AUTOMATED INSPECTION OF HUMAN PRESENCE INSIDE VEHICLES THROUGH HEARTBEAT DETECTION TECHNOLOGY

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Abstract: Unauthorized access to high-risk facilities may put in danger people, infrastructure and the business itself. Nevertheless, in a recent past, security was not among the major port concerns, which were focused mainly on its trade efficiency. That changed after the September 11th events in 2001, when new international security standards were released. These standards require, among other items, access control to the port perimeter. Ports are critical nodes in complex transportation systems, and any security procedure must be put in place without affecting the port efficiency, which means, for a commercial port, the continuous flow of cargo trucks. This paper presents a system that detects any human presence inside a vehicle or cargo container, without the need to access the cargo or the interior of the vehicle. This is achieved through the use of seismic sensors, which are easily mounted on the truck frame. These sensors measure the subtle vibrations on the vehicle surface, caused by the shock wave generated by any human heartbeat, no matter where the person is hidden. A commercial system has already been successfully installed in several ports in Europe and Africa and U.S. prisons, and is recently available in Latin America. This heartbeat detection system is quick and easy to use, cost effective and has little staff involvement. This allows the application of the inspection procedure to change from some sample vehicles to a very large number or even all vehicles. Some theory, challenges and future developments involved in this application are also presented.

Keywords: Port security. Human detection. Heartbeat detection. Ballistocardiography, Seismic sensors.

1 Introduction

Perimeter security is of great importance in facilities where unauthorized access may put in danger people, equipments, installations and the business itself. Some examples include prisons, high-risk industries (e.g. nuclear, mining and some manufacturing plants) and ports.

Regarding prison infrastructure, several vulnerability assessments reveal the perimeter and vehicle sallyport as the weakest links. The intense flow of incoming and outgoing vehicles seriously compromise the perimeter. Although local policy may authorize or even require vehicle searches, they become labor intensive and their margin for error is high, when executed “manually”, simply because the vehicles are often filled with piles of boxes, materials or even garbage. For instance, one inmate could eventually try to hide inside a truck, and any escape is too many when it comes to public safety. (JOYNER, 2018)

When it comes to port security, the scope is to prevent any intentional unlawful acts that could eventually threaten personnel safety (workers, passengers or crew) and affect economy (e.g. property damage, loss of revenue, trade disruption). Ports are
critical nodes in very complex intermodal transportation systems. Some of the ports’ main characteristics are:

- They have complex and critical infrastructures.
- They are important control points within the transport network and national borders.
- They sometimes involve a mix of public and private spaces.
- They involve an important mix of trusted and announced flows of persons with unannounced or unknown flows, including stowaways and illegal immigrants.
- They involve the access and control of pedestrians, drivers or passengers transiting through public or restricted spaces by a large variety of means.
- Their security is subject to specific international regulations. (ANDRITSOS, 2013)

Specially in commercial ports, security must be assured without penalizing excessively the trade, which generally means the flow of hundreds or thousands of trucks per day. There is no single solution for border security challenges, but layers of defense, aided by new technology, can help better manage the challenges.

The aim of this paper is to present a technology that can remotely detect human presence inside cargo trucks, without the need to access the cargo. A commercial system is already installed in several ports with proven results, without compromising the port efficiency.

2 Port security

The notion of safety and security are considerably close to each other, and may sometimes cause confusion, especially in those languages where only one word for both terms exists (French and Portuguese, for example). Safety is usually associated to the protection against non-intentional hazards, while security is perceived as a protection against intentional threats (crime, terrorism, corruption, behavioral misconducts, etc.). Security, then, aims at identifying potential intentional threats and preventing (or minimizing the probability of) them from happening.

Up until the September 11th events in 2001, security was not among the major port concerns, which were driven mainly by economic efficiency. In response to these events, the International Maritime Organization (IMO) agreed on new security standards for maritime transport, which resulted in the International Ship and Port facility Security (ISPS) code - an amendment of the Safety of Life at Sea (SOLAS) convention - released in 2004, and became one of the cornerstones of maritime security at world level. The amendments of the SOLAS convention and ISPS code, even if subject to interpretation, are mandatory for the Member States (Brazil among them). (SECURITY REGULATION, CONFORMITY, ASSESSMENT & CERTIFICATION, 2011)

Port facilities may be subject of periodic security inspections to guarantee certifications (certified ports are listed within IMO’s website), and subsequently, a high level of accordance to the standards. Among others, the following items are evaluated...
Identification of perimeter protection, access control and personnel clearance requirements for access to restricted areas of the port.

Identification of the port perimeter and, where appropriate, the measures for access control.

The goal of access control is to ensure that only authorized people enter the port perimeter, by controlling the flow of persons within some access points (i.e. entrances and exits). It is usually executed by a combination of human, locks and IT systems.

Person identification and authorization is usually automated though badges or even biometric identification, and do not present a bottleneck to the continuous inflow of vehicles. The detection of unauthorized human presence inside vehicles, though, is typically poorly automated, limited to a few random vehicles and consumes considerable time and human resources. Not to mention that human guards may be subject to bribery or threatening conduct. X-ray scanners are sometimes used for cargo verification, but truck cabins are not inspected to avoid the driver exposure to radiation.

It is interesting to mention that human presence detection may have different objectives, depending on the location, such as finding illegal immigrants hidden among the cargo in Europe and in the United States, and preventing that truck drivers access the port with their families hidden inside the cabin in Latin America.

3 Ballistocardiography in Medicine

Before explaining the automated method of human presence detection, some explanation about the human body and earlier developments is necessary. Ballistocardiography (coined from the Greek, (ball) “throw” + (kardia) “heart” + (graphia) “description”) is a method for obtaining a representation of the heart beat-induced repetitive movements of the human body, occurring due to acceleration of blood as it is ejected and moved in the large vessels. (PINHEIRO, 2010)

In medicine applications, if a patient is placed on a table with very low friction, these body movements can be detected by a sensitive accelerometer on the table. This exam is called ballistocardiogram (BCG), and one of the first machines (shown in Figure 1) was made by Nihon Kohden in 1953.

![BCG machine](https://proceedings.science/p/89375)

Figure 1 - BCG machine made by Nihon Kohden in 1953. Source: Nihon Kohden.

The theory supporting this technique has been known, then, for over 50 years, but due to the small ratio of blood mass, when compared to the mass of the body and table, the experimental errors were large. Recent modern signal processing
techniques, though, have allowed the reduction of these errors, turning this almost 
forgotten physiological measurement into a field with renewed interest.

Its main application continues to be for medical purposes, primarily as a non-
intrusive indicator about the cardiovascular system status, through the body’s 
vibrations caused by cardiac and respiratory signatures. (PINHEIRO, 2010) Since the 
ballistocardiographic curves are recognized to show abnormalities indicating a failing 
heart (SELZER, 1988), it is an accurate indicator of the heart’s age, much better than 
the chronological age of a person.

4 Heartbeat detection system

Sensitive accelerometers, such as the ones used in medicine, are also applied 
as seismic sensors, converting ground motion (e.g. earthquake signals (HAVSKOV, 
2004) and snow avalanches (HECK, 2018)) into an electrical signal. Advances in 
seismic sensor technology, data acquisition systems, digital communications, 
computer hardware and software allowed the development of reliable real-time 
earthquake information systems that, in some cases, even provide warning seconds 
before the arrival of seismic waves, a concept called front detection. (ALLEN, 2009; 
KANAMORI, 1997) It is an important measure not only to alert public services and 
minimize impact to the general population, but also to trigger quick response actions 
in industrial facilities - such as preventing leaks of hazardous gas, executing 
emergency shutdown and sounding alarms - to prevent secondary disasters.

Special seismic sensors are, finally, the main components of a proven solution 
that detects the presence of persons hidden inside vehicles, measuring subtle 
vibrations on the vehicle surface caused by the shock wave generated by the human 
heartbeat. (SHAHBAZIAN, 2008) This is a simple, quick to use and extremely effective 
method. A patented commercial solution named MicroSearch® was - and continues to 
be - developed by ENSCO Inc., an international technology enterprise headquartered 
in the United States, working in the aerospace, avionics, national security and rail 
sectors since 1969.

As already mentioned, the heartbeat detection technology is based on a 
physiological characteristic common to all humans: it measures the vibration produced 
by the beating human heart. No matter who and where the person is hidden (inside the
container, behind cargo boxes, under heavy blankets, etc.), its presence will be detected.

The heartbeat detection system is composed by the following components, shown in Figure 2: (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016)

- 2 vehicle sensors;
- 1 to 3 ground sensors;
- control box module;
- USB and sensor cables (for wired sensors);
- AC/DC power supply;
- Computer and signal processing software.

The vehicle sensors (shown in Figure 3), made by polycarbonate or steel, are designed to be temporarily magnetically attached to the vehicle’s chassis or steel frame on the bottom side of the vehicle. From the outside, they detect the very slight vibrations caused by the heartbeat of a person inside the vehicle. In the initial versions of the system, these sensors were linked to the control box module through electrical...
Recent developments resulted in a new option with wireless sensors, with easier installation and more accurate readings.

Figure 3 - Vehicle sensors. Source: (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016).

Ground vibrations are sensed by up to three ground sensors to filter environmental vibrations that could interfere with the detection signals (e.g. nearby traffic, generators, construction equipment). The signal processing software also filters any other vibrations that fall outside heartbeat frequency ranges.

Vehicle and ground sensor signals are connected to, and monitored by, the control box module. Vibration data is filtered and analyzed in this module and results passed on to the system computer or tablet. The software application supplies the user interface for conducting vehicle tests, entering vehicle and driver data, generating reports, and managing data and user configurations.

An optional camera may be provided with the system, to capture an image of the vehicle, including license plate for storage in the database.

Inspections can be executed from small/light to very large/heavy vehicles. Before a test can be conducted, the operator must configure a sensor sensitivity, which is dependent on vehicle weight. This fine tuning parameter is important to guarantee that any human presence will be detected, while reducing the chance of false detections. Figure 4 shows the recommended configuration values for each weight range.

<table>
<thead>
<tr>
<th>Vehicle Weight (Pounds)</th>
<th>Vehicle Weight (Kilograms)</th>
<th>Sensor Sensitivity Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5,000 pounds</td>
<td>&lt;2268 kilograms</td>
<td>1</td>
</tr>
<tr>
<td>5,000-15,000 pounds</td>
<td>2268 – 6803 kilograms</td>
<td>2</td>
</tr>
<tr>
<td>10,000-40,000 pounds</td>
<td>4535 – 18143 kilograms</td>
<td>3</td>
</tr>
<tr>
<td>30,000-70,000 pounds</td>
<td>13607 – 31751 kilograms</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 4 - Sensor sensitivity configuration. Source: (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016).

The heartbeat detection system is adaptable to various operational scenarios, depending on the nature of the guarded facility. The system can even be mounted on a light vehicle to serve as a mobile inspection station. Regardless of the scenario, the
inspection procedure is detailed below: (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016)

1. Driver turns off vehicle engine and all other engines on the vehicle (generators, refrigerators, etc.).
2. Driver and any passengers close all windows.
3. Driver and any passengers exit the vehicle and close the doors.
4. Operator places vehicle sensors on front and rear frame (as shown in Figure 5).
5. Operator places ground sensor(s) (as shown in Figure 5).
6. System inspects vehicle in less than 1 minute.
7. Result is displayed in the computer and sent to remote location (if desired).

Figure 5 - Sensor placements. Source: (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016).

Figures 6 and 7 show the signals of vehicle and ground sensors, and the results for a “pass vehicle“ (no person detected) and “search vehicle“ (person detected).

Figure 6 - “Pass vehicle“ inspection result. Source: (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016).
Wind has long been a technical challenge for any heartbeat detection system due to its ability to create vibrations that either mask or mimic the subtle ones being detected on a vehicle. Every vehicle reacts differently to the wind and wind is a very dynamic event that changes in speed and direction constantly. High winds may cause the vehicle to experience significant vibrations and eventually cause the system to abort a test.

Because of this, an optional anemometer may be added to the system, to measure and display wind speed and direction. While the wind effect on system performance is not completely mitigated, this information may add value to the operator’s experience and decisions on how to achieve the best use of the system.

Winds of less than 7 mph (approximately 11.2 km/h) rarely affect the detection system. Between 7 and 15 mph (approximately 24.2 km/h), the effect of the wind depends on the specific vehicle and wind direction. Wind velocities greater than this can produce a test “aborted” indication. (MICROSEARCH SET-UP, MAINTENANCE AND USER’S MANUAL, 2016)

In some cases, the container stacks can serve as a barrier for protection against the most common winds. Nevertheless, in some locations the wind profile may require the use of a building (without any special requirements) for the vehicle inspections.

The inspection results can be automatically sent to monitoring rooms, far from the inspection locations, where the operators are not subject to bribery or threatening conduct. These remote operators could eventually request a more detailed search and follow it live through cameras.

ENSCO has several successful implementation cases in European and African ports, as long as in U.S. prisons. To our knowledge, this state-of-the-art technology is still not implemented in any Latin American facility, where the brazilian company Ledefi Automacao serves since recently as a local representative.

5 Conclusions
Port facilities require a high degree of security verifications without penalizing the trade, especially in commercial ports. Human presence detection inside the vehicles gains major importance in locations with possible occurrence of illegal immigration, terrorist events or any unauthorized access. The intense and continuous flow of vehicles, specially cargo trucks, demands an automated human detection technique without the need to access the interior of the vehicle.

This article presented a commercial solution successfully installed in several port and prison facilities, which detects, using highly accurate seismic sensors put in the front and rear frames of the truck, the presence of human heartbeat without accessing the cargo or the truck cabin. Its main benefits are:

- Exposes individuals hiding in vehicles at border and port security checkpoints.
- Dramatically increases detection of individuals, not easily seen by security staff, in vehicles and containers even with good visual inspection procedures.
- Patented ground sensors filter out environmental vibrations for more precise results.
- Rugged weatherproof design allows reliable operation in extreme climates, including dry, dusty, wet and cold environments.
- Provides a proven technology-driven force multiplier to augment manual procedures and speed up inspection timeframes, providing accurate results in less than two minutes.
- Visually and audibly alerts security officers to the presence of individuals hiding inside vehicles.
- Compact portable units make it easy to move among multiple locations.
- Database documents results and stores details, such as when vehicle inspections were conducted and by whom.

This heartbeat detection system is quick and easy to use, cost effective and has little staff involvement, allowing ports to increase their security inspections without affecting their efficiency.

The development of the system continues, focused on reducing the effects of the wind and eventually avoiding the need to turn off the vehicle engine.

REFERENCES


