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Application of the Smart Portal in Transportation*

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DISCLAIMER

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ABSTRACT

Under a program sponsored by the Department of Energy, the Oak Ridge complex is developing a "Portal-of-the-Future", or "smart portal." This is a security portal for vehicular traffic which is intended to quickly detect explosives, hidden passengers, etc. It uses several technologies, including microwaves, weigh-in-motion, digital image processing, and electroacoustic wavelet-based heartbeat detection.

A novel component of particular interest is the Enclosed Space Detection System (ESDS), which detects the presence of persons hiding in a vehicle. The system operates by detecting the presence of a human ballistocardiographic signature. Each time the heart beats, it generates a small but measurable shock wave that propagates through the body. The wave, whose graph is called a ballistocardiogram, is the mechanical analog of the electrocardiogram, which is routinely used for medical diagnosis. The wave is, in turn, coupled to any surface or object with which the body is in contact. If the body is located in an enclosed space, this will result in a measurable deflection of the surface of the enclosure. Independent testing has shown ESDS to be highly reliable.

The technologies used in the smart portal operate in real time and allow vehicles to be checked through the portal in much less time than would be required for human inspection. Although not originally developed for commercial transportation, the smart portal has the potential to solve several transportation problems. It could relieve congestion at international highway border crossings by reducing the time required to inspect each vehicle while increasing the level of security. It can reduce highway congestion at the entrance of secure facilities such as prisons. Also, it could provide security at intermodal transfer points, such as airport parking lots and car ferry terminals.

KEYWORDS: smart portal, transportation security, ballistocardiographic signatures, systems integration, intruder detection, smuggling, counterterrorism, border crossing, wavelets, real-time instrumentation

1. INTRODUCTION

The Intelligent Transportation System (ITS) is not merely a collection of electronic widgets that have something to do with transportation. Rather, it is defined in the *National ITS Program Plan* (NPP) as an integrated system with specific goals and objectives.[1] At the top of the list of goals is improvement of safety, with increased efficiency and reduced traffic congestion following closely behind. At a cursory glance, one might wonder how these goals are advanced by an electronic system designed to detect intruders hidden in enclosed spaces. However, as this paper will show, all three of these goals are greatly advanced by such a system.

The NPP sees the North American Free Trade Agreement (NAFTA) as having a significant impact on surface transportation. There are 400 million highway border crossings per year, and the number is expected to grow rapidly under NAFTA. The NPP notes that 85% of all the trade between the United States, Canada, and Mexico moves by land. Although "enhanced border crossing" is not explicitly listed as an NPP user service, the Plan does note that electronic methods will be required to make highway border crossings fast, secure, and reliable in the NAFTA era.

The NPP includes several user services that involve security.[2] The Public Travel Security user service minimally addresses the problem of terrorism. Improving the efficiency of traffic flow at international border crossings is one of the goals of the Commercial Vehicle Electronic Clearance user service. In short, security issues are considered in the NPP, albeit tangentially. Nevertheless, part of the intelligence in ITS will eventually be devoted to security, and one of the intelligent systems will be a smart vehicle portal.

The U.S. Department of Energy (DOE) has for a long time been concerned with the problems of smuggling and terrorism in surface transportation.[3] DOE has recently developed a highly successful implementation of a prototypical smart portal.[4] Originally intended to enhance security at DOE facilities, it is a security portal for vehicular traffic and is intended to quickly detect explosives, hidden passengers, etc. It uses several technologies, including weigh-in-motion (WIM) and image processing. An especially novel and powerful component of the smart portal is the Enclosed Space Detection System (ESDS), a system that detects the ballistocardiographic signature of intruders hidden in enclosed spaces.

2. INTERNATIONAL BORDER CROSSING

The most obvious transportation problems involving concealed persons are at highway Ports of Entry at international borders. This is more true than in the past and will be a growing problem in the future. In recent years, the U.S. Border Patrol has become very aggressive at sealing the open country between Ports of Entry.[5] Most dramatic has been Operation Gatekeeper, in the vicinity of San Diego. A consequence of tightening the border in open country is that an increasing number of increasingly ruthless attempts are made to smuggle illegal aliens through highway Ports of Entry.

If border crossing problems are to be solved or mitigated by electronic systems, it is necessary to understand what actually occurs at border crossing Ports of Entry. DOE researchers recently visited several highway border crossings between Mexico and California to test the ESDS under real-world conditions. In addition, while they were there, they observed the following present practices and constraints.

2.1 Government inspection

Four different federal agencies are involved in checking vehicles entering the United States at highway Ports of Entry. The Immigration and Naturalization Service (INS) checks for illegal and improperly documented aliens. The Customs Service checks for contraband, particularly drugs. The Department of Agriculture (USDA) checks for attempts at smuggling agricultural contraband, especially foreign birds. In addition, the National Guard maintains a presence to provide assistance as might be needed.

Away from the Ports of Entry, several other organizations are involved. The Border Patrol is responsible for the border between Ports of Entry. It also operates highway checkpoints well inside the border. In addition, state agencies have various responsibilities. For example, the California Highway Patrol is interested in enclosed space detection at weigh stations.

Two of the agencies use trained dogs as part of the inspection process. Customs uses dogs to search for drugs, and the dogs are trained accordingly as "drug dogs." Although the primary mission of INS is to locate illegal aliens, many of their dogs can find both people and drugs. The dogs are an integral and very important part of the inspection process.

To appreciate the issues involved with border crossings, consider the border crossing at San Ysidro, California. San Ysidro is at the end of Interstate 5, at the border between the United States and Mexico. Being between San Diego and Tijuana, two of the most populous cities in their respective countries, it is the busiest border crossing in the world. It handles only passenger cars and buses. It has 24 lanes entering the United States, with traffic volume ranging between 30,000 and 70,000 vehicles per day. On average, it passes 40,000 vehicles per day, and the first major constraint becomes obvious. The average inspection time per vehicle works out to less than a minute.

The vehicle check begins with a process of "walking the line." As seen in Fig. 1, the actual portal is in U.S. territory, about 50 feet inside the border. Vehicles line up at the portal. Both Customs and INS agents walk up and down the lines of vehicles, making a visual inspection. Sometimes they use dogs and sometimes they do not.

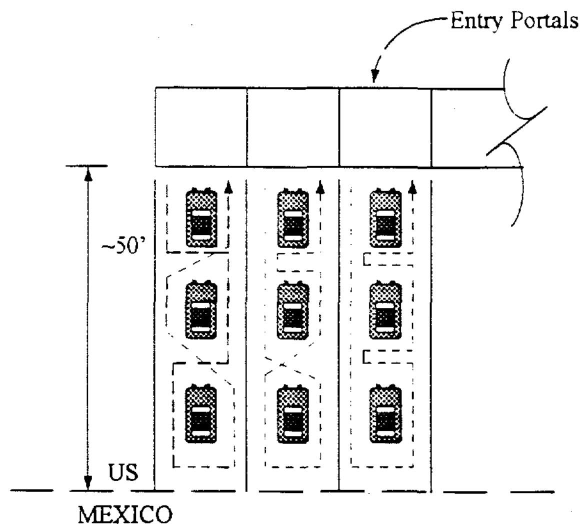

Fig. 1. Walking the line.

The object of "walking the line" is to make a preliminary judgment of which vehicles require further inspection. This is done by looking for anything suspicious, making eye contact with vehicle occupants, observing indications from the dog or anything else that arouses the agent's suspicion. The decision is based on the experience and judgment of the agent and/or the dog.

If a vehicle requires further inspection, the agent directs the vehicle to the secondary inspection area. This is shown in Fig. 2. It consists of parking spaces, each two vehicles long with two long tables between each pair of parking spaces. The tables can be used for various kinds of searches. The secondary inspection area is well suited for electronic inspection devices. It is roofed, fenced, well illuminated, and reasonably well protected from the wind.

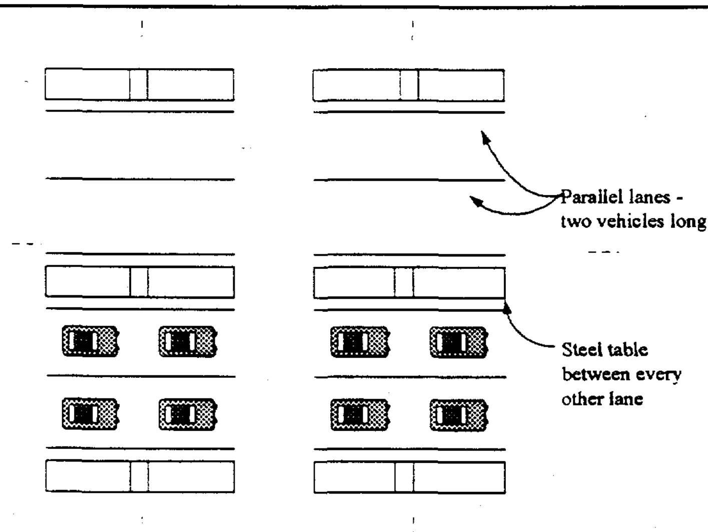

Fig. 2. Secondary inspection area.

The scope and duration of the examination in the secondary inspection area are highly variable and depend on the reason that the vehicles were pulled out of the line, the current number of vehicles under inspection, the completeness of their documentation, and other factors. It might take 5 minutes, or it might take hours. If there is a problem with the documentation, the vehicle occupants must go into the Port of Entry for further discussion with INS agents. Vehicle examinations range from cursory searches to literally dismantling the vehicles, depending on the answers from the occupants and/or indications from the dogs. Many vehicles are allowed to exit the secondary inspection area after questioning. Other entrants may be led away in handcuffs with their vehicles confiscated.

Commercial vehicles passing from Mexico into California use the Otay Mesa portal, several miles east of San Ysidro. This is a smaller portal than San Ysidro and has fewer northbound lanes. It handles a much smaller volume of passenger traffic than San Ysidro. The secondary inspection area of both portals is similar. Both portals use "walking the line" as a method for selecting vehicles for secondary inspection. Because of its lower passenger volume, not as many illegal aliens are caught at Otay Mesa as at San Ysidro. Because of its high volume of commercial traffic, Otay Mesa is the site of the International Border Crossing (IBEX) operational test.

In addition, at Otay Mesa, vehicles are selected for secondary inspection by a randomized process called "blocking." At random times a contiguous block of 20–30 vehicles is pulled out of the primary line and lined up in the secondary inspection area. Agents with dogs then walk this secondary block for some random duration. Again, based on the judgment of the agent and/or the dog, individual vehicles may be selected for detailed inspection while the rest of the block is allowed to pass. Sometimes several contiguous groups are blocked in succession, and sometimes appreciable time passes between blocks. The idea is to keep the blocking as unpredictable as possible. The objective of blocking is to create a high-stress situation designed to induce suspicious behavior in smugglers.

At Otay Mesa, tractor trailers are inspected by the Customs Service at a facility across the road from the regular secondary inspection area. INS or USDA agents do not operate in the Customs Service facility. It is noteworthy that the Customs Service mission is primarily aimed at drugs and other contraband goods. If a Customs Service search turns up illegal aliens or birds, they are turned over to INS or USDA respectively.

In the development of electronic instrumentation for border crossings, these differences between federal agencies need to be taken into account. They have different missions, sometimes use different physical facilities, and even have different operating philosophies. Because they have different problems, they require different solutions.

2.2 Smuggling

The increasingly tight controls enforced by the Border Patrol in the open country between Ports of Entry and the reasonably high probability of successfully sneaking through a highway portal have combined to make the smuggling of illegal aliens a lucrative business. The going rate varies from $100–1000 per passenger per day. Successful delivery is not guaranteed.

The concealment methods attest both to the desperation of the illegal aliens and to the ruthlessness of the smugglers. One popular method is to hollow out the space behind the dashboard and hide a person in the space. Another is to pull the stuffing out of a seat, restuff it with several live illegal passengers, close it back up, and hide the whole business by having several legal passengers sit on the restuffed seat. In one case, two people were wrapped around the engine of a Yugo. In another case, an agent drilling into the panel of a recreational vehicle inadvertently drilled into a hidden passenger.

Since a vehicle must be modified for effective smuggling, the same vehicles tend to be used again and again. This does give a slight advantage to U.S. agents. License tag numbers are checked, and after a time agents do begin to recognize vehicles that regularly pass through the portal. However, it takes time for these patterns to form and for agents to recognize them.

The problem for the agent is not merely to find the hidden passenger but to find the increasingly cleverly concealed hiding spaces. This is both time consuming and dangerous. With 40,000 vehicles passing through the San Ysidro portal in a typical day, it is utterly impractical to spend more than a few minutes inspecting any but the most suspicious looking. Even worse is the danger to the agent. Inserting a hand into a concealed space might lead to contact with anything—a syringe, a venomous animal, or even a dismembered body part. There is an obvious and urgent need for a rapid, minimal-contact method of electronically clearing vehicles that do not have concealed passengers.

2.3 Technological solutions

The Secure Electronic Network for Travelers' Rapid Inspection (SENTRI) is a multiagency (including U.S. Department of Transportation) effort to develop a fast commuter lane at international borders for low-risk travelers. The idea is to have both the car and its occupants (up to four) licensed to use a fast commuter lane. As the scheme is envisioned, any of the licensed occupants would be allowed to drive. Being licensed as a fast commuter does not exempt the licensee from the risk of being pulled over for a secondary inspection.

The fast commuter lane is urgently needed but is beset with practical problems. The transponder identifying the vehicle as a licensed fast commuter must be difficult to counterfeit, and some means is needed to assure that it has not been remounted on an unauthorized vehicle. In addition, a real-time biometric method must be used to assure that the occupants are the legitimate license holders.

In addition, there is the obvious risk that the fast commuter license will be used as a smuggler's pass. To counter this, methods such as WIM are needed. If the reported weight is significantly out of line with what is expected for a vehicle of a given size and number of passengers, it can be pulled over for secondary inspection. In addition, it would be desirable to have the biometric system be able to detect signs of stress, to tell whether or not legitimate license holders are being coerced into smuggling.

The Border Patrol requires electronic systems that are different from those used at Ports of Entry. They operate checkpoints on highways inside the United States, and they can stop trucks that were passed at the border crossing portal. Since the Border Patrol does not have the elaborate inspection infrastructure such as exists at Ports of Entry, they require smaller, faster, and cheaper equipment than might be used by other agencies. Systems based on heartbeat detection seem to be ideally suited for Border Patrol checkpoints.

Systems for remote vital sign detection and remote stress analysis would be most useful for INS operations. Present practices such as "walking the line" and "blocking" are effective at inducing stress, but these methods require a judgment of the subject's stress reaction. These practices would be much more effective, both at quickly and conveniently passing the legitimate traveler and at identifying the smuggler, if they were supported by a real-time noncontact vital sign detector.

In addition, INS needs instrumentation to speed up and reduce the risks associated with operations in the secondary inspection areas. The basic objective is to be able to tell as much as possible about the vehicle from a rapid external inspection. WIM and heartbeat detection technologies both appear to be the most promising.

A whole vehicle X-ray system is being tested at Otay Mesa. It was developed by American Science and Engineering. It uses backscatter and forward transmission. The system can identify a range of objects, including concealed weapons, explosives, organics, and concealed occupants. It requires about 6 minutes to operate.

3. INTERMODAL COUNTERTERRORISM

In addition to border crossings, there are several other areas in which smart portal technology is of interest to the transportation community. Smart portal technology was originally developed for use at the point of interface between the transportation system and secure facilities, generally intended to keep intruders out. It can also be used in the other direction at facilities such as prisons, where the idea is to prevent people from sneaking out, hidden in departing vehicles. This is more of a problem for the facility than the transportation system, but delays at a security portal cause congestion in the transportation system.

However, there is an issue even more relevant to the transportation community. The ITS is viewed as a single integrated intermodal system. The major objectives of ITS are to get travelers swiftly and safely to their destinations.

Increasingly, terrorism is a major threat to that safety. Although not yet widely appreciated, one of the functions of the intelligence in ITS will be to mitigate the terrorist threat.

One of the most effective ways to counter terrorism in the transportation system is to place detection electronics at the points where various transportation modes interact. Highway vehicles are convenient for the concealment of explosives or people, but large transportation systems (with large numbers of potential victims) are a preferred target of terrorists. Where better to stop terrorism than at the point where highway vehicles interact with high-volume transportation modes?

This is particularly true at airports. Ultimately, airport security will need to be addressed as a total security problem rather than as a collection of detecting widgets. Within such a total security system, a device for detecting hidden persons in cars attempting to enter airport parking lots and access areas could prevent terrorist acts by preventing the terrorist from even entering airport grounds. Probably even more important, a great many vehicles (catering trucks, fuel trucks, etc.) drive right up to airplanes preparing to depart. One of the greatest weaknesses in the present practices of airport security is that there is no efficient means for detecting intruders hidden in these support vehicles.

A truly effective tightening of airport security would have an undesired side effect. Although presently less widely used, and less well known, other intermodal transportation systems could become inviting targets for terrorists. It is easy to imagine that unsecured intermodal systems such as car ferries, car trains, or pallet-based automated highways will become more widely used in the near future than they are now. It is also easy to imagine that these unsecured systems would be easy prey to anyone seeking to kill a large number of people with small risk of being detected.

There are two fallacies that presently bedevil efforts at counterterrorism. The first is the assumption of the rational terrorist. It is often assumed that the terrorist is unwilling to die in the act, but there is no basis for believing this. The second is that if you ignore it, it won't happen. Although the NPP has safety and security as objectives, it practically ignores counterterrorist measures.

A system for detecting persons hidden in vehicles overcomes both of these fallacies. It detects intruders, including those bent on suicide. More to the point, it does so by putting a good, fast, and cheap detector at the intermodal interface point through which the intruder must pass.

4. SMART PORTAL

The objective of the DOE Smart Portal Project is to significantly improve the functional security operations of portals that control personnel and vehicular access to areas containing special nuclear material (SNM). The vehicle under inspection is stopped in the portal, and the engine is turned off. If necessary, sensors can be attached to the vehicle. It is desirable to make the inspection as fast as practicable. For the safety of the security personnel, it is desirable to make the inspection as nonintrusive as possible. While faster and less intrusive than conventional security methods, the smart portal nevertheless provides a higher level of overall security.

To demonstrate how this can be done, an integrated system of state-of-the-art sensors is being installed in an existing portal at the Y-12 Plant in Oak Ridge, Tennessee. This provides a realistic test and evaluation basis for the project. The sensor systems simultaneously deployed at this portal include: (1) the ESDS, a heartbeat sensor system for detecting unauthorized personnel hidden in vehicles ranging in size from passenger-size cars through 18-wheel tractor trailers; (2) several types of real-time digital imaging systems for examining the undercarriages of vehicles for hidden contraband, (3) SNM detection systems for both personnel and vehicles, and (4) a WIM system for weight measurement of moving vehicles entering and leaving the portal.

Two different digital imaging systems are used to visually inspect the underside of vehicles that drive through the security portal. The two systems use different methods, line scan and area scan, to electronically scan the vehicles. The line scan system was purchased from Remotec, Inc., of Oak Ridge. The area scan system, Fisheye, was borrowed from the Police Scientific Development Branch in England.

The goals of the SNM detection program are to develop specifications for SNM vehicular portal monitoring of ^{235}U, factor cost and benefit into its design, and recommend possible upgrades. To achieve these goals, a select group of

DOE contractor physicists and engineers was assembled to evaluate the existing capabilities for detecting SNM and recommend possible improvements. The team has developed a set of top-level requirements for the portal SNM system. Because of funding constraints, further work on SNM detection has been delayed until FY 1997.

The WIM system uses a bending plate–strain gauge type of sensor. Transducer hardware was furnished by PAT Equipment Corporation and has been installed at the McGhee Tyson Air National Guard Base, Tennessee Transportation Technology Test Track, where it will be tested and calibrated prior to final installation at the Y-12 portal. The transducer pads are installed in ground, and it has been determined that the inbound WIM transducers would be located ~75 feet from the guardrail/portal entrance. The vehicles would queue up 75 feet prior to the transducer. The entire 150 feet will be leveled and will preferably be a concrete base. The outbound system will have the same 150-foot requirement and will be located some distance prior to the portal to assure that a level surface can be provided.

5. ENCLOSED SPACE DETECTION SYSTEM

If a live human being is located in an enclosed space, small but theoretically detectable deflections of the surface of the enclosure will result. Each time the heart beats, it generates a small but measurable shock wave that propagates through the body. The wave, plotted as a ballistocardiogram[6] (Fig. 3), is the mechanical analog of the electrocardiogram, which is routinely used for medical diagnosis. The wave is, in turn, coupled to any surface or object with which the body is in contact.

Fig. 3. Human ballistocardiogram.

In the case of the smart portal, the enclosure is the vehicle being inspected in the portal. The sensors, either geophones temporarily placed upon the vehicle or microwave motion detectors standing a few feet back from the vehicle, produce an analog signal proportional to the movement of the outer surface of the vehicle. The analog signal is amplified and low-pass filtered before being fed to an analog-to-digital converter.

When the operator initiates the start of a test, the program collects data from the sensors at a predetermined rate and for a predetermined duration of time. The data are analyzed using wavelet transform techniques to determine if a person is in the vehicle. The entire operation takes less than 20 seconds.

At the present level of development, the geophones give more reliable performance than the microwave sensors. Since the use of geophones requires the operator to physically place the geophones on the vehicle before the test and remove them after the test is over and since the microwave sensors require no physical contact, development of the microwave sensors is still continuing. While the use of microwave sensors would relieve the operator of having to place sensors on the vehicle, they require a structure above the vehicle on which to mount the sensors. Therefore, the geophone remains the preferred sensor for portable systems.

The operator interface uses a video touchscreen. The operator selects from one of the four vehicle types that best matches the vehicle to be tested. Each of the four vehicle types has unique analysis parameters. These parameters tell the system how many sensors to interrogate and what detection limits are to be used in the analysis routines. The operator also tells the system if the wind conditions are calm or windy. The system adjusts the detection limits used in the analysis routine to correspond to the wind conditions. The results of the analysis (including the decision to pass, search, or try again) are displayed on the video screen.

A portable ESDS has been built and tested. It can be powered from ac mains or a 12-volt car battery. Either microwave or geophone sensors can be used, but the geophone is usually the sensor of choice.

6. ESDS WAVELET DETECTION ALGORITHM

A fast, continuous wavelet transform based on Shannon's sampling theorem in frequency space has been developed for use with continuous mother wavelets and sampled data sets. The continuity of the wavelet function is kept up to the point of the time-scale sampling, and Shannon's theorem lets us view the Fourier transform of the data set as the samples of a continuous function in frequency space. Thus the time-scale grid used to represent the wavelet transform is independent of the time-domain sampling of the data function. This allows versatile representations of the transformed data to be rapidly altered and displayed.

The fast, continuous wavelet transform has been applied to forensic audio reconstruction, speaker recognition/identification, and (in ESDS) the detection of micromotions of heavy vehicles associated with the ballistocardiac effect due to any occupants. Audio reconstruction is aided by selection of desired regions from background-noise regions in the 2-D representation of the magnitude of the transformed signal. Methods of ridge and skeleton reconstruction are then selectively applied to the selected regions to recover the sounds of interest, unencumbered by masking noise. To separate micromotions imparted to a mass-spring system (e.g., a vehicle) by an occupant's beating heart from gross mechanical motions due to wind and traffic vibrations, a continuous wavelet, based on the frequency content of a canonical ballistocardiogram, was used to analyze a 20-second time series.

By using a family of mother wavelets, as in a set of Gaussian derivatives of various orders, different features may be extracted from the underlying data. For example, consider the Gaussian-derivative wavelet transform of a speech signal shown in Fig. 4. The "blobs" reveal the glottal-closing rate, while the ridges of a high-order wavelet give good indication of the formant frequencies and allow easy word segmentation.

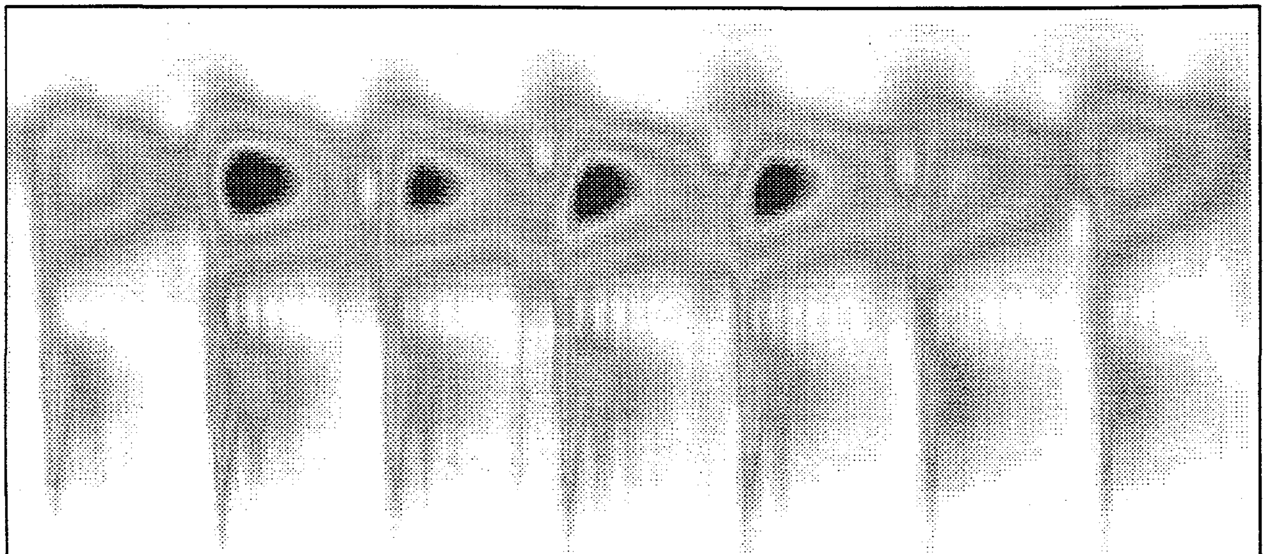

Fig. 4. Continuous wavelet transform of time series.

With these properties in mind, we proceed to analyze a particular canonical ballistocardiogram signal taken from the open literature. The main spectral peaks show a clear, harmonic pattern. Of course, any particular individual's heart signal would not have the same frequency or spacing, and the repetition rate can vary nominally from 50 to 150 beats per minute. These constraints led us to choose a wavelet in the Fourier space that was constructed to have both a variable scale (the spacing) and a variable location (main frequency). Thus, our wavelet transform results in a 2-D plot of intensity versus both scale and position (Fig. 5).

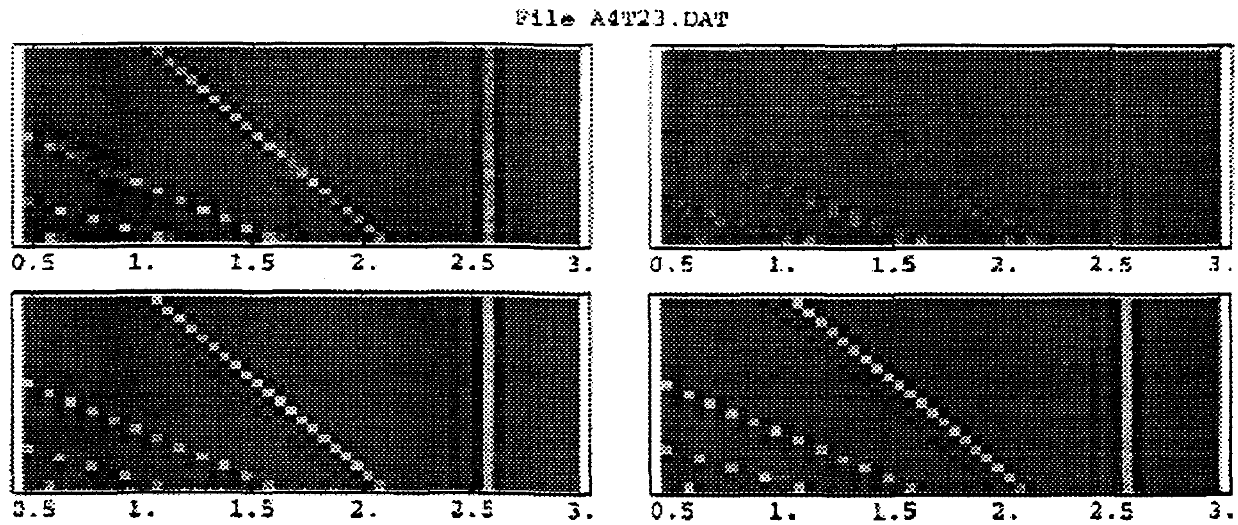

Fig. 5. Wavelet analysis of intruder ballistocardiogram.

The original ESDS used Fourier analysis, and improvement has been made in its detection capability by the use of wavelet analysis. A wavelet approach to analyzing ESDS detector signals is appropriate for two reasons: the signal-to-noise ratio is very unfavorable for a positive identification of a ballistocardiogram signal and the ballistocardiogram signal itself has some particular wavelet-like characteristics that could lead to a sensitive method of analysis. The ballistocardiogram signal is quasiperiodic (approximately once per second) and shows a particular spectral pattern; there seem to be only a few significant harmonic components. Wavelet methods are well known for their ability to analyze impulse-type signals, even of irregular period, and they also can be made to function as high-quality low-pass filters. The first continuous wavelet algorithm developed for ESDS was tested using 114 data sets previously obtained from various vehicle scans. These tests resulted in a 95.7% correct detection rate.

It may seem somewhat odd to use continuous wavelets in a real-time system. Wouldn't discrete wavelets be computationally cheaper? The conventional dyadic discrete wavelet lacks the scale resolution to reliably extract the heartbeat from the noise. To obtain finer scale resolution, 11 sets of experimental data were analyzed using three levels of the four-channel discrete 16-coefficient wavelet filters developed by Alkin and Caglar.[7] The high regularity filter produced slightly more reliable results than the high coding gain filter, but neither was a dramatic improvement over the discrete Fourier methods originally used in ESDS. None of these discrete methods are nearly as reliable as continuous wavelet methods.

Additional continuous wavelet algorithms have been developed and tested on recent ESDS data sets taken from the Y-12 portal installation. The goal is to develop methods of ballistocardiac analysis that are insensitive to vehicle weight as well as vibration effects due to the wind and passing traffic. The possibility of using phase information inherent in the transformed data is being explored with the hope of allowing a relaxed threshold setting for the data acquisition phase. Preliminary results suggest that this method reduces sensitivity to vehicle weight.

Recent microwave data from the Y-12 portal have been examined with the view of correcting for the presence of wind and vibration effects. Prefiltering of the microwave channel with the three geophone channels measuring the vibration of the structure is able to remove most of the effect of wind, at least up to 16 miles per hour. The resulting spectra show presence or absence of intruder signatures in the correct frequency range without masking peaks.

7. RESULTS

An independent test of the ESDS was performed by the Thunder Mountain Evaluation Center (TMEC) at Fort Huachuca, Arizona. The TMEC evaluated the performance and operational effectiveness of the ESDS. Its testing took approximately 6 months and used a wide variety of vehicles. Except for railroad boxcars and diesel trucks with the engines left running, TMEC's evaluation of the ESDS using geophones obtained a very high correct detection rate. TMEC found that the use of *a priori* knowledge of the size of the vehicle and wind conditions substantially improved the reliability of the system. The general impression was that ESDS was well suited for border crossings, prisons, etc. Several operational recommendations emerged from the test and have been incorporated into the system.

An ESDS portable unit has been operated in several INS secondary inspection areas. It was demonstrated at San Ysidro for 8 hours on August 27, 1996, and at Otay Mesa for 6 hours on August 28 and 2 hours on August 29. After 5 minutes of training, INS agents at both locations were able to use it to inspect vehicles. Checks were run on a wide range of vehicles, such as sedans, recreational vehicles, panel trucks, and vans. All tests were done by temporarily setting two geophones on the exterior of each vehicle. As is typical in the operation of the ESDS, minor adjustments of the instrument were made to compensate for ambient breezes.

In addition to the demonstrations at the California–Mexico border, ESDS has been demonstrated to the Georgia and Oregon Departments of Corrections and to Canadian immigration officials. It has also been installed in two prisons in California and one in Tennessee.[8] All observers have been impressed with the simplicity of using the system and its ability to reliably detect persons hiding in vehicles. GeoVox Security Corporation in Houston, Texas, has signed a licensing agreement with the Lockheed Martin Office of Technology Transfer to manufacture and sell the ESDS as a commercial product.

Repeated tests and demonstrations have shown ESDS to be easy to use and nearly 100% reliable. It provides three valuable benefits. First, if a vehicle does not contain a hidden passenger, the ESDS can establish the fact within 20 seconds of operation. Contrast this with a physical search that requires many minutes. Using ESDS, the throughput of a portal can be greatly increased while enhancing the level of security.

In fact, ESDS significantly enhances the level of security and could change the entire pattern of alien smuggling. It is estimated that at least nine out of ten hidden aliens successfully evade present detection methods; the odds of success are good enough to make smuggling a popular business. The high level of reliability demonstrated by ESDS in various tests can reasonably be expected to be repeated when used in everyday practice. The odds of success should be reduced enough to make alien smuggling not worth the risk.

The third benefit is dramatically increased safety for the agents conducting the inspection. Operation of the ESDS does not require that the agent touch anything in the interior of the vehicle. For every vehicle that can be dismissed without a physical search, the risk of encountering dangerous objects is eliminated.

ESDS is a substantial contribution to ITS technology. It has been extensively and independently tested and shown to be highly effective at detecting people hidden in vehicles. It greatly simplifies border crossing inspections while increasing the level of security. It would be very effective as an intermodal counterterrorist device. If widely used near the entrances of secure locations such as prisons and weapons plants, it would substantially reduce highway congestion.

8. ACKNOWLEDGMENTS

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