modular CBRNE sensors. Any hardware device can be used in "plug-and-play" mode. JCID-on-a-chip can support field-programmable, gate-array-supported sensor hardware platforms as well as other types of software-based chip sets. Holster is a key component in the net-centric CBRNE information technology of the future because it provides a common interface for many different types of sensors, some of which are sunder development. Holster is an important step forward in modular information technology management, which is important as DoD and DHS collaborate to build interoperable information systems for sharing data.

JCID-on-a-chip architecture and application layer protocol can combine with any hardware device, such as a sensor, in a "plug-and-play" mode, including networking and wireless capabilities. JCID-on-a-chip is under development as a software-defined sensor concept, architecture and approach to modular CBRNE sensors. JCID-on-a-chip can support the ability to load to Field-Programmable Gate-Array-supported sensor hardware platforms as well as other types of software-based chip sets. Available CBRNE sensors have widely varying interfaces making system integration and networking complex. Updatable and reconfigurable hardware can support digital circuit and interface protocols, as well as sensor-data fusion in field-programmable memory and gate-array integrated circuits in the device. Configurable I/O translation software modules can be loaded dynamically into hardware platforms containing MEMS sensors.

Products of DoD research have demonstrated, for example, the firmware-reconfigurable JCID-on-a-chip technology in a supporting Holster environment. Holster and wireless JCID-on-a-chip sensor integration support a network-centric approach [7] realizing massively concurrent distributed processing. Holster provides hardware packaging and connectors, electrical power, and common services including "plug-and-play" configuration, communication protocols, information assurance, and wireless networking infrastructure to integrate CBRNE sensors. It supports scaleable and upgradeable modules that can accommodate any CBRNE sensor in a "plug-and-play" architecture. The prototype will include the ability to a) use of any configuration of JWARN sensor network; b) deploy sensor networks of different configurations; and c) share sensor data simultaneously with JWARN and other CBRNE users.

5. HOLSTER

The requirements and architecture to support network-centric sensor-data interoperability are described in [7]. Holster is a supporting environment that provides the necessary standard interface [7] and common physical hardware-docking specification for modular [7], "plug-and-play" CBRNE sensors [2]. This includes hardware packaging, connectors, electrical power, and common services including modular configuration, communication protocols, information assurance, and wireless networking [7] infrastructure for sensor-data integration and fusion as defined in [8]. Holster supports scaleable and upgradeable modules through a software-based approach [2]. This open architecture enhances the capability to detect a variety of CBRNE threats [2]. JCID-on-a-chip/Holster sensor interfaces are implemented with external and internal Personal Computer Memory Card International

Association (PCMCIA) devices that are independent of specific platform using wired or wireless networks [2].

6. Wireless Sensor Distribution and Data Fusion

Quick deployment of wireless CBRNE sensors that have information components is both desired [7] and possible [5]. Cluster deployment of sensors, such as those described above, from various platforms, such as an unmanned aerial vehicle (UAV), is both robust and modular [5]. These lightweight sensors are amenable to distribution on the ground in near-real time via a delivery system similar to a sonobuoy acoustic-sensor system [5]. To cover wide areas in opaque environments, sensor networks must share and fuse data autonomously and collaboratively from multiple sensors into a coherent real-time Common-Operational Picture (COP), described in [8] to provide knowledge for situational awareness and target discrimination [5]. Ground vehicles and personnel on foot also can deploy sensors.

To support the dissemination of fused data throughout the COP, an information exchange environment is needed that is conducive to multiple data-fusion [8] steps (as needed) that can support operations in a variety of storage and display formats. Fusion algorithms need to be tested, used, managed, and upgraded in this environment. Moreover, fusion algorithms need to be robust enough to be able to handle changes in sensor hardware, which is bound to occur when sensors are added dynamically [7] to the environment.

7. Conclusions

Joint DoD programs can provide DHS the following "plug-and-play" capabilities: (a) use any configuration of JWARN sensor network; (b) deploy sensor networks of different configurations; and (c) share sensor data with various government components at the federal, state and local level in a net-centric environment without interrupting other applications. Successful integration will result in a revolutionary system for CBRNE identification with performance far superior to current systems. The mature integrated devices will be lightweight, low cost, deployable in arrays and capable of detection with little temperature or humidity sensitivity with potential operational applications in early detection and decontamination monitoring.

This combination of technology is unique and superior to current technology. These components have been patented, requiring a search to ensure that the technology is new and innovative and that no one else has produced it. Literature searches also indicate no known equivalent system of technologies either in use or on the drawing boards in research laboratories.

Compact, hand-held sensor instruments are commercially available to detect CBRNE agents. They operate under line power or, for a limited time, on batteries. They are neither automated nor engineered to operate in a networked environment. Legacy systems generally have slow response times with limited specificity, and high false-positive rates. They also detect only small number of known threat agents and cannot be reconfigured efficiently to meet emerging threats. Many of these legacy instruments are bulky and require reagents, which are neither small nor configurable efficiently for automation. They are user intensive, often sensitive to environmental conditions, and cannot be modified easily to meet emerging threats.

The intelligent system will be automated and require little user intervention. The MEMS and KASER sensors and system will decrease significantly false positives and provide confirmation of threats in near real time. The high-level system interface will be designed as a fixed infrastructure that can be interfaced with JWARN and enable new sensor types to be integrated in a plug-and-play fashion to meet future operational needs and emerging threats. The sensors, their supporting information-system, a wireless network, expert system, and data-fusion capability will be integrated into the cell interface. Hardware will be small and lightweight for low power consumption. DHS will not need to pay license fees for Government-system components.

These technologies offer high payoff potential. The technology's revolutionary miniaturization of sensor and communication systems will use patented technology to detect biological and chemical agents, and demonstrate sensors integrated into a cell-phone communication system. Compared to current systems that cost $25K-$100K and requires much user intervention, the new technology includes: (a) sensor is less than width of human hair, (b) light source, sensor, communications, and battery together are less than 1 cubic inch, (c) specific, (d) easily expandable, (e) uses less than 10 mW for a lifetime of ~80 h. on lithium-ion battery, (f) cost ~$50 using sensor fabrication of existing IC infrastructure, (g) can detect CBRNE agents in parallel, (h) can analyzing liquids & vapors, and (i) provides a flexible sensor network with GPS capability. The Holster [2] backbone provides infrastructure and interoperability with joint defense networks. (j) KASER can process data in multiple formats, provide alerts, and support integration with DHS systems. (k) An open-system prototype can support a wide range of implementations to meet DHS objectives.

In contrast, miniaturization is already underway at SSCSD with MEMS for optical chemical detection. SSCSD continues research in machine learning and expert systems. The MIPS/MEMS FPI/SERS sensors developed at SSCSD consume a few mW of power with 1 sec. analysis times.

These disposable MEMS-based chemical sensors are about 1cc in size and can be placed in arrays. The optical biological sensor based on KASERs can analyze bacterial species in less than 10 sec. KASER outperforms neural networks, genetic algorithms, and case-based reasoners. Both types of sensors can be reconfigured to detect new threat agents. The next-generation chemical and biological threat detection systems will have a wireless networking capability designed into the system, and the CBRNE sensors can be expanded to meet emerging threats using the KASER expert system and the arrayable nature of the MEMS-based chemical sensor. Such a system can be automated, will require very little user intervention, and will be versatile for numerous operational applications.

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References

[1] P.A.. Mosier-Boss and S.H. Lieberman, "Environmental Applications of Surface Enhanced Raman Spectroscopy (SERS)," in *Recent Research Developments in Applied Spectroscopy*, **2**(83), 1999.

[2] M. Ceruti, "Chemical and Biological Threat-Detection Systems of the Future," *Chem-Bio Defense Quarterly*, **4**(2), 18-21, April 2007. http://www.jpeocbd.osd.mil/documents/Vol_4_Issue_2.pdf

[3] G.J. Chaitin, "Information-Theoretic Limitations of Formal Systems," *J. of the ACM*, **21**, 403-424, 1974.

[4] G.J. Chaitin, "Randomness and Mathematical Proof," *Scientific American*, **232**(5), 47-52, 1975.

[5] S.M. Diamond and M.G. Ceruti, "Application of Wireless Sensor Network to Military Information Integration," *Proceedings of the 5th IEEE International Conference on Industrial Informatics (INDIN 2007)* 317-322, July 2007.

[6] Y. Dote and S.J. Ovaska, "Industrial Applications of Soft Computing: A Review," *Proceedings of the IEEE*, **89**(9), 1243-1265, 2001.

[7] D.W. Godso, C. Datte, R. Patel, F. Mirabile, J.S. Steinman, "Network Ready CBRN Sensors: A Way Forward," *Proceedings of the IEEE Sensors Application Symposium (SAS 2006), February 2006.*

[8] S.C. McGirr, "Resources for the Design of Data Fusion Systems," *Proceedings of the 4th International Conference on Information Fusion*, Aug. 2001.

[9] S.H. Rubin, S.N.J. Murthy, M.H. Smith, and L. Trajkovic, "KASER: Knowledge Amplification by Structured Expert Randomization," *IEEE Transactions on Systems, Man and Cybernetics – Part B: Cybernetics*, **34** (6), 2317-2329, December 2004.

[10] S.H. Rubin, "Computing with Words," *IEEE Transactions on Systems, Man and Cybernetics*, **29**(4), 518-524, 1999.

[11] S.H. Rubin, "On the Fusion and Transference of Knowledge: Part I (II)," *Proceedings of the 2003 IEEE International Conference on Information Reuse and Integration*, 144-149 (150-159), 2003.

[12] S.H. Rubin, "On the Auto-Randomization of Knowledge," *Proceedings of the IEEE International Conference on Information Reuse and Integration*, 308-313, 2004.

[13] S.H. Rubin, "System and Method for Knowledge Amplification Employing Structured Expert Randomization (KASER)," *U.S. Patent No.* 7,047,226, May 16, 2006.

[14] D. Swanson, T.L. Wright, M.G. Ceruti, D.R. Wilcox, and S.C. McGirr, "Software Reuse, Design, and Development of Agents in the Knowledge Management for Distributed-Tracking (KMDT) Program," *Proceedings of the 2nd International Workshop on Ontology, Conceptualization, and Epistemology for Software & Systems Engineering (ONTOSE 2007)*, June 2007.

[15] R.L. Waters and M.E. Aklufi, "Micromachined Fabrey-Perot Interferometer for Motion Detection," *Applied Physics Letters*, **81**, 3320, October 2002.

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