Automated non-intrusive cargo inspection system using gamma-ray imaging (ROBOSCAN 1M)

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Abstract: Non-intrusive inspection of cargo containers has become a key issue in recent years to parry terrorist activities and to easily verify the shipping content at customs in order to avoid contraband. Such systems are mainly based on X- and gamma-ray radiography which offer inside images of the cargos. In this article we present a non-intrusive inspection system based on gamma-ray imaging called ROBOSCAN 1M. The system has a lower radiation field compared to existing X-ray systems, providing a smaller operational area and exclusion safety zone. It requires also less maintenance at a lower cost. It is also able to scan containers, vehicles, rail cars, while automatically detecting radioactive materials.

Key–Words: Gamma rays, Cargo inspection, Image processing, Transportation, Security

1 Introduction

In present days, there is a worldwide need for effective scanning of cargo containers in order to detect possible contraband such as drugs, explosives, nuclear materials or weapons, as well as the check of declared manifests. The manual inspection of large containers is not practical because of the time constrains and the high labor requirements for unpacking and repacking the cargo content. Therefore, there is a need for non-intrusive scanning systems.

Most non-intrusive cargo screening systems are based on the use of a radiation (X- or gamma-rays). Those systems can provide high-resolution intensity images of the cargo contents and are well suited for detecting metal-based objects such as weapons. The images obtained from the systems are easy to interpret due to the high contrast shapes obtained from the scanning. The most used technologies are based on X- and gamma-rays [5, 10, 12].

X-ray based inspection systems are the most common form of non-invasive inspection technology. Those systems can detect differences in material densities in order to produce an image of the cargo content. The images obtained from the scan is visually inspected by the human operator in order to detect anomalies in the cargo content, together with the use of dedicated software. Due to the nature of X-rays methods, specific materials cannot be detected [3]. Therefore, the use of more advanced technologies such as gamma-rays is needed in order to detect specific materials like drugs and explosives [1, 4].

Gamma-ray non-intrusive inspection systems are an alternative to standard X-ray systems. They use gamma-rays in order to produce an intensity image or 3D mapping of the cargo content. Few of the detectable substances are carbon, nitrogen, silicon, oxygen. chorine, iron or aluminium.

The average inspection throughput of gamma-ray systems is more than 10 times greater than the fastest X-ray system. The gamma-ray inspection systems can be produced also as mobile or fixed-site units, and they cost 3-20 times less than the X-ray systems in terms of initial capital investment.

2 System description

The non-intrusive inspection system radiographies containers, vehicles, rail cars or any other large objects, providing as well under side video image, automatic radioactive materials detection, documents integrity checking, having the capability to save complex files containing the results of all mentioned performed inspection in to a unique folder.

2.1 Overview

The system can be used to inspect the a.m. items by passing through a radioactive materials detector, then through an under side video imaging subsystem, finally being scanned with gamma-ray, to create a radiography, that can be evaluated together with the under view real image, according the content of transport

Figure 1: Visual representation of the system. The sensors are mounted on an articulated arm placed on a truck. All command and control is made at distance using a dedicated equipment mounted inside a Mobile Control Center (MCC)

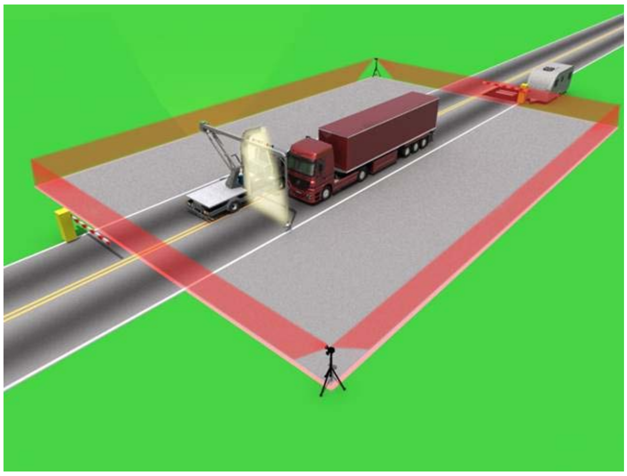

Figure 2: Operational deployment of the system. The Mobile Scanning Unit (MSU) moves along the inspected container. For security reasons, an exclusion zone is delimited and signaled using perimetric sensors. The Mobile Control Center (MCC) is operated outside this region

documents that can be checked with Video Spectral Comparators (VSC) in order to detect the eventually forged documents.

2.2 The Mobile Control Center (MCC)

All mobile scanning systems, that are presently known, have the operator's cabin mounted on the truck's chassis, exposing the operating crew to professional and/or accidental irradiation risks. The present system eliminated this risk by separating the operator's cabin on *Mobile Control Center* (MCC) organized inside a caravan that during scanning process is placed outside of the exclusion area and during transport is attached to the scanner vehicle. From this cabin the operator can remote control all processes by Wireless Local Area Network (WLAN).

Another major difference between the known systems and the presented one is that ROBOSCAN 1M doesn't need a driver to control the truck's movement (drive direction, sense, steering, brakes, vehicle's parameters, etc.) These functions are managed by a *driverless* subsystem that controls all the commands and parameters of the truck (figure 1).

The operation of the system is fully automated, allowing to be controlled by a single person, insuring in the same time additional inspections by detecting radioactive materials in the scanned cargo and generating a underside video image, extremely useful for a better understanding of the radiography, as well to determinate if additional objects where attached on the underside of the vehicle with fraudulent intention.

The non-intrusive inspection method manage the access of the vehicle that is to be scanned in the exclusion zone, through an automated traffic flow management subsystem that automatically controls the entry/exit barriers and traffic light (figure 2). The vehicle to be inspected, pass through a radiation materials detector and over a special designed video camera subsystem to realize the underside video image, finishing by placement in a marked area in order to be scanned.

2.3 The Mobile Scanning Unit (MSU)

As the driver leaves the exclusion zone, the perimeter protection of the exclusion area is automatically activated, followed by the initiation of the scanning process by remote commands transmitted to a *Mobile Scanning Unit* (MSU) in order to switch on the radiation source and to initiate the slow, constant movement along the scanned truck/container. The movement is automatically controlled by electronic and informatics modules, connected with the control center in WLAN, used to transfer commands, real time status information and image data.

The scan process is automatically stopped in one of the following cases, when the detector boom reached the end of the scanned vehicle and consequently, the detectors receive the maximum level of radiation, at the end of the programmed scanning length, when the protection limiter of the movement is triggered, when the perimeter protection of the exclusion area has been breached, when the proximity sensor has been triggered, indicating dangerous distance between the detector boom and the scanned vehicle, when obstacles are detected by the sensors placed on front and rear of the MSU.

The emergency stop of the scanning process can be as well, manually commanded any moment by the operator or any other person accessing the emergency stop buttons, placed on the outside of the MCC and MSU. During the scanning process, the scanned image is displayed on the operators monitor and at the end of this step, the perimeter protection of the exclusion area is automatically deactivated and the scanned vehicle may leave the scanning area.

The MSU's most important device is the controlled articulated arm which is composed of several photomultipliers (gamma-ray detectors) placed along the arm. The MSU has a detector boom made of the upper detector area and the lower detector area, the two areas having separated folding systems during transport, but with unitary functionality during scanning operation. The upper area is sustained by the steel boom, supporting as well the radiation source. The detector boom is made up of five segments oriented under different angles in order to insure optimal distance and orientation of the detectors toward the radiation source and it is made out of light alloy assembled in a "T" shape.

The subsystem for the automated control of speed/sense motion and steering of MSU is built with an electric motor that drives the steering column and an electronic command module. The subsystem receives information about the units relative positions and generates automatically the commands to drive the mobile on the desired trajectory.

The hydraulic motion subsystem that drives the MSU in slow motion, is made out of a mechanical gearbox equipped with a revolution sensor, a hydraulic motor, a variable flow hydraulic pump controlled by an electronic module, commanded by an automated motion control dedicated software application.

The automated traffic management subsystem consist in two barriers and optional two traffic lights, wireless commanded by a dedicated software application and the exclusion area protection subsystem consist in four Passive Infra Red (PIR) motion detection sensors, a control module for the sensors status and an emergency automated radiation source shutdown module in case that the exclusion area has been breached.

2.4 The Processing Unit

The subsystem for acquisition, processing, storage and displaying of scanned image is made out of a number of radiation detectors (400 for the standard resolution and 800 for the high resolution option) that

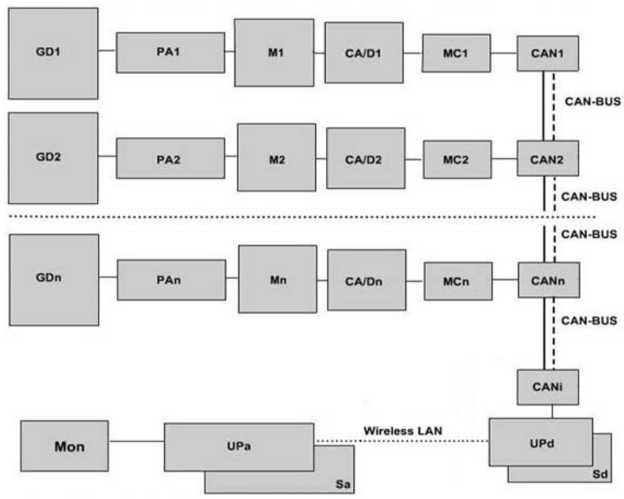

Figure 3: Schematic description of the sensors module. The gamma-ray detectors GDn are connected individually to a data acquisition board. All data is transmitted to the processing unit using a CAN bus

are connected to the input electronic imaging subsystem, running a dedicated software application, connected through WLAN to another processing unit that runs another dedicated software application in order to display the radiography on a monitor (figure 3).

The subsystem has n groups, each of 16 radiation detectors GD1 ... GDn, every group being connected to one electronic module, that includes a preamplifier with 16 parallel channels PA1 ... PAn, which signals are multiplexed in one of the M1 ... Mn multiplexors, and then converted analogue-digital in one of the CA/D1 ... CA/Dn converters, and through one MC1 ... MCn microcontrollers and one of the CAN1 ... CANn modules, the signals passes through a CAN-BUS to a processing unit UPd running a dedicated software application Sd. Through a CANi interface, the information is transmitted further through a wireless LAN, to a process unit UPa running a software application Sa that displays the radiography on a monitor Mon. In the frame of the detector boom some electronic modules are mounted, each one commanding groups of 16 detectors each, the number of modules used is determined by the length of the detector boom. The detector boom is connected to a data processing unit which is also connected with the CANi interface.

The dedicated software application Sd, running on the UPd unit, receives data from the CANi interface and sends them through a radio modem to the mobile control center, where they are interpreted in order to create a radiography of the scanned object. This image is displayed on the monitor Mon, and another application allows the operator to apply differ-

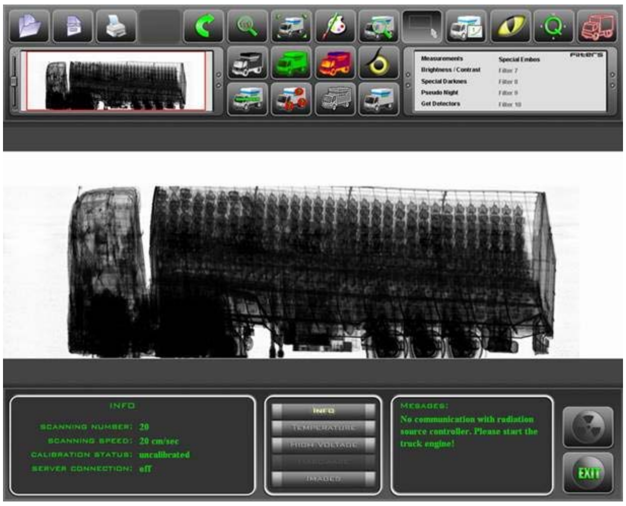

Figure 4: Graphic user interface (GUI) of the control and image visualisation software.

ent proprietary software filters on the image, in order to enhance some parameters of the image. The wireless LAN is used to connect the data processing units Upa and Upd. The under view video imaging subsystem consist in a special dedicated optic unit, integrating video cameras, lens and illumination and an image acquisition hardware and software module.

The radiation material detector gate consists in a gamma and neutrons detectors and the software module to interpret the output signals and to generate an alarm in case radioactive materials are detected in the cargo. The software application indicates the approximate position of the radioactive material detected in the cargo.

The document checking subsystem consists in a optical module integrating a video camera with high zoom lens, different wave length light Infra Red (IR), Ultra Violet (UV), direct, tangential and transparent Visible Light (VL) sources and an image acquisition hardware and software module.

The computerized management subsystem consist in a cluster of computers running several dedicated software applications to control and manage all subsystems and full operation of the inspection system, insuring in background the control of all automatic processes and recording all commands, responses to commands and systems operation parameters in black box file, similar with those used in aviation.

2.5 Data and image processing

The articulated arm is moved along the scanned container. Each of the detectors gives a voltage proportional to the penetration into the corresponding material. The detectors positions are precisely determined. As the arm moves from one side to the other, an intensity image is formed. Because the detectors are not place exactly at a pixel position, an irregular grid results. Therefore, an image reconstruction algorithm must be implemented. Using the Delaunay triangulation, each pixel of the final image can be interpolated from the detectors intensity and position. This algorithm has been proven particulary fast enough comparing to the arm movement and was implemented using DirectX functions.

The most common image characteristics quoted for non-intrusive inspection systems are penetration, contrast detail and resolution [10]. For example, the penetration is measured as the maximum thickness of steel through which one can see a lead brick. In our case the penetration has 175 mm. The spatial resolution of the images is important for the detection of small objects. The ROBOSCAN M1 system has a resolution of 4 mm in standard mode or 2.5 mm in high resolution mode, depending also on the scanning speed which can vary between 0.2 m/s and 0.8 m/s.

The image is acquired and processed in a proprietary format and is displayed on the screen. Different image enhancement algorithm have been implemented in order to facilitate the use or detection of various regions of interest (ROI). Among the algorithms included, we mention color and sharpness masks, zooming, filtering, interpolations or different quantization planes representation (figure 4). Other algorithms are envisaged but only after a full study of the objects which are be regularly found in those specific images [2, 8, 9, 11].

2.6 Results and conclusions

The results obtained using such a system are very good. From an economical perspective, the use of gamma-ray based systems permits a lower maintenance cost and a global estimated price at least ten times lower that those for a X-ray based system.

The images acquired from the gamma-ray detectors as well as their spatial configuration allow the user to obtain high quality view of the scanned cargo. Also, the user can inspect various sized objects and, with the help of penetration performances, various materials. In figure 5 we can easily see the content difference between the left and the right compartments of a tank. Those kinds of tricks are frequently used by contrabandists to mask their shipment by filling on compartment with pressurized gas and the other, in this case, with cigarettes.

Another way of detecting irregularities in content is to evaluate the correct intensity response to gamma-rays. This is obtain only using experienced trained

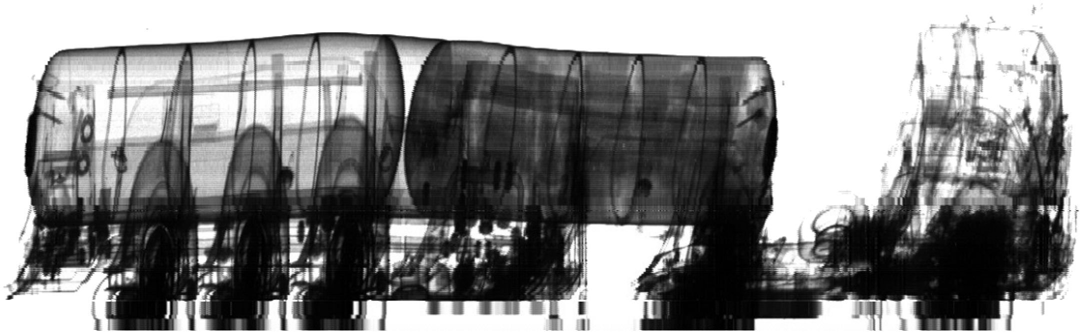

Figure 5: Gas tank used by contrabandists to hide illegal contents. The left compartment contains pressurized GPL gas while the right compartment is filled with cigarettes.

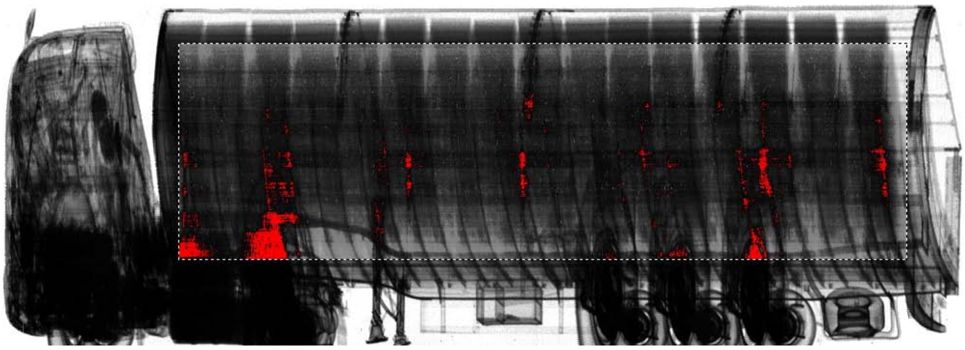

Figure 6: Use of gamma-ray intensity response to evaluate the shipment content of a trailer. Cigarettes detected in a paper box transport container.

operators. The process can be automatized only after collecting expert information to create a intensity response pattern database. Figure 6 presents such a case. The response intensity is abnormal for a paper box content, and corresponds to an illegal cigarette transport.

The systems has been practically implemented and is currently tested in customs and confirms the advantages of the gamma-rays comparing to X-rays. Because the radiation source is natural, maintenance is not needed comparing to accelerators which need a costly annual maintenance. This allows prices lower than similar systems that require accelerators. The system is also completely automatized and distance controlled. Therefore, irradiation risks are avoided because the human operator is placed outside the potentially dangerous area.

Several improvements can be envisaged, though. In order to further improve the gamma-ray sensitivity, the photomultipliers will be replaced with solid-state detectors which are smaller and more sensitive. Therefore, the image resolution will be higher.

In order to speed up the image reconstruction during the continuous scanning, better interpolation algorithms will be created. Finally, an automatic pattern recognition algorithm will be used in order to increase the global detection performances and ease the visualization of suspect objects inside the scan [6, 7].

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