Explosive detector

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Zusammenfassung

A system and method for the detection of shoe bombs using ultrasound imaging. The system allows clients to pass through security without removing their shoes. For this device, the client steps onto a coupling platform that has an ultrasound transducer underneath that scans and captures a video of the shoe. Detection software then converts the video to images and analyze them, issuing an alert when there is a possible anomaly in the shoe. This creates a more effective security process for airports, allowing more passengers to be analyzed per minute than the current method of removing shoes and scanning them with X-ray technology. The system allows security to have a clear image of the shoe and be silently alerted to shoes that may contain a threat.

Beschreibung

EXPLOSIVE DETECTOR

BACKGROUND OF THE INVENTION

Related Applications

[0001] This application claims the benefit of U.S. Provisional Application No. 61/603,770, filed Feb. 27, 2012, the entire contents of which are incorporated herein by reference.

Field of the Invention

[0002] The present invention relates to a device for detecting explosives. More particularly, the present invention relates to a device for detecting shoe bombs. Background of the Related Art

[0003] Currently, airport security has become a top priority around the globe. As a result, security measures have become more stringent and invasive, making travelling slower and a greater hassle. Airport security screenings can cause long lines, delays, congestion, and missed flights. Of the many security risks, a recent development has been the threat of shoe bombs. In order to protect against possible threats in the form of explosives hidden in shoes, passengers and airport personnel are currently required to physically remove their shoes and have them cleared by x-ray scanners. This is not only an inconvenience, but also a time consuming step. The requirement for shoe removal leads to congestion at the scanning stations and possible missed flights.

[0004] According to the TSA, "The removal of footwear takes time, reduces the efficiency of the checkpoint, creates safety concerns with footwear removal and contributes to passenger dissatisfaction. In addition, scanning footwear through the X-ray machine increases the volume of items that the Transportation Security Officers (TSO) at the X-ray machine must visually screen." (nationalsecurityzone.org.) Due to these factors, the Department of Homeland Security currently has a program to encourage the development of a device to streamline the detection of shoe explosives (FBO.gov).

[0005] There have been several competing products in development. These have primarily detected metal objects however, and were not approved by the TSA because they did not meet standards. A major issue with a metal detecting device is the amount of false positives from steel-toed shoes. A product called the PassPort, offered by L3 Communications - Cy Terra Corporation (see www.cyterra.com/products/passport.htm) detects explosives by 'sniffing' them for chemical signatures of explosives, but does not appear to be considered by the TSA as a viable detection method either. A novel technique being worked on by biologists at Colorado State University involves using plants to detect explosives. Proteins in the plants are altered so that the plants turn white in the presence of explosive materials. The modified plants have been able to detect TNT but this was only in a lab in the absence of people and where conditions could be controlled. (See Colorado State University Biologist Produces Plant that Detect Environmental Contaminants, Explosives,

www.news.colostate.edu/Release/5553/, Jan. 26, 2011.)

[0006] Previous techniques used to detect any kind of foreign and possibly dangerous material in shoes have either required passengers to take off their shoes to be put through an X-ray, or have had limitations on the types of materials that could be recognized. Types of competitive devices have included those that can only detect metal and those that can only detect chemicals. X-ray machines are limited in their ability to detect materials that may be rotated at odd angles. Competing technologies with high success rates pose the threat of ionizing radiation, which make them incompatible with human use. Other technologies, such as microwave and chemical testing, have shown to be unreliable. (See New Hope for Terahertz, http://web.mit.edu/newsoffice/2010/terahertz-laser-1216.html, Dec. 16, 2010; and TSA Scraps Airport Screening Program, www.nbcnews.com/id/30875442/#.USqCK_I0Ua8, May 22, 2009.)

SUMMARY OF THE INVENTION

[0007] A fast, safe, and reliable mechanism is provided to scan shoes for explosives, without the need for shoe removal. The present invention utilizes ultrasound to identify cavities made in shoes, in addition to explosive materials contained in them. This can be done because differences in the properties between the shoe material and explosive material are visible when scanned. This provides an advantage over some existing devices, which require the presence of metal to trigger suspicion. This device is unobtrusive and can simply be stepped on before or after walking through a metal detector. This system enhances security while creating more effective checkpoints for both security personnel and travelers.

[0008] One object of the present invention is to detect shoe bombs in an efficient and effective manner. It is designed in a way that allows users to keep their shoes on and accommodate different leather and rubbers that are used to make shoes. In addition, the system can be installed in pre-existing security checkpoints with little need for drastic alteration. It can be setup in the ground in an unobtrusive manner where the user simply steps on it before or after passing through a metal detector. There is the added benefit of a software component using image analysis that can automatically detect possible cavities containing explosives. This makes the device more effective at detection and decrease reliance on security personnel.

[0009] The technology works by having a user stand on a scanning platform. The platform contains an ultrasound transducer, which moves along the length of the foot. As the transducer moves, it emits ultrasound which penetrates the sole of the shoe. The reflected signal is then collected for analysis. The signals are then combined to form a composite image. Post-processing on this image is then performed to determine if there is any form of anomaly contained within the shoe. If an anomaly is detected, the user is alerted. The length of the shoe can be scanned in under 6 seconds, thereby greatly increasing the convenience afforded to passengers, while retaining threat detection capabilities. Furthermore, the use of ultrasound allows for imaging the interior of an object without the use of potentially harmful agents.

[0010] Thus, the basic structure of the system includes a coupling platform, ultrasound with a transducer, and an image analysis program. The input to the coupling platform is the person's shoe and that triggers the ultrasound transducer. The transducer is on a mechanical system that allows it to scan the length of the shoe to produce a complete image from toe to heel. The transducer has a maximum depth of 35 cm and an imaging field of approximately 7 cm. The transducer is positioned laterally underneath the shoe and is translated across the center of the length of the shoe. A guide is drawn onto the platform to ensure the user steps in a location that gives the best results. The received signal is then relayed to the ultrasound imager. A program is designed in order to filter the image and then determine whether or not the shoe has been tampered with.

[0011] The coupling platform consists of a water-filled enclosure housing the ultrasound transducer. A cutout in top of the box is covered with a sturdy plastic film that produces little reflection so as to create the best possible image of the shoe. The passenger steps directly onto the film in order to be checked by security.

[0012] The ultrasound consists of a transducer with a mechanical scanner as well as an ultrasound imager and display screen. The ultrasound has the ability to produce a video of the entire shoe due to the scanning properties of the transducer mechanical system. The scanner is moved across the length of the shoe in under six seconds to ensure the video captures the entire shoe. Frames are taken from the video at specific increments and tested for anomalies. They are displayed onto a screen and then run through a program that determines whether or not the shoe has been tampered with.

[0013] Image processing is carried out by a processor having software using a variety of image processing techniques. Speckle reduction and contrast limited adaptive histogram equalization are utilized to detect objects that are rendered otherwise undetectable by subtleties in pixel intensity. A size detection algorithm is used to determine the size of anomalies in the image and help determine whether an anomaly is dangerous based on prior research done on the amount of explosives needed to do harm. Each detected object is traced using morphological image processing techniques, namely Moore-Neighborhood tracing. An alert is displayed if objects are determined to be a threat, allowing for security officials to further investigate the shoe in question.

[0014] More particularly, the image analysis module of the system is composed of different modules. When a shoe is scanned in the system, a video of the scan is imported into the image analysis program where it is broken down into frames. The result of this video decomposition is 180 separate frames corresponding to a 6 second video at a frame rate of 30 fps. To reduce analysis time every 4th frame is chosen for analysis from the 180 frames. Each frame is then globally contrast enhanced to ensure that anomalies that could potentially be undetectable in the original images are able to be observed.

[0015] After global contrast enhancement is carried out, a technique called morphological image transformation is performed. A modification of this technique is used where each pixel is of the image is scanned through to check if its grayscale value meets the minimum intensity required to be traced. Once the first pixel that exceeds the grayscale threshold of 150 is detected the module begins its trace. It traces all subsequent adjacent pixels to the initially detected that exceed the threshold value. The trace is carried out by moving from pixel to pixel in a clockwise direction, tracing the outer edge of any potential anomaly that a cluster of pixels composes. This process is repeated for the rest of the image until the last pixel has been scanned.

[0016] Once each anomaly has been detected and traced, their sizes are then calculated. The minimum cross-sectional area of an anomaly that is considered dangerous when filled with PETN, a common explosive compound used in conceal bomb attack, is 1.9 cm2. If any of the previously detected anomalies have an area that is greater than or equal to 1.9cm2 they are tagged as a threat. Once all anomalies have been analyzed for size a silent alarm is then triggered in the form of a pop-up on the operator' s screen. This alarm alerts the operator as to how many threats have been detected in the shoe and requests immediate action is taken to resolve the potential threat.

[0017] The invention has many applications, including threat detection at points of entry (airports, ports, train terminals) from shoes containing explosives. Advantages of the present invention include: stream-lined protocol for testing, fast (6 second scan time), reliable, no need for shoe removal, no exposure to ionizing radiation, compatible with COTS technology.

[0018] These and other objects of the invention, as well as many of the intended advantages thereof, will become more readily apparent when reference is made to the following description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

[0019] FIG. 1 is a top view of the shoe bomb detector in accordance with one embodiment of the present invention;

[0020] FIG. 2 is a perspective view of the shoe bomb detector of FIG. 1 ;

[0021] FIG. 3(a) is a side cross-sectional view of the shoe bomb detector of FIG. 1 with a shoe;

[0022] FIG. 3(b) is a perspective view of the shoe bomb detector of FIG. 1 in use by a user;

[0023] FIG. 4 is a block diagram showing general operation of the image analysis module of the computing device;

[0024] FIG. 5 is a side view of the rod fittings;

[0025] FIG. 6 shows the structuring element (disk) used in speckle reduction;

[0026] FIG. 7 shows an original image;

[0027] FIG. 8 shows the image of FIG. 7 after speckle reduction;

[0028] FIG. 9 shows the image of FIG. 8 after contrast enhancement (CLAHE);

[0029] FIG. 10 shows binary conversion of the image of FIG. 9;

[0030] FIG. 11 shows the Moore neighborhood of pixels around a detected pixel;

[0031] FIG. 12 shows the impact of first step and direction for tracing anomalies;

[0032] FIG. 13 shows an original (left) cavity in a show and analyzed (right) image showing boundary tracing;

[0033] FIG. 14 shows binary conversion of non-contrast enhancement image (left) vs. binary conversion of contrast enhancement image (right);

[0034] FIG. 15 shows size detection using a threshold; and

[0035] FIG. 16 shows multiple binary objects being traced by the boundary detection sub-module (16 objects in total). DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0036] In describing a preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents that operate in similar manner to accomplish a similar purpose. Several preferred embodiments of the invention are described for illustrative purposes, it being understood that the invention may be embodied in other forms not specifically shown in the drawings.

[0037] Mechanical Module 100

[0038] Turning to the drawings, FIGS. 1-4 show the shoe bomb detector 10 of the present invention. The detector 10 includes three main elements: a mechanical module 100, and electrical module 120, and a computing device 200. The mechanical module 100 houses the electrical module 120, which scans the shoes and generates an output signal. The computing device 200 analyzes the output signal and displays a report.

[0039] The mechanical module 100 comprises a housing or coupling platform 101 having a base and a cover 104. The base includes side walls 102a-d and a bottom. The base and cover 104 together form a complete enclosure and define an interior space 108 that houses the electrical module 120. The cover 104 is separate from the base, but is preferably removably or permanently mounted to the base by fasteners or the like. The housing 101 is formed as a box generally having a rectangular shape so that the cover 104 is elongated. The cover 104 has a wide central elongated opening 103. A transparent plastic film 106 is provided at the opening 103 of the cover 104. The film 106 produces little reflection, so that it does not interfere with signals transmitted by the ultrasound transducer. The film is also transparent.

[0040] The housing 101 houses the water bath and the ultrasound sensing device 124 (preferably an ultrasound transducer, as shown) at the interior space 108, as well as the cover 104 forming the coupling platform that the user stands on. The enclosure 101 holding the water is watertight, large enough for a size 14 male shoe to stand on, and strong enough to support the weight applied on it. High heel shoes can not be used on the platform because they may tear the plastic film 106 and do not couple to the surface. The platform surface is a durable plastic film material 106 that serves as a coupling surface between the ultrasound transducer 124 and the user's shoe. In accordance with an embodiment of the invention, the film material 106 is offered by ZAGG, Inc. under the brand name INVISIBLESHIELD™, which was originally created to serve as a protective coating for helicopter blades for the United States military and is now commercialized as a screen protector for electronic devices. (See www.zagg.com/support/whatis.php, which is hereby incorporated by reference.)

[0041] The film 106 is extremely durable and is used here for its thinness, plastic nature, and ability to support large amounts of weight. In a test by the manufacturer, a sheet of the material approximately one square meter supported in excess of 1000 lbs. without ripping. The film 106 allows the ultrasound to pass through the cover 104 to the user's shoe and does not affect the ultrasound images. It should be noted, however, that other suitable variations can be provided, such as that at least of a portion of the cover (or the entire cover) be made of a clear solid plastic. However, a film is preferred since it provides a greater degree of conformation with the sole of the user's shoe. Since ultrasound operates on the properties of impedance mismatch, having disturbances (such as gaps) between two transfer mediums will cause loss of energy in the propagating signal. So if the surface was flat and did not conform at all there would be large air gaps between it and the treads of the shoes. This will ultimately degrade the image, making it much harder if not impossible to derive any valuable information from the scan. The film has a thickness of about 0.2 mm thick, but any suitable thickness can be provided. [0042] If the film gets dirty from the shoes it may cause artifacts in the scanned images as a result of the ultrasound being reflected from any particles between the sole of the shoe and the film. The film can be easily cleaned, and a cleaning mechanism can be built into the platform to clean the surface after a designated number of scans. This cleaning mechanism could be as simple as a cleaning spray and a wiper that travels across the surface of the film, removing debris left from the previous user.

[0043] Water is used as a transfer medium for the ultrasound waves generated by the probe. Ultrasound does not travel well through air, so having a hollow platform would cause too much static in any signal returned to the probe to be effective at determining the contents of the shoe. The water also establishes a positive pressure within the chamber of the platform. This positive pressure keeps users from sinking into the platform too much and potentially damaging the probe. It also allows for the film to conform more effectively to the sole of the shoe should it have any treads. Ultrasound operates on the principle of impedance mismatch between surfaces. To ensure that the maximal amount of energy is transferred from the platform to the shoe, the impedances of the two mediums need to be close. The smaller the impedance mismatch, the more signal is transmitted into the shoe being scanned. If air exists between gaps in the treads of a shoe and the platform surface, then the signal at those locations will be distorted as much of the signal will not transmit into the shoe. Filling those spaces caused by the treads allows more of the signal to be transmitted into the sole, creating better images to be used for analysis.

[0044] The current volume of water in the platform is a function of space needed to use the current equipment involved in the scan. Since a probe (approximately 3 inches in length) needs to be scanned under the shoe in a vertical orientation, a certain amount of negative space is required for its movement to remain smooth and unimpeded. [0045] The depth of the platform is limited by the height of the transducer. The invention can be made shallower and smaller overall depending on the scanning methods that are utilized. This requires an upgrade in terms of the type of transducer being used in the platform.

Currently, a simple handheld probe is scanned under the shoe using a linear actuator stabilized by a metal track running longitudinally through the box. This causes the need for copious amounts of space for movement. In an alternative embodiment, is to use a phased array ultrasound transducer, such as shown by www.olympus-ims.com/en/ultrasonics/intro- to-pa/, the contents of which is hereby incorporated by reference. This would completely remove the need for a mechanical scan. This allows the platform to be made much smaller in volume, requiring less water to fill. This also reduces scan times as this type of transducer does not need to wait for a mechanical scan to reach its end. Instead, it scans electronically. The transducer moves smoothly even with the absence of air in the box. Again, if using the alternative method stated above, this becomes irrelevant.

[0046] The amount of air in the box is currently minimized with a system of valves placed strategically in the box. The box is filled with water from a valve located on the bottom of the box. While the box is filling with water, a valve located at the top of the box is open. This allows air to escape as the water displaces it. To completely remove the air an active removal method (pumping air out actively through suction) can be provided.

[0047] The electrical module 120 includes a metal rod 122, ultrasound transducer 124, mount 126, and linear actuator 128. The rod 122 passes through the container. The transducer 124 is mounted to the rod 122 by the mounting device 126. An external linear actuator 128 connected to the rod 122 moves the transducer 124 along the length of the shoe so that it can be scanned in its entirety. The mechanism ensures that the transducer can scan the length of the shoe in under 6 seconds due to the fact that the ultrasound scanner records 6-second video clips. In addition, an IR proximity sensor and receiver mounted on the top of the box detect when a shoe is on the platform and automatically start the scanning mechanism.

[0048] Though a linear actuator 128 is, other suitable mechanisms can be provided. For instance, an air cylinder or rack and pinion can provide the necessary movement to allow the transducer to scan the length of the shoe. In addition, the actuator 128 is shown outside of the interior space 108 of the housing 101 to avoid providing electrical power and concerns due to the water. However, the actuator 128 can be located inside the interior space 108 and the bar 122 need not extend outside of the interior space 108. For instance, supports can be provided internal to the housing 101 to retain the bar 122 as it moves. Or, the entire detector 10 can be located inside a larger housing enclosure.

[0049] The actuator is shown being external to the interior space 108. In accordance with an alternative embodiment, a phased array probe is utilized. This eliminates the need for any type of mechanical scan, which means there would be no rod in the box at all. The external actuator and rod increases the length of the device significantly. The box can then be much smaller and still carry out the same function using a phased array probe and have less reliability issues from moving parts (the actuator and O-Rings on either side of the box for the rod to pass through).

[0050] One feature of the system is that it is able to be easily added to existing airport security checkpoints. The entire structure is approximately 28" long by 16" wide by 10" deep. This length includes the enclosure 101, rod 122 and externally mounted actuator mechanism 128. This size provides a platform area of the film 106 that is large enough to comfortably accommodate up to a size 14 men's shoe. The system 10 can be implemented so that the top surface of the film 106 is flush with the floor with little modification to the airport, such as by providing an opening in the floor of the building and running the cable 129 to a nearby computer 200. The system 10 can also be installed on top of the floor with a small ramp leading up to it and off of it. The majority of the weight of the system is from the water that it is filled with. The water can be drained through a valve 112 in one side 102 of the housing

101 for transportation purposes and then refilled when implemented. If available, degassed water can be used to minimize reflections from gas bubbles in the water.

[0051] Thus, the following is a list of requirements and specifications for the mechanical module of the system. Requirements include: (1) the system is watertight and able to support the weight of a human being; (2) the system creates an efficient coupling surface for flat-soled shoes; (3) the system is able guide the transducer to scan the length of a shoe; (4) the system is able to be installed in the floor of security checkpoints; and (5) the system is able to detect when a user steps on it. Specifications include: (1) the system supports humans weighing up to 300 lbs; (2) the coupling surface couples with flat-soled shoes up to size 14; (3) the system moves the transducer across the shoe in 6 seconds; (4) the system is approximately 18" x 16" x 10"; and (5) the system detects when a user with a shoe at least 4" long steps on it.

[0052] Mechanical Design

[0053] A prefabricated Fibox polycarbonate NEMA enclosure is utilized that is watertight and strong enough to support weights in excess of 150 lbs is the main structure of the system. The enclosure lid 104 has an 8"xl4" rectangle opening 103 cut out in the center. This area is where the user's shoe is scanned. The opening 103 forms a flat shelf 105 about the periphery of the top of the cover 104. A sheet of INVISIBLESHIELD™ film is then applied with its own adhesive to the entire top surface of the lid 104 (i.e. , the shelf 103) to create the coupling platform of the cover 104.

[0054] The cover 104 has an O-Ring around it and can be screwed down onto the base of the box to create a seal. Side 102A has a circular hole cut out 1 inch from the base, which serves as the cable entry port. This hole is blocked with a plug 110 that lets the cable 129 pass through a hole in the center. Sides 102B and 102C have 2" circular holes made for the fitting for the rod as well as 0.75" holes for bulkhead fittings to attach valve connectors. Bulkhead fittings compatible with ¾" NPT valves were attached on either end of the box wall and sealed with O-rings. Valves 112 are attached to the installed bulkheads, which allow for the filling and release of water into the interior space 108. As shown in FIG. 4, fittings allow the 3/8" stainless steel rod 122 to move through them while keeping the box watertight. These fittings are comprised of one main piece with threading and large plastic nuts that are screwed on either side. When the nuts are screwed in they hold two O-rings on either side of the wall in place and create a watertight seal that allows the rod 122 to move. To prevent leaks from the valve bulkheads, a silicone sealant can be provided around them.

[0055] A linear actuator 128 is installed on one side of the box and connects to and moves the rod 122 that the ultrasound transducer 124 is mounted to, such as a Firgelli L16 Linear Actuator described at http://www.firgelli.com/, the contents of which are hereby incorporated by reference. This is done by mounting a shelf off the side of the box to hold the actuator in place. It allows for the movement of the transducer 124 back and forth along the length of the shoe by pushing and pulling the rod 122. The actuator 128 has a controller unit that allows it to be connected to a computer 200 that controls the actuator 128. The transducer is connected to the rod 122 with a mount 126 so that it is approximately 2.5 cm below the platform film 106 with a shoe on it. This mount 126 can be made using several connected clamps that can be adjusted to position the actuator at different heights.

[0056] The rod 122 has an axis that is substantially parallel to the longer side of the housing 101 so that the transducer 124 can move the length of the film 106 under the cover opening. Thus, the transducer 124 moves the entire length of the user's shoe, and can move the entire length of the opening 103 from one end of the opening 103 at side 102b to an opposite end of the opening 103 at side 102c. The rod 122 is positioned so that the transducer 124 is located substantially along the central axis of the cover opening 103. It will be appreciated, however, that the rod 122 can instead be positioned across the width of the housing 101 rather than the length of the housing 101, and the transducer 124 can scan along the width of the opening 103 and user's shoe rather than the length of the opening 103 and shoe.

[0057] The system is fitted with an IR proximity sensor 116 on the side of the platform surface to detect when a user stands on the platform, such as an IR Proximity Sensor (Sharp GP270A21YK), http://www.sparkfun.com/products/242, the contents of which are hereby incorporated by reference. The sensor 116 is positioned on the top of the box in a mount made of foam and points across the platform surface. On the opposite side of the box 101 another foam reflector mount 118 is positioned to ensure a constant IR signal is returned. The sensor 116 and reflector 118 are preferably positioned at the middle of the opening 103 along the longer side of the housing 101 and cover 104. The sensor 116 connects to a breadboard installed on the side of the box, and then to an Arduino Pro 328 microcontroller that is plugged into a computer 200 via USB.

[0058] This sensor 116 emits and receives an IR signal and has a range of 10-80 cm. The amount of IR signal received correlates to a voltage that is then converted to a corresponding distance value. The IR sensor 116 allows for scanning to begin automatically instead of requiring an operator to manually control the system. Of course, the mounting of the sensor 116 and mount 118 can be performed in any suitable manner, and more than one IR sensor / reflector 116, 118 can be provided along the length of the opening 103.

[0059] With no shoe on the platform, the sensor 116 measures a distance of approximately 16 cm. This is the distance from the mounted sensor on one side of the box, to the reflector mount 118 across the platform. When a shoe or foot is placed on the coupling platform, the distance read dropped to values ranging from 6 to 9 cm. Thus, a distance threshold of 10 cm can be used as the basis of detecting when a shoe is on the platform. [0060] The housing 101 is preferably made of a plastic, though metal or polycarbonate can also be used. In addition, other suitable mechanisms can be utilized to move the ultrasound transducer, such as an XYZ robot, a motor with a worm gear drive having a screw-shaped gear that is driven by a spur gear. The actuator has a stroke of about 5", but a greater stroke can be provided. And, an alternative method can be provided to detect when a user steps on the platform. For instance, a pressure detector can be installed in the box that includes a pressure transducer to give constant measurements of the pressure inside the box. It can detect when a user stands on the box due to the increase in pressure, and be located at the interior space 108 so that it does not project outside the housing 101. However, the IR sensor does not need to be immersed in the water and therefore does not require additional wiring inside the watertight housing 101. It also eliminates the need for the sensors to be calibrated to specific weight ranges, and works for shoes of any size provided they are on the platform in the right location. When there is no user, the IR sensor registers a distance of

approximately 10 inches (i.e. , the width of platform). However when a shoe is on the platform, the sensor registers significantly smaller distances.

[0061] In addition, while the transducer 124 is shown being permanently installed in the housing 101, the housing 101 can also be configured to allow the transducer to be easily removable for repair and replacement, while remaining watertight.

[0062] The Computing Device 200

[0063] The computer 200 controls operation of the entire detector 10, including the linear actuator 128, scanner 124, and image analysis. The computer 200 can be a separate or central computer or computing device having a processor 202 to perform various functions and operations in accordance with the invention. The computer 200 can be, for instance, a personal computer (PC), server or mainframe computer. In addition to the processor 202, the computer can include hardware including one or more of a wide variety of components or subsystems including, for example, a co-processor, input device 208, monitors 204, and a memory or storage device 206 such as a database. All or parts of the system and processes can be implemented by software or other machine executable instructions which is stored on or read from computer-readable media for performing the processes described.

[0064] Though a personal computer 200 is shown, other computing devices can be utilized, such as a mobile phone, tablet, or other. Unless indicated otherwise, the process is preferably implemented automatically by the processor 202 in real time without delay. The computer readable media may include, for instance, hard disks, floppy disks, DVD, memory stick, CD-ROM, downloadable file, read-only memory (ROM) or random-access memory (RAM). The computer 200 can also have a wireless modem 210 that wirelessly communicates with a remote computer or can communicate by wired connection such as a cable.

[0065] The Ultrasound Assembly 120

[0066] The ultrasound assembly 120 is controlled by the computing device 200, which includes an acoustic ultrasound module. The following is a list of requirements and specifications for the acoustic ultrasound module. Requirements include that the system: (a) use ultrasound waves to penetrate the soles of shoes; (b) penetrate shoes above the coupling surface; (c) image various materials; (d) detect anomalies within the shoe. Specifications include that the system: (a) use a 5-lMHz transducer; (b) penetrate shoes up to 5 cm above coupling surface; (c) image rubber soled shoes and mimic explosive materials with acoustic impedance values within the range of 0.96-4.53 MRayls; and (d) detect anomalies as small as 2.7 cm3.

[0067] The ultrasound module 120 scans the sole of a shoe and produces an image that can be analyzed for suspicious cavities by the image analysis software. Based on the requirements of the module, it is necessary for the ultrasound device to be equipped with a transducer 124 that produces ultrasound waves capable of penetrating a variety of materials to the necessary distance. The image of the shoe is created using pulses that are sent and received by the transducer. The probe constantly sends ultrasound waves into the surrounding area and generates the image based off of the time it takes for them to be reflected back and how strongly they are reflected. In B-mode ultrasound specifically, the system sends out wide bandwidth sound pulses towards the area of interest. The ultrasound imager constructs an image based off of these reflections it receives.

[0068] The clarity of the image obtained by the transducer 124 depends on the frequency of the transducer 124 as well as the gain and depth settings on the ultrasound. The transducer 124 with a lower frequency (5-1 MHz) produces the clearest image when the depth of penetration was set at 4.7 cm and the gain was adjusted accordingly. The depth of penetration can be adjusted to about 8 cm in order to take into account the space between the top of the transducer and the bottom of the shoe when it is placed in the box. The film is capable of stretching over 6 inches if the box is not pressurized with water. When the box is pressurized the film stretches different amounts depending on the water pressure level and weight being applied. To ensure that the shoe is scanned and the transducer is not hit when someone is on the platform, a distance of 8 cm is used between the film and the transducer. The maximum depth of penetration for the transducer is 35 cm so this is an attainable adjustment. The field of view for the transducer is about 4 cm wide and 2 cm tall. This was determined by measuring the amount of phantom that could be view on the screen of the ultrasound. The spatial resolution can be estimated at 1 mm. Adjusting the gain compensates for attenuation and noise that can occur in the image. The gain amplifies the intensity of the returning signal in either the near field or the far field in order to make the image brighter and clearer on the screen. The success of the settings for the ultrasound was determined by imaging a variety of phantoms that held air cavities along with cavities that contained materials that could mimic those used in explosives. A successful outcome resulted from testing when cavities could be seen in the phantoms. When the cavities were successfully seen, the image showed clear gray scale differences between the "explosive" material and the shoe material.

[0069] Phantoms were created to test the range of materials that could be analyzed by the system. Preliminary testing was done using phantoms that were made from yoga mat foam material (listed on the table as polyethylene). Three layers of foam were glued together using silicone glue and then cavities were cut into the foam. Some cavities were left as air filled cavities while others were filled with toothpaste (sodium fluoride) and salt (sodium chloride). This provided an idea of the feasibility of whether or not phantoms with large acoustic impedance differences could be detected. This was sufficient in determining which mode and frequency transducer should be used.

[0070] Phantoms were then created with cavities that housed materials with acoustic impedance values more closely matching to that of "explosive material". The most common material used in explosives was found to be pentaerythritol tetranitrate. The density was researched and the speed of sound was measured and then the acoustic impedance was calculated using the following equation: $Z=\rho\upsilon$, where: Z = Acoustic Impedance, p = Density, and υ = Speed of Sound through Material.

[0071] The materials used to imitate pentaerythritol tetranitrate were epoxy, silicone caulk, and silicone sealant (clear and white). Epoxy most closely matched the acoustic impedance of the explosive material while the other materials were used to find a range of acoustic impedance differences that could be detected. A yoga mat foam phantom was created with cavities cut into it and filled with these three materials. A rubber shoe phantom was also created with the materials in it to further test the abilities of the ultrasound to detect material differences.

[0072] The acoustic impedance values shown in Table 1 were calculated based off of material densities as well as measured speed of sound values. The speed of sound and attenuation of each material were measured using the transmission method with a function generator, oscilloscope, and pulser receiver (Panametrics 5073PR). Once the speed of sound was determined, the researched density was used in the acoustic impedance equation to find the acoustic impedance of the material.

Material	Speed of Sound (m/s)	Density (g/cm^3)	Acoustic Impedance (MRayls)
Polyethylene (Foam)	1288	0.90	1.16
Rain Boot Rubber	1313	1.30-2.10	1.71-2.76
Sodium Fluoride	3.68	2.56	9.31
Sodium Chloride	2.59	2.17	5.62
Black Rubber	N/A	N/A	N/A
White Rubber	1641	1.30-2.10	2.13-3.45
Loctite Glue	1509	1.95	2.94
Silicone Caulk	N/A	N/A	N/A
Silicone Sealant (Clear)	1595	0.96	1.53
Silicone Sealant (White)	999.46	0.96	0.96
Epoxy	2024	2.24	4.53
Pentaerythritol Tetranitrate	2.63	1.77	4.65

Table 1 : Acoustic Impedance Values

[0073] The cavities created in the phantoms varied in size so that the image analysis software could test its ability to detect lethal and nonlethal anomalies. Cavities were made above and below the threshold volume value of 2.7 cm3 (correspond to an area of 1.9 cm2). This cavity is based on the relative volume that would fit 6 grams of pentaerythritol tetranitrate, which is the determined amount necessary to inflict damage, (http://en.wikipedia.org/wiki/

Pentaerythritol_tetranitrate)

[0074] The present invention is especially useful for flat sole shoes. Treads on shoes would not guarantee that the film on the platform would couple successfully enough to obtain clear images of the shoe. If any air is stuck between the film and the shoe it will prevent images from being captured due to scattering. The coupling issue could be rectified by putting a coupling gel on top of the film that could fill the crevices of the shoe. The gel would remove any concerns regarding trapped air but could be disliked by customers that would not want to clean their shoes after the process. Shoes with sharp points (such as high heels) can also cause disruptions in the film because they could puncture the film completely. The invention works best with shoes having material that can be imaged through easily, and that don't match the impedance of the "explosive" materials too closely (within about 0.2 Mrayls) to provide a sufficient difference between their acoustic impedances to be detectable on the ultrasound. Rubber shoes are currently those that work best due to the large difference in the "explosive" material acoustic impedance and those of rubber.

[0075] Two types of ultrasound systems were considered to fulfill the requirements necessary for the module: A mode and B mode. A Sonosite ultrasound machine was used with a 5-1MHz transducer to test the feasibility a B mode ultrasound would have when scanning phantoms with various empty and filled cavities. Phantoms were created using yoga mat foam with a variety of cavities that were either air filled or filled with materials that could mimic explosives. Each phantom was imaged in order to determine whether or not the cavities could be clearly seen on the screen of the ultrasound. Once it was determined that the cavities could be found, phantoms with material filled cavities were used to see if that was differentiable on the screen. A similar method was used to test the effectiveness of A mode ultrasound. A pulser receiver (Panametrics 5073PR) was used with a 500 kHz transducer to see whether cavities could be distinguished on the graphs produced on the oscilloscope. The output of the pulser-receiver was connected to an oscilloscope and the resulting waveforms were analyzed.

[0076] Based on the results of testing it was determined that B mode ultrasound would be the most effective form to use in order to have data that could be analyzed by a program for suspicious cavities in shoe material. The differences in acoustic impedance and therefore material were not as evident in the A mode results as they were in the images procured from B mode testing. The clear difference in layers was essential for the image analysis portion of the system, which leads to B mode ultrasound being the clear choice for the system.

[0077] Once the mode was chosen for ultrasound, the frequency of the transducer can be analyzed. The transducer 124 can process a range of different types of shoes made of various materials. The transducer frequency was chosen based on the materials that the signal could penetrate as well as the clarity of the images produced. A low frequency transducer is preferred having B mode ultrasound at a frequency of 5-3 MHz. A lower frequency transducer (5-1 MHz) is able to penetrate all of the layers of the shoes, for example having 3 layers each 1 cm thick.

[0078] A higher frequency transducer (13-10 MHz) could not penetrate the top layer of the phantom. This resulted from high scattering of the ultrasound waves and absorption. The scattering caused significant problems with the higher frequency transducer due to the air pockets within the foam. The higher frequency resulted in a lower wavelength that could not pass through the air pockets and reflected the signal back to the probe before it could penetrate the lower layers of the foam. The combination prevented clear images from being obtained.

[0079] The success of this module depends on the clarity of the video that is sent to the following module for image analysis. The anomalies need to be distinct from the rest of the shoe so that the image analysis software can detect the differences in the gray scales. If layers of the shoe cannot be penetrated or the materials have close acoustic impedances values, the module will not give a successful input to the image analysis module.

[0080] The Image Analysis Module

[0081] The computing device 200 receives image data from the transducer 124 via cable 129. The computing device 200 includes an image analysis module 220 (FIG. 5) that analyzes the received image data and displays results on the display device 204. The general operation of the image analysis module 220 is shown in FIG. 5. An ultrasound video in the form of a 6 second .avi file is sent from 124 to 200. This file is taken in to the image analysis module where it is decomposed into frames and then analyzed for anomalies. The probe we had access to did not support live computer connectivity. In a final version of the invention, a more sophisticated probe with live connectivity would be constantly analyzed in real time on the computer instead of sending individual video files.

[0082] The following is a list of requirements and specifications for the image analysis module of the system. Requirements include that the system can: (a) analyze ultrasound video of scanned shoes; (b) split ultrasound video into individual frames for analysis; (c) automatically detect anomalies inside of scanned shoe and alert operator; (d) determine size of abnormal cavities in shoes; and (e) analyze ultrasound video of scanned shoes quickly.

Specifications include that the system can: (a) analyze videos of scanned shoe with a frame rate of 30 fps and resolution of 640x480 pixels; (b) select every 4^{th} frame of the 180 total frames that compose the ultrasound video, analyzing a total of 45 static frames in any given ultrasound video; (c) compare grayscale values to determine differences in acoustic impedance; (d) silently alert operator of anomaly detection through use of a pop-up message on the computer screen; (e) determine area of anomalies as small as 1.9 cm^2; and (f) analyze ultrasound videos of scanned shoes in 10 seconds. However, it takes 6 seconds for the linear actuator to physically move the transducer beneath the shoe. It takes 10 seconds to analyze the data from the scan and present the results to an operator. Removing the linear actuator component of the device would drastically reduce this time.

[0083] As shown in FIG. 5, the image analysis module 220 includes of a variety of sub-modules that work together to produce a final coherent analysis of the ultrasonically scanned object, including: video decomposition module 222, speckle reduction module 224, contrast enhancement module 226, and pixel grayscale comparison/size analysis module 228. To facilitate ease of use for operators with different experience levels, a GUI is used to prompt the operator to import the offline ultrasound scan video. It then instructs the operator to click a button that starts the analysis program in its entirety.

[0084] The first sub-module that is utilized during image analysis is the video decomposition module 222. The video decomposition module is preferred over static frame decomposition. They are referencing the same thing, but "video" is higher since the video is decomposed into the static frames. Preferably static pictures are taken from a phased array transducer and analyzed in real time. This would negate the need to convert a video file into its component frames, saving on some processing time. Due to the fact that the Sonosite imager is not able to automatically record static images at specifically spaced temporal intervals during the scan, the Sonosite's video capture feature can be used to record scans. This limitation necessitates the requirement for the image analysis module to have the ability to decompose a video file, which in the case of the Sonosite is an ".avi" file, down to its individual static images, or frames, with which analysis can be carried out upon. Due to the fact that 180 frames compose a 6 second video recorded by the Sonosite, image analysis would take too long if every single frame was to be analyzed. To reduce this analysis time only certain frames from the video are selected. By using only certain frames, there is the chance that anomalies could be missed if the proper frames are not used in the analysis.

[0085] Calculations can be done to prevent overlooking anomalies. These calculations account for the minimal calculated volume of a cavity considered to be dangerous if filled with PETN, the probable shape of the cavity, the velocity of the ultrasound transducer, and the distance traveled by the transducer over the course of one full scan. The probe travels 13 inches in 6 seconds (length of the video). Since 2.17 inches/second = 30 frames/second, 30 frames capture 2.17 inches. Assuming a cubic volume of 2.71 cm^3 from previous calculations the length of each side of a cubic anomaly would be: $V = * L_2 * L_3$

$V = L^3$

$2.71\ cm^3 = L^3$

$L = 1.39$ cm

$L = 0.55$ inches

2.17 inches / 0.55 inches = 30 frames / x

X = 7 frames To ensure detection every time every 4th frame was chosen as the selection criteria as opposed to every 7th. This prevents an anomaly from potentially being missed. [0086] From the calculations it was found that every 4th frame of the 180 total frames must be sampled in order to eliminate oversight of anomalies located in the shoe, assuming that the shape of the cavity was a cube of equal dimensions in the x, y, and z directions. Every 4th static image frame is then exported as an image of ".png" file type, totaling 45 static ".png" images altogether. The dimensions of each image are 640x480 pixels. Grayscale values in this image are displayed in a range from 0 to 255 where 0 indicates a completely black pixel and 255 indicates a completely white pixel. This not only reduces analysis time, but also maintains analytical integrity. [0087] Another method for converting the ultrasound video into something that could be used in analysis can be utilized, such as converting the ultrasound video into a panoramic image. Since the ultrasonic transducer is taking cross-sectional images of the shoe, a simple panoramic image could not be made by stitching together the 180 decomposed frames longitudinally. Thus, for this method to work, an additional step would need to be taken. However, this would require a three dimensional reconstruction of the shoe from the frames and would take considerable time during analysis that is not feasible for implementation at a busy location.

[0088] Once the static image frames are selected and exported from the decomposition sub-module 222, they are automatically imported into a speckle/noise-reduction sub-module 224. This sub-module 224 serves to reduce background noise in the image frames, creating a more uniform background against which further analysis can take place. This removes potentially confounding factors such as speckle that could cause the image to become distorted when further analytical techniques are applied. The ultrasound image undergoes speckle reduction in order to remove speckle that could otherwise interfere with an accurate analysis of the image. A significant reduction (about 80%) in speckle/noise provides a more uniform background to each image, making them significantly easier to analyze in subsequent sub-modules. One example of speckle reduction is shown in FIG. 8.

[0089] To implement the speckle reduction module, a morphological transformation technique called "opening" is performed. This technique is comprised of two separate and sequential morphological techniques called erosion and dilation. To perform these techniques, a special MATLAB function is utilized. This MATLAB function, called imopen, performs these morphological transformations on a grayscale image using a single structuring element object. The structuring element used for speckle reduction in this case is a disk with a radius of 15. The structuring element then serves as a litmus test for objects in the image that constitute as speckle. If an object in the image cannot completely contain the structuring element in its entirety, then the opening operation removes that object from the image.

[0090] FIG. 6 illustrates the disk-shaped structuring object used in the speckle reduction sub-module. The creation of the structuring element and subsequent morphological opening is shown in the following code:

```
I = rgb2gray (enhance);

struct = strel('disk',15);

background = imopen(I, struct));
```

```
enhance2 = I - background;
```

[0091] When speckle reduction is initially carried out on the image frames, the result of the morphological opening is stored as a separate image space called "background." This stored morphological transformation map is then subtracted from the original image, denoted as "I", removing the speckle and resulting in an image with a background of a more uniform intensity. This speckle reduction can be seen between FIGS. 7 and 8, where FIG. 7 shows an original test image, and FIG. 8 shows original image after speckle reduction.

[0092] Returning to FIG. 5, once the static image frames are filtered for speckle by the speckle reduction sub-module 224, they are automatically imported into the contrast enhancement sub-module 226. The contrast enhancement sub-module 226 serves to enhance any areas where the grayscale difference between pixels may not be easily discernible by the image analysis program. The ultrasound image undergoes contrast enhancement in order to make otherwise undetectable grayscale differences between objects in the image more easily differentiated for anomaly detection. The difference between two pairs of pixels must increase by at least 30 shades in order to be considered sufficiently different when it comes time for binary conversion.

[0093] The image analysis program implemented by the processor 202, has the ability to discern between pixels that have a minimum difference of 30 shades of the grayscale. The type of contrast enhancement utilized in this analysis is a local contrast enhancement technique called Contrast- Limited Adaptive Histogram Equalization (CLAHE). This technique is implemented in MATLAB using the adapthisteq function. The following code illustrates its implementation:

```
enhance3 = adapthisteq(enhance2);

figure, imshow(enhance3);
```

[0094] Adapthisteq is an image processing function for contrast enhancement provided in the MATLAB 201 la Image Processing Toolbox. This function performs contrast-limited adaptive histogram equalization in which small regions, referred to as tiles, of the image are individually operated upon rather than operating upon the entire image at once. Each image frame is split into a 256 x 256 matrix of tiles for contrast enhancement. While the tile size can be reduced to obtain a more detailed contrast enhanced image, this comes at the cost of execution time. In order to preserve expediency in the program execution time, a matrix of 256 x 256 tiles was chosen as it provides good contrast enhancement with minimal execution time.

[0095] Once the image has been decomposed into a matrix of 256 x 256 tiles, the contrast of each tile is enhanced so that the histogram of its output is approximately identical to the histogram specified by the distribution parameter, which is a flat histogram for the purposes of this analysis program. After contrast enhancement of each tile, bilinear interpolation is utilized to combine neighboring tiles and eliminate artificially induced boundaries that were created during the initial decomposition. This results in a unified, contrast enhanced image. FIG. 9 contains an example of an image after contrast enhancement (CLAHE).

[0096] Images are shown, for instance, in FIGS. 15-19, as well as a Table 2 below, detailing the intensity difference.

	Initial Coordinate (X,Y)	Final Coordinate (X,Y)	Grayscale Initial	Grayscale Final	Grayscale Difference	Total Difference (CE-Reg)
Image #1 (Reg.)	[111,138]	[153,138]	94	23	71	52
Image #1 (CE)	[111,138]	[153,138]	127	4	123	
Image #2 (Reg.)	[111,138]	[153,138]	83	26	57	48
Image #2 (CE)	[111,138]	[153,138]	114	9	105	
Image #3 (Reg.)	[111,138]	[153,138]	79	25	54	65
Image #3 (CE)	[111,138]	[153,138]	130	11	119	
Image #4 (Reg.)	[111,138]	[153,138]	65	10	55	48
Image #4 (CE)	[111,138]	[153,138]	110	7	103	
Image #5 (Reg.)	[111,138]	[153,138]	73	26	47	51
Image #5 (CE)	[111,138]	[153,138]	113	15	98	

Table 2

[0097] After contrast enhancement has been carried out, each image frame is then converted into a binary image by the pixel module 228 (FIG. 5). FIG. 10 shows binary conversion of an image. Each image is converted to binary, through a MATLAB function called im2bw, based on a threshold value between 0 and 255. Any pixel with a value greater than the threshold value, and lower than 255, will be mapped as a white pixel in the binary image. Alternatively, any pixel with a value less than the threshold value, but greater than 0, will be mapped as a black pixel in the binary image. Due to the variation that can be observed in ultrasound images, one specific threshold is hard to define as a threshold that will unequivocally work for all images. To remedy this problem a variable threshold is used. The threshold that is used is a global image threshold formed through the use of Otsu' s method, which chooses the threshold in order to minimize intraclass variance of the black and white pixels. This threshold is unique to each individual image and is implemented through the use of the graythresh function, which computes a global threshold, referred to as "level", that can be used to convert an intensity image to a binary image. The following code determines the gray threshold and converts the intensity images to binary:

```
level = graythresh(enhance3);

bw = im2bw(enhance3, level);
```

[0098] After a binary image has been created, additional noise filtration can be carried out. In this case, the noise that is filtered is smaller clusters of white pixels that are not connected to large image objects. The filtering of these small objects is carried out using the MATLAB function bwareaopen. In this method, all connected objects that have fewer than 300 connected pixels are removed from the image. This method allows for a reduction in the amount of objects that are analyzed. Since it has been determined previously that objects with an area of 1.9 cm2 or greater, which is a pixel quantity of 8281, are those that pose a significant threat, then smaller objects can be discarded. Accounting for a 25% error in calculation, the pixel quantity that is used to filter these smaller objects is about 25% less than the maximum pixel quantity used to diagnose an object as non- threatening, which is a pixel quantity of 8280. This ensures that objects that could still be potentially harmful are not completely phased out of the analysis. FIG. 10 shows the product of the binary conversion. The following code demonstrates this noise reduction method:

```
bw2 = bwareaopen(bw, 300);
```

[0099] The reason for creating a size threshold is the fact that every anomaly in a shoe is not necessarily one that presents a significant danger to others. For example, this program detects all anomalies inside of a shoe if they meet the pre-established criteria that have been stated in this section. However, the physical significance of the anomalies must also be taken into consideration. In order to create an explosion of significant size experts contend that as little as 6g of PETN, a plastic explosive, is required (Indiatoday). Thus, the cross-sectional area in which 6g of PETN can be placed serves as the minimum size of an anomaly that is to be considered a threat and cannot be ignored. The minimum cross sectional area of a 3.39 cm^3 cube in which 6 g of PETN can fit is 2.25 cm^2. To show the effectiveness of contrast enhancement FIG. 14 shows binary conversion of non-contrast enhanced image (left) vs. binary conversion of contrast enhanced image (right).

[00100] Taking this minimum area criterion of an anomaly into account, the program is able to ignore anomalies that are much smaller than this cross sectional area of 2.25 cm^2. Taking compressibility of derivative substances of PETN, and even compressibility of PETN itself, this cross sectional area only serves as a baseline measurement by which detection is considered successful. To implement further safety measures the program considers anomalies that have a cross sectional area that is 20% less than the pre-established minimum for uncompressed PETN. Thus, a cross sectional area of a minimum size of 1.90 cm^2 is sufficient to be considered physically harmful, and subsequently a threat. [00101] The next step in the image analysis process is size determination of all significant objects in the image, by the pixel module 228 (FIG. 5). All significant objects at this point are objects composed of white pixels. These objects have made it through multiple filtration steps and have been deemed to pose a significant threat based on pre-selected criteria. The first step in this process of size determination is the use of MATLAB function bwconncomp. This function returns all connected components found in the binary image in the form of structure "cc". "CC" is a structure that contains the four fields Connectivity, ImageSize, NumObjects, and PixelldxList. These four fields completely characterize the images connected components and allow for further exploration into specific properties of specific regions of the image, which is the method through which object size is determined. After the structure "cc" is created specific region properties can be accessed through the regionprops function in MATLAB. Regionprops is passed the structure "cc" where it computes shape measurements.

[00102] The specific region property measurement that is accessed for the purposes of this program is the area measurement. Through an iterative for loop call, the area of each object in the binary image is accessed and compared against the area of 1.9 cm2. If the area of the object being analyzed is greater than 1.9 cm2, then it is deemed a threat and a silent pop-up

warning is prominently displayed on the operator's screen, alerting him/her of the potential threat that has been detected. FIG. 15 shows one of the three square images used to test the size detection. Three squares of varying sizes were used to test the threshold. The following lines of code exemplify this size determination method:

```
cc = bwconncomp(bw, 4);

ultrasounddata = regionprops (cc, 'basic');

k = size(ultrasounddata);

for k = l:k

if (ultrasounddata(k).Area/l 14800) >= (3712/114800) figure, imshow(warning);

break

end
```

[00103] To further emphasize detected anomalies inside of a shoe, boundary detection is used to trace their contours with a red line in order to make them stand out against the image background. The method with which anomalies are traced is the Moore-Neighbor Tracing Method enhanced with the Jacob's Stopping Criterion. The Moore-Neighbor

Tracing Method begins on an external pixel of an object. Each pixel in an image has a Moore neighborhood. "The Moore neighborhood of a pixel, P, is the set of 8 pixels which share a vertex or edge with that pixel." (Moore-Neighbor Tracing) These pixels are namely pixels PI, P2, P3, P4, P5, P6, P7 and P8 shown in FIG. 11, which shows a Moore neighborhood of pixels around detected pixel.

[00104] When a white pixel is detected Moore-Neighbor tracing begins by moving around the detected pixel in a clockwise or counterclockwise direction inside of its Moore neighborhood. When the first pixel of identical value in the Moore neighborhood is reached, the trace begins anew in the Moore neighborhood of the newly detected pixel. The iteration of this process many times gives rise to a contour trace of the boundary of an object in an image. To stop the trace a specialized stopping algorithm called Jacob's Stopping Criterion is used. This stopping method calls for the tracing algorithm to "stop after entering the start pixel a second time in the same manner it was entered initially." (Moore-Neighbor Tracing)

[00105] To implement this tracing algorithm in the image analysis program, a

MATLAB function called bwboundaries is used, which is found in the MATLAB 201 la

Image Processing Toolbox. This function works only on binary images where nonzero pixels belong to an object and 0 pixels constitute the background. When a non-zero pixel is first detected in the program's scan of an image, bwboundaries begins tracing the contour of the object using the Moore-Neighbor Tracing Method. In order to successfully trace the object, a "first step" and direction parameter must be utilized (Mathworks). The first step can either be identified as "North" or "South" and the direction can be designated as either "clockwise" or "counter clockwise." These parameters mainly serve to determine whether the inner boundary or outer boundary of the anomaly is traced during analysis. This first step and direction impact on boundary tracing can be seen in FIG. 12. See www.mathworks.com/ help/toolbox images/fl 1-11942.html#f 11-24711, which is herein incorporated by reference.

FIG. 12 shows the impact of the first step and direction for tracing anomalies.

[00106] To ensure the external contour of an object is traced, a clockwise trace direction with a first step in the north direction is used for this analysis. The tracing occurs in the same step direction until it closes the loop, thereby containing the anomaly within the traced boundary. This process is repeated throughout the entirety of the image, tracing the contour of all objects in the image with a red line. The following code shows the implementation of this tracing algorithm:

```
figure, imshow(enhance);

title('Object Found');

hold on; boundary = bwboundaries(bw);

for m=l:k

detect = boundary {m} ;

plot(detect( : ,2) ,detect( : , 1 ),'r' ,'LineWidth',2) ;

end
```

[00107] The previously stated code imports a binary image, scans through it finding the anomalies, and traces them with a line. FIG. 16 shows multiple binary objects traced by the boundary detection sub-module (16 objects in total). The line of each traced object is then superimposed onto the original ultrasound image, creating a composite image showing where the anomalies are located in the ultrasound scan. FIG. 13 demonstrates this process, and shows an image with a boundary-traced object. The picture on the left is a shoe containing an anomaly and on the right the anomaly has been traced. It shows the original (left) cavity and analyzed (right) image showing boundary tracing. [00108] Table 3 shows Total Frame Decomposition Count of Analyzed Video, and Table 4 shows Frame Decomposition Indexing to ensure every 4th frame is chosen. Table 3 shows that the video decomposition module operates properly. Ten .avi files with known total frame amounts were input into the module. The amount of static frames generated from each .avi was compared to the known frame amount. All ten trials the practical frame count matched the theoretical frame count after decomposition. Table 4 details the function of frame selection. The program selects every 4th frame to reduce analysis time. This table shows what frames were selected (by their index) and how many in total were selected out of certain amount of total frames passed to the module. The index and resulting frame selection total count serve to confirm the correct frames are chosen during the process.

Test Trial	File Type	Total Frame Count	Total Decomposed Frames
1	.avi	180	180
2		72268	72268
3		1530	1530
4		70153	70153
5		180	180
6		40328	40328
7		58654	58654
8		180	180
9		180	180
10		180	180

Table 3

Total Frame Count	Frames Printed (by Index)	Total Frames Expected	Total Frames Printed
5	1,5	2	2
10	1,5,9	3	3
15	1,5,9,13	4	4
20	1,5,9,13,17	5	5
25	1,5,9,13,17,21	6	6
30	1,5,9,13,17,21,25	7	7
35	1,5,9,13,17,21,25,29	8	8
40	1,5,9,13,17,21,25,29,33	9	9
45	1,5,9,13,17,21,25,29,33,37	10	10

Table 4 [00109] To create a more accurate detection method for the presence of dangerous anomalies in shoes two criteria are used in determining if a threat exists from a detected object in a scan.

[00110] When both the size and boundary criteria are satisfied a silent alarm is triggered as a visual alert for the operator in the form of a pop-up message. This pop-up window silently alerts the operator that something has been detected inside of the shoe that would not normally be there. It tells the operator to perform additional security checks on the shoes, which in this case could require the person to remove their shoes and place them in an X-ray machine as is traditionally done at security checkpoints. It also refers the operator to the image containing the anomalies with traced boundaries that is outputted by the system. This allows the operator to see the relative size of the anomaly and also location within the shoe.

[00111] It is further noted that other suitable methods can be used to convert the ultrasound video into something that can be used in analysis, such as the conversion of the ultrasound video into a panoramic image. However, since the ultrasonic transducer is taking cross-sectional images of the shoe, a simple panoramic image could not be made by stitching together the 180 decomposed frames longitudinally. In order for this method to work, an additional step is needed, namely to provide a three dimensional reconstruction of the shoe from the frames. However, that would require considerable time during analysis that might not be feasible for some applications.

[00112] The binary conversion module is able to qualitatively show the success of contrast enhancement on the analyzed images. This qualitative test was done by analyzing images and comparing their binary images both before and after contrast enhancement had taken place. It is evident from FIG. 14 that without contrast enhancement, there would not be enough of the anomaly present in the image when it came time for size detection to determine whether the anomaly was indeed a threat. In FIG. 14, a binary conversion of non-contrast enhanced image is shown on the left and binary conversion of contrast enhanced image is shown on the right. After contrast enhancement, an anomaly can be detected and an alert issued where the anomaly is larger than the threshold for detection of 1.9 cm2 (equivalency of 8281 pixels). Without contrast enhancement, the first binary image would have been analyzed, causing it to pass size detection without a warning being issued since it is well below 8281 pixels with a size of 1536 pixels.

[00113] The next step in the process is performed by a size detection module 228. This sub-module has a threshold designated for detection, which is 8281 pixels. This sub- module solely tests for object size. Images containing, for example, a square (see FIG. 15) whose area is greater than or equal to the threshold area causes a warning pop-up to be issued to the operator. Images having a square whose area is smaller than the threshold by 50% had no warning issue and was not detected as a significant threat.

[00114] The last sub-module is the boundary detection sub-module. This sub-module ensures that any object that is present in the binary image is traced and properly

superimposed onto the original image. The image is analyzed by the boundary tracing algorithm, which returns contours and superimposes them directly on top of the locations of each object. FIG. 16 shows an example, where the image on the left contains one

"detectable" object in the binary image, and the image on the right contains 16 "detectable" objects in the image. In both cases, all objects are detected and traced.

[00115] A specific sequence of events is triggered when a user stands on the scanning platform. The IR sensor activates the Lab VIEW software operating at the computer 200 to start the scanning process when sufficient weight is added to the platform. The scanning process involves the moving of the ultrasound transducer in the water bath, as well as recording the ultrasound images in the memory device 206. Once the ultrasound images are recorded the software enhances and analyzes the images for anomalies. Scanning starts automatically when a user stands on the platform, and the image analysis discovers and alerts the "security personnel" to any shoe cavities.

[00116] The image analysis module includes the components shown in Table 5.

Name of the Module	What it Does	Which Modules Call it	Which Modules it Calls
Video Decomposition Module	-Decomposes videos into individual frames -Selects every 4th frame out of 180 frames in chronological order	Pressing the instructional GUI button	Contrast Enhancement Module
Contrast Enhancement Module	-Applies techniques for global contrast enhancement -Differentiates potential anomalies from the background of the analyzed image	Video Decomposition Module	Morphological Image Transformation Module
Morphological Image Transformation Module	-Applies the image analysis technique of morphological boundary tracing to images, allowing for anomalies to be detected and traced	Contrast Enhancement Module	Anomaly Size Analysis Module Silent Alarm Module
Anomaly Size Analysis Module	-Determines the size of detected anomalies -Used as check system to ensure that only anomalies that could pose a potential threat are made known to the operator	Morphological Image Transformation Module	Silent Alarm Module
Silent Alert Module	-Decides whether to trigger a silent alarm based on whether anomalies are detected and whether their sizes are appropriate for concern by the system operator based on previously calculated standard sizes that present danger	Morphological Image Transformation Module Anomaly Size Analysis Module	Alert GUI

Table 5

[00117] Shoe Bomb Detector Operation

[00118] The operation of the shoe bomb detector 10 will now be discussed. As discussed above, the components for the detector 10 include the coupling platform and a computer running the Lab VIEW and MATLAB. The coupling platform consists of the prefabricated NEMA enclosure 101 with an IR sensor 116, linear actuator 128, and ultrasound transducer 124 installed. The coupling platform must first be filled with water through one of the valves 112. It can then be installed in a security checkpoint, either in the ground or above the ground with ramps leading up to and off of it. When installing it, connections must be made from the IR sensor 116, actuator 128, and ultrasound transducer 124 to a computer 200 that the operator is using. These can be plugged into the computer's USB ports. Lab VIEW and MATLAB are used on the computer 200 so that the interface program and image analysis script can run.

[00119] Once the platform housing 101 is in place and the connections to the computer 200, the operator must start the Lab VIEW interface program. Once this program is started, the system is fully automated except the popup alert. It detects when a user is on the platform, initiates the scan, and analyzes the ultrasound video. When an anomaly is detected, the computer operator is required to dismiss the popup before the program continues. To turn the system off, the operator has to stop the Lab VIEW program and turn off the coupling platform electronics.

[00120] Preferably, the entire operation of the detector 10 is controlled by the computing device 200 (a personal computer in the embodiment shown). Accordingly, the IR sensor 116, the linear actuator 128, and the ultrasound transducer 124 are all connected to and controlled by the same computing device 200 so that the electrical and software modules of the

computing device 200 can interface together. The linear actuator 128 connects to the computer 200 through its linear actuator controller unit and the IR sensor 116 connects through a microcontroller. Both can be used in one central program implemented by the computer 200.

[00121] Accordingly, when a user steps on the platform, at the position indicated by the guide 14 printed on the film 106, the IR sensor 116 detects the presence of the shoe due to a change in distance. The sensor 116 continually takes distance measurements so that it can immediately detect when a shoe is on the platform. A threshold distance can be set that determines if a shoe is present. By placing shoes on the platform of the box and obtaining distance measurements, the ideal threshold was found to be approximately 10 cm. Once the distance reading goes below this value, the "Shoe Detected" light goes on. This light indicator is controlled by a Boolean logic that outputs a 1 when the distance measured is under the threshold (shoe present) and 0 when the distance is above the threshold (no shoe). The IR light/receiver 116 is located on the surface of the platform, pointing across to a reflector 118. When the beam is crossed by a shoe, the receiver measures a shorter distance. 116 is connected to the computer 200 which is taking in the distance measurement values.

[00122] Along with this light, the Boolean output also controls the linear actuator 128 motion sequence that moves the transducer 124 across under the shoe and back. The output goes to the computer 200 which then actuates the linear actuator 128. The linear actuator 128 movement sequence is controlled by two the computer 200. These can be contained within a case structure loop that performs a different task based on the input it receives. The first actuator computer routine extends the actuator fully when the Boolean input value is 1 to scan the shoe that is present. The next computer routine is triggered when the shoe is removed from the platform and retracts the actuator to its original position. A timer function is also present that delays the computer from extending the actuator for 2 seconds. This delay allows for the shoe on the platform to settle into the coupling surface (since the film is flexible and bends under the weight of the user) before scanning begins.

[00123] The transducer 124 transmits the image data to the computing device 200 via cable 129. The program implemented by the computer 200 analyzes and displays the ultrasound images of scanned shoes. This allows for one seamless program that contains all hardware and software aspects of the device. Similar to the linear actuator movement sequence, this can be within a case loop and only run once a shoe is detected and the actuator has fully extended. Once the scan is complete and an anomaly is detected, the computer 200 can launch a popup that the operator must view and dismiss before the shoe-scanning program continues. The pop up occurs to warn the operator that an anomaly was detected and that further action should be taken. [00124] The computer 200 is preferably a fully automated detection program and operates in real-time. However, the system can also record videos and import them offline into the image analysis program. In addition, the computer 200 preferably interfaces with a program called LAB VIEW, which is a program used for data acquisition and interfacing between hardware and a computer and is offered by National Instruments. See

www.ni.com/labview/, the content of which is hereby incorporated by reference. The imaging can be in MATLAB and exported as a MATLAB script to be run within LAB VIEW. When sufficient pressure is present to start the scan, the MATLAB script is activated to produce the GUI instructing the user to import the ultrasound scan video to the MATLAB program. Once this is done the MATLAB image analysis model functions as its own entity, independent of other Lab VIEW functionalities.

[00125] When a shoe is placed on the platform, it takes an average time of 22.37 seconds for the system to detect it and then extend and retract the actuator. Thus, the system 10 can process approximately two users per minute, or 30 seconds per scan.

[00126] In order to create an efficient system capable of shoe bomb detection, this system fulfills certain essential requirements, including that: (1) the system is capable of detecting foreign plastic materials in shoes utilizing ultrasound to image the footwear; (2) the system is safe for human use; (3) the system is able to support the normal range of weight of a human being; (4) the system does not require the user to remove their shoes; (5) the device alerts the operator when it detects an anomaly; (6) the system scans the shoes quickly; and (7) the system is easily incorporated into existing security checkpoints.

[00127] In order to fulfill the requirements of the system the following specifications are provided: (1) the system detects explosives using impedance mismatch (minimum of 1.55 g/cm2s) of materials in shoe with an accuracy of 85%; (2) the system utilizes B mode ultrasound at a frequency of 5-3 MHz; (3) the system uses a diagnostic ultrasound that is FDA approved; (4) the system supports humans weighing up to 300 lbs.; (5) the system creates an efficient coupling surface for leather flat soled shoes; (6) the system has a pop up alert that remains on the screen until the operator closes out of it; (7) the system scans the shoes at a rate of 2 users per minute; and (8) the system is contained in a box with dimensions

28"xl0"xl0".

[00128] The device is in compliance with the 21 CFR 801.109 standard

(www.accessdata. fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=801.109) that indicates that any potentially harmful device must be labeled with a caution announcement. The ultrasound module also complies with the 21 CFR 892.1550 standard

(http://cfr.vlex.com/vid/1550-ultrasonic-pulsed-doppler-imaging-19715615) referring to any ultrasonic pulsed Doppler imaging system. It is also in accordance with the 21 CFR 892.1570 standard (http://cfr.vlex. com/vid/1570-diagnostic-ultrasonic-transducer-19715625) referring to any diagnostic ultrasound transducer.

[00129] For materials at temperatures above -29°C (-20°F) and below the creep range, the maximum allowable design stress is established as follows. For -29 to 38°C (-20 to

100°F), the lesser of one-fourth of the specified minimum tensile strength or two-thirds of the specified minimum yield strength at room temperature. Above 38°C (100°F), the lesser of one-fourth of the tensile strength or two-thirds of the yield strength at the elevated temperature. These criteria apply for vessels with internal/external pressures exceeding 15 psigs. Since the vessel in this system is far less than that, it can easily meet these

requirements. The box structure also complies with the spirit of this United Facilities Criteria document detailing the design and construction of cathodic protection systems. These are necessary to prevent corrosion of submerged metallic structures. The constructed box for this project complies by having either no exposed metals, or, if some metals are exposed, a sacrificial metal to provide cathodic protection is provided. [00130] The following documents are incorporated herein by reference: (1) "Acoustic Properties of Plastics." Acoustic Properties of Plastics. Onda Corporation. Web. 13 Dec. 2011.

http://www.ondacorp.com/images/Plastics.pdf. (2) Anderson, S. B. "TSA Opens up Request for Design of Shoe Scanners for Airports." Medill National Security Zone.

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[00131] (13) Guidelines for Pressure Vessel Safety Assessment. U.S. Department of

LAbor, 2010. PDF. (14) "Image Processing Techniques. " Image Processing Techniques. NDT Resource Center. Web. 13 Dec. 2011. www.ndt-ed.org/EducationResources/

CommunityCollege/Radiography/AdvancedTechniques/Real_Time_Radiography/ImageProc essingTechniques.htm. (15) "JBW I Drive Systems." JBW I Partner in Der Antriebstechnik. JBW. Web. 10 Dec. 2011. www.elektromotore.eu/en/index.php7navi main=Antriebstechnik. (16) "Matlab in Labview. " National Instruments. National Instruments. Web. 10 Dec. 2011. http://fomms.rii.coin/t5/LabVIEW/matlab-code-convert-into-the-labview/td-p/881944. (17) "Napolitano Sees Air Travelers Keeping Shoes On In the Future I Executive Gov. " Executive Gov I. Web. 13 Dec. 2011. www.executivegov.com 2011/09/napolitano-sees-air-travelers-keeping-shoes-on-in-the-ruture/. (18) "Opportunities - Federal Business Opportunities:

Opportunities." Home - Federal Business Opportunities: Home. FBO, 17 May 2011. Web. 13 Dec. 2011. https://www.fbo.gov/index?s=opportunit.y. (19) "Parcel Bombs Could Rip 50 Planes in Half : Europe News - India Today. " News - Latest News - Breaking News India -

Live Update - India Today. Web. 13 Dec. 2011. http://indiatodav.intoday.in/storv/parcel-bombs-could-rip-50-planes-in-half/l/l 18746.html.

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[00133] The foregoing description and drawings should be considered as illustrative only of the principles of the invention. The invention may be configured in a variety of shapes and sizes and is not intended to be limited by the preferred embodiment. Numerous applications of the invention will readily occur to those skilled in the art. Therefore, it is not desired to limit the invention to the specific examples disclosed or the exact construction and operation shown and described. Rather, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.