INTERNATIONAL ASSOCIATION OF PROFESSIONAL SECURITY CONSULTANTS

Evidence-Based Security Practices

WEAPON DETECTION IN PUBLIC ACCESS FACILITIES

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INTRODUCTION

Accurate detection of weapons is an effective measure to prevent shooting events. In recent decades, there has been an increase in shooting violence in the United States. These events have occurred in different scenarios, including high-conglomeration public events, recreational events, hospitals, concerts, and even schools. One of the main factors considered to play a crucial role in these events is the general population's high availability and easy access to firearms. This concern encouraged the development of multiple technologies focused on producing weapons detection equipment that is efficient, accurate, reliable, and safe for security personnel and users and improves the level of security in these spaces. This research presents some statistics of firing events in the United States, contextualizes the need for a weapons detection system, describes the findings of a literature review of technologies currently available and under development for weapons detection, describing their operation and how it has been implemented in security systems. Finally, some essential operational considerations in implementing a security system for weapons detection are discussed as important aspects in evaluating its effectiveness.

STATISTICS

According to the Gun Violence Archive, in 2021, there were 692 mass shootings, with 28 involving four or more fatalities.[1] The US Department of Justice designated 61 active shooter incidents, where 103 people were killed and 140 wounded. The highest number of casualties occurred at FedEx Ground Plainfield Operations Center, Indianapolis, Indiana, with eight killed and seven wounded. The incident with the highest number killed occurred at King Soopers Grocery Store, Boulder, Colorado, where ten people died.[2]

Thirty-two active shooter incidents occurred in commerce-related environments, from grocery stores to manufacturing sites. Four shooters were employees, three were former employees, and one was a former business owner. Two incidents occurred at educational locations, including one middle school and one at a high school. In both scenarios, the shooters were students. One incident happened at a healthcare location inside a clinic.[3] Overall, active shooter incidents increased by 52.5% compared to 2020.

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[1] D Victor and D B Taylor, 'A Partial List of Mass Shootings in the United States in 2022', *The New York Times*, 29 (2021).

[2] US Department of Justice, 'Active Shooter Incidents in the United States in 2021', May, 2021, 1–30.

[3] US Department of Justice.

Although there is no available report from the DOJ for 2022, the Gun Violence Archive counted 648 mass shootings, where 21 involved five or more fatalities. The shooting where most people were killed was the massacre in which 19 children and two teachers were killed at an elementary school in Uvalde, Texas, on May 24, only ten days after the Buffalo supermarket shooting event took place where ten people were shot and killed.[4]

In the US, the total lifetime cost of homicides, including medical expenses and lost economic productivity, is estimated at $25.1 billion. Approximately 73.330 people are injured annually from gunshot wounds, reflecting that gun violence in the US is a public health problem.[5]

Evidence indicates that shootings covered by media result in increased gun sales in the following months, indirectly increasing the likelihood of access to firearms in youth, leading to increased child accidental firearm deaths. The effects of shooting exposure go beyond physical injuries and fatalities. Among the survivors, exposure to public mass shootings is associated with adverse psychological outcomes and potentially profound and lasting suffering of shooting victims' families.[6]

In schools, it is estimated that four of every five firearms carried into schools come from students' homes to "show and tell." Generally, guns are not challenging to obtain in the US through legal and illegal transactions.[7] The presence of firearms increases the risk of violent episodes, and the recent increases in shooting events demonstrate the need to implement effective measures to identify and control weapons in schools and several public settings.

DEFINING THE END USER OBJECTIVE

The methodology of implementing a weapon screening program varies according to the specific needs of the end user, the level of risk calculated for security events, and the availability of resources to establish the program. This goes beyond simply controlling the entry of threats for an audience. In general, it is considered that a weapon screening program should include security personnel (operations), inspections (after detection), and the

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[4] Victor and Taylor.

[5] Mitchell L. Doucette and others, 'Impact of ShotSpotter Technology on Firearm Homicides and Arrests Among Large Metropolitan Counties: A Longitudinal Analysis, 1999–2016', *Journal of Urban Health*, 98.5 (2021), 609–21 <https://doi.org/10.1007/s11524-021-00515-4>.

[6] David Hemenway and Eliot Nelson, 'The Scope of the Problem: Gun Violence in the USA', *Current Trauma Reports*, 6.1 (2020), 29–35 <https://doi.org/10.1007/s40719-020-00182-x>.

[7] Randy M. Page and Jon Hammermeister, 'Weapon-Carrying and Youth Violence', *Adolescence*, 32.127 (1997).

placement of weapons detectors at the entrances to a venue. However, it is essential to consider the consequences of over-implementation in some scenarios.

For example, the placement of structural security measures (such as metal detectors, access control systems, cameras, and video management systems) in schools has been considered after lethal shooting events in these spaces, under the rationale that doing so provides a measure of control of the entry of weapons and therefore decreases the probability of shootings. However, there is no evidence to support this,[8] as demonstrating the efficacy of such measures is not feasible due to ethical considerations like not providing security measures to some schools and comparing them to schools with security measures to reach a conclusion. On the other hand, one thing that can be evaluated is the impact of implementing structural security measures on the perception of security of educational staff and students. Studies show that implementing more safety measures results in a decline in student perception of safety.[9] In the school environment, many factors increase the risk of violence, which extend to the external environment, such as the family environment or even the availability and access to firearms. Establishing controls at different levels, different from the implementation of screening programs, can contribute to the entry control of security threats.

Another area in which the implementation of security screening measures has been proposed is in hospitals and emergency care centers. Interestingly, some studies evaluate the effectiveness of establishing metal detectors at the entrance of emergency departments (ED),[10] in which it is concluded that implementing these technologies reduces the entry of weapons into ED. Another study compared the admission of firearms in two urban hospitals. During an observation period of 8 months, 3706 metal weapons were confiscated. The researchers highlight the importance of implementing hospital detectors and screening measures to protect patients, their families, and health personnel.[11]

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[8] James H. Price and Jagdish Khubchandani, 'School Firearm Violence Prevention Practices and Policies: Functional or Folly?', *Violence and Gender*, 6.3 (2019), 154–67 <https://doi.org/10.1089/vio.2018.0044>.

[9] Jennifer M Reingle Gonzalez, Katelyn K Jetelina, and Wesley G Jennings, 'Structural School Safety Measures, SROs, and School-Related Delinquent Behavior and Perceptions of Safety', *Policing: An International Journal of Police Strategies & Management*, 39.3 (2016), 438–54 <https://doi.org/10.1108/PIJPSM-05-2016-0065>.

[10] S. Terez Malka and others, 'Weapons Retrieved after the Implementation of Emergency Department Metal Detection', *Journal of Emergency Medicine*, 49.3 (2015), 355–58 <https://doi.org/10.1016/j.jemermed.2015.04.020>.

[11] Harold K Simon, Naghma S Khan, and Carlos A Delgado, 'Weapons Detection at Two Urban Hospitals', *Pediatric Emergency Care*, 19.4 (2003) <https://journals.lww.com/pec-online/Fulltext/2003/08000/Weapons_Detection_at_Two_Urban_Hospitals.6.aspx>.

In general, there are a variety of circumstances in which implementing screening systems may or may not deliver the expected results. At outdoor public events, for example, the shooter can open fire from a distance without going through any safety measures. Or in some institutions, individuals may carry objects small enough that control measures do not correctly identify them.

In summary, establishing a screening program should consider several factors of risk level, social context, psychological impact, and availability of resources to decide how to properly set weapons detection measures. In the following sections, we will outline the technologies available, how implemented and their effectiveness, how operations and inspections can work with the technologies, and how the perception of these technologies and operations affects the environment in which they are utilized.

WEAPON DETECTION TECHNOLOGY: IS IT EFFECTIVE AND HOW DOES IT WORK

All weapons detection technologies (except video management systems) use different frequency ranges of the electromagnetic (EM) spectrum to emit and/or capture signals that are analyzed to develop images or warning systems for operators. These systems are classified according to the frequency at which they operate, such as the frequency of the earth's magnetic field and its distortions, induced magnetic fields, ultrasound, electromagnetic resonances, millimeter wave, terahertz, infrared and X-rays:

Metal Detection and Earth magnetic field distortion

Advantages	Disadvantages
This technology can be used to build walk-through detectors and portable detectors.	Not suitable for the detection of small and non-metallic objects
Detectors don't generate a signal to identify an object, therefore they don't affect personal medical electronic devices.	Does not detect non-ferromagnetic metals (Like copper, brass, lead, aluminum, and certain types of stainless steel)
Accurately detects any moving ferromagnetic object.	System is susceptible to movement-induced errors that may cause false-positives
Portable devices with this technology can detect ferromagnetic objects from a few meters away.	

How does Metal Detection and Earth Magnetic Field Distortion work?

This technology is based on passive sampling of the earth's magnetic field. Detectors exist as walk-through devices and portable devices known as Gradiometer Metal Detectors. They can be used for mine detection and concealed weapon detection. This technology is used to build passive metal detectors, so they don't affect the function of personal medical electronic devices. These detectors respond to moving ferromagnetic metals by triggering an alert until all metal objects are removed from the person.[12]

These detectors are usually set as a walk-through type of device with a series of gradiometers that respond to changes in the local magnetic field of the earth caused by ferromagnetic objects, and the system displays the location of the metal object within the portal.[13]

As an alternative, this technology can also be implemented as a lightweight, portable, and inexpensive unit to detect a person carrying metal objects from a few meters away. The military frequently uses it for mine detection and police officers as it allows estimating not only the presence of a potential handgun or mine but also its size. These detectors are not suitable for detecting small and non-metallic objects.

A critical consideration of this system is that the object must be ferromagnetic, so weapons not constructed of ferromagnetic metals will not be detected. Some examples of these non-ferromagnetic metals include copper, brass, lead, aluminum, and some stainless steel. In addition, these systems are susceptible as any vibration or movement-induced errors can cause false-positive alerts.[14]

Inductive Magnetic Field Methods

Advantages	Disadvantages
Exist as walk-through Metal Detectors and Wide-Area-Metal-Detection (WAMD)	Produces Electro-Magnetic Signals that potentially interfere with Medical Electronic Devices

[12] Alan Agurto and others, 'A Review of Concealed Weapon Detection and Research in Perspective', *2007 IEEE International Conference on Networking, Sensing and Control, ICNSC'07*, April, 2007, 443–48 <https://doi.org/10.1109/ICNSC.2007.372819>.

[13] Carlos Morón and others, 'Magnetic Sensors Based on Amorphous Ferromagnetic Materials: A Review', *Sensors (Switzerland)*, 15.11 (2015), 28340–66 <https://doi.org/10.3390/s151128340>.

[14] Lyle G Roybal, Philip M Rice, and Joseph M Manhardt, 'New Approach for Detecting and Classifying Concealed Weapons', in *Surveillance and Assessment Technologies for Law Enforcement* (SPIE, 1997), MMCMXXXV, 96–107.

In addition to Concealed weapon detection, can also detect unexploded ordnance.	Non-metallic objects are not detected.

How do Inductive Magnetic Field Methods work?

This technology creates a time-varying magnetic field around a coil that induces currents in a nearby metal object, generating its magnetic field. These fields induce a voltage in the detector device's receiver coil, which can be amplified to reveal the presence of a metallic object. The current creating the field alternates or is pulsed, allowing the created magnetic field around the metallic object to collapse or decay depending on its size. Different things have specific time-decay responses, which can be compared to those in a previously established library of threats to classify the metallic object accordingly.[15]

This technology can detect landmines, unexploded ordnance, and concealed weapons. Walkthrough weapon detectors consist of a source, detector coils, and a magnetic field. Conductive metal passing through the detector creates a secondary magnetic field that the system detects. These devices have a sensitivity issue for non-metallic materials or are of minimal dimension, considerably reducing their reliability.[16]

One of the most interesting applications lies in the creation of Wide-Area-Metal Detection (WAMD), which allows metal detection in crowds and can be used to locate metal weapons. To do this, the WAMD uses a large horizontal magnetic field (HMF) generator and video management systems to monitor a wide area of people. The individuals with concealed metal objects alert the video management system operator to request a further inspection of the subject.[17]

Acoustic and Ultrasonic Detection

Advantages	Disadvantages
Detects solid objects (like metal and plastic weapons)	Does not differentiate between weapons and innocuous objects (resulting in high false-positive detection rate)

[15] Carl V. Nelson, 'Metal Detection and Classification Technologies', *Johns Hopkins APL Technical Digest (Applied Physics Laboratory)*, 25.1 (2004), 62–67.

[16] Agurto and others.

[17] P Pati and P Mather, 'Open-Area Concealed-Weapon Detection System', in *Proc.SPIE*, 2011, , 801702 <https://doi.org/10.1117/12.883879>; Prasanta Pati and Peter Mather, 'Transmitter and Receiver Coil Design for Open Area Concealed Weapon Detection System', *University of Huddersfield Repository*, 2010.

Identifies shape, size, and orientation of the object	Although it be used to produce images, their quality is not the best due to its lack of clothing penetration
Can be implemented in portable, lightweight, and inexpensive devices	When used to produce images, the resolution is an issue due to clothing penetration properties of ultrasound

How do Acoustic and Ultrasonic Detection work?

This technology depends on the acoustic reflectivity of the materials to detect a specific object. Solid objects provide high acoustic reflectivity, allowing the detection of metal and plastic weapons. It will enable identifying its shape, size, and orientation. These detectors can be implemented in lightweight, portable, and inexpensive devices to identify the location of concealed objects by adding a high intensity aiming light to point in the direction of the object.[18]

Since this device detects solid objects, it can detect metallic and non-metallic objects. Still, the limitation is that it does not differentiate between weapons and innocuous hard objects. This translates into a high false-positive detection.

Ultrasound can also be used for imaging using a short pulse with wide frequency bandwidth to detect objects. Still, the resolution is an issue since the acoustic penetration of clothing is poor. Lower ultrasound frequencies can improve clothing penetration at the expense of image resolution. These limitations make this technology inferior compared to millimeter wave imaging.[19]

Electromagnetic Resonances (EM)

Advantages	Disadvantages
Provides information about the size, and material composition of the object by identifying its EM signature.	System detection depends on the dataset used for detection. If a type of weapon is not available in the dataset, the detector will not identify it.

[18] Norbert C Wild and others, 'Handheld Ultrasonic Concealed Weapon Detector', in *Proc.SPIE*, 2001, MMMMCCXXXII, 152–58 <https://doi.org/10.1117/12.417527>.

[19] David M Sheen and others, 'Comparison of Active Millimeter-Wave and Acoustic Imaging for Weapon Detection', in *Proc.SPIE*, 1997, MMCMXXXV, 120–28 <https://doi.org/10.1117/12.266792>.

Insensitive to the target's size and orientation	The human body has its own EM signature. Noise produced by human body increases false-positive classification rate and reduces reliability.
Used for walk-through weapon detectors	Noise can be addressed by modifying antenna arrays, but it decreases sensitivity to certain orientation of the objects to be detected
Classifies objects (threat or non-threat) based on information available in its database.	

How do Electromagnetic Resonances work?

These are active devices that produce radiofrequency signals. The detector uses radar to sweep a range of frequencies and records the EM resonance response. The signal reflected by objects in a target provides an EM signature, a unique spectrum for the object compared to known signatures to classify the object as a potential threat.[20] In addition, low-frequency fields provide information about the physical characteristics, size, and material composition of the metallic object and are insensitive to the target's shape and orientation.[21]

This technology can build walk-through metal detectors with a giant magneto-resistive sensor array to measure the spatial magnetic field and provide image visualization and feature extraction. To classify the objects, a cross-correlation technique can be implemented to train the system using a database and improve the overall accuracy performance of the system.[22]

The limitation of this technology lies in the amount of available data in the correlation library. If an object's EM signal is unavailable in the library, the system will not identify the object as a threat. An additional limitation of these systems is that the human body has an EM signature of its own. Therefore, this system must reduce the noise by identifying the human body signature and subtracting it from the composite person-object signature. This increases the false-positive classification rate and reduces its reliability. To address this, the antenna arrays

[20] D J Kozakoff and V Tripp, 'Antennas for Concealed Weapon Detection', in *2005 5th International Conference on Antenna Theory and Techniques*, 2005, pp. 65–69 <https://doi.org/10.1109/ICATT.2005.1496885>.

[21] Agurto Goya, Open Areas, and Original Citation, 'New Proposal for the Detection of Concealed Weapons : Electromagnetic Weapon Detection for Open Areas', 2009.

[22] Abdalrahman Al-qubaa, Gui Yan Tian, and John Wilson, 'Electromagnetic Imaging System for Weapon Detection and Classification', *The Fifth International Conference on Sensor Technologies and Applications*, 2011, 317–21.

can be modified by incorporating a circularly polarized focus, but it also decreases the system's sensitivity to the orientation of a concealed weapon.[23]

Millimeter Wave (MMW)

Advantages	Disadvantages
Large sensors can be used scan the whole body	This technology requires high performance components, making it relatively expensive
Passive sensors don't interfere with personal medical electronic devices. Active sensors produce signal like a cellphone and are not considered a health hazard.	
Can be combined with Machine Learning (ML) to improve system detection performance	
Recent developments in the design of this technology have resulted in more cost-effective detection devices and yielding images with satisfactory resolutions for weapon detection.	
Accurate detection of concealed weapons	

How does Millimeter Wave work?

There are two types of MMW screening devices: Passive and Active.

Passive sensors only provide information on what is detected in the environment. Surfaces emit different amounts of natural radiation dependent on temperature and emissivity. Metals have strong reflectivity and reduced emissivity, which allows them to produce reflections of other sources' radiations.[24] This technology has improved imaging quality and increased the field of view to perform whole-body scans.[25] Passive sensors don't emit any Electro Magnetic Radiation onto people.

Active sensors produce a signal to stimulate the environment, propagate to the objects or targets of interest, interact with them, and reflect them or scatter energy to the sensor. The

[23] Pooja Pratihar and Arun Kumar Yadav, 'Detection Techniques for Human Safety from Concealed Weapon and Harmful EDS', *International Review of Applied Engineering Research*, 4.1 (2014), 71–76 <http://www.ripublication.com/iraer.htm>.

[24] David M Sheen and others, 'Weapon Detection Using a Wideband Millimeter-Wave Linear Array Imaging Technique', in *Proc.SPIE*, 1994, MMXCII, 536–47 <https://doi.org/10.1117/12.171271>.

[25] Bao-hua Yang and others, 'Design of a Passive Millimeter-Wave Imager Used for Concealed Weapon Detection BHU-2D-U', *WSEAS Transactions on Circuits and Systems*, 13 (2014), 94–103.

known properties of these signals allow extraction of the emitted target signal from competing sources. The signs can penetrate through walls, and it has been proposed as an alternative for through-the-wall imaging systems (TWIS) for special operations, SWAT, and other military personnel.[26] Further developments allowed the creation of real-time video rate cameras to detect objects at a range of 10-40 feet[27] that can be classified as threats by adding identification algorithms to the systems.[28] Active sensors emit Electro Magnetic radiation onto people comparable to a regular cell phone; therefore, they are not considered a health hazard.

Introducing Machine Learning (ML) technologies dramatically improves system classification performance. For example, with ML Neural Networks (NN), the system improves the overall performance and can also provide precise classifications of the concealed object.[29] The introduction of newer ML methods like Fast Recurrent Convoluted Neural Networks (R-CNN) further improves these systems' precision performance to accurately predict the presence of a concealed weapon by 94% in real-time and provides real-time results.[30]

The use of ML technology has also been implemented for passive MMW detectors. Using the You Look Only Once version 3 (YOLOv3), providing them with a mean average precision (mAP) of 95% and the processing power needed does not add substantial costs. Another essential advantage of these passive detectors is that they can be implemented during large passenger flows.

Some variations of this technology have been developed. One of them is the Multi-polarized MMW active sensors, which, as its name suggests, adds the analyses of polarization features of objects to provide more information about the concealed objects.[31] These devices use an

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[26] G Richard Huguenin, 'Millimeter-Wave Concealed Weapons Detection and through-the-Wall Imaging Systems', in *Proc.SPIE*, 1997, MMCMXXXVIII, 152–59 <https://doi.org/10.1117/12.266735>.

[27] Al Pergande, Chen-Jung Lui, and Larry T Anderson, 'Video-Rate Concealed Weapons Detection', in *Proc.SPIE*, 2000, MMMMXXXII, 30–33 <https://doi.org/10.1117/12.391836>.

[28] D. Novak, R. Waterhouse, and A. Farnham, 'Millimeter-Wave Weapons Detection System', *Proceedings - 34th Applied Image Pattern Recognition Workshop, AIPR 2005*, 2005, 15–20 <https://doi.org/10.1109/AIPR.2005.34>.

[29] David A Andrews and others, 'A Multifaceted Active Swept Millimetre-Wave Approach to the Detection of Concealed Weapons', in *Proc.SPIE*, 2008, , 711707 <https://doi.org/10.1117/12.800360>.

[30] Chenyu Liu, Minghui Yang, and Xiaowei Sun, 'Towards Robust Human Millimeter Wave Imaging Inspection System in Real Time with Deep Learning', *Progress in Electromagnetics Research*, 161 (2018), 87–100.

[31] Xun Li and others, 'Multi-Polarized Millimeter-Wave Imaging for Concealed Weapon Detection', *9th International Conference on Microwave and Millimeter Wave Technology, ICMMT 2016 - Proceedings*, 2 (2016), 892–94 <https://doi.org/10.1109/ICMMT.2016.7762477>.

ultra-wideband (UWB) Multiple-Input multiple output (MIMO) radar that works with lower frequencies, making them more cost-effective and yielding images with satisfactory resolutions for weapon detection.[32]

Tera Hertz Imaging

Advantages	Disadvantages
Can be used to build pass-through metal detectors	Requires the person to remain static to perform the analysis.
Detects metals, chemicals, biological agents, and concealed weapons	This technology also requires high performance components, making it relatively expensive
Produces images as an outline of the clothing and the reflection of the carried objects like keys, chains, phones, or weapons	
Can be combined with Machine Learning (ML) to classify objects detected.	
Accurate Detection of concealed weapons	

How does Terahertz Imaging work?

This technology uses Tera Hertz (THz) electromagnetic waves to detect and identify the transmission and reflectivity of metals, chemicals, biological agents, and concealed weapons. Metals block or reflect THz waves and ceramics and knives partially reflect them. Skin, instead, absorbs the THz waves. The resulting images of scanning a person are the outline of clothing and the reflection of the carried objects like keys, chains, phones, or weapons. These systems provide real-time capability and high spatial resolution.[33] The inclusion of ML technology allows the system to classify the objects detected on a target. Different ML algorithms have been implemented in THz imaging systems, including YOLO and R-CNN with

[32] Wenyi Shao and Todd Mccollough, 'Advances in Microwave Near-Field Imaging', *IEEE Microwave Magazine*, April, 2020, 94–119; Erman Anadol and others, 'UWB 3D Near-Field Imaging with a Sparse MIMO Antenna Array for Concealed Weapon Detection', in *Proc.SPIE*, 2018, , 106331D <https://doi.org/10.1117/12.2314454>.

[33] John F. Federici and others, 'THz Imaging and Sensing for Security Applications - Explosives, Weapons and Drugs', *Semiconductor Science and Technology*, 20.7 (2005) <https://doi.org/10.1088/0268-1242/20/7/018>.

unreliable mAP. The most recent algorithm implemented was the Improved Faster R-CNN (IFRCNN), increasing classification mAP to 85% for knives and 70% for handguns.[34]

Other technologies show potential to be incorporated into THz imaging to improve accuracy and reduce the costs of these detectors. These include using plasmonic sensors and self-switching diodes (SSD), which are still in development.[35]

One limitation of radar-based sensors (like THz imaging and MMW) is that they require the person to remain static to perform the analysis. However, a prototype framework to create a walk-through scanning device that can provide accurate time weapon detection in walking persons has been proposed that allows real-time weapon detection that can be used in crowded areas with high experimental accuracy.[36]

Infrared Imaging

Advantages	Disadvantages
Useful for night vision detectors.	IR wavelength is not enough to penetrate through thick clothes, reducing its reliability
Can be combined with other technologies like MMW and VMS	If the weapon has similar temperature to human body, it will not be detected

How does Infrared Technology work?

This is a commonly used detection system, handy for night vision. This technology is based on different wavelengths that are detected according to temperature. Most infrared sensors have a peak sensitivity of around the average wavelength emitted by the human body. The main drawback of this technology is that wavelength does not have to be small enough to pass through clothes and are absorbed by it and then re-emitted. This causes the concealed weapon to be undetectable under clothing unless the target is wearing tight clothing. Another

[34] Jinsong Zhang and others, 'Terahertz Image Detection with the Improved Faster Region-Based Convolutional Neural Network', *Sensors*, 18 (2018), 1–19 <https://doi.org/10.3390/s18072327>.

[35] Shahrir R. Kasjoo and others, 'A Brief Overview of Detectors Used for Terahertz Imaging Systems', *AIP Conference Proceedings*, 2203.January (2020) <https://doi.org/10.1063/1.5142112>.

[36] Nagma S. Khan and others, 'Real-Time Concealed Weapon Detection on 3D Radar Images for Walk-through Screening System', *Proceedings - 2023 IEEE Winter Conference on Applications of Computer Vision, WACV 2023*, 2023, 673–81 <https://doi.org/10.1109/WACV56688.2023.00074>.

drawback is that when the weapon temperature approaches to that of the human body, the detector does not identify anything.[37]

To overcome these drawbacks, images provided by IR detectors have been combined with visual sensors (like video management systems) and MMW sensors to increase their detection performance.[38] ML technology also allows the classification of fused images from IR and VMS or MMW sensors. The application of CNN and Logistic Regression shows an accuracy of 90% and a precision of 86.6%.[39]

X-Ray Imager

Advantages	Disadvantages
Real-time detection of concealed weapons in cargo, luggage, and bags.	Increased presence of electronics in bags (like laptops and tablets) has an impact in detection capability
Easy identification of metallic objects	Requires continuous operation by security staff
X-Rays with color mapping have a detection rate of up to 97%	X-rays are biologically harmful and cannot be used for detection of threats in persons.
Can be combined with Machine Learning (ML) to aid operator	

How do X-Ray Imagers work?

X-Ray imagers are arguably the most widely known technology for concealed weapon detection and are commonly used in airports. This technology uses ionizing radiation from a source to be projected to a target and received in a sensor that detects the radiation attenuation. The radiation is absorbed depending on the object's density, changing the energy it delivers to the sensor. This allows the creation of real-time imaging of elements like luggage and cargo. The denser the material, the darker the color of the resulting grayscale image.

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[37] Agurto and others.

[38] Zhiyun Xue and Rick S. Blum, 'Concealed Weapon Detection Using Color Image Fusion', *Proceedings of the 6th International Conference on Information Fusion, FUSION 2003*, 1.February (2003), 622–27 <https://doi.org/10.1109/ICIF.2003.177504>; Mahadevi Parande and Shridevi Soma, 'Concealed Weapon Detection in a Human Body by Infrared Imaging', *International Journal of Science and Research*, 4.9 (2013), 2319–7064 <www.ijsr.net>.

[39] Saksham Gosain, Ayush Sonare, and Shreyas Wakodkar, 'Concealed Weapon Detection Using Image Processing and Machine Learning', *International Journal for Research in Applied Science and Engineering Technology*, 9.12 (2021), 1374–84.

Metallic objects completely block X- Rays, resulting in an easy-to-identify image for the device operator. To facilitate accurate detection of concealed weapons, a color mapping scheme that is dependent on object density can be used to transform the grayscale images, increasing the detection rate of low-density threats to 97%.[40]

Machine learning technology has also been implemented on X-Ray images to aid the operator in weapon detection. For example, the scanned elements in baggage can be segmented to extract the objects by applying Feature Extraction and then using a ML algorithm known as fuzzy k-nearest neighbor (KNN) to classify the objects as illicit or non-illicit[41] and alert the operator for further manual inspections.

Even with these improvements, operators and manual screening still play a crucial role, and exhaustion can negatively affect detection performance. Additionally, the increasing presence of laptops inside bags limits detection capability. These issues can be addressed by implementing ML and deep-learning algorithms. Using supervised and unsupervised approaches for X-Ray imagers has strengths and weaknesses. However, the most critical limitation to creating reliable detection is the need for large, well-balanced datasets to train these algorithms.[42]

Regardless of technological improvements in X-ray imagers, their widely known limitation is the potential biological harm that X-Rays can produce, making them unsuitable for detecting threats being carried.

Video Management Systems and AI Algorithms

Advantages	Disadvantages
Video Management Systems (VMS) are widely available and are already installed in many locations, and Artificial Intelligence (AI) can be added to existing VMS.	There is no reliable data on the accuracy and detection rate of AI implementation; VMS can be used to detect brandished weapons

[40] B R Abidi and others, 'Improving Weapon Detection in Single Energy X-Ray Images Through Pseudocoloring', *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, 36.6 (2006), 784–96 <https://doi.org/10.1109/TSMCC.2005.855523>.

[41] Mohamed Mansoor Roomi, 'Detection of Concealed Weapons in X-Ray Images Using Fuzzy K-NN', *International Journal of Computer Science, Engineering and Information Technology*, 2.2 (2012), 187–96 <https://doi.org/10.5121/ijcseit.2012.2216>.

[42] Samet Akcay and Toby Breckon, 'Towards Automatic Threat Detection: A Survey of Advances of Deep Learning within X-Ray Security Imaging', *Pattern Recognition*, 122 (2022), 108245 <https://doi.org/10.1016/j.patcog.2021.108245>; S Sarkar and others, 'Design of Weapon Detection System', in *2022 3rd International Conference on Electronics and Sustainable Communication Systems (ICESC)*, 2022, pp. 1016–22 <https://doi.org/10.1109/ICESC54411.2022.9885601>.

AI to detect concealed weapons can substantially increase security level provided by VMS	After adding AI to the VMS, the system accuracy strongly depends on the method used to train the detection algorithm.
VMS with AI do not require continuous human operator monitoring.	

How do VMS and AI work?

Video Management systems (VMS) are widely available for intruder detection and remote alarm verification. However, the essential drawback is that they require continuous supervision by human operators. Additionally, it is estimated that the concentration of a Security Officer monitoring the system decreases after 20 minutes.[43] Despite these limitations, these systems are used in most public locations.

With the introduction of AI algorithms, Machine Learning (ML) and deep learning, the security level provided by these systems can be substantially increased by maintaining constant surveillance of the video footage and improving the detection rate of threats.[44] Several ML methods are being proposed with varying results. For example, the implementation of FRCNN using a predetermined image dataset to train the algorithm and testing it on two different types of detectors yielded an average precision (AP_{50}) of 85.45%.[45] The threat detection triggers an alert to the operator to monitor the threat.

As an alternative to training these ML algorithms, YouTube videos and Gun movies have been proposed as large databases. The proposed algorithms use methods like Gaussian Mixture Model (GMM) to detect weapons in video sequences and a combination of Scale Invariant Feature Transformation (SIFT) and Human Inspired Particle Swarm Optimization (HIPSO) to decrease the system complexity and training time of the classifier. Finally, the selected vectors

[43] M Milagro Fernandez-Carrobles, Oscar Deniz, and Fernando Maroto, ‘Gun and Knife Detection Based on Faster R-CNN for Video Surveillance BT - Pattern Recognition and Image Analysis’, in *Proc.SPIE*, ed. by Aythami Morales and others (Cham: Springer International Publishing, 2019), pp. 441–52.

[44] Fernandez-Carrobles, Deniz, and Maroto.

[45] Fernandez-Carrobles, Deniz, and Maroto; A Goenka and K Sitara, ‘Weapon Detection from Surveillance Images Using Deep Learning’, in *2022 3rd International Conference for Emerging Technology (INCET)*, 2022, pp. 1–6 <https://doi.org/10.1109/INCET54531.2022.9824281>.

are processed by a Support Vector Machine (SVM) to classify the object as a weapon or non-weapon. This method is reported to have an accuracy between 95.34% and 98.60%.[46]

Another proposed algorithm consists of two decision arms that include a second parameter in the decision-making system, leading to increased accuracy in triggering the alerts. The system uses ML methods, including "BagOfFeatures" and K-means clustering, and Support Vector Machine (SVM) to process video management footage, with an average accuracy of 94.67%. The second arm of the system identifies the object materials using MMW. Combining the results of video footage and material testing and analyzing them using a Fuzzy Logic Function, the final decision is reported to have an 83% accuracy of alert triggering.[47]

Lastly, a ML training method that has drawn attention to weapon detection is the You Look Only Once (YOLO). Different versions of this method yield different results. The use of YOLOv4 has been reported to have an accuracy of 66.67%.[48] The use of YOLOv5 has been reported to have increased by 91% and 96.6% accuracy.[49]

Other approaches and ML methods have been proposed for Concealed Weapon Detection in Video Management Systems. However, there are substantial challenges to address before considering them as a reliable and robust threat detection method: A specific dataset for weapon detection is unavailable, the need for a heterogeneous model that identifies a wide variety of weapons of the same class, shapes and colors, the constructive use of contextual information and the detection of small objects and the need for low-computing network.[50]

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[46] Kiran Kalla and Gogulamanda Jaya Suma, 'Weapon Detection in Surveillance Videos Using Human Inspired Particle Swarm Optimization Algorithm and Support Vector Machine', *International Journal of Intelligent Engineering & Systems*, 15.4 (2022) <https://doi.org/10.22266/ijies2022.0831.11>.

[47] Collins Ineneji and Mehmet Kusaf, 'Hybrid Weapon Detection Algorithm, Using Material Test and Fuzzy Logic System', *Computers and Electrical Engineering*, 78 (2019), 437–48 <https://doi.org/10.1016/j.compeleceng.2019.08.005>.

[48] W. E. I. B. W. N. Afandi and N M Isa, 'Object Detection: Harmful Weapons Detection Using YOLOv4', in *2021 IEEE Symposium on Wireless Technology & Applications (ISWTA)*, 2021, pp. 63–70 <https://doi.org/10.1109/ISWTA52208.2021.9587423>.

[49] Naresh Yeddula and B. Eswara Reddy, 'Effective Deep Learning Technique for Weapon Detection in CCTV Footage', *2022 IEEE 2nd International Conference on Mobile Networks and Wireless Communications, ICMNWC 2022*, 2022 <https://doi.org/10.1109/ICMNWC56175.2022.10031724>; Lucy Sumi, Shouvik Dey, and Lucy Sumi, 'YOLOv5-Based Weapon Detection Systems with Data Augmentation YOLOv5-Based Weapon Detection Systems with Data Augmentation', *International Journal of Computers and Applications*, 2023, 1–9 <https://doi.org/10.1080/1206212X.2023.2182966>.

[50] Pavinder Yadav, Nidhi Gupta, and Pawan Kumar Sharma, 'A Comprehensive Study towards High-Level Approaches for Weapon Detection Using Classical Machine Learning and Deep Learning Methods', *Expert Systems With Applications*, 212.August 2022 (2023), 118698 <https://doi.org/10.1016/j.eswa.2022.118698>.

OPERATIONAL CONSIDERATIONS

Establishing a venue screening policy and user screening procedures allows control of the items brought into a venue. This should be a part of a venue's overall security plan. In general, a venue screening policy should outline what is acceptable to bring in and what is not. Each venue should have a Code of Conduct outlining prohibited items. The screening procedures should outline how to conduct proper patron screening, describe how to interact with the individuals being searched, state how to identify prohibited items during screening, and explain how to respond to items discovered. It is essential to create public awareness so that patrons are informed that they will be searched before entering the venue, and failure to allow it will result in denial of entry. Valuable methods to create awareness include signs, websites, tickets, periodic announcements, and social media.

Each venue must decide the procedures, protocols, and equipment to provide an acceptable level of security. An essential factor to consider in how much time and effort will be dedicated to screening is the "patron flow rate." Events with a high flow rate will have reduced times to conduct screening.

In addition to the available equipment to conduct screening (disposable gloves, flashlights, containers, radios), the staff can use any of the previously mentioned technologies to improve the screening efficiency and flow rate. Walk-through detectors (WTD) facilitate screening. Locations for these detectors should be well-lit, covered from rain (if feasible), and have enough power supply to operate the amount of WTD. The equipment should be tested and documented to ensure proper operation and verification that the technology is working as intended. Some non-threat items can trigger the detector alert depending on WTD's technology.

Upon alert triggering, the individuals should be placed for secondary screening, which means further inspection to determine the presence of a threat. However, secondary screening should also be set for people with medical conditions, who are in a wheelchair, have a prosthetic limb, or are pushing baby strollers. Handheld devices for concealed weapons detection can also be used for secondary searches. Additional information about operational considerations can be found in the *Patron Screening Best Practices Guide* by the US Department of Justice.[51]

A crucial factor in the level of safety is the number of staff designated to carry out inspection activities. Although no statute or standard determines it, the number of staff generally

[51] Commercial Facilities Sector-specific Agency, 'Patron Screening Best Practices Guide', March, 2016.

depends on several factors, such as the size of the venue, the number of entrances, the number of people expected to attend, and the desired level of security.[52] A frequently used method is to use the ratio of security staff to patrons or determine staffing needs based on the hours to be staffed per week. An important consideration is that although Security Officer staffing may be reduced during low traffic times, more Security Officers may be required simultaneously in cases of a high flow of visitors or due to secondary screening needs.

EVALUATING EFFECTIVENESS

Determining a threat detection technology's theoretical level of precision and accuracy does not guarantee its external validity in any scenario. As previously mentioned, factors such as the level of risk and the social, economic, and locative context can favor implementing more robust screening programs and need a specific type of technology to have a high detection rate. Although there are only sometimes sufficient resources for a sufficiently robust system, systems can be evaluated to determine their effectiveness in real life and find flaws that can be improved.

For example, the TSA regularly tries to sneak guns and simulated bombs through checkpoints or in checked baggage. The results of this testing program provided nine recommendations to address the vulnerabilities discovered.[53]

The efficiency of threat detection technologies can be calculated through measures such as Mean Average Precision (mAP) but assessing staff efficiency can be more complicated. Despite multiple training courses focused on maintaining adequate personnel preparation, human error is subject to fatigue, loss of attention, visual distraction, or high workloads.[54] These variables are not easily measurable, but their role in the efficiency of a threat detection system is crucial. Regardless of the level of technological development available for the security of a venue, the role of security staff is vital both for the operation of equipment and

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[52] Lasorsa & Associates, 'Staff to Patron Ratios: How Many Security Guards Do I Need?', 2017 <https://www.lasorsa.com/2017/08/09/staff-patron-ratios-many-security-guards-need/> [accessed 10 April 2023].

[53] United States and Government Accountability, 'Aviation Security: Tsa Improved Covert Testing but Needs to Conduct More Risk-Informed Tests and Address Vulnerabilities', *Key Government Reports. Volume 20: Homeland Security - April 2019*, April, 2019, 23–88; Government Accountability Office, 'Aviation Security: TSA Should Ensure Screening Technologies Continue to Meet Detection Requirements after Deployment', December, 2019 <https://www.gao.gov/assets/gao-20-56.pdf>; Michael Goldstein, 'TSA Misses 70% of Fake Weapons but That's an Improvement', *Forbes*, November 9, 2017 <https://www.forbes.com/sites/michaelgoldstein/2017/11/09/tsa-misses-70-of-fake-weapons-but-thats-an-improvement/?sh=52a3e5372a38>.

[54] Kalla and Jaya Suma; Sarkar and others.

for the implementation of protocols in the identification of a security risk. For this reason, efficiency evaluation activities should contemplate strategies to control these factors, such as providing adequate rest intervals, establishing the appropriate number of staff for a control point, and ensuring adequate hydration and balanced work schedules.

LIMITATIONS

Weapons detection technologies have evolved substantially over the past two decades, and for now, there is no glimpse that the development of new technologies will slow down. The emergence of machine learning and artificial intelligence has opened the door to various innovations that set previously unimaginable quality standards when implemented in known weapons detection technologies. However, the same accelerated pace sets a critical limitation since scientific documentation of these advances is not readily available. Even if it is, new advances are already being explored that question what is currently available to support weapons screening systems.

CONCLUSION

Technological advances have allowed the development of highly accurate, effective, safe weapons detection devices with real-time detection, which, when implemented in a security system, establish an adequate level of security for the development of social, educational, hospital, commercial and recreational activities. Threats from gunfire to people's safety can occur at any location. The recent increase in the incidence of mass trigger events indicates the importance of implementing security systems that are highly efficient in detecting threats to mitigate the risk of these life-threatening events.

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APPENDIX: RESEARCH SUMMARY TABLE

Study Title:	Journal	Year	Topic	Findings
THz imaging and sensing for security applications - Explosives, weapons, and drugs	Semiconductor Science and Technology	2005	THz Imaging	The paper describes the use of THz radiation for CWD systems and mentions how it compares to Millimeter Wave (MMW) imaging, the application of THz spectroscopy to CWD through barrier materials, the configuration of various THz systems (Transmissive vs reflective detection, pulsed THz detection vs Continuous wave (CW) and close proximity vs stand-off detection), uses and advantages and future prospects.
Gun and Knife Detection Based on Faster R-CNN for Video Surveillance BT - Pattern Recognition and Image Analysis	Proc.SPIE	2019	CCTV and Machine Learning CNN	System for gun and knife detection based on Faster R-CNN methodology using two different approaches (GoogleNet and SqueezeNet). Best result was using SqueeeNet with a mAP50 of 85.5% for gun detection. GoogleNet 46.68% mAP50
Weapon detection using a wideband millimeter-wave linear array imaging technique	Proc.SPIE	1994	MMW	The research describes the initial development of the Millimeter Wave Illumination for the detection of concealed weapons, including the hardware, the methods, and the resulting images from a test target in a metalized mannequin.
Comparison of active millimeter-wave and acoustic imaging for weapon detection	Proc.SPIE	1997	Acoustic Imaging and MMW	The paper discusses the differences between Millimeter Wave and Acoustic Imaging and recognizes that the latter has important limitations to be considered like the degree of acoustic penetration of heavier cloth, which seems to be very poor, and that the image acquisition time is severely constrained, slowing down an effective real-time operation of the scanner. However, the advantage that this technology has is that it is a relatively easy and low-cost alternative. Millimeter Wave does not have this limitation.
Antennas for concealed weapon detection	2005 5th International Conference on Antenna Theory and Techniques	2005	EM Resonance or MMVave	The paper describes the elements, array architecture, power, and range of radio frequency antennas for conceded weapon detection. This is an early-stage paper about the use of radio frequencies for CWD, and also describes that an alert subsystem can alert authorities about a concealed weapon or trigger systems like video surveillance cameras to track the suspect..
Millimeter-wave concealed weapons detection and through-the-wall imaging systems	Proc.SPIE	1997	MMW	Describes a Prototype product created by Millimetrix (Gateway Scanner). Civilian applications: Airport, Courtrooms, Correctional Facilities, office buildings schools, banks, and other financial institutions. The technology can be implemented as a Gateway Scanner, a hand-held scanner, that provide image in a few seconds, and in video surveillance cameras. In addition, describes a future product for a through-the-wall imaging system (TWIS). Two people should be able to carry the system. The battery lasts for about one hour or one connected to the power source.
Concealed weapon detection from images using SIFT and SURF	2016 Online International Conference on Green Engineering and Technologies (IC-GET)	2016	MACHINE LEARNING ALGORITHMS SIFT and SURF X-Ray	The algorithm can be implemented to different types of Imaging systems (MMW, THz , IR, X-Ray). The method detects weapons of different shapes of guns from scanned images and is invariant to scaling rotation, occlusion, and change in illumination. The true positive rate was 90%, this one that is in early development

Concealed Weapon Detection in a Human Body by Infrared Imaging	International Journal of Science and Research	2013	Infrared	Proposed a method to use IR for CWD. They use image fusion to help humans or computed in detecting CW using IR and visual sensors, and the process is conducted by Discrete Wavelet Transform (DWT) Method. The method is proposed as a low-cost option for CWD.
Concealed weapon detection using color image fusion	Proceedings of the 6th International Conference on Information Fusion, FUSION 2003	2003	Infrared and Image Fusion	Proposed Method: use of Color Image Fusion Technology using Discrete Wavelet Frame approach. The method can be used to detect weapons under clothes or bags without human presence.
Concealed Weapon Detection using Image Processing and Machine Learning	International Journal for Research in Applied Science and Engineering Technology	2021	Infrared and Image Fusion	Proposes a process flow for CWD: Using both, RGB images and IR/Thermal images, image processing using Discrete Wavelet Transform, Analyses fusion image, and detects the hidden object. The paper explores alternatives to image processing using Convolutional Neural Networks (CNN) and Logistic Regression. The performance parameters were Accuracy 90%, Precision 86.6%, Recall 92%, and F1 Score 89.65%.
Data Processing Unit for Energy Saving in Computer Vision: Weapon Detection Use Case	Electronics	2023	DATA PROCESSING EFFECTIVENESS	Describes benefits of using Data Processing Units (DPUs) as an alternative to alleviate the workload of 24-hour servers, measures workload reduction of CCTV CWD system (43% reduction of workload and 98% savings during night hours), and proposes a framework that can be adapted to other computed-based detection systems. The methodology is beneficial when there is no constant flow of people, but active surveillance is necessary (like universities, public institutions, military buildings, and museums).
Video-rate concealed weapons detection	Proc.SPIE	2000	MMW and IR Image Fusion	Describes the design of a new CWD system that integrated real-time video rate millimeter wave camera that detects Concealed Weapons at a range of 10-40 feet and an infrared camera to provide a fusible image to aid operators in detecting and classifying targets on subject individuals. At the time of the paper, the prices of the modules were considerable. The paper was a relative introduction to MMW technology for CWD.
Design of Weapon Detection System	2022 3rd International Conference on Electronics and Sustainable Communication Systems (ICESC)	2022	X-ray and Machine Learning	The research promotes an approach that sees things in X-ray pictures for the detection of perilous merchandise. The machine learning algorithm uses a K-means clustering (SURF process) to remove unrelated objects from the scene using color-based segmentation, and the item (gun) is located using Harris interest point detector and the Fast Retina Key Point (FREAK). The system uses an ARM LPC2148 processor (Considerably inexpensive)
Detection of Concealed Weapons in X-Ray Images Using Fuzzy K-NN	International Journal of Computer Science, Engineering, and Information Technology	2012	X-ray and Machine Learning	Uses Fuzzy K-NN classification technique to identify CW from X-Ray images.
Millimeter-wave weapons detection system	Proceedings - 34th Applied Image Pattern Recognition Workshop, AIPR 2005	2005	MMW	Proposes a new EM solution for CWD (handgun, knife, box cutter, etc.). The described system can operate effectively at distances of up to 10 meters.

Hybrid weapon detection algorithm, using material test and fuzzy logic system	Computers and Electrical Engineering	2019	CCTV and Machine Learning	A Hybrid Automatic detection system is proposed, using a combination of metallic test and image test arms. The proposed algorithm receives parameters from the metallic test, which enhances accurate conclusions and reduces the false alarm rate. The researchers achieved a 94% accuracy after a series of partitioning the dataset.
Electromagnetic Imaging System for Weapon Detection and Classification	The Fifth International Conference on Sensor Technologies and Applications	2011	EM Resonance	Describes a weapon classification technique to using a walk-through metal detector (WTMD) and Hand-held Metal Detector (HHMD) with a giant magnetic-resistive sensor array to measure the spatial magnetic field used in the study. This technique is more advanced in object characterization and allows for discrimination between different objects.
Object Detection: Harmful Weapons Detection using YOLOv4	2021 IEEE Symposium on Wireless Technology & Applications (ISWTA)	2021	CCTV and Machine Learning	Describes the use of YOLOv4 in a CCTV in Malaysia using the Darknet framework, using two datasets to train the AI. Single-class detection managed a 66.67% to 77.78 accuracy on average, whilst the multiple-class object managed 100% accuracy. The model detects specifically handguns and knives. The system can be implemented on a microcontroller such as a Raspberry Pi and can be set up to send notifications when a weapon has been detected. The model was not trained using largely available datasets of weapons.
Handheld ultrasonic concealed weapon detector	Proc.SPIE	2001	Acoustic and Ultrasound	The paper describes the development of a handheld, battery-operated prototype of concealed weapon detector that was built and tested to detect metallic and non-metallic weapons using ultrasound frequencies (40 kHz) from a distance range of about 12 feet (4 meters). The detector emits an audible alarm and using a high-intensity light the operator can determine the location of the concealed object. The research paper does not provide information of the Accuracy of detection.
Effective Deep Learning Technique for Weapon Detection in CCTV Footage	2022 IEEE 2nd International Conference on Mobile Networks and Wireless Communications, ICMNWC 2022	2022	CCTV and Machine Learning YOLOv5	YOLOv5 is one of the most advanced object detection models. The proposed detection system can be used for the class of knives, the class of pistols, and the class of axes. The YOLOv5 is used for object detection using a Pytorch for object detection. The model had a mean average precision (mAP0 of 96.6% and an F1 score of 96%/
A multifaceted active swept millimeter-wave approach to the detection of concealed weapons	Proc.SPIE	2008	MMW	Automated Technique for detection of concealed handguns that relies on swept illumination of the target to induce scattered fields and aspect-independent responses from the concealed object. Broad frequency allows for information about the object's size to be deduced. allows us to distinguish personal objects (keys, mobile phones,) from handguns.

Impacts of Metal Detector Use in Schools: Insights From 15 Years of Research	Journal of School Health	2011	Metal Detectors in Schools	Literature search for the study about the perception of installing metal detectors at schools, using either walk-through metal detectors or wand-style. It mentions that the strongest evidence supporting the use of metal detectors comes from Ginsberg and Loffredo, but also mentions that it has several limitations in evaluating pre-post study design, which potentially leads to reporting bias. Schrek found that the presence of metal detectors was not associated with a risk of being robbed or physically attacked. Regarding student perceptions, most students don't agree with them, and school principals reported that detectors were associated with decreased perception of school safety. The effect of detectors can potentially make students react with heightened feelings of vulnerability or aggression. There is insufficient evidence to draw conclusions on the beneficial effect of metal detector use.
Improving Weapon Detection in Single Energy X-Ray Images Through Pseudo coloring	IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)	2006	X-Ray and Pseudo coloring	Linear and nonlinear pseudo coloring to be applied to X-ray luggage scans, particularly to detect low-density weapons. The system uses a friendly user interface, and the study of effectiveness proved the advantages of using color over grayscale. Rate of improvements in weapon detection of up to 97% was achieved using color (Color is 40% better, on average than gray level enhancements alone, as results from original data were detection of 57% of the cases).
Design of a Passive Millimeter-wave Imager Used for Concealed Weapon Detection BHU-2D-U	WSEAS Transactions on Circuits and Systems	2014	Passive MMW	Describes a new passive millimeter-wave imager BHU-2D-U, which is an improved version of the model BHU-2D. It has an enlarged field of view (FOV) and can the U-shaped antenna can be used for whole-body scan., and the smaller antenna
Imaging for Concealed Weapon Detection	International Journal of Computer Applications	2015	MMW Image Fusion	Describes a method for CWD, that is based on millimeter wave imaging and built-in intelligence for detection. It can be implemented with infrared images or millimeter wave images and image fusion. The method is robust and can detect concealed weapons in public spaces.
New Proposal for the Detection of Concealed Weapons: Electromagnetic Weapon Detection for Open Areas		2009	EM	The paper proposes a cost-effective weapon detection system based on pulse detection technology that can work in open areas without invading individual privacy. There are magnetic sensors on the market like the flux-gate magnetometer, the search-coil magnetometer, SQUID magnetometer, and GMR.
Weapon Detection from Surveillance Images Using Deep Learning	2022 3rd International Conference for Emerging Technology (INCET)	2022	CCTV and Machine Learning	Build an automatic handgun detection System that can be equipped with surveillance Cameras. They propose an automatic gun detection system based on deep learning (Pretrained Mask RCNN model). The model had a precision of 88,45%. The system detects weapons in real-time and is unaffected by size, scale, rotation, and even partial occlusion. This implementation also improves system performance and reduces time complexity and space.

Open-area concealed-weapon detection system	Proc.SPIE	2011	Inductive Magnetic Field Methods	The paper proposes a new concealed weapon detection system to be used in open areas, using Electro Magnetic Induction (EMI). The paper describes the basic phenomenon behind EMI effects on metal objects, the induced surface current, and the secondary magnetic field created. It also provides details on the design of the transmitter, the receiver, and the analysis process of the signal. The system is also connected to CCTV cameras to enable remote operators to track individuals carrying threat items in the detection space.
Multi-polarized millimeter-wave imaging for concealed weapon detection	9th International Conference on Microwave and Millimeter Wave Technology, ICMMT 2016 - Proceedings	2016	MMW	Describes research on multi-polarized MMW imaging. The technique can be useful to provide more information about the target.
Towards Robust Human Millimeter Wave Imaging Inspection System in Real Time with Deep Learning	Progress in Electromagnetics Research	2018	MMW and Machine Learning	The paper proposes a novel framework for concealed weapon detection and shows that the algorithm has a high precision (correctness ratio of a detector) and recall (used for judging the detection ratio). The proposed method has a precision of 93% and a recall of 90% (better performance than other frameworks). The method is a is an improved two-stage Faster RCNN.
Standoff detection of concealed handguns	Proc.SPIE	2008	Millimeter Wave	The research describes the development of a new portable Millimeter Wave device that can be used from a distance. The method described by the researchers allow for differentiating concealed weapons from other objects such as keys or mobile phones. This provides a means of detecting handguns under practical conditions at a stand-off distance. The study focuses on the technology itself and does not provide accurate detection data.
Terahertz Image Detection with the Improved Faster Region-Based Convolutional Neural Network	Sensors	2018	THz and Machine Learning	The paper proposes a classification method based on transfer learning, and then, an improved Faster R-CNN (IFRCNN) method is proposed which is compared to other prediction models. The reason is that it extracts features from the whole body and then classifies them.
Towards automatic threat detection: A survey of advances of deep learning within X-ray security imaging	Pattern Recognition	2022	X-ray and Machine Learning	The paper reviews computerized X-ray algorithms, discusses the classical Machine Learning Approaches used, and investigates modern algorithms used. The paper has a diagram that explains the taxonomy of X-ray security imaging papers, the Machine Learning approaches (object classification and detection), and deep learning (both supervised and unsupervised). It also mentions the limitations of the current datasets to train the machine learning algorithms, the lack of work about the utilization of multiple view imagery, adaptations between different x-ray scanners, and improving detection.
UWB 3D near-field imaging with a sparse MIMO antenna array for concealed weapon detection	Proc.SPIE	2018	MMW	Contrary to millimeter Wave, UWB are more cost-effective and yield images with resolutions for contraband detection without concerns to personal privacy.

Transmitter and Receiver Coil Design for Open Area Concealed Weapon Detection System	University of Huddersfield Repository	2010	Inductive Magnetic Field Methods	Describes the problems of Open Area Concealed Weapon Detection (OACWD) and proposes a solution to address the interaction between the transmit and receive coil arrays, which depending on their interaction can produce noise.
Real-time Concealed Object Detection from Passive Millimeter Wave Images Based on the	Sensors	2020	MMW and Machine Learning	The paper proposes a real-time detection method for detecting CW using passive millimeter wave (PMMW) imagery based on the YOLO. The system had a detection speed of 36 frames per second (FPS) and a mean Average Precision (mAP) of 95% on a 1080Ti GPU laptop. The designed system can be used for real-time detection during large passenger flows in terms of trade of detection accuracy detection speed and computation resources.
Weapon Detection in Surveillance Videos Using Human Inspired Particle Swarm Optimization Algorithm and Support Vector Machine	International Journal of Intelligent Engineering & Systems	2022	CCTV and Machine Learning	An automated model for effective weapon detection in CCTV videos using deep learning models (HIPSO-SVM). The model results in high accuracy of 95.34 and 98.6 on YouTube and Gun movies databases, which is better than existing models.
Real-time Concealed Weapon Detection on 3D Radar Images for Walk-through Screening System	Proceedings - 2023 IEEE Winter Conference on Applications of Computer Vision, WACV 2023	2023	THz MMW and 3D imaging	The paper describes a prototype of a walk-through screening system capable of performing CWD on walking persons, using the same technology detection used in airport detectors that require the person to be stationary. The system consists of two parallel radar sensor panels forming a gate. Each panel contains multiple antennas that transmit and receive radio waves. The model achieves good accuracy
Weapons Retrieved after the Implementation of Emergency Department Metal Detection	Journal of Emergency Medicine	2015	Metal Detector Efficiency	A retrospective review of security records over a 26-month period of the weapons was detected after a metal detector was placed at the entrance of a private community teaching hospital Emergency Department. The number of retrieved guns decreased between 2012 to 2013 (182 to 47), but the number of knives, chemical sprays, and other weapons increased. The implementation of an ED metal detector is effective in reducing the entrance of weapons into ED.
YOLOv5-based weapon detection systems with data augmentation YOLOv5-based weapon detection systems with data augmentation	International Journal of Computers and Applications	2023	CCTV and Machine Learning	The article shows the taxonomy of object detection models, which can be classified into two: Traditional approaches and deep neural networks (two-stage detectors and one-stage detectors). It describes the differences between the YOLO versions and compares them to the Yolov5. The mean Average Precision (mAP) obtained was 90% and 91% for non-augmented and augmented UGM datasets.