NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

DEVELOPING AN OPERATIONAL AND TACTICAL METHODOLOGY FOR INCORPORATING EXISTING TECHNOLOGIES TO PRODUCE THE HIGHEST PROBABILITY OF DETECTING AN INDIVIDUAL WEARING AN IED

by

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13. ABSTRACT (maximum 200 words)

Among the many weapons currently used by terrorist organizations against public welfare and coalition forces in Iraq and Afghanistan, human-born Improvised Explosive Devices (IEDs) present a significant threat. Commonly referred to as "suicide bombers," these individuals enter crowded public areas in order to detonate the IED, inflicting lethal damage to the surrounding individuals. Constructed of non-standard parts and hidden under layers of clothing, these human-born IEDs go undetected until detonated. Currently, there are no detection systems that can identify suicide bombers at adequate standoff distances.

The purpose of this research is to develop a methodology that combines current technologies to increase the probability of identifying a suicide bomber at a checkpoint or marketplace with an adequate standoff distance. The proposed methodology will employ each sensor technology incorporating unique detection threshold values. We will analyze our proposed methodology utilizing a simulation model that provides both the probability of detecting a bomber and the probability of a false detection. These simulations will allow us to determine the threshold values for each sensor that result in the best probability of detection of a suicide bomber and allows for a small probability of false detections.

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ABSTRACT

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The purpose of this research is to develop a methodology that combines current technologies to increase the probability of identifying a suicide bomber at a checkpoint or marketplace with an adequate standoff distance. The proposed methodology will employ each sensor technology incorporating unique detection threshold values. We will analyze our proposed methodology utilizing a simulation model that provides both the probability of detecting a bomber and the probability of a false detection. These simulations will allow us to determine the threshold values for each sensor that result in the best probability of detection of a suicide bomber and allows for a small probability of false detections.

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LIST OF ACRONYMS AND ABBREVIATIONS

AS&E	American Science and Engineering
CenSSIS	Center for Subsurface Sensing and Imaging Systems
CIA	Central Intelligence Agency
CW	Continuous Wave
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOA	Department of Army
GHz	Gigahertz
IED	Improvised Explosive Device
IR	Infrared
JIEDDO	Joint Improvised Explosive Device Defeat Organization
LADAR	Laser Detection and Ranging
LIDAR	Light Detection and Ranging
MMW	Millimeter-Wave
NEC	Numerical Electromagnetic Code
RADAR	Radio Detection and Ranging
RCS	Radar Cross-section
RPI	Rensselaer Polytechnic Institute
SVIED	Suicide Vest IED
THz	Terahertz
TNT	Trinitroluene

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I. INTRODUCTION

A. BACKGROUND ON SUICIDE BOMBERS

> Over the last twenty-five years, suicide attacks have emerged as one of the most effective methods used on a large scale by terrorist organizations.
>
> – L. Wells III and B.M. Horowitz

An individual who is willing to sacrifice his own life by causing a detonation in an attack is a significant force multiplier when employed against a conventional security force (Wells III & Horowitz, 2005). The purpose of a suicide attack is to create fear, mayhem, and chaos within a region. The doctrine of asymmetric warfare views suicide attacks as a result of an imbalance of power in which groups with little power resort to suicide bombing as a convenient tactic to demoralize the targeted civilians or government of their enemies. As of 2005, suicide attacks have been used in only seven of the sixty-nine countries that have had violent uprisings in the last half century, but the effects of suicide attacks are much more lethal than most armed attacks (Berman & Laitin, 2005).

B. DEFINITION OF A SUICIDE BOMBER

Suicide bombings can be defined as violent, politically motivated attacks, carried out in a deliberate state of awareness by a person who blows himself up together with a chosen target (Bloom, 2004). A successful suicide attack is accomplished with the preconceived notion that the attacker will have certain death.

> Suicide bombing as a practice encompasses attacks of military targets that are immune via ordinary insurgent tactics, the assassination of prominent leaders (who would ordinarily not be accessible by other means), and the attack of large numbers of civilians, mimicking indiscrimination to create generalized fear. (Bloom, 2004)

Suicide attackers can be classified into two categories, state or non-state. The majority of the groups that commit suicide attacks are insurgent or terrorist groups that are competing for control with an established state (Bloom, 2004).

Most terrorist groups using suicide attacks are usually in conflict with an established state. Suicide attacks are used when opposing sides have disputes or differences regarding racial, ethnic, religious, or national sovereignty issues. It is the preconceived plan of the terrorists groups that their suicide bombings will frighten and overwhelm the opposing force or organization, while also raising awareness of the dedication and resolve of their cause (Dickson, 2008).

Financially, suicide attacks are relatively inexpensive. The price of the materials used in a suicide attack in Israel can be obtained for about $150 (Cronin, 2003). This allows terrorist groups to easily purchase and produce suicide bombs without drawing the attention of authorities or government organizations. Economically, the price to produce a suicide bomb and to have an individual successfully carry out an attack is a small price to pay when compared to the casualties and destruction resulting from the attack (Dickson, 2008). On the other hand, finding members in the terrorist group and training them to carry suicide attacks and give their lives to its cause is a costly venture. This means terrorist groups conduct suicide attacks only when necessary (Berman & Laitin, 2005).

C. SUICIDE BOMBING TARGETS

Depending on the target of a suicide bombing, public protest or objection will vary. Terrorists not only target civilians, but they also target military personnel, military bases or installations, international organizations, and non-governmental organizations.

> The public response to the tactical use of suicide bombing depends on how the tactic is used by the insurgent organizations, against whom, and for what purpose. If suicide terror does not resonate and the domestic environment is antagonistic to it, it will be rejected by the rank and file. Violence will fail it win over the 'hearts and minds' of the public, the insurgent groups' goal. (Bloom, 2004)

It makes sense for suicide attackers to choose targets that will have the largest impact to the conflict's opposing side. Since military installations are usually heavily guarded or hardened, many times the easiest targets are civilian installations or soft targets (Dickson, 2008). For the use of anti-personnel suicide bombings, attack planners have adapted and learned many new techniques. Where facilities cannot be penetrated, jihadists have become adept at identifying places where crowds gather. When the supporting population detests attacks on civilians, the terrorist groups will refocus their efforts to attacking military or hard targets while accepting the increased risk of mission failure by trying to attack the more fortified targets.

Places where large crowds congregate are prime targets of opportunity for suicide bomber attacks. Past suicide bombings have taken place at airports, military bases, public buildings, market centers, subways, schools, banks, and malls (Toet, 2003). These are all places that include infrastructure that is important for carrying out the routine functions of a society. Most target areas can be categorized into two main scenarios: a marketplace or crowded public area, and an entry control point or checkpoint (Dickson, 2008).

The typical marketplace is an open area that is filled with many people moving in different directions with many entrances and exits for people to transit. This scenario has a high probability for having large numbers of casualties and injuries due to the large number of people.

The second scenario is an entry control point or checkpoint. This scenario is commonly used by military and security personnel while screening individuals as they pass through an unsecure area to a secure area. Many times, there are current technologies installed at these checkpoints to reveal concealed weapons. Each of these scenarios allow for the use of differing technologies for weapons detection. Some detection technologies are more applicable in certain situations and areas. For instance, the entry control point or checkpoint may allow the use of technologies that work at short distances and screen individuals one at a time. While in a typical marketplace scenario, a detection system would have to scan large areas and accurately pinpoint the suicide bomber at greater distances (Dickson, 2008).

D. CHARACTERISTICS OF SUICIDE BOMBERS

In order to better recognize suicide bombers, it will help to understand the demographics of suicide bombers and the organizations to which they belong. Terrorist organizations are diverse and adaptable. For example, Al Qaeda has members from multiple countries, each with varying cultures. A suicide bomber has no single identifying feature or characteristic that makes him or her stand out from the surroundings. This makes identifying or profiling potential suspects very difficult. The typical traits of a suicide bomber have changed from the past. The connection between economic and social status has diminished among the people that carry out suicide bombings. In the past, most suicide bombers were under-privileged, lower-class youths with little education and social status. These trends are becoming less noticeable as the profile of a typical suicide bomber has evolved. Also in the past, males mostly carried out suicide attacks, but recently, since the Iraqi insurgency, more females have been used to carry out suicide bombings. From a report written by the Israeli Security Service (Shin Bet), it was noted that in the past, terrorist organizations are trying harder to exploit "weak" members of the population such as children, women, the sick and those who suffer from social problems or have low esteem, to carry out suicide attacks.

This is the supposition that women and children are seen as tender, delicate and innocent, and as such stimulates less suspicion than men (Dickson, 2008).

Another adaptation of the terrorist groups, besides expanding their potential sources of people to carry out the suicide bombings to women and weak members of the population, is to recruit members from higher social classes. An increasing number of suicide bombers are people who have an educated background, are employed, and maintain an average lifestyle for the society they are living in. Terrorist groups are able to recruit members of this stature because of the increased knowledge and understanding they have of the ideological message of the terrorist organization (Berman & Laitin, 2005). The Israeli Security Service reported that since 2000, suicide bombers are predominately single men; however, they are relatively educated and aged between 17 and 24. The Israeli Security Service found that about 21% of suicide bombers had an elementary or college education (Zedalis, 2004).

Religious groups are not the only organizations using suicide bombings for terror. There are many groups secular in nature that engage in terrorist acts. The differences between the insurgents or terrorists and the state may be a combination of ethnicity, language, and religion (Dickson, 2008). When hyper-segregation is present inside a society, ideas of otherness are easier to promote by insurgents, and it becomes easier for a people to dehumanize people on the other side and recognize them as legitimate targets for suicide attacks (Bloom, 2004).

Suicide attackers can be categorized into two types of people. The first type are people who have been raised from within the terrorist organization. This type of person believes in the greater good for which the organization stands for and is willing to sacrifice his own life to support the greater cause. The second type are people brought from the outside of the terrorist organization to the inside. They are educated from other sources besides the terrorist organization but are drawn into the organization for personal reasons. Others are drawn into suicide attacks for the awards they or their families are promised to receive. Awards can be monetary or spiritual in nature. An example of this would be the satisfaction that honor has been restored to a family through acts of vengeance from the suicide attack (Bloom, 2004).

E. COUNTERING SUICIDE BOMBERS

Countering the suicide bomber threat is categorized into four areas: prevention, detection, neutralization, and response (Dickson, 2008).

1. Prevention

It is the primary goal to stop all attacks in the first step; however, this is an extremely difficult process. Prevention is extremely reliant on accurate and timely intelligence. Various intelligence agencies are constantly gathering and assembling information regarding terrorist organizations in the attempt to thwart suicide bombings. It is not uncommon for suicide attacks to be routinely stopped before they are initiated. In June 2003, the Israel Defense Force was able to prevent twenty-five suicide attacks (Dudkevitch, 2003). Many of these potential attacks were discovered at checkpoints, by security guards, and by aerial surveillance technologies. This is important because this illustrates proof that suicide bombers can be identified using various tactics or identification methods.

Another prevention technique is to deny or decrease the ability of attackers to obtain the required materials for the weapons. This is also a daunting task because many of the weapons and explosives can easily be purchased on black markets, or they can be made with everyday household items. In the United States, for example, between 1993 and 1997, over 10 tons of explosives were stolen (Nunn, 2004).

2. Detection

Preventing an individual from carrying out his intended actions is extremely difficult. When potential suicide bombers are identified through accurate intelligence, there is usually little time and communication to determine their actions and intentions. When law enforcement agencies are not able to prevent a suicide bomber from carrying out an attack, the next process is to detect the suicide bomber while he is en route to his target. What makes the process of detection difficult is that the suicide bomber has the flexibility to change course or change targets while on the move.

3. Neutralization

The desired end state the security forces want to achieve will affect the type of detection method required. If the goal is to neutralize or kill the suicide bomber before he can initiate his attack, then the method used for detection must not produce any false alarms. This will prevent innocent and unarmed people from unnecessarily getting hurt. If the goal is to pull aside potential suspects and conduct further searches, then a less certain or accurate method may be used. In addition to determining who the suicide bomber is, security forces must also determine the type and size of the explosive threat. This information is important in preparing emergency personnel so they can set up outside the lethal blast and fragmentation range of the explosives.

4. Response

Dealing with an identified suicide bomber is the fourth major area of interdiction. The primary goal should always be to interdict and divert the suicide bomber from a crowded area to limit the number of casualties. The ideal situation would be to disable the suicide bomber and disarm the explosive device with no injuries.

The United States Alcohol Tobacco and Firearms Agency has established guidelines dealing with suicide bombers. Since a suicide bomber has already chosen to end his life, it is very difficult to persuade the suicide bomber to stop his intended actions. The "close and negotiate" tactics will not work. This makes it extremely difficult to disarm the threat. While there are many attempts at thwarting these attacks by addressing the root-cause issues for the destructive behavior of suicide bombers, the continuing focus must try to stop any attack that may be in the planning phase or in progress. The use of current and emerging technologies will be a crucial element to identify and prevent suicide attacks (Dickson, 2008).

F. UNITED STATES SECURITY CONCERNS

The use of suicide bombers as a terrorist tactic poses a significant question to security forces. How do you stop a suicide bomber on his way to the target?

Individuals who carry improvised explosives on their bodies and detonate those explosives in public places are a significant security problem that the United States Department of Defense and its allies face when operating in certain regions of the world and when conducting operations against jihadist organizations. Past examples of this problem are most evident in the Israeli and Palestinian conflict. The government of Israel and the Israeli Defense Force has yet to solve the advanced detection of Palestinian suicide bombers as they pass through checkpoints (Greneker et al., 2005). Since 2001, suicide bombers have murdered over 500 Israeli civilians (Kaplan & Kress, 2005).

Between 2000 and 2002, only 1% of attacks in Israel were attributed to suicide attacks, but 44% of the Israeli casualties were a result of these attacks (Nunn, 2004). Since the United States started its campaign on the global war on terror in 2001, suicide bombers in Iraq and Afghanistan have killed hundreds of civilians and military troops (Kaplan & Kress, 2005).

1. Recent Suicide Bombings

On February 1, 2010, a female suicide bomber walking among Shiite pilgrims in Baghdad detonated an explosive belt, killing 54 people and wounding more than 122. The suicide bomber hid the explosives underneath her abaya (a black dress worn head to toe by women) as she joined a group of pilgrims on the outskirts of Baghdad's Shiite-dominated neighborhood of Shaab. The bomber set off the explosives as she lined up with other women to be searched by female security guards at a security checkpoint just inside a rest tent (Associated Press, 2010).

In Afghanistan, on December 30, 2009, a suicide bomber infiltrated a CIA base, killing seven Americans and seriously wounded six others. The bomber was Humam Khalil Abu-Mulal al-Balawi, a Jordanian doctor, who was working as a triple agent for Al-Qaeda. The CIA had invited al-Balawi to its base in Khost, eastern Afghanistan, believing he was about to divulge the whereabouts of Osama bin Laden's deputy, Ayman al-Zawahiri. Al-Balawi was able to enter the base through the checkpoint without being screened. Concealed beneath his clothes was an explosive device detonated once inside.

In the first example, detection equipment was used but not applied, allowing for any standoff detection. The female suicide bomber was able to gain access into the target area. Security personnel scanning people using handheld scanners provided no early warning or detection indicators. If the female suicide bomber was detected, it would have been too late. She was already inside her target area surrounded by a large group of people. In the second example, the CIA bombing shows that a suicide bomber can strike at any time and that one can never know who suicide bombers are, even though the bomber passed through a security checkpoint.

The chance of suicide bomber attacks in the Iraqi and Afghan theater of operations continues to stay high. Most of the checkpoints and base entry points are not equipped with the appropriate equipment to screen for potential suicide bombers (Alexander et al., 2009). Neither the Iraqi nor Afghan governments have the technology or equipment to set up surveillance and screening areas for their respective marketplaces or public areas.

The Congressional Research Service Report for Congress on Terrorists and Suicide Attacks in August 2003 stated:

> Suicide attacks by terrorist organizations have become more prevalent globally and assessing the threat of future suicide attacks against the US has gained strategic importance. While suicide attacks have been employed internationally for centuries, the degree at which this tactic could be used to carry out operations against Americans was more widely appreciated since 9/11. The vulnerability of the US homeland to suicide attacks was amply demonstrated, virtually all previous such attacks by foreign actors against US citizens had happened on foreign soil. (Cronin, 2003)

The hidden and indiscriminate nature of suicide bombers and the difficulty to detect them make it that much more of an issue for security forces.

2. U.S. Government Actions

In 2004, the Defense Advanced Research Projects Agency (DARPA) convened a panel of experts through the National Research Council to study methods to detect suicide bombers from a standoff distance. The National Research Council's comprehensive report detailing how sensors operating in the X-ray, Infrared, Millimeter Wave, and Terahertz, in principle, can detect a suicide bomber wearing explosives from standoff distances of at least 10 meters. A significant issue with this is that 10 meters is not an adequate standoff distance to protect security personnel from an explosive's blast over pressure and fragmentation, and the existing technologies are not affordable and reliable for widespread deployment (Kaplan & Kress, 2005).

One of the main problems and concerns in detecting suicide bombers with sensor technology is that the detection needs to occur at operational and tactically relevant ranges. For military utility in detection of suicide bombers, significant standoff is required in order to reduce exposure to prematurely detonated devices and prevent destruction of equipment. Another challenge and issue is deciphering the clutter and false alarms or false positives from the sensor equipment. Creating automatic differentiation of potential items of interest from a wide range of items carried on a body can save precious time when security decisions need to be made. There also must be some method for data and sensor fusion. To maximize detection, there must be combination, alignment, and analysis of data from multiple sensors in real-time. A last challenge in detecting a suicide bomber is to conduct crowd surveillance searches, pinpointing the sensors on a moving individual within a larger crowd.

The overarching goal in developing a detection methodology is to detect a weak signal or a small identification characteristic from multiple sensors in a noisy and dynamic background, and then present the signals in real-time to security personnel, so they can make a security decision in a timely manner.

II. LITERATURE REVIEW

A. HISTORY OF JIEDDO

In October 2003, the Army Chief of Staff established the Army IED Task Force in an effort to counter the escalating use of Improvised Explosive Devices (IEDs) in Iraq and Afghanistan. This task force reached out to all DoD components, the private sector and academia to improve threat-intelligence gathering, acquire Counter-IED technologies and develop Counter-IED training (JIEDDO, 2006).

The early success of the Army IED Task Force influenced then-Deputy Secretary of Defense Paul D. Wolfowitz to transform the entity into a Joint IED Task Force. Reporting directly to the Deputy Secretary, the task force was able to leverage the experience and expertise of warfighters across the DoD, enhance its network attack focus, increase the acquisition of device-defeat tools and build a robust set of IED-specific force training operations. In February 2006, DoD Directive 2000.19E converted the joint task force into a permanently-manned entity comprised of military, government civilians, and contractors: the Joint IED Defeat Organization (JIEDDO, 2006).

B. VISUAL INDICATORS

Although technology exists to detect concealed explosive devises on people, they are not 100% accurate (Committee on the Review of Existing and Potential Standoff, Explosives

Detection Techniques, 2004; Beaty et al., 2007). As such, it is ultimately the individual security personnel that assess the situation and decide on what appropriate action needs to be taken. In order for those security personnel to make the best decision at the time, they need to have an understanding of visual indicators common to a suicide bomber. Table 1 provides a list of visual indicators established by Israeli authorities and psychologists in an effort to help their security personnel identify potential suicide bombers.

The wearing of heavy clothing, no matter what the season. Long coats or skirts may be used to conceal explosive belts and devices.
An unusual gait, especially a robotic walk. This could indicate someone forcing or willing himself or herself to go through with a mission.
Tunnel vision. The bomber often will be fixated on the target and for that reason will look straight ahead. He or she also may show signs of irritability, sweating, tics, and other nervous behavior. (The Al Qaeda terrorist Ahmed Ressam, who was captured at a border crossing in Washington state while driving a car filled with bomb-making materials, caught the attention of authorities because of his excessive sweating, furtive eyes, and other nervous movements.)
The appearance of being drugged. The suicide truck bomber who attacked the U.S. Marine Barracks in Beirut in 1983 had been drugged before the attack and was tied to the seat of his vehicle.
Signs of drug use – including, for example, enlarged pupils, a fixed stare, and erratic behavior.
Bags or backpacks (used to carry explosives, nails, and other shrapnel). The bomber generally holds his/her bag or backpack tightly, sometimes gingerly, and may refuse to be separated from it.
A fresh shave – a male with a fresh shave and lighter skin on his lower face may be a religious Muslim zealot who has just shaved his beard so as not to attract attention, and to blend in better with other people in the vicinity.
A hand in the pocket and/or tightly gripping something – this could be someone clutching a detonator or a trigger for an explosive device. Such triggers, which may be designed in the form of a button, usually are rather stiff so that they will not be set off accidentally. (One Israeli acquaintance described how he and several guards shot a would-be bomber numerous times, but found his twitching finger still on the button – and still posing a danger, therefore.)
Evasive movements. It seems obvious that anyone who tries to avoid eye contact, or to evade security cameras and guards, or who appears to be surreptitiously conducting surveillance of a possible target location, may be a bomber.

Table 1. List of visual indicators of a suicide bomber (From Livingstone, 2005).

C. THE IED THREAT

Over the past two decades, terrorist groups have started resorting to the use of IEDs to advance a particular cause (Committee on Defeating Improvised Explosive Devices, 2007; Wells III & Horowitz, 2005). Due to the limited skill required, IEDs are the weapon of choice for terrorists worldwide, giving them the ability to conduct spectacular attacks for a relatively small investment. As such, IEDs have become the number one killer of coalition forces in Iraq and Afghanistan. Terrorists have realized the public relations benefit of explosive attacks far outweigh those of attacks using more conventional weapons.

IEDs can be almost anything with any type of material, and with readily available explosive technologies, online training sources, IEDs are continuing to provide the enemy with inexpensive, lethal standoff weapon systems (JIEDDO, 2006). In their annual report for FY08, JIEDDO (Meigs, 2007) presented data showing their progress. Figures 1-3 are copies of JIEDDO’s figures.

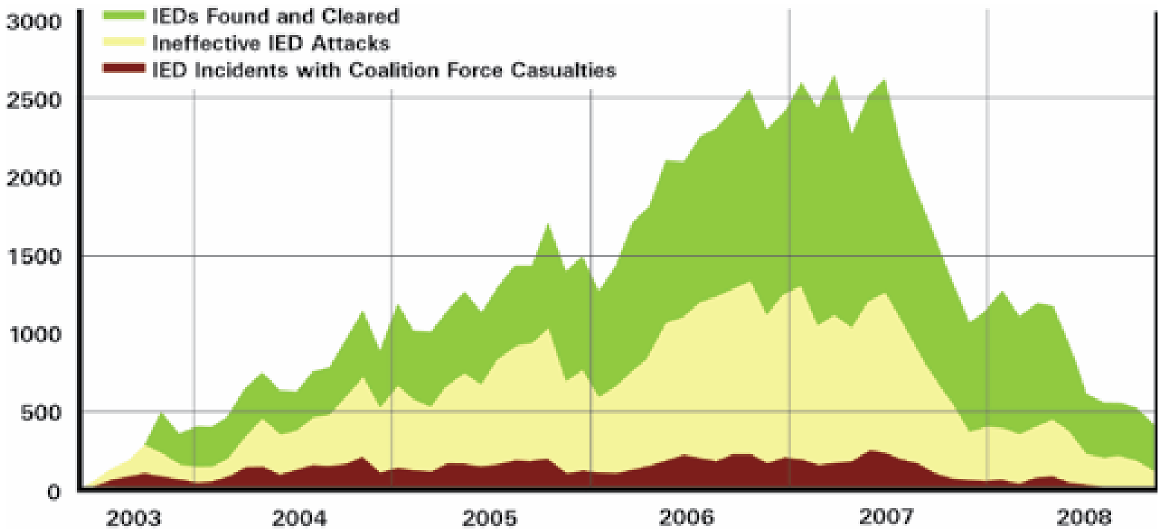

Figure 1. IED Activity report by JIEDDO, 2003-2008 (From Meigs, 2007).

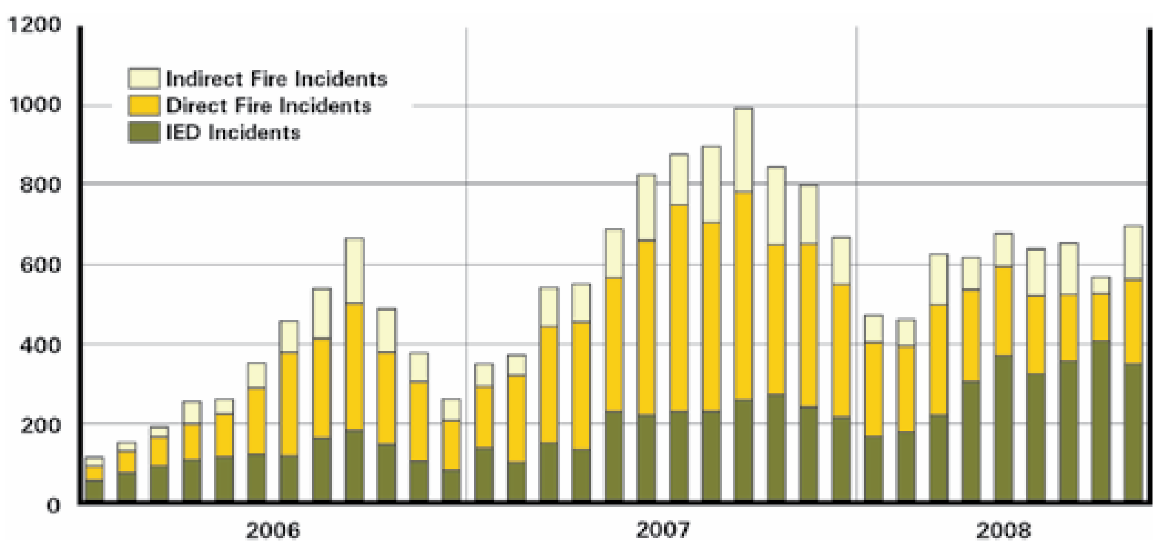

Figure 2. Comparison of Incidents through 2008 (From Meigs, 2007).

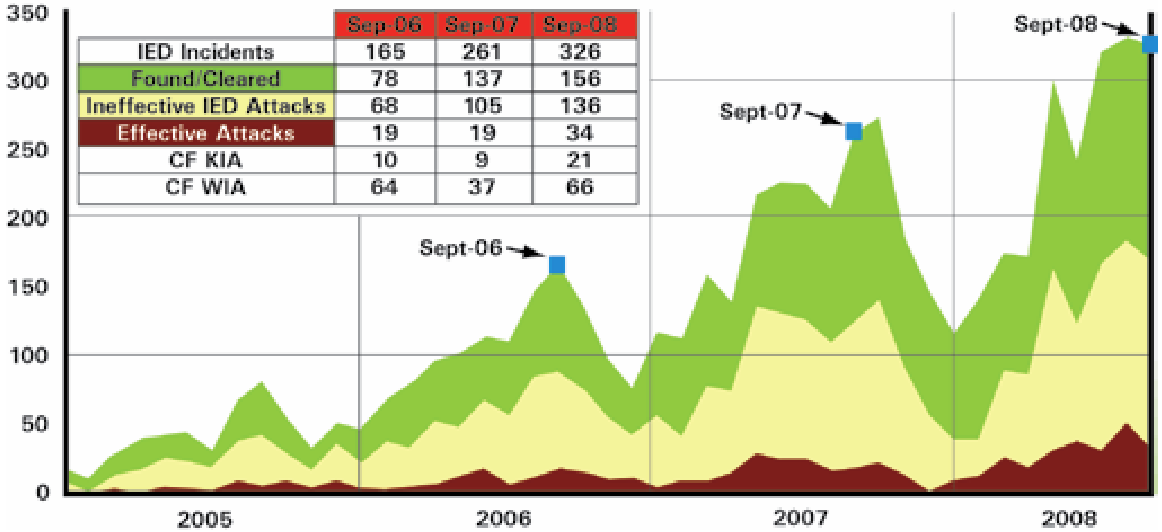

Figure 3. Report from Afghanistan by JIEDDO Annual report FY08 (From Meigs, 2007).

An improvised explosive device is designed to destroy, incapacitate, harass, or distract by incorporating destructive, lethal, pyrotechnic, or incendiary chemicals to cause death or injury (DOA, 2005). They can be produced in varying designs and sizes, but always contain explosive materials, detonators, and a triggering mechanism. Some of the most common IEDs are command-detonated, victim detonated, and suicide vest. This thesis is focused on the detection of Suicide Vest IEDs (SVIED) (JIEDDO, 2006; Mostak & Stancl, 2007).

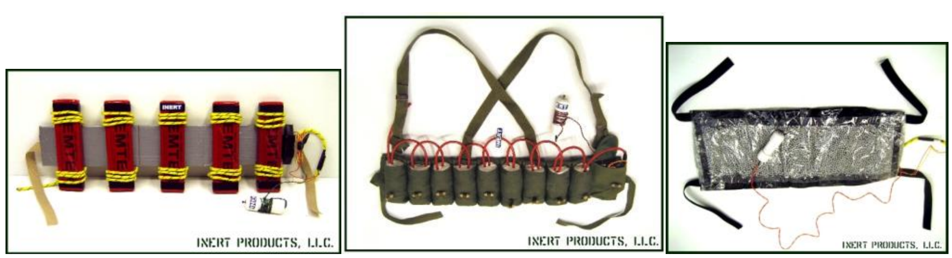

Figure 4. Illustration of possible suicide vest IEDs. Note the varying materials for detection (e.g., metal, wires, plastic)

It is clear from the data in Figures 1-3 that as more and more terrorist organizations share information and realize the potential psychological, social, and political impacts of IEDs, this weapon will undoubtedly continue to be a threat to the U.S. military and coalition forces throughout the world (DOA, 2005).

People who do not want to be caught with a weapon will go to great lengths to conceal it (Wells III & Horowitz, 2005). Since weapons may be carried on the body in ways that make it unobservable to the casual eye or even a thorough visual search, technologies to detect these hidden objects are sought after (Costianes, 2005). The ideal detection technology would be fast, accurate, work from long distances, and be safe for people. Being able to detect at a safe standoff distance provides both decision makers and security personnel more time to accurately respond to the threat (McMakin et al., 1996). The ability to detect threats from a standoff distance becomes critical when the flow of crowds is not in an organized and controlled manner (Chen et al., 2005). Since there is such a large array of different components used in making weapons, we need detectors that are capable of detecting all types of materials. Most current systems used in today's detection systems are usually designed to detect metal objects.

The desired concealed weapon detection system will be able to detect threats in real time, at long standoff distances, and through clothing or other masking devices. Some of today's current sensors provide few of the ideal capabilities, and there is currently no single sensor that satisfies all these characteristics well enough to be used as a stand-alone system (Slamani et al., 1999). The most common sensors used today sense certain wavelengths in the electromagnetic spectrum. These sensors are either active or passive (Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004).

Active sensors send low-power radiation waves in order to illuminate the scene. The sensor is then able to measure reflected waves that reach the sensor. Passive systems require no illumination or applied radiation to operate. The passive systems only detect electromagnetic waves that are already present. As a result of the radiation exposure inflicted on subjects from active sensing, warnings are usually required to be posted with active detectors. If warnings are posted, the effectiveness of a covert detection scheme is decreased (Chen et al., 2005).

Through our research, we found that it is extremely difficult to detect a concealed SVIED at long range due to most of the current technology only providing a standoff distance of 10 to 50 meters (Beaty et al., 2007; Dickson, 2008). When developing a product line for a standoff detection framework, scenarios and assumptions must be taken into consideration. For example, we assume that an average person walks at a rate of 1 m/s. Therefore, if a standoff detector has an effective range of 30 m and a potential suicide bomber is approaching a checkpoint from 30 m away, there is a 10-second window during which identification and appropriate action must be made before the bomber is close enough to inflict major damage or casualties. Performing standoff detection under these tight time constraints requires an orthogonal systems approach (Knudson et al., 2009). An orthogonal systems approach to standoff detection provides advantages, such as increases in standoff range, increased spatial resolution, and increased time for decisions makers.

The two primary areas explosive detection techniques usually focus on are either bulk explosives or traces of explosives. For this thesis, we will be focusing on bulk explosive detection techniques. Bulk explosive detection is usually carried out by imaging characteristics of the explosive device (e.g., metal, liquid) or the explosive itself. Most explosives detection techniques are limited by fundamental physical limits or by the specific circumstances of a scenario, such as background interference (Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004).

D. EXISTING DETECTION TECHNIQUES

1. X-Ray

For many years, X-ray technology has been used to search for explosives and other contraband in luggage and cargo containers (Mostak & Stancl, 2007). There are some health concerns with the X-ray radiation being ionizing, but for imaging out to standoff distances of 10 to 20 meters, the health issues may be insignificant.

Traditional X-ray imaging, represented in Figure 5, requires a detector on the opposite side of the target from the transmitter (University of Florida, 2005). This detector could be made out of low-cost plastic monitored by an inexpensive camera with a wireless link to a data analysis base. These items can easily be concealed and replaced if they are damaged. X-ray images provide good resolution and are able to detect shapes of objects shadowed as a result of their high X-ray absorption.

Current X-ray imaging, represented in Figure 6, use backscatter, which collocates both the detector and transmitter (Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004). Since the incident and backscattered X-ray penetrate deep into organic materials, where atoms contain fewer electrons than the atoms in materials made of heavier elements, the organic materials appear bright on the backscattered image (University of Florida, 2005).

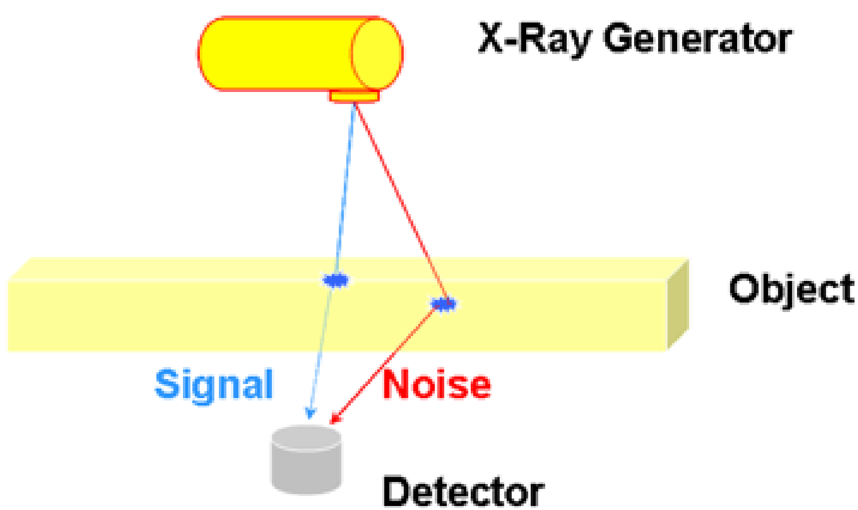

Figure 5. Representation of traditional X-ray with detector being located across from transmitter (From University of Florida, 2005).

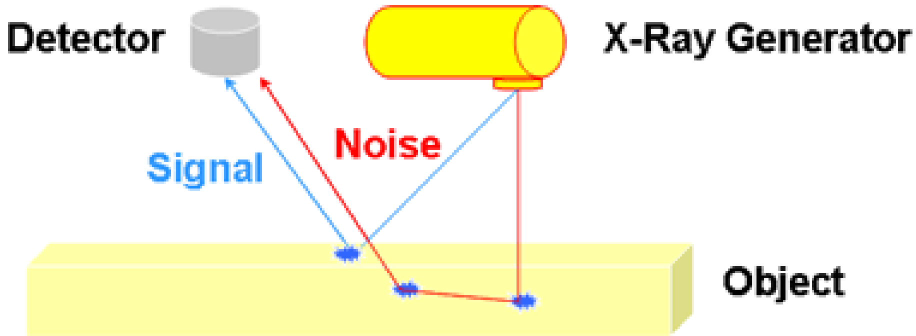

Figure 6. Representation of X-ray with backscatter and collocated detector and transmitter (From University of Florida, 2005).

There are concerns with the potential for degreased quality of the transmission image with X-ray systems because their susceptibility to absorption in the air and the angular spread of the beam (Dickson, 2008). There are computer tomographic X-ray images that can provide great detail, but they also require significantly longer times for scanning and data analysis. Continued research in areas of X-ray imaging technology, such as high-photon flux X-ray sources, pulsed X-ray sources, smaller focal spots for scanned beams, and focused X-ray beams have potential to increase the standoff distance up to 15 meters (Beaty et al., 2007).

The use of X-ray imaging technology brings about additional privacy concerns because X-ray technology produces images of private body parts (Transportation Security Administration, 2010). This creates a difficult public-acceptance obstacle to overcome. A possible solution is to develop computer image analysis software that could interpret the image and eliminate the images of people that are clear of any potential weapon. This could reduce the concerns of innocent people not wanting images of their private body parts to appear on a screen for someone to analyze and record (Electronic Privacy Information Center, 2010).

2. Infrared

Infrared (IR) detectors measure the natural thermal radiation given off by objects that we are unable to see with the human eye. Any object with a temperature above absolute zero (-459.67 degrees Fahrenheit or -273 degrees Celsius) radiates in the infrared (Hermans-Killam, 2010). IR technologies use these properties of absorption, reflectance, and transmittance along with other information in order to calculate and display the temperature of objects giving off radiation. IR detectors detect radiation omitted by the object of interest, as well as scattered radiation from the atmosphere (Kribus et al., 2003).

In the IR spectral range (wavelengths between 1 and 10 microns), explosive packages, clothing, and most other items are opaque to radiation, but the body or other objects near room temperature passively emit thermal IR radiation. This thermal IR radiation can easily be detected with simple, relatively inexpensive IR imaging cameras (Dickson, 2008). Figure 7 depicts the radiation sources detected by the infrared camera.

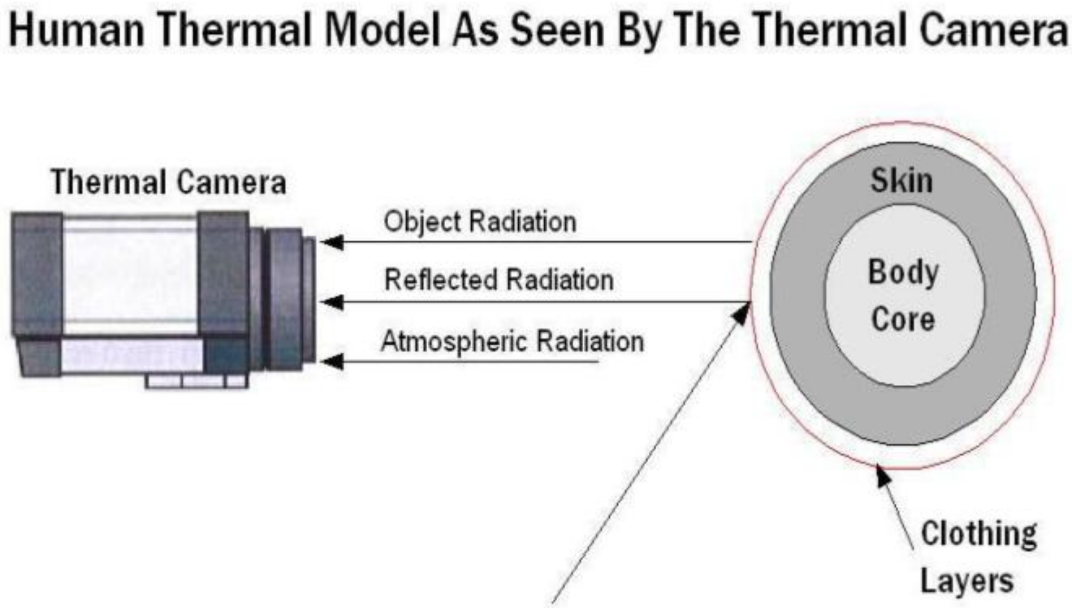

Figure 7. Infrared radiation measurement from a human (From Dickson, 2008).

Background radiation can have a significant impact on the situation when the emitted radiation from the object of interest is the same as the reflected background radiation at the wavelength of interest. This occurs in measurements at moderate temperatures in a terrestrial environment using the 8-14µm infrared band (Kribus et al., 2003).

Since exterior clothing used to cover the explosives should be slightly different in temperature than clothing near the skin, infrared imaging is a good technology for scenarios involving SVIEDs. Using the same scenario requirement for a standoff detection technique being able to detect a suicide bomber within 10 sec, the IR detection scheme can easily meet this timeframe requirement. The ability for an IR detection scheme to filter motion video from a rapidly changing real-time complex scene is a major advantage in standoff detection. Some additional advantage of the thermal imaging technique is its simplicity and ability to produce an image in the absence of visible light (Socolinsky & Selinger, 2002). Whether it is day or night, the same IR image is produced given the same conditions (Xue & Blum, 2003).

One of the most significant drawbacks to infrared imaging in an outdoor setting is background interference, such as environment temperature, wind, rain, and humidity. This interference affects the differences in object temperatures and makes identifying a SVIED more difficult to detect (Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004). The larger the difference in temperature, the more obvious the threat appears. Conversely, the smaller the difference in temperature, the less obvious the threat appears. For example, if an object is carried close to the body, over time, it comes into thermal equilibrium with its surrounding. This makes it hard for the sensor to differentiate between the weapon and the rest of the body (McMillan et al., 2000).

Difficulty in differentiating objects in an image also arises when the weapon is hidden under multiple layers of clothing. This and other masking techniques cause the threat to appear with less contrast and diffused into the background (Slamani et al., 1999). A possible solution is to use wavelengths longer than 20 microns, since they will penetrate clothing layers for detection better than shorter wavelengths (McMillan et al., 2000; Liu, 2006). Another disadvantage is the lack of selectivity on an IR detection system, which requires a person to identify a unique shape from an image. Since the image may be blurred by the effects of thermal conduction and air convection in and around clothing, false readings become an issue.

3. Terahertz

As the radiation wavelength increases to the terahertz (THz) rage, wavelengths longer than 300 microns corresponding to 1-THz frequencies, clothing and many other materials become nearly transparent. Imaging in this region allows detection of explosives hidden beneath clothing without the danger of ionizing radiation. THz spectroscopy and imaging presents several advantages, such as high-resolution imaging and the ability to penetrate dielectric materials (Sullivan et al., 2007). Excellent resolution can be attained when THz imaging is used in the scattering mode. Although THz technology presents many advantages, there are limiting factors that need to be overcome to extend the standoff distance. Water absorption presently limits the effective range of THz instruments for use in imaging to approximately 10 m. However, THz imaging can achieve up to 100 m on a clear day.

A potential compact, low-cost THz technology listed by the National Research Council in "Existing and Potential Standoff Explosives Detection Techniques" is the quantum cascade laser. These are tiny semiconductor lasers that operate down in frequencies as low as 1.5 THz. They also identify another potential compact source based on nonlinear mixing between closely spaced diode laser sources and Raman shifted laser lines in the infrared. This mixing is done to form coherent beams in the THz range. One of the primary advantages of the shorter-wavelength THz regime, between 10 mW and 1 W, is enhanced image resolution. Frequency ranges from 100 GHz to 1 THz provide the best imaging. This frequency range provides good resolution at adequate standoff distances while encountering the least amount of absorption from the atmosphere and clothing (Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004).

An example of a terahertz imaging system currently available on the commercial market is represented in Figure 8.

Figure 8. T5000 Terahertz imaging system (From ThruVision Systems Limited, 2010).

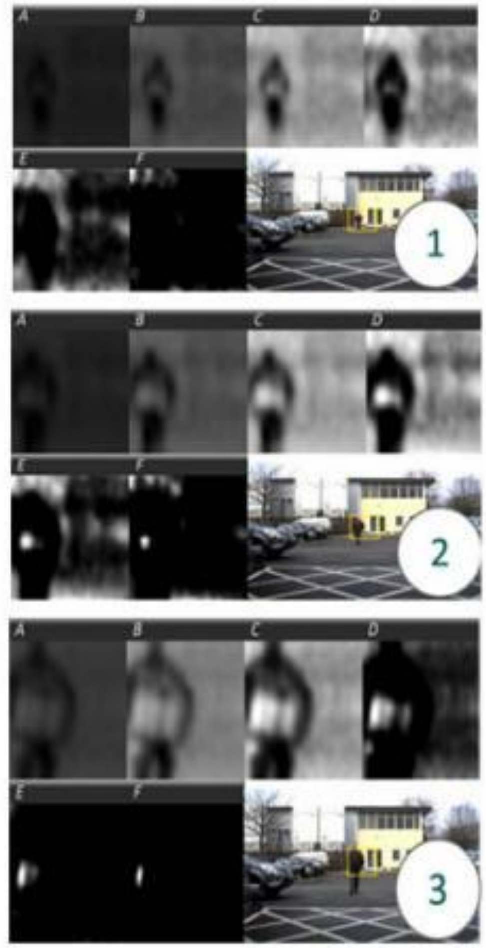

Figure 9. Images from the T5000 Terahertz imaging system representing 25 m, 20 m, and 10 m resolution of an individual wearing a suicide vest (From ThurVision Systems Limited, 2010).

4. Passive Millimeter Wave Radar (MMW)

In a passive Millimeter Wave Radar (MMW) system, there is no dedicated transmitter emitting radio energy. Instead, the receiver uses scattered electromagnetic waves naturally emitted by objects. The radar detects these scattered waves, and with the use of imaging techniques the waves are processed into a practical visual quantification of the shape of the object. Unlike some of the other technologies, radar is capable of operating at night and varying weather conditions (e.g., rain, fog and dust). Radars can also measure a variety of characteristics of a target such as range, direction, and speed.

Passive MMW technology is based on measurement of emissivity between objects and is effective for standoff detection at distances around 10 m. The passive MMW technology does not expose people to man-made radiation, and is, therefore, completely harmless to all in the area. This passive MMW imaging approach is very effective for the detection of concealed weapons because its high transparency of clothing, and the high emissivity of human flesh compared to the majority of other materials. Continued research and development with passive millimeter wave imaging for explosive detection is leading to new technologies that offer the remote detection of not only metal, but also non-metal weapons, and plastic explosives concealed under multiple layers of clothing (Huguenin, 2004). An example of MMW radar technology available on the commercial market is represented in Figure 10.

Figure 10. ST150 passive MMW imager (From Sago Systems Incorporated, 2007.

Figure 11. Image produced by the ST150 passive MMW imager detecting an individual wearing a suicide vest (From Sago Systems Incorporated, 2007).

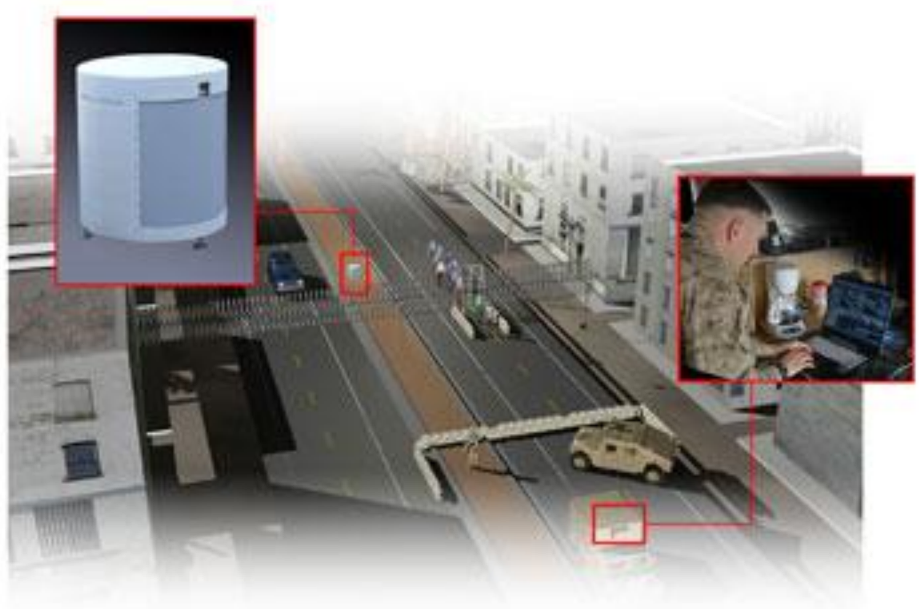

Figure 12. SAGO Systems Inc. MMW technology used in a tactical checkpoint environment (From Sago Systems Incorporated, 2007).

5. Active Radar

Unlike passive MMW technology, active MMW technology uses a transmitter and receiver. The radar transmits radio frequency energy that is reflected off the body and other objects to generate a three-dimensional image of the person and anything else carried on the body in ranges up to 200 meters (Gorman et al., 2005).

Radars are capable of determining a target's principal range (via echo time delay), speed (via Doppler shift) and radar cross section (via echo strength and characteristics) (Kingsley & Quegan, 1992).

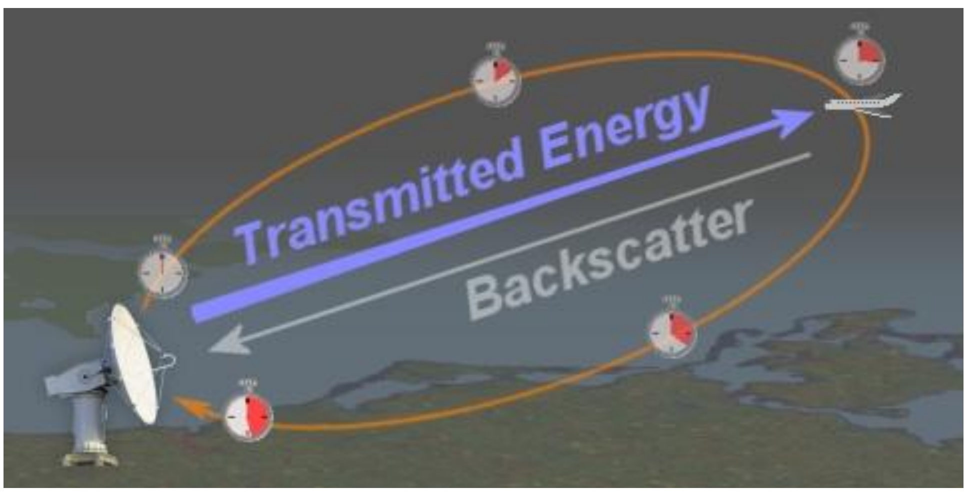

Figure 13. Basic principle of radar operation shown for echoes from an aircraft (After Wolff, 2010).

The major concern with active MMW technology is that the images produced show the entire body without clothes, exposing the genital areas, which creates privacy and religious concerns (Electronic Privacy Information Center, 2010). This is why passive MMW technology has become more popular for concealed weapon detection. However, active MMW technology does provide capabilities that passive MMW technology does not yet provide. The use of active MMW emissions provides the capabilities to penetrate common building materials such as concrete and brick. This would allow for the observation of people and other objects within a room from outside that room, providing a significant advantage to security forces. The security personnel could identify the location, posture, and activity before entering the room (Huguenin, 2004).

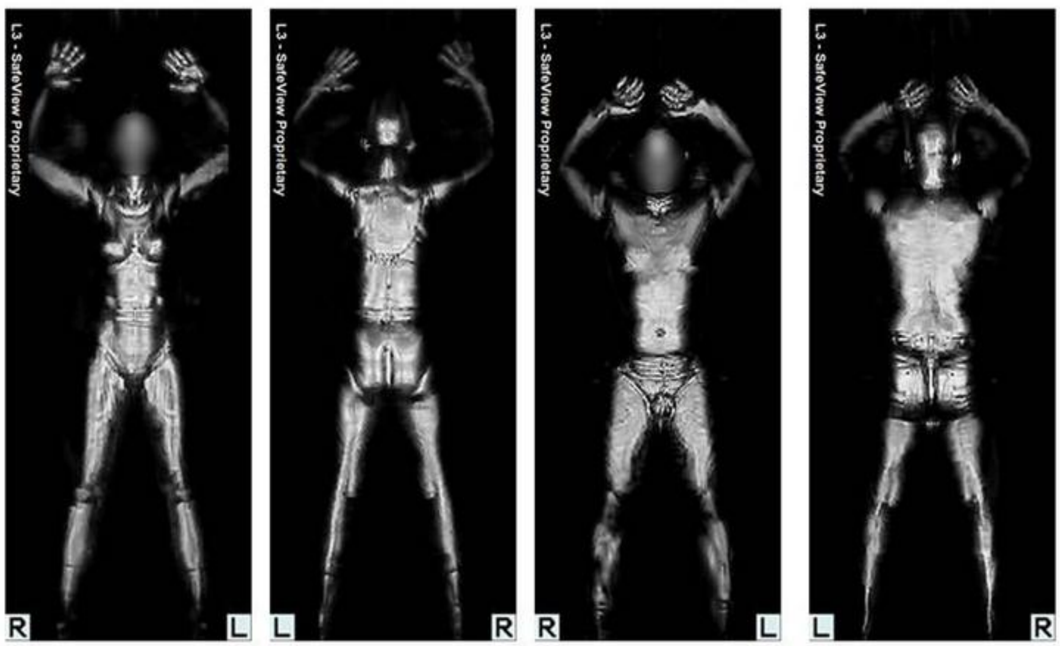

Figure 14. Images from an active MMW system (From Energy Probe Research Foundation, 2010).

E. CURRENT RESEARCH CONDUCTED USING EXISTING DETECTION TECHNIQUES

1. Standoff Technology Integration and Demonstration Program

In September and October 2008, the U.S. Department of Homeland Security’s Standoff Technology Integration and Demonstration Program conducted a field test at the Toyota Center in Kennewick, Washington. The program and test used a spiral development approach, which involves identifying commercially available technical solutions; modifying or maturing them to meet the architecture requirements of a free-flowing crowd; integrating them into a system of systems; testing them in live operational environments; and providing feedback to vendors, industry, and academia. In the 2008 field test, the countermeasure architecture addressed person-borne threats in the form of suicide bombers and leave-behind bombs. The goals of the test were to evaluate a baseline integrated system architecture for technology performance and cost-effectiveness in a live venue situation. The overhead layout of screening zones at the Toyota Center are shown in Figure 15 and Figure 16.

Figure 15. Overhead view of Toyota Center showing screening zones (From Knudson et al., 2009).

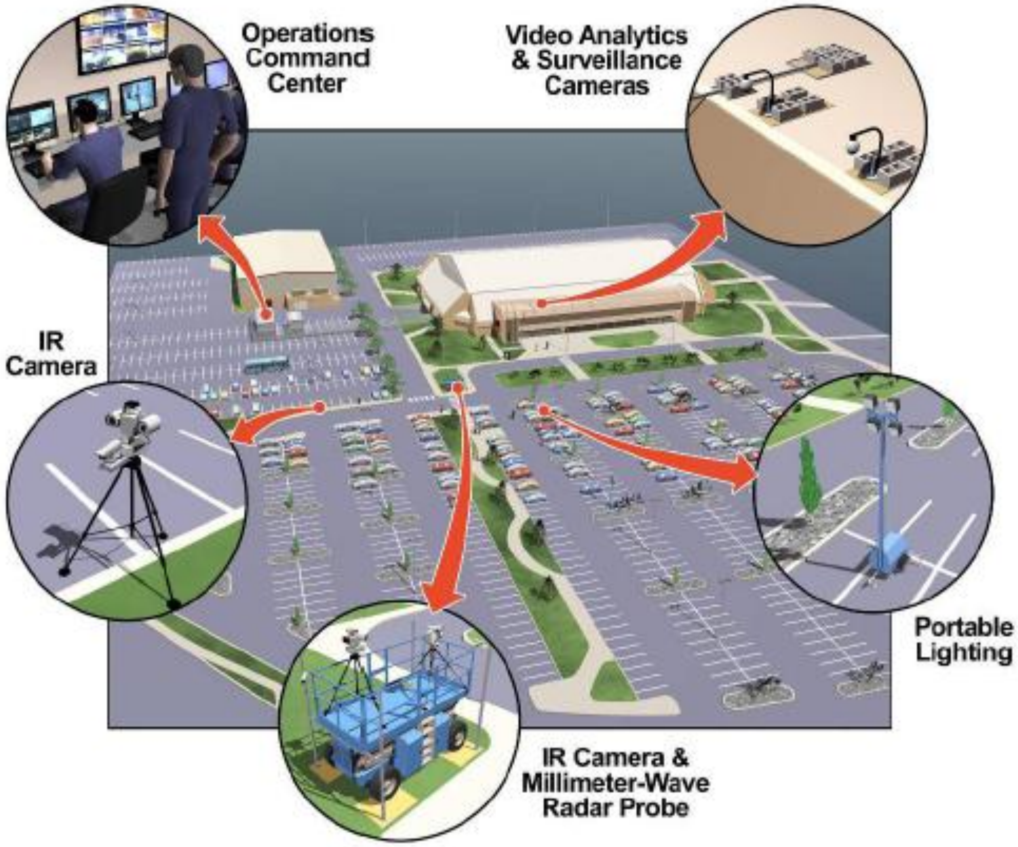

Figure 16. Illustration of sensor locations at Toyota Center (From Knudson et al., 2009).

Another goal of the test was to use commercial technologies that would be able to operate at explosive standoff distances of 20 meters or greater. Long-wave (8-12 micron) and mid-wave (3-5 micron) infrared cameras were deployed to detect concealed objects, such as a suicide bomber’s vest, by the thermal anomaly created when these objects obscure thermal radiation from the body.

Figure 17. Crowd surveillance with infrared camera (From Knudson et al., 2009).

Several systems integration interfaces were developed to overcome the challenge of an unpredictable moving crowd environment. A tracking and handoff system was created in order for two sensors to screen the same individuals. Also, an integrated user console was developed which provided the user up to three different outputs. Each output had the ability to display the potential threat using the three detection technologies, infrared, millimeter-wave, and visible wavelength camera. The data acquisition and management used in the test is shown in Figure 18. This illustration shows the flow of information used in the system.

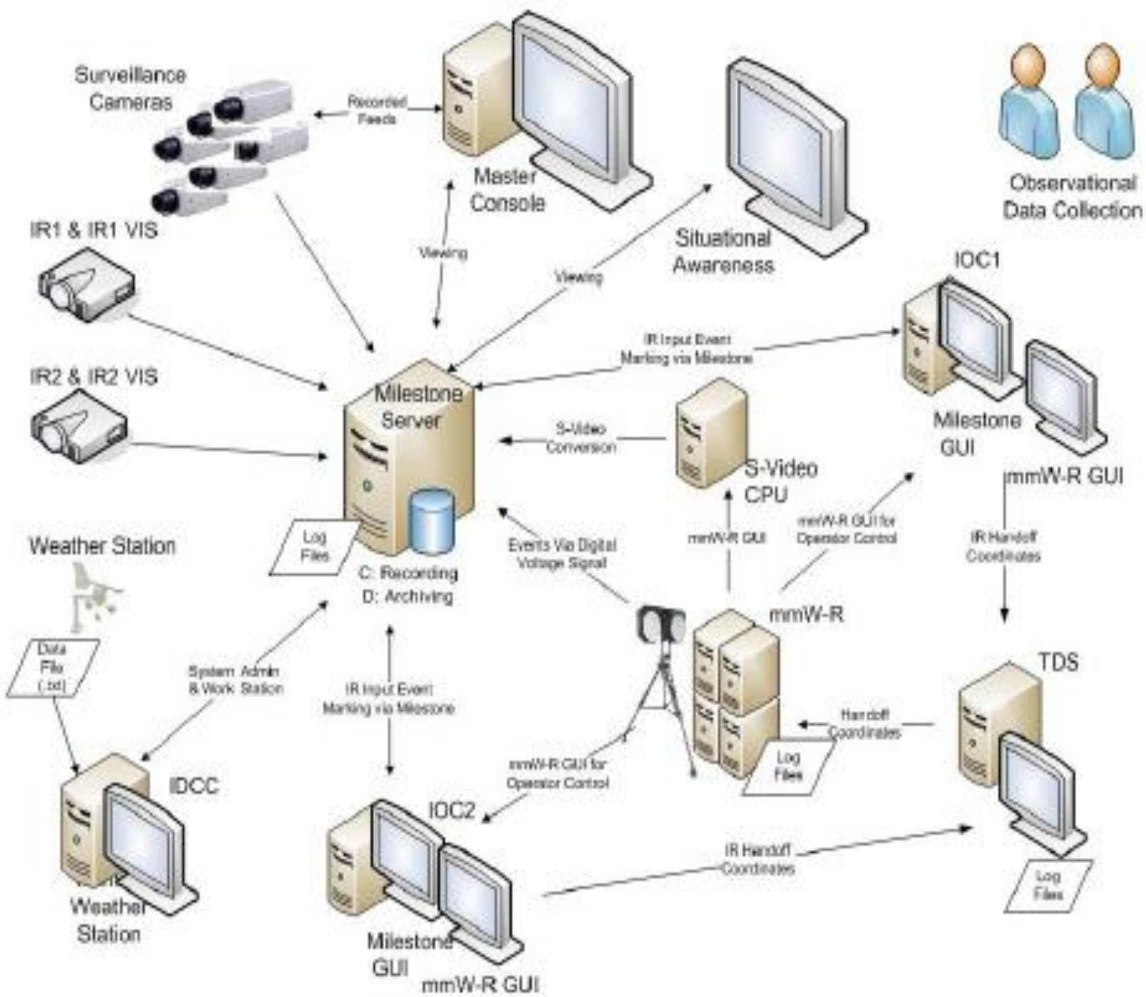

Figure 18. System integration schematic (From Knudson et al., 2009).

The most significant challenge during the characterization tests and the live operations was crowd density effects. During the test, Zone 1 crowd sizes averaged 23% singles, 44% couples, and 15% with groups of three, with the remaining 18% comprising groups of four or more people. Higher crowd densities resulted in blocking effects, lack of sufficient spacing between individuals, and lack of sufficient dwell time to make a threat determination.

The most significant conclusions made from the Toyota Center field test were:

- Longer operator training resulted increased accuracy of detecting concealed objects.
- Using an orthogonal design improved the overall detection capabilities of the system.
- Displaying screening results from the infrared and millimeter-wave systems on a single platform gave operators more information for interdiction and security decisions.
- The overall system architecture had a number of limitations. In order to apply this system to a large venue or massive crowd environment, the line-of-sight issues such as parked cars, the number of approach angles, and standoff distance requirements must be fulfilled by employing more sensors.

2. Center for Subsurface Sensing and Imaging Systems

In 2007, the Center for Subsurface Sensing and Imaging Systems (CenSSIS), funded by the Department of Homeland Security, supported the research performed by Northeastern University and industry partners called "BomDetec – Wide Area Surveillance and Suicide Bomber Detection." The BomDetec system experimented with the development a detection system capable of locating suicide bombers at distances sufficient to prevent them from approaching densely populated or strategically important areas.

The intent of their research was to synthesize four technologies—intelligent video, radar, X-ray, and terahertz-into one system to detect suicide bombers up to 50 meters. Their methodology uses the intelligent video to find a suspicious individual, and then have the other three sensors aimed at the individual and scan for the presence or absence of explosive material. The radar can be used at distances of 50 meters, while the X-ray and terahertz are used at distances of 10 meters or less. The schematic for their proposed system is shown in Figure 19.

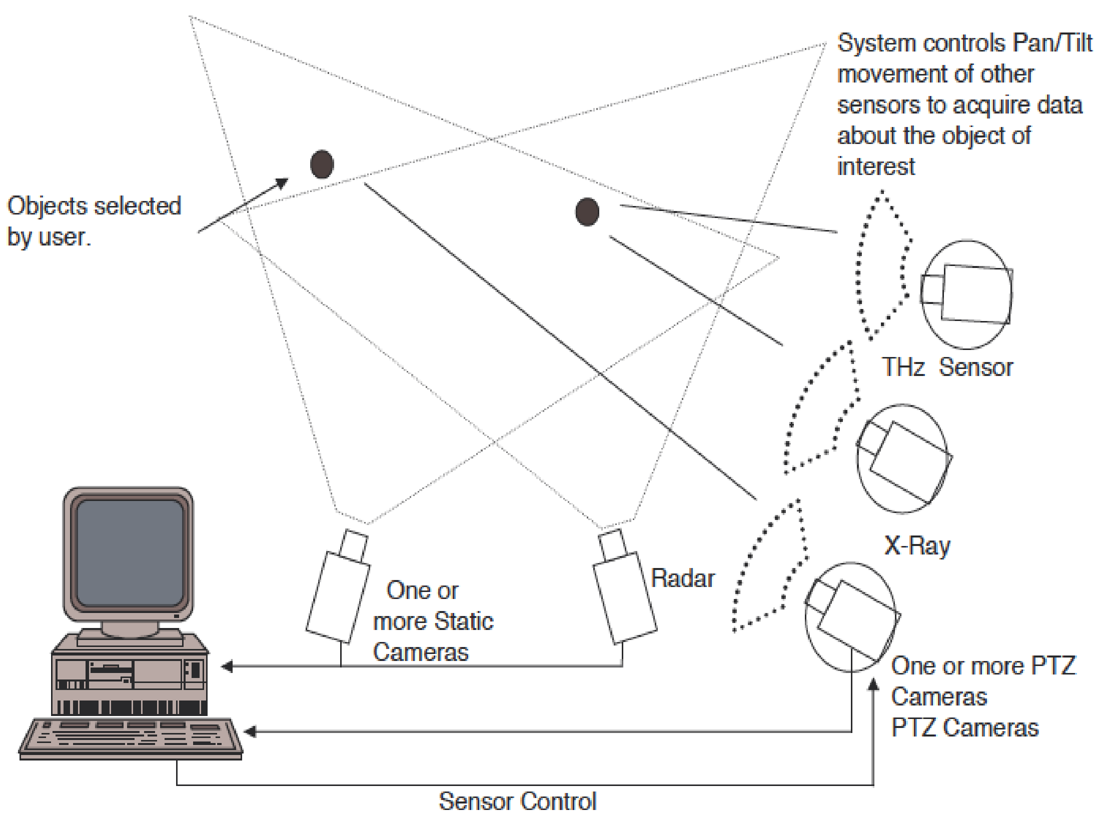

Figure 19. Proposed BomDetec system operation (From Beaty et al., 2007).

Northeastern University is working with several industry partners: American Science and Engineering (AS&E), PPT, Raytheon, Rensselaer Polytechnic Institute (RPI), and Siemens. Siemens is working on the development of the intelligent video systems. The purpose of intelligent video is to enable the system operator or security personnel to locate suspicious behavior or appearance visually at distances exceeding 50 meters and to isolate individuals for further detection. Figure 20 is a screen capture of the intelligent video system tracking several individuals.

Figure 20. Intelligent video screen shot (From Beaty et al., 2007).

Northeastern University, PPT, and Raytheon are working on the development of the millimeter-wave radar system to detect metal objects up to 50 meters in distance. Figure

21 and Figure 22 show the beam width of the transmitted radar wave and the back scatter return showing a radiation intensity plot of a suicide vest.

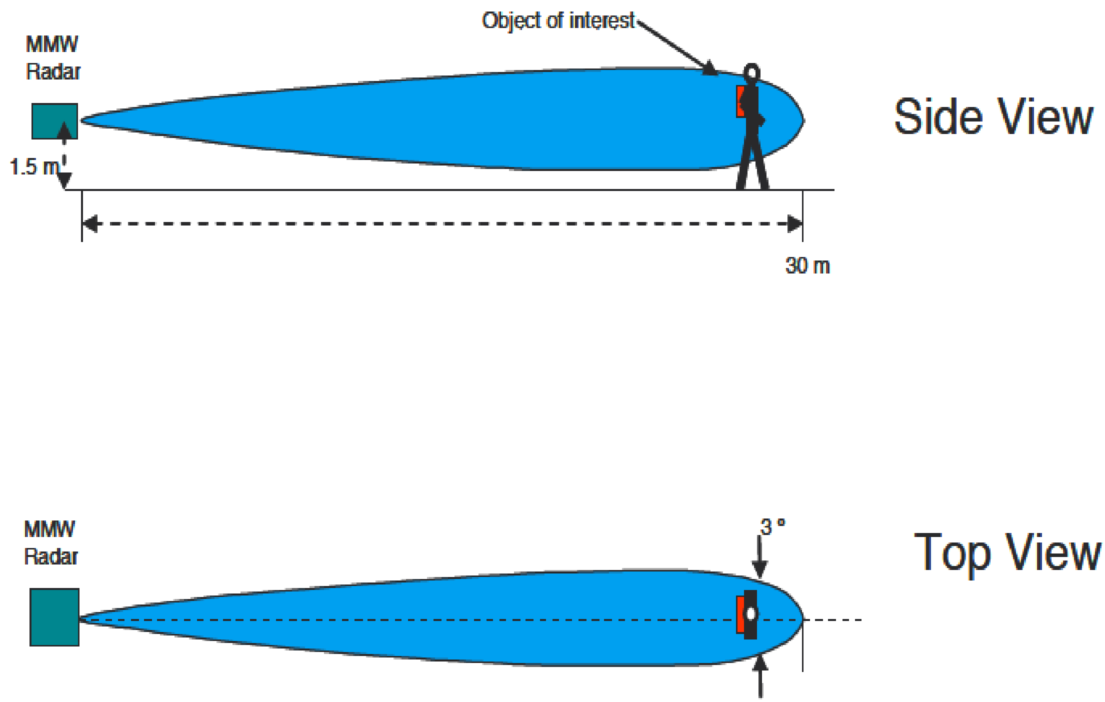

Figure 21. MMW Radar emission illustration (From Beaty et al., 2007).

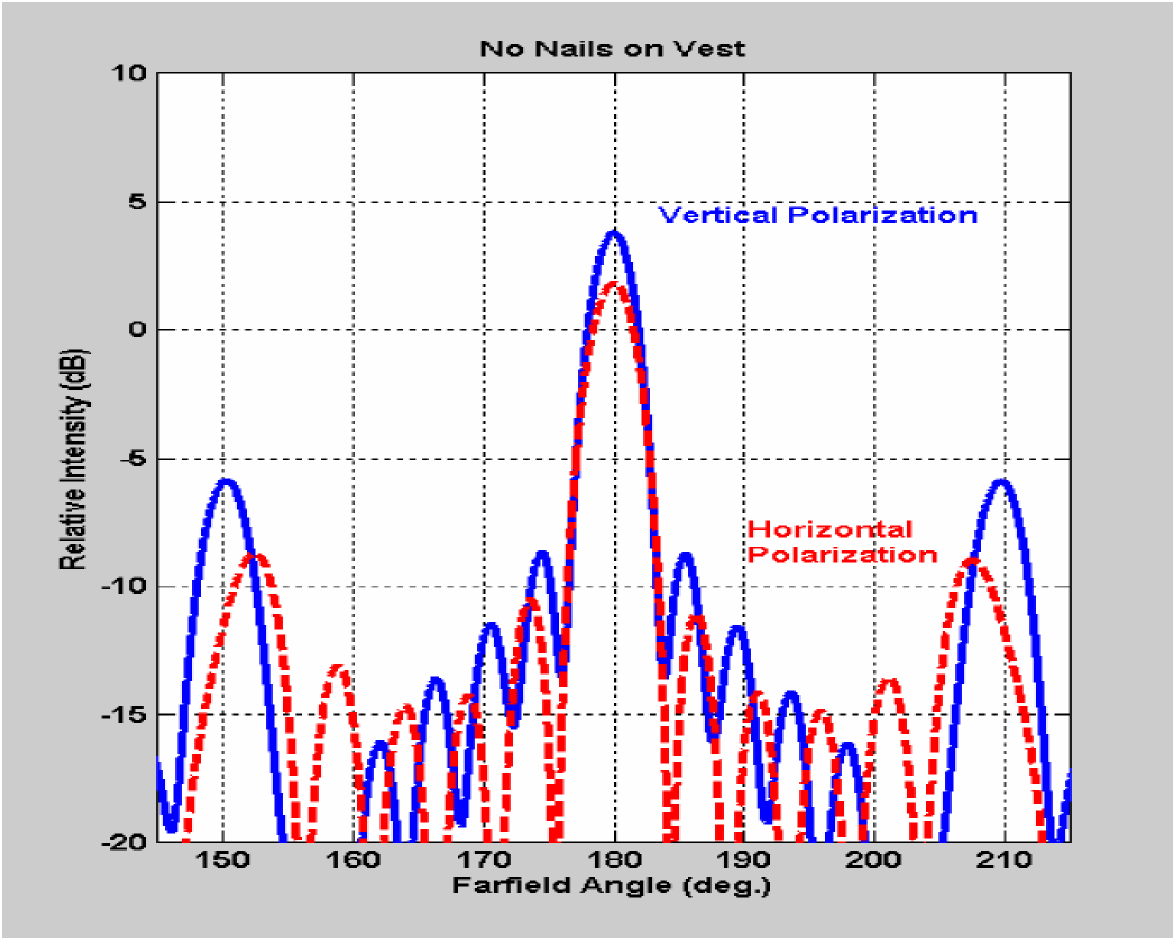

Figure 22. Backscatter return of radar waves detecting a suicide vest (From Beaty et al., 2007).

The X-ray backscatter system is being developed by AS&E. This system is designed to be used at distances of 10 – 20 meters. X-Ray backscatter provides more resolution than does the radar system and can provide information, such as location on body and shape, about the explosives.

The Terahertz radiation technology research is being headed by Rensselaer Polytechnic Institute. This technology will be used to examine suspects at the closest distances, 0 – 10 meters, in order to confirm the presence of explosive materials. THz technology exploits the absorption spectra that are specific to certain molecules in order to identify dangerous materials, since many molecules show sharp absorption features in the THz range.

Further research in the BomDetec system will be to continue to find suitable sensors for detection and to integrate all the individual sensors and technologies into one mobile system.

3. Sensing and Detecting Wires for IED Detection

The research conducted by Professor William Fox and Professor John Vesecky from the Naval Postgraduate School and Kenneth Laws from the University of California at Santa Cruz, called "Sensing and Identifying People Carrying Wires on their Body for IED Detonation," dealt with developing NEC simulations and gathering experimental data using a GunnPlexer Doppler radar to detect wires and metallic objects on people. One of the main purposes of the research was to find metrics that could be used to build models for detection rates. They determined the best metric was the Vertical-Vertical/Horizontal-Horizontal ratio of the radar cross section.

The conclusions drawn from their empirical modeling showed that the VV/HH ratio for people wearing wires was different from people without wearing wires at level of significance $\alpha = 0.05$ (Fox et al., 2009). They created a simulation of a crowd of people and randomly picked people with wires on their body. Using their calculated metric and a experimentally determined threshold value, they were able to pick out the person wearing wires on their body

83.4% of the time, with a false alarm rate of picking individuals who were not wearing wires 22% of the time (Fox et al., 2009).

The illustration, Figure 23, is the proposed detection scheme used. It incorporates the Doppler radar with a video system. The video images are used to compute the position and velocities history of the individuals as they walk through the field of view. The video system is also used to characterize the individuals from which the radar system will single out individuals who have wires on their body. The main objective of the radar system is to detect the individuals who have wires on their bodies based on the radar cross section that is returned.

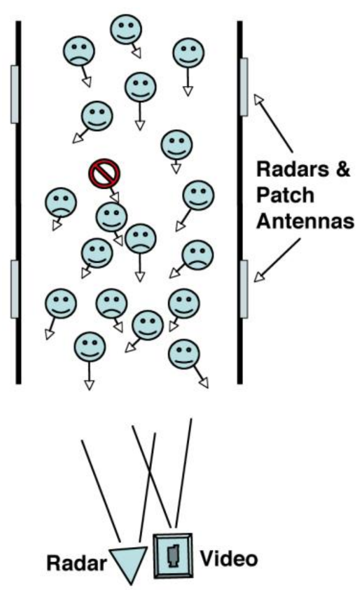

Figure 23. Proposed detection scheme (From Fox et al., 2009).

The conclusions of the research found that CW Doppler radar in the frequency range from 0.5 to 3.0 GHz was the best for detecting wires on a person. Radar frequencies at 10 GHz produced radar cross sections of the human body that are too large to differentiate between individuals with wires and without wires. Using a polarization metric alone, they found that in order to get the best signal-to-clutter ratio, the frequency band of the radar should be from 0.7 to 2.6 GHz. In this frequency, the signal-to-clutter ratio was above 10 dB overall the band (Fox et al., 2009). Also, using a Gunnplexer, they were able to detect wires on a body in various configurations. The best metric determined was using a radar cross section VV/HH polarization ratio. Using this metric, they were able to detect wires on a person with a success rate of 83.4% (Fox et al., 2009).

4. Infrared Camera Used for Suicide Bomb Detection

The master's thesis "Handheld infrared camera use for suicide bomb detection: feasibility of use for thermal model comparison," written by Matthew Dickson at Kansas State University, determines the feasibility of modeling the heat signature produced by a suicide bomber. The heat signatures are then compared to images of human subjects. The purpose of the research is to create a detection system using the models created as a comparator and signal for positive detection of a suicide bomber.

One of the main conclusions from Dickson's research was that the detection ranges using the thermal imagers could not distinguish the temperature difference at distances greater than 25 feet. More powerful thermal images or imagers with a telephoto lens must be used to extend the detection range greater than 25 ft.

Another conclusion from Dickson is that one sensor cannot alone detect a suicide bomber. Multiple sensors of different technologies must be used and the data from the sensors must be fused. Fusing the data allows for supporting information, which leads to more accurately detecting suicide bombers with fewer false alarms and false positives.

The last major conclusion from Dickson's research is the ability of the system to detect and determine small temperature differentials. The human eye has no problem distinguishing a large temperature differential on a person; however, as the temperature gradient decreases, the human eye has problems accurately detecting potential threats. In order for a system to run without human discretion, computers must be able to differentiate small temperature changes and alert the operator.

In Dickson's testing, he found that over a temperature scale of 45° F, there needed to be a temperature difference of 3° F to be reasonably certain an object was underneath the individual's clothing (Dickson, 2008). This equated to a threshold of at least a 7 – 10 % temperature change of the object on the person's torso compared to the temperature of the torso for the given temperature scale used on the thermal imager (Dickson, 2008).

Figure 24 is the flowchart showing the basic operation of a thermal imaging system with a computer and human decision factor. Figure 25 is the algorithm used by Dickson to indentify concealed objects using a thermal imager. Figures 26 and 27 are images taken from Dickson's research showing the same metallic pipe bomb from distances of 25 feet and 6 feet.

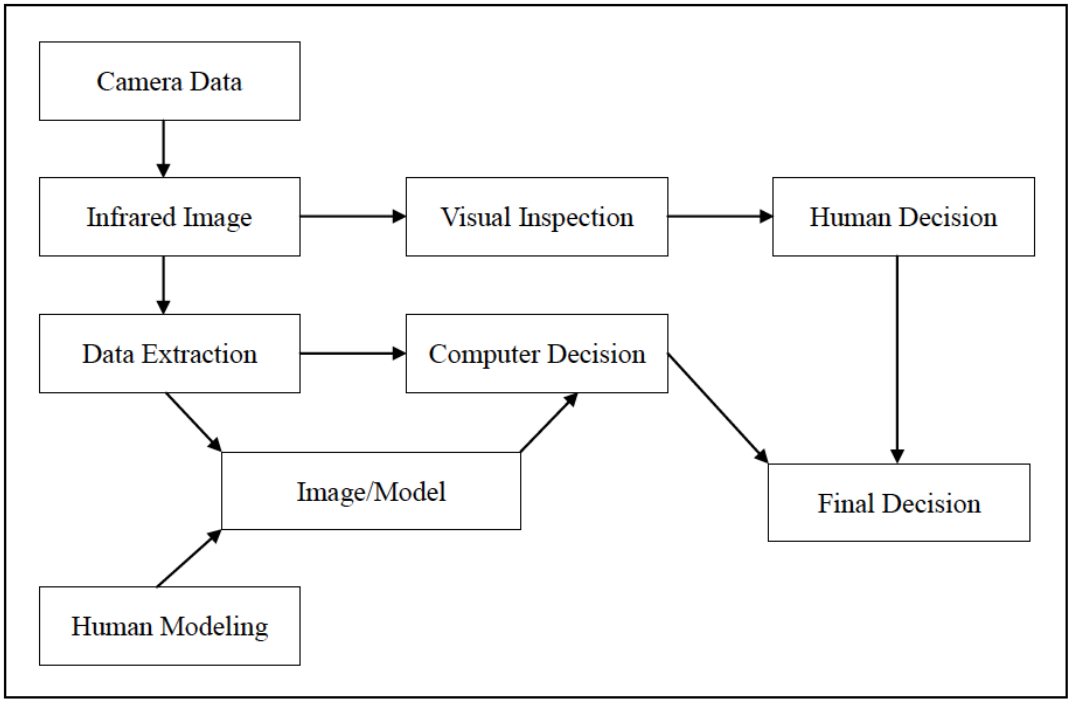

Figure 24. Possible infrared camera system operation (From Dickson, 2008).

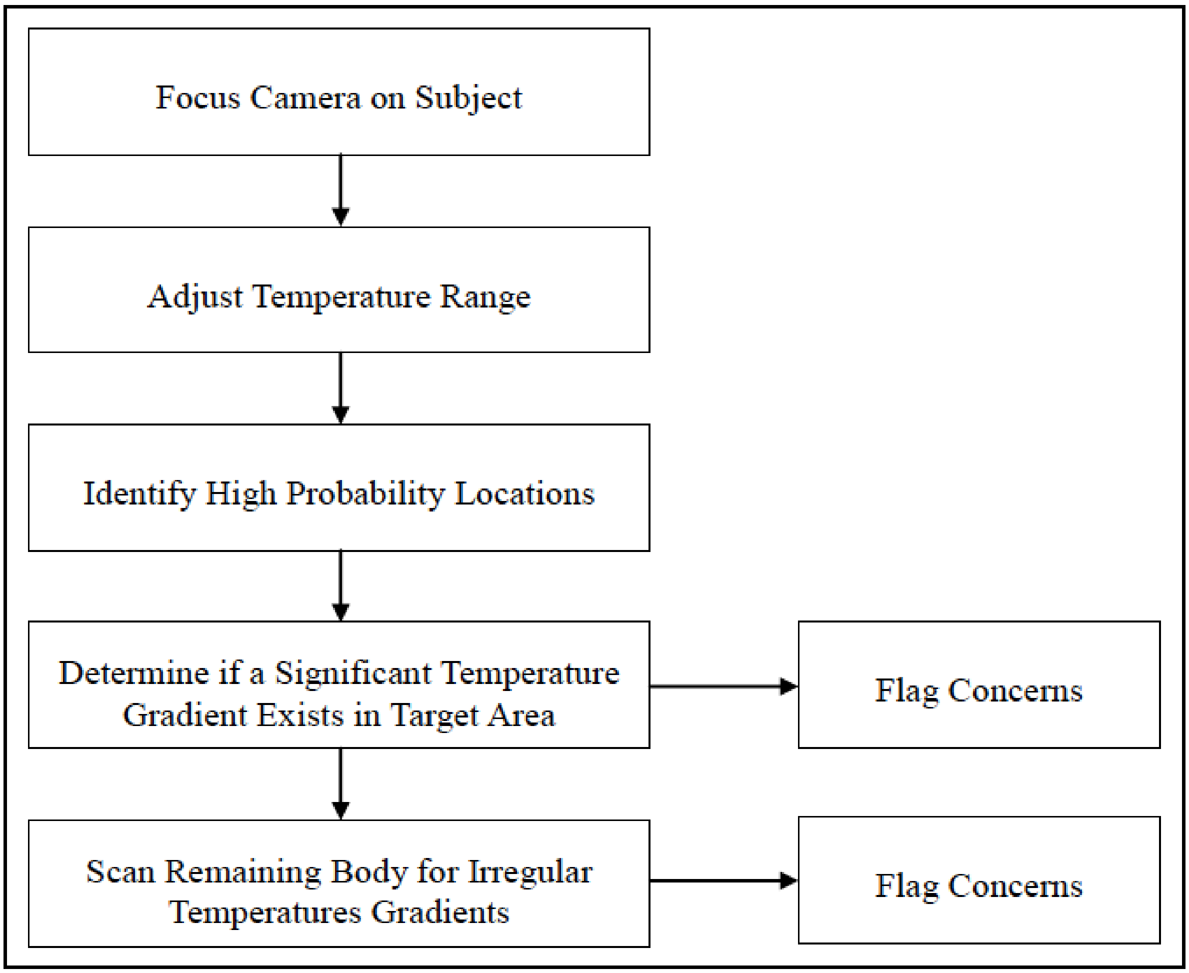

Figure 25. Guide to finding a bomb with infrared camera (From Dickson, 2008).

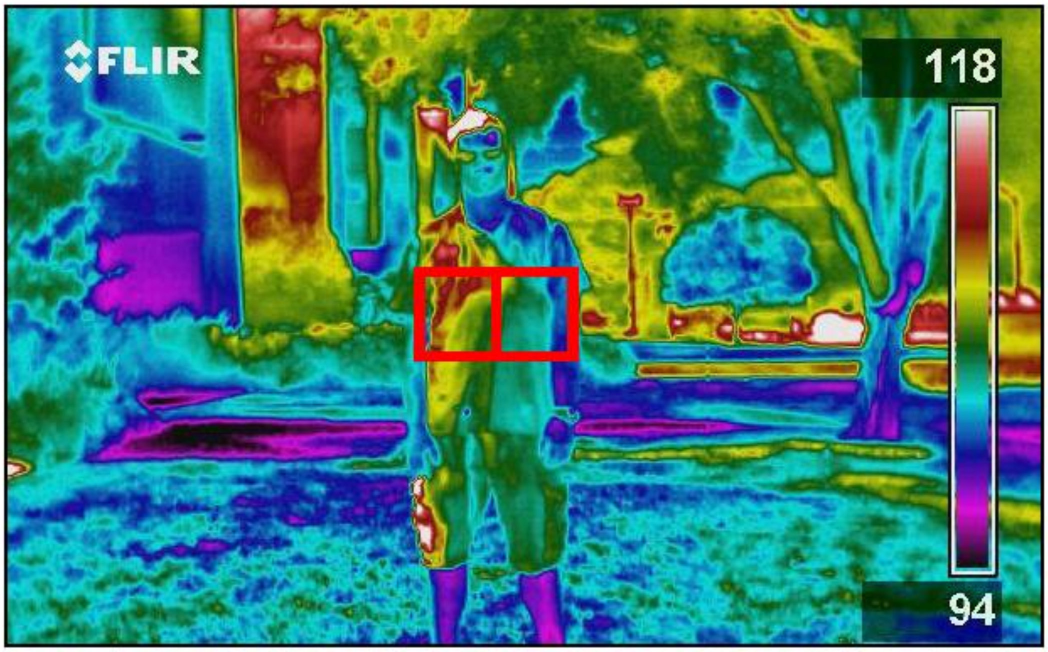

Figure 26. Metal bomb package shielded by one T-shirt at 25 feet (From Dickson, 2008).

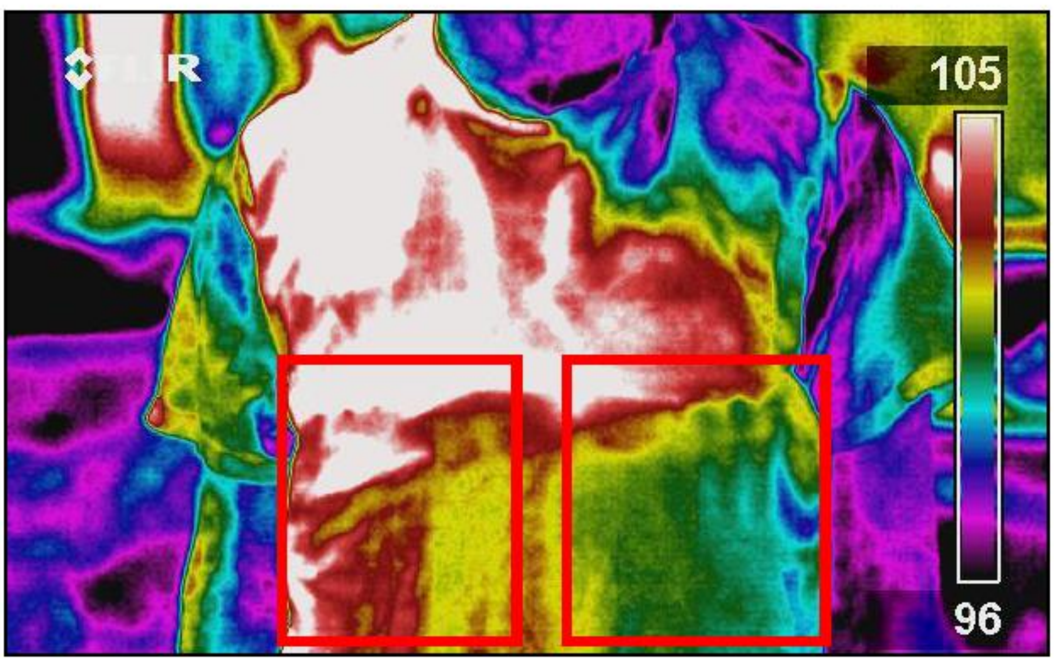

Figure 27. Metal bomb package shielded by one T-shirt at 6 feet (From Dickson, 2008).

5. Millimeter-Wave and Lower Terahertz

The researched performed by Naomi Alexander et al., called “Suicide Bomber Detection” focused on using millimeter-waves and lower Terahertz waves to image objects and explosives worn underneath an individual’s clothing.

> Radiation in the millimeter-wave and the lower Terahertz range, having the useful property of being able to penetrate clothing in addition to fog and rain, makes it a clear candidate for imaging under various weather conditions whilst avoiding contact between Force Protection personnel and potential suicide bombers. (Alexander et al., 2009)

The frequencies they used were 35, 94, and 220 GHz.

The main objectives of their study were to characterize the transmission and reflection properties of the most commonly worn fabrics and explosive suicide vest materials. They also obtained images simulating real case scenarios to test practical detection ranges and standoff distances. The images were taken indoors and outdoors in order to study the affects of the environment on the imager. Lastly, they preformed an analysis of their trial results to determine the ideal imager operating frequency for the best standoff range.

They made several significant conclusions from their study. The first finding was that as the operating frequency of the imager increases, the detection capability increases, with the optimum frequency at 94 GHz. However, from the research, they found that the transmission of the materials experimented increases with decreasing frequency. This means that the materials in which the imager is most looking for are more transparent at 35 GHz than at 94 GHz, which makes them more difficult to detect (Alexander et al., 2009).

The research also revealed that indoor detection capability is very high. The main reason for this finding is that there is minimal radiation from the outside environment affecting the imager. They were able to detect threats 80% of the time at every standoff distance in indoor simulations. The detection limit is a function of the imager resolution. They concluded that the minimum-sized object that can be detected with the imager at a standoff distance (d) is approximately:

$$\text{Size(m)} = 6.5 \times 10^{-3} \bullet d$$ (Alexander et al., 2009).

In outdoor situations, the detection capability is much lower than the indoor capability. The detection rate was less than 50% in outdoor simulations. They did find that the detection rates can increase when comparisons are made to the threat and no-threat images. The research team made several recommendations to help increase the outdoor detection rates. The first was to have extensive operator training in order to indentify less resolute characteristics on the images. Another recommendation is to develop a standard set of no-threat images that could then be used for comparison to the actual images taken of potential suspects.

The last conclusions they made were that the larger the surface area of the threat object, the more pixels will be used to represent the object on the imager. This will make the object easier to detect because it will standout from the background. Lastly, they found that the only atmospheric condition that affects the imager was the temperature in the indoor simulations. If the temperature contrast is decreased, the detection capability decreases. Humidity, fog, and rain had little to no affect on the imager capability (Alexander et al., 2009).

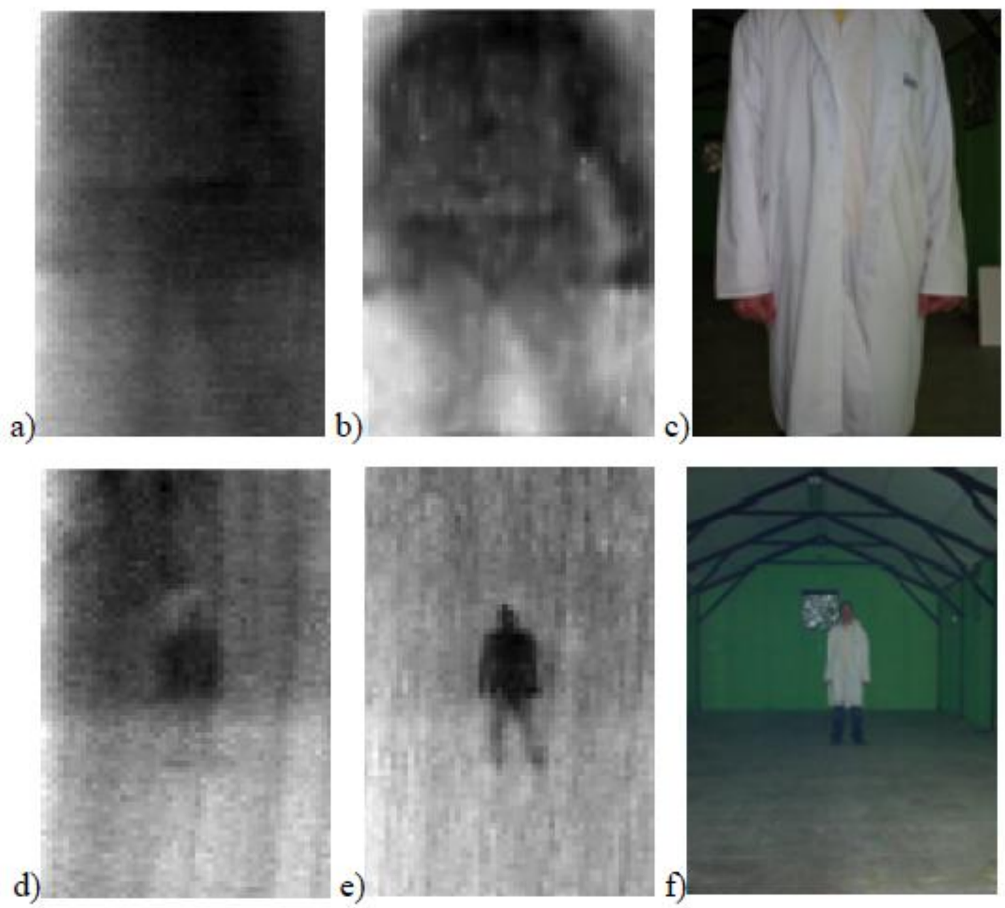

Figure 28. MMW and Terahertz images of an individual with no threat on the body (From Alexander et al., 2009).

Figure 28 represents indoor images of an individual with no threat or object on the body. Caption (a) is using 35 GHz at 2.65 meters. Caption (b) is 94 GHz at 2.65

meters. Caption (c) is a visible image taken at 2.65 meters. Caption (d) is 35 GHz at 9.9 meters. Caption (e) is 94 GHz at 9.9 meters. Caption (f) is a visible image at 9.9 meters.

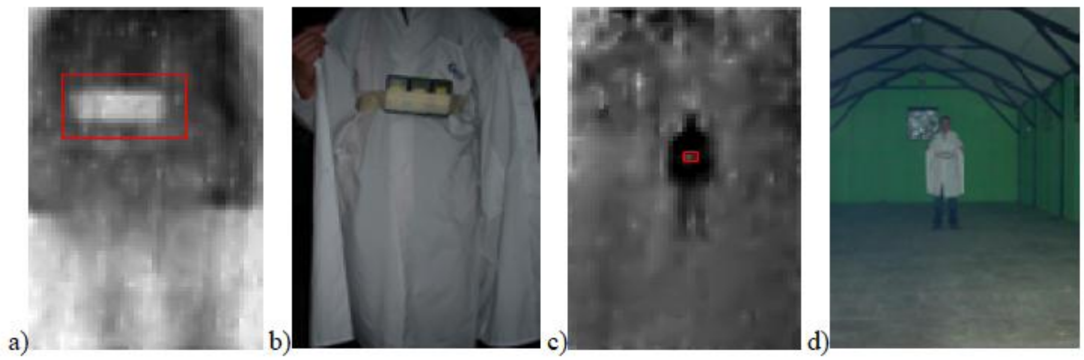

Figure 29. MMW and Terahertz images of an individual with TNT on the body (From Alexander et al., 2009).

Figure 29 represents images taken of an individual wearing a suicide vest made of TNT with a cotton robe. Caption (a) is at 94 GHz from 2.65 meters. Caption (b) is a visible image from 2.65 meters. Caption (c) is 94 GHz at 9.9 meters. Caption (d) is a visible image at 9.9 meters.

6. Future Research Technology

Future technology: The System and Method for Standoff Detection of Human Carried Explosives is a patent submitted in November 2005. The design was created by John Gorman, Robert Douglass, and Thomas Burns Jr. This system is designed to be portable and automatically detect explosives carried on humans up to distances of 200 meters. The sensors incorporated in the design are radar, with center frequencies operating between 10 – 100 GHz, and visual cameras, which may include at least one Ladar, Lidar, infrared, multispectral, hyperspectral, or imaging radar, which are all controlled by a multi-sensor processor.

The processor receives data from the radar and visual cameras and atomically tracks individuals in the field of view. The system works by continually tracking individuals and cueing the narrow beam radar on the individual of interest. As the radar continually collects data on the individual, over time, the data is fused producing range profiles and associated features until sufficient evidence is produced to determine if explosives are present or not present. Once a determination is made, the system alerts the user via a handheld display. To date, no field tests have been performed with this design. Figure 30 is the flowchart showing the sequence of operations for the detection method, and Figure 31 is an illustration of the system incorporating the visual camera with the radar for detection.

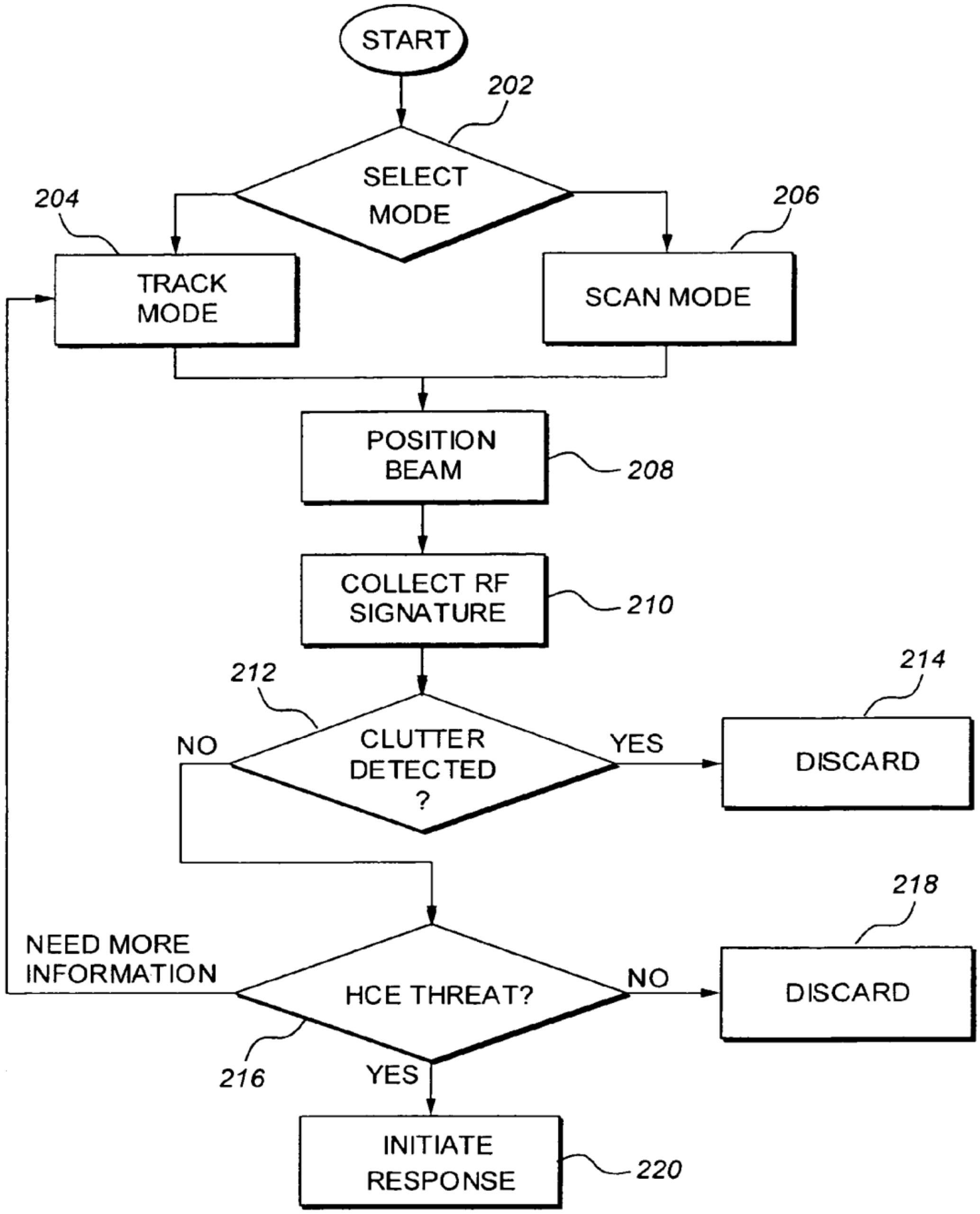

Figure 30. Detection method flowchart (From Gorman et al., 2005).

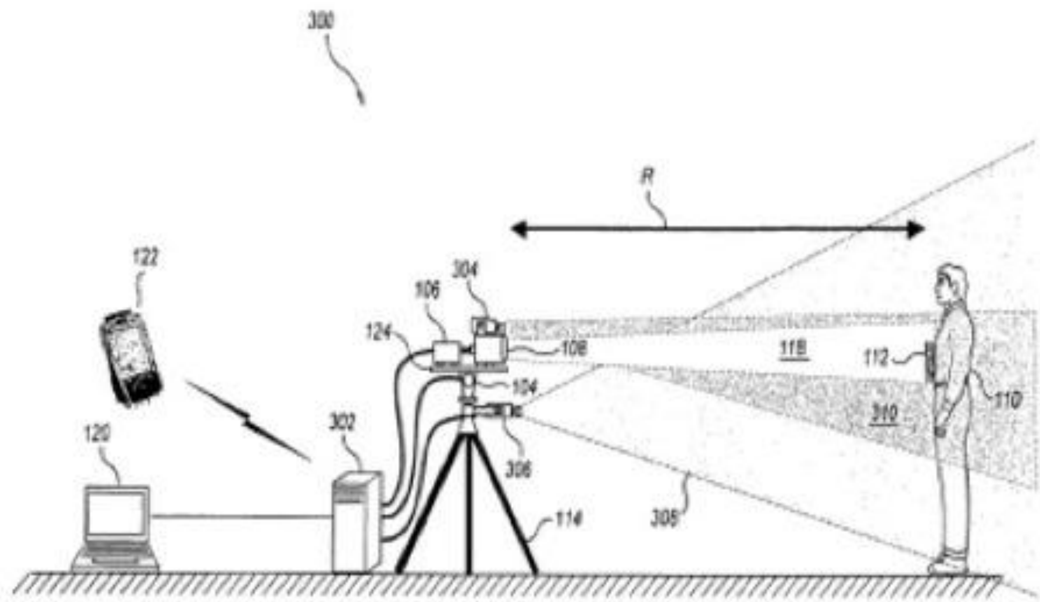

Figure 31. Illustration of system using radar and visual camera (From Gorman et al., 2005).

III. PROPOSED METHODOLOGY

A. METHODOLOGY FRAMEWORK

1. Purpose

The purpose of our methodology is to propose an accurate detection system that can identify a suicide bomber at an adequate explosive safety standoff distance. According to Explosive Ordinance Disposal guidelines, a safe standoff distance is proportional to the cube root of the net explosive weight of the explosives used in the device, multiplied by a destructive factor. A typical suicide bomber with 30 lbs of explosives results in a safe standoff distance of 100 meters (Gorman et al., 2005).

This methodology recommends multiple sensors, each with a unique type of technology. The accuracy of each detection system will be determined by the ability of the system to identify a suicide bomber when there is a suicide bomber actually present and in detection range of the sensor(s), and for the system to not identify a suicide bomber when there are no suicide bombers present. The detection system will use the sensors orthogonally. An orthogonal system involves using different independent technologies for detection. Independent sensors will scan the intended environment, either actively or passively, for threat indicators. As the sensors continue to scan and receive indicators of a suicide bomber with an explosive vest and wires, the data from all the sensors will be fused together to determine if there is an actual threat present. Figure 32 illustrates and outlines the detection system framework.

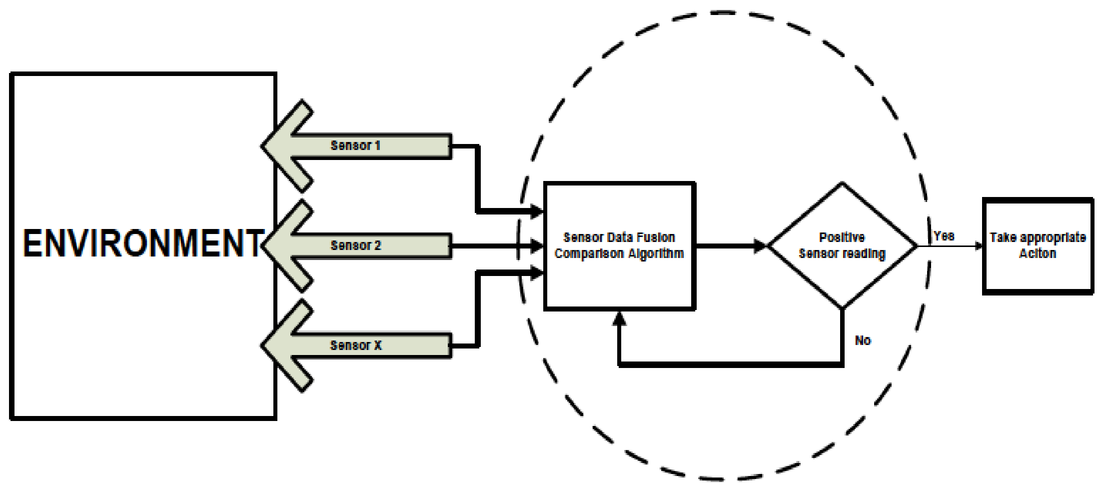

Figure 32. Baseline methodology framework (After Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004).

The proposed system works by having one or many sensors scan the environment. The sensors may be placed in the same location or spread out over different locations in order to scan a larger portion of the environment. The system works independently of where the sensors are placed. The data from each sensor is fed into a central processing unit, indicated by the dashed circle in Figure 32. If one sensor has scanned and received data from an individual but needs amplifying information to accurately determine if a suicide vest and wires are present, then the system will automatically aim another sensor to begin prosecuting the same individual to receive more data. The system will have the ability to automatically aim sensors at a target by using video tracking systems. The tracking system will be controlled in the central processing unit. The central processing unit also includes the comparison algorithms that fuse the data from the multiple sensors. The comparison algorithms are constructed using the sensors in a parallel or series sequence based on sensor detection ranges and location of the sensor in relation to the intended target environment.

a. Orthogonal Detection

The advantage of using an orthogonal detection system of multiple sensors is that the sensitivity and specificity is increased for the overall system. The sensitivity is the ability of the system to identify explosive vests if an explosive vest is present. This increases because the use of multiple independent sensors will be able to detect more of the possible indicators of an explosive vest. The specificity is the ability of the system to identify explosive vests only if an explosive vest is present. This is increased because more sensor types are used in an orthogonal system and each sensor independently detects indicators of an explosive vest only when an explosive vest is actually present. The orthogonal detection system will also reduce the probability of false alarms. This happens because the different independent sensor types are less likely to report false positives at the same time.

b. Detection Thresholds

The proposed detection system must be able to fuse and analyze data at real-time speeds. This is needed so the user of the system can have the most amount of time in order to make a security decision. Each sensor will gather data from the environment, then process and analyze the data resulting in a value that is used to determine the strength of detection that a suicide vest is present. The processed values are compared to threshold values corresponding to each sensor. If the processed value is above a high-level threshold, then that is a strong positive indicator of a suicide vest. The sensor has identified a clear and evident characteristic of a suicide vest. If two or more processed values from separate sensors are above a low-level threshold, then this is also a positive indicator of a suicide vest. Since two different and independent sensors are identifying different minute characteristics of a suicide vest, they system determines that this is enough information to support the presence of a suicide bomber. If the processed values are below the low-level threshold, then there is no indication of a suicide vest and the sensors will continue to scan the environment.

As indicated in the previous paragraph, each sensor will have a corresponding low-level threshold parameter value, γ_S, and high-level threshold parameter value, η_S. These values are a function of the specific sensor used and the distance or range that the sensor is used when scanning a potential suicide bomber. These values will need to be predetermined and calculated based on field tests and computer simulations for each sensor. Using the best values for these parameters is critical for the individual and overall sensitivity and specificity of the sensors and the system as a whole.

The processed values are different for each sensor. Certain sensors are able to receive and present a quantitative value. Active Radar waves are able to transmit electromagnetic waves and detect the returned wave and measure the cross sectional area of a target. The size of the cross sectional area and the strength of the signal received is proportional to the amount of metallic material on the target.

Infrared imaging sensors are able to detect a temperature differential and relative size of an object on a person from its received background image. If the temperature differential of the object compared to the person on which the object is on is large enough, the object will be more noticeable on the display and easier to decipher.

These processed values from the sensors must be compared to a pre-calculated value in order to determine if there is a threat. The pre-calculated values are the threshold values for the sensors. The threshold values are determined from running simulations and field tests. For the Radar, experimentation can determine that the signal strength, frequency, and size of the radar cross sectional area correspond to a specific amount of metallic material on a person. If the high-level threshold for the Radar is set to X meters^2, and the Radar is receiving a radar cross sectional area that is greater then X meters^2, then that Radar sensor is detecting a threat over the high-level threshold.

This concept is the same for the infrared sensor. The threshold values are determined from conducting field test and simulations. If the high-level threshold value is set at Y degrees temperature difference, and the infrared sensor is sensing an object on a person that varies in temperature above *Y* degrees, then the infrared sensor is detecting a threat over the high-level threshold.

Separate from active Radar and Infrared, Millimeter-wave, Terahertz, and X-ray are passive sensors that receive and process data that is qualitative in the form of images. Due to the time constraints while detecting suicide bombers, it is not feasible for users of these sensors to analyze the images, compare the image to images with suicide vest characteristics, and determine if there is a potential threat. Computer image analysis software must be utilized to process the images and determine if there is a threat. The image analysis software must be able to compare the images from the sensor to images and data compiled from simulations and field tests. Data from field tests and simulations compose images, images of individuals with and without suicide vests or explosives on their body, taken at various angles, distances, and temperatures. The more exact the sensor image characteristics match the image characteristics in the software, then the stronger the detection of a threat. The low-level and high-level threshold values for each sensor are determined by how accurate an image matches an image in the image analysis software.

For example, the high-level threshold for a Terahertz sensor could be set for a 75% match. If the Terahertz sensor receives an image, and the image is processed using image analysis software that produces a 80% match to pre-processed and stored image, then the Terahertz sensor is detecting a threat over the high-level threshold.

Sensor	High-level Threshold η	Low-level Threshold ϒ	Metric
Radar RCS	1	0.3	Ratio of VV/HH Radar Cross Section Area
Radar speed of target	|s+SE|	|S-SE|	Absolute speed compared to norm
Infrared	7%	3%	Percent Temperature Change for the Given Temperature Scale
X-ray	90%	50%	Image analysis match
Millimeter-wave	90%	50%	Image analysis match
Terahertz	90%	50%	Image analysis match

Table 2. Detection threshold values.

2. Users of the System

After the detection system determines that a suicide bomber is present, the final step in the system is to initiate a response to the user. It should be solely up to the user, with their commander's guidelines and intentions, to determine what the next course of action is after a suicide bomber has been identified. Standard operating procedures and rules of engagement will factor in on how each situation is handled. The purpose of the system is to detect suicide bombers at an adequate standoff distance, which will allow the users more time to make a decision. The more time the users of the system have to make security and force protection decisions, there will be minimal damage and lethality to surrounding infrastructure and people.

The baseline methodology will be applied to two scenarios that have real-world implications. The first scenario will be a security checkpoint. The second scenario will be an open area to the public or marketplace.

B. CHECKPOINT SCENARIO

1. Checkpoint Definition

Security checkpoints are normally erected and controlled within adjoining areas under military or law enforcement control. Security checkpoints have been employed within conflict-ridden areas all over the world to monitor and control the movement of people and materials in order to prevent violence. Most notably are the checkpoints along the Israeli and Palestinian borders, and the security checkpoints in Iraq. Checkpoints have also been used in less hostile regions or situations. Examples are large public gatherings such as events at the Olympic Games or The Super Bowl. In both the military and civilian examples, the purpose of the checkpoint to is screen people as they pass from an unsecure area into a secure area.

The U.S. Army Field Manual 3-07-22 states that checkpoints are set up to check and control the movement of personnel, vehicles, and materiel, and prevent actions that aid the enemy. During counterinsurgency operations, such as Operation Iraqi Freedom, checkpoints assist the commander in maintaining the initiative against the insurgents by disrupting, interfering with, and deterring insurgent operations, and disrupting the insurgents' decision making cycle. The field manual also states that it is important to conduct checkpoints and roadblocks with interpreters, host nation police, or other host nation security forces (DOA, 2004).

2. Purpose of Detection System at Checkpoints

The probability of suicide bomber attacks against U.S. troops and its allies while deployed in hostile regions of the world continues to remain high. All of the checkpoints and entry control points are not equipped with the equipment to screen for suicide bombers at a standoff distance. The ideal use of the detection system is to scan and identify people at a safe standoff distance that avoids unnecessary contact between security personnel and potential suicide bombers. The standoff distance is the distance from the approaching potential suicide bomber to the actual checkpoint or the area where crowds gather waiting to pass through the checkpoint. Adequate standoff distance shall be any distance greater than 10 meters, but the further the distance the better (Committee on the Review of Existing and Potential Standoff, Explosives Detection Techniques, 2004).

Although people can approach a checkpoint from multiple directions, security personnel can take positive control of the situation by directing and funneling people into lanes or lines that lead to the checkpoint. Having the approaching people in an organized formation or line creates the ideal scenario for using the sensors. A narrower search area is now needed to scan the approaching people. This allows more time for the sensors and the security personnel's vision to focus on the people at further distances.

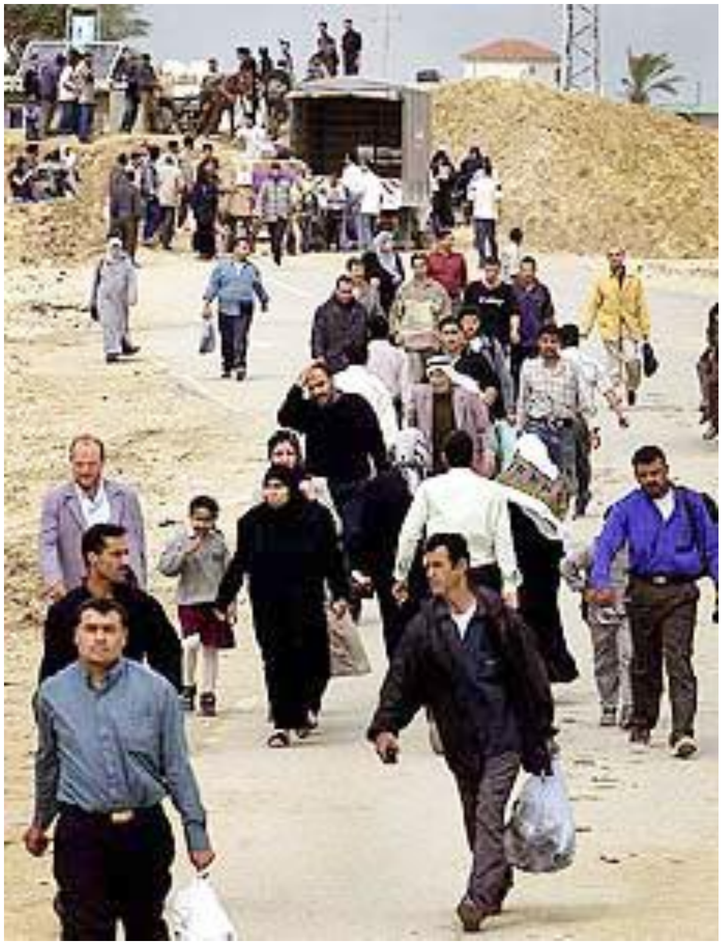

Figure 33. Individuals approaching a checkpoint.

Many times at checkpoints, as in Figure 33, large crowds can congregate, which make it more difficult to indentify suicide bombers. This is a key reason why long-range sensors need to be used scanning in a narrow search area.

Figure 34 is an illustration of an Israeli checkpoint along the Palestinian border. Concrete barriers are used to control the flow of pedestrian traffic and direct people towards the checkpoint.

Figure 34. Israeli checkpoint with barriers to control approaching people.

3. Checkpoint Detection System Operation

Figure 35 illustrates the sequence and operation of the detection system for a checkpoint. The checkpoint detection system applies the baseline detection methodology, Figure 32, but uses the sensors based on their respective detection ranges. There is a long-range detection operation and a short-range detection operation.

The detection distance that distinguishes the two sets of operations is 10 meters. This is due to the detection ranges of the X-ray, Terahertz, and MMW sensors. All three of these sensors have a maximum range of 10 meters, while the Infrared and Radar sensors have ranges that can be used up to 100 meters.

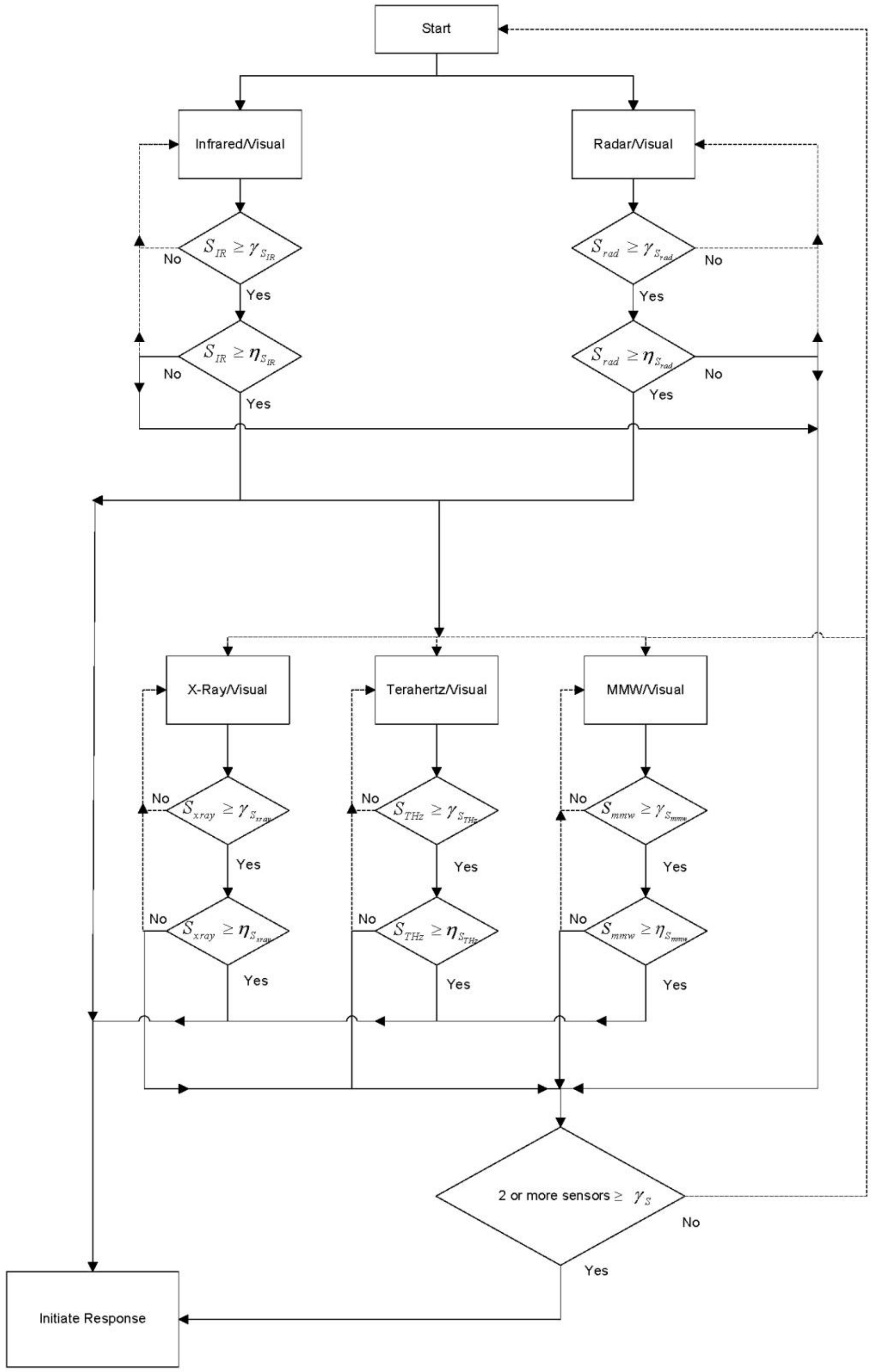

Figure 35. Checkpoint detection flowchart.

a. Long Range Detection

The methodology for a checkpoint is structured to work in a sequence based on the detection distances of the sensors. As discussed earlier, this will allow for the detection of suicide vests at the furthest range possible, resulting in the best standoff from the checkpoint. The Infrared and Radar sensors can both be used up to distances of 100 meters. However, this does not prevent these sensors from scanning and tracking individuals as they move closer to the checkpoint entrance. Figure 36 shows a simplified view of the long-range sensors. The sensor in Figure 36 is aimed at the individual. The range of detection (R), is the standoff distance which can be up to 100 meters. The data from the sensor is fed to the central processing unit, which is displayed to the users.

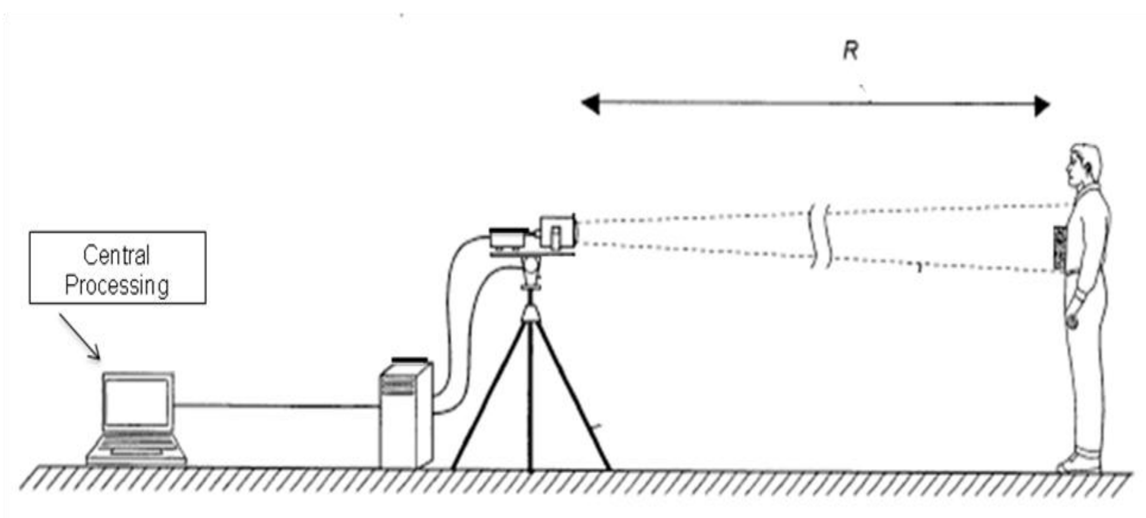

Figure 36. Long range detection scan (After Gorman et al., 2005).

At ranges up to 100 meters, the Infrared and Radar sensors will be scanning approaching people. They can work in unison or independent of each other. As Figure 35 depicts, one or both of the sensors scans and receives data. The Infrared sensor scans passively and indicates temperature differentials on a person. If the temperature differential found on a person is above both the low-level threshold γ_{IR} and high-level threshold η_{IR}, the system will initiate a response indicating that at the scanned range, there is a strong indication that the person is wearing a suspicious device indicative of a suicide vest. If the temperature differential found on a person is only above the low-level threshold, the system will need further information and will continue to scan and monitor approaching people.

The Radar sensor works in a similar fashion but is an active scanner. The Radar sensor generates and pulses an electromagnetic wave at the approaching people and receives a return wave. The return wave produces data in the form of a radar cross sectional area. The larger the signal of the cross sectional area, the larger amount of metallic material is on a person. If the cross sectional area signal strength of a person is above the low-level threshold γ_{Radar} and high-level threshold η_{Radar}, the system will initiate a response to the user, indicating that at the scanned range, a person has a strong indication of wearing a suicide vest based on the amount of metal found on the person's body. If the cross sectional area of a person is only above the low-level threshold γ_{Radar}, the system will need further information and will also continue to scan and monitor approaching people.

In the case where both sensors received data that was only above their respective low-level thresholds and not above their respective high-level thresholds, the system will also initiate a response. The flow chart shows that when data from a sensor is above its low level threshold but below its high-level threshold, it is sent to a decision node. This decision node receives data from all the sensors meeting this criterion. When the same individual is scanned from two or more sensors and the data from the sensors meet this criterion, the system will initiate a response to the user that there is a strong indication that the person is wearing a suicide vest.

b. Short Range Detection

The next process of the flow chart involves the sensors that have a maximum detection range up to 10 meters. There are three technologies used: X-ray, Terahertz, and MMW. The principle function of these three sensors works the same as IR and Radar. Any one of the three sensors can be used to scan an individual as well as up to all three sensors used to scan an individual. The data from all short-range sensors will also be combined (fused) and analyzed. An illustration of the short-range sensors working together is shown in Figure 37. The sensors are continually scanning individuals as they are making their way toward the checkpoint. All the data from the sensors are being fed into a central processing unit. The data from the long-range sensors will also be combined and (fused) with the data from the short-range sensors when the long range sensors have tracked an individual into ranges closer than 10 meters.

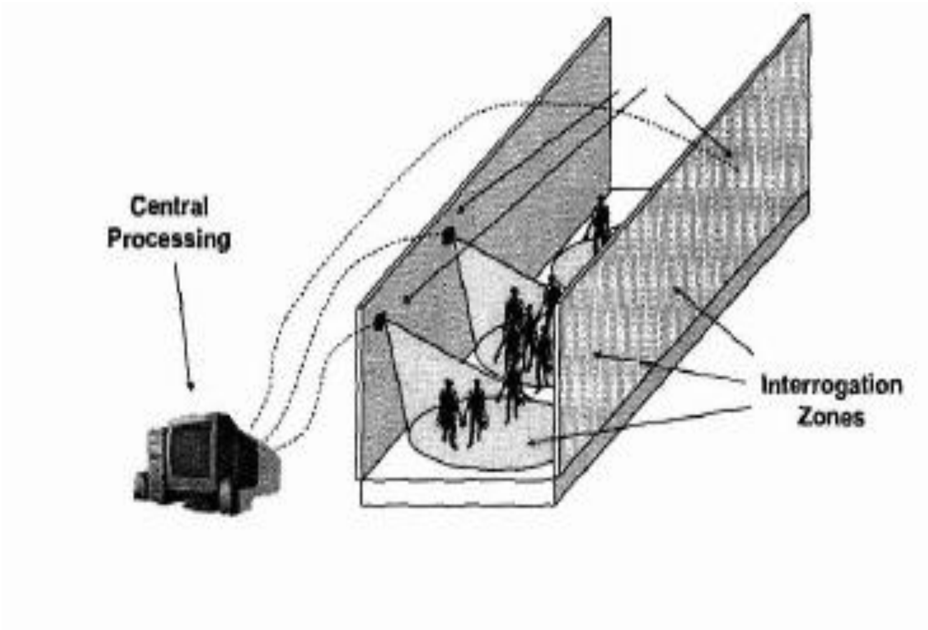

Figure 37. Short-range detection sensors (After Costianes, 2005).

If data from any one of the three short-range sensors is above their respective high-level threshold η_S, then the detection system will acknowledge this as a strong indication of a suicide vest and initiate a response to the user. If the data from two or more sensors are above their respective low-level threshold γ_S, then the detection system will also acknowledge this as a strong indication of a suicide vest and initiate a response to the user. The process of the short-range sensors scanning and combining data from each other as well as combining any data from the long-range sensors is a constantly occurring through the feedback loop in the detection system.

The last and final process, after individuals reach the checkpoint without any sensors resulting in a response from the detection system, is for security personnel to conduct a pat down or magnetic wand search for any explosive or metallic material that was not found by the sensors. Figure 38 shows an Israeli soldier conduct a security search on an individual before they can pass through the checkpoint.

Figure 38. Israeli soldier conducting personnel search at a checkpoint.

C. MARKETPLACE SCNEARIO

1. Marketplace Definition

The next scenario for applying a suicide bomber detection system is in a marketplace or any public area in which large crowds gather. Examples can be town centers or public transportation stations. This type of setting is much more difficult to detect and indentify a suicide bomber than a checkpoint. The difficulty increases because there are many ways to enter and exit a marketplace or public area, and the amount of people and crowd size makes its very demanding for the sensors to accurately pinpoint an individual. Unlike the checkpoint, in which security can take positive control of the crowds by corralling them, security personnel cannot control the movement of people in the marketplace. The movement of people is chaotic, sporadic, and unpredictable.

Figure 39 is the Dora Marketplace in Baghdad. This is a typical outdoor Iraqi marketplace with local civilians shopping. The area is open, with several ways to enter and exit, either through the streets or adjacent buildings. Also, the people can move as they please throughout the area. There are no control points to monitor foot traffic. During the early stages of Operation Iraqi Freedom, the Dora Market was a hotbed for Al Qaeda and insurgent activity.

Figure 39. Dora Marketplace.

2. Suicide Bomber Attacks in Marketplaces

An example of the scope and complexity that is required to identify a suicide bomber is illustrated in the photos below. Figure 40 is a picture of a market in Lahore, Pakistan, taken on December 2009. The street is flooded with shoppers, making it difficult for any security personnel to find suspicious-looking individuals who could be potential suicide bombers.

Figure 40. Marketplace in Lahore, Pakistan.

In the same market in Lahore, on December 9, 2009, two suicide bombers entered into the crowds of shoppers and diners. Within seconds, the two suicide bombers detonated themselves, killing 51 people and wounding over 140 more. Ball bearings were found around the blast sight, indicating that the two suicide bombers packed their explosives with the ball bearings to increase fragmentation and lethality. Figures 41 and 42 show the damaging effects from the two explosions.

Figure 41. Lahore Marketplace explosion damage.

Figure 42. Lahore Marketplace explosion damage.

As discussed and shown above, a marketplace is a much more complex scenario to detect and identify a suicide bomber. Military, law enforcement, or other security agencies will never be able to stop all attacks. However, in a high-probability target area, setting up a detection system will increase chance of identifying a suicide bomber. Kaplan and Kress state that suicide bomber detectors and sensors can play an important role for the use of known targets. However, detection systems are not likely to prove effective in protecting civilian populations from random attacks. Simply stated, there are not enough sensors to have in every public place to detect every potential suicide bomber (Kaplan & Kress, 2005).

3. Marketplace Detection System Operation

Applying the baseline methodology to a marketplace or any public area, one of which is considered of value or a known target, would have to consist of an array layout of multiple sensors spread throughout the area. All sensors would be in operating in their respective detection ranges that makes it possible to have all different sensor technologies focus in on a certain area. Similar to the checkpoint methodology, all the data from the sensors will be sent to a central control unit to fuse and analyze.

Figure 43 shows a simple illustration of the sensor positioning for a marketplace scenario. A single sensor or a group of sensors are positioned in three different areas. They are labeled as "Detection System." Each Detection System is able to scan the area using different sensor technologies and to scan the area from contrasting angles or viewpoints. This allows for a more complete area of the environment to get scanned. All the data from the Detection Systems are fed into the Secure Area that houses the processing unit to fuse and analyze the data at real-time speeds.

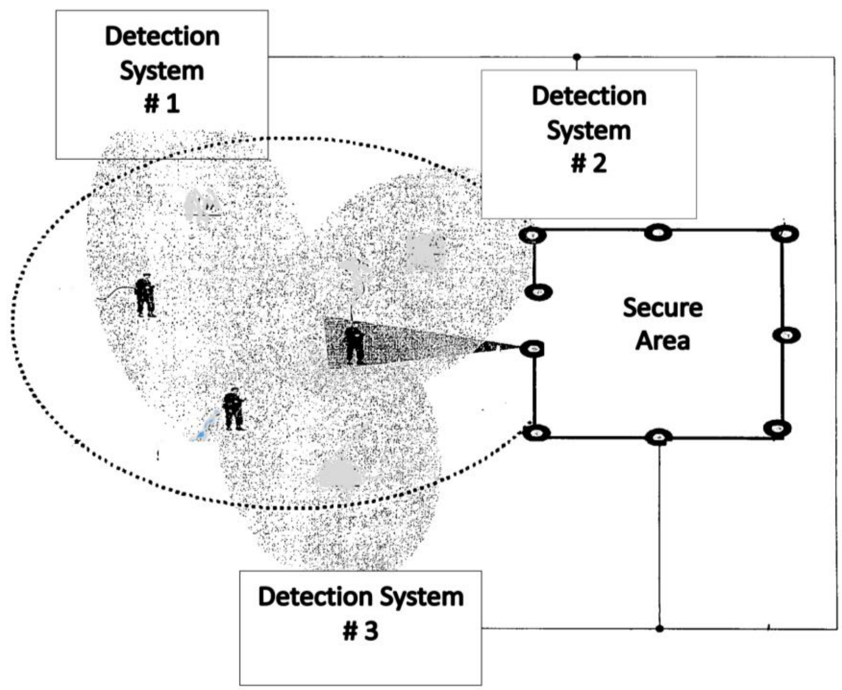

Figure 43. Possible marketplace sensor positioning (After Gorman et al., 2005).

Figure 44 shows a potential layout of the sensors over a larger area, such as a city block. The illustration is a depiction from the Kaplan and Kress report, "Operational effectiveness of suicide-bomber-detector schemes: A best-case analysis." At each location where a "Sensor" is shown, there can either be a single sensor or several sensors, making it its own detection system, as shown in Figure 43. Thus, the system as a whole can be viewed as a system of smaller systems. This expands the area in which the entire detection system can scan. Instead of the sensors focusing in on a small area or section of a marketplace, the system as a whole can now have the ability to view a much larger portion of the environment and track individuals as they move throughout the area.

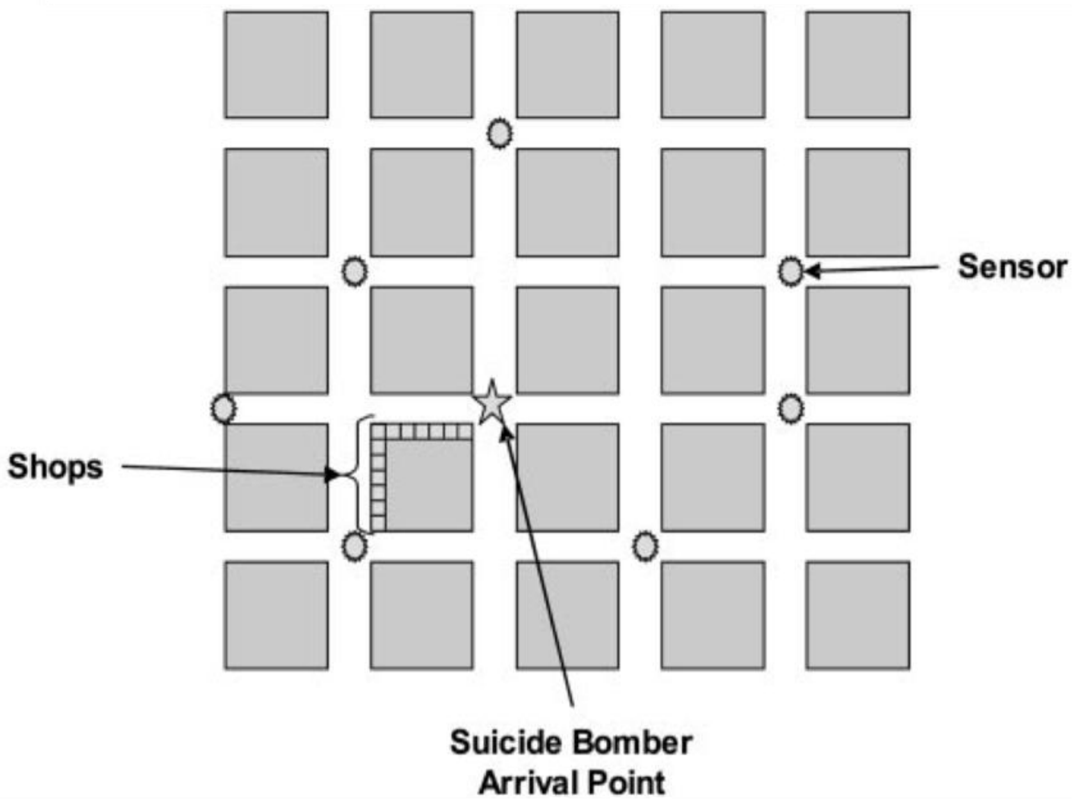

Figure 44. Sensor layouts in a city block (After Kaplan & Kress, 2005).

The flowchart and sensing methodology is depicted in Figure 45. The process is adopted from the baseline detection methodology shown in Figure 32. The sequence of operations for a marketplace scenario incorporates using all the different sensor technologies in a parallel process. This is similar to the checkpoint methodology except all the sensors can be scanning an individual at the same time; there is no distinguishing range or operation distance. This is a result of having the sensors positioned in different locations from each other and in relation to the area they are scanning.

The system will work by having one, all, or any combination of the sensors working and scanning simultaneously. As the sensors receive data, they will compare it to their respective low-level threshold values, η_S, and high-level threshold values, γ_S. If one or more sensors receive data that is above the high-level threshold, then the system will initiate a response to the users that there is a strong indication of a suicide vest.

If a sensor receives data that is above its low-level threshold value but below the high-level value, the system does not initiate any response to the user. The system will have the sensor continue to scan the individual incase the sensor data increases above the high-level threshold. Also, the system will automatically aim other sensors that are in range to the individual to receive supplemental data. As the system continues to scan and receive data from two or more sensors, all the sensor data is fused together in a central processing unit. If any of the additional sensors now aimed at the individual receive data that is above their respective low-level threshold, then there are now at least two sensors that are receiving data that is above their low-level threshold. Meeting this criterion will have the system initiate a response to the user that there is a strong indication that the individual scanned is wearing a suicide vest.

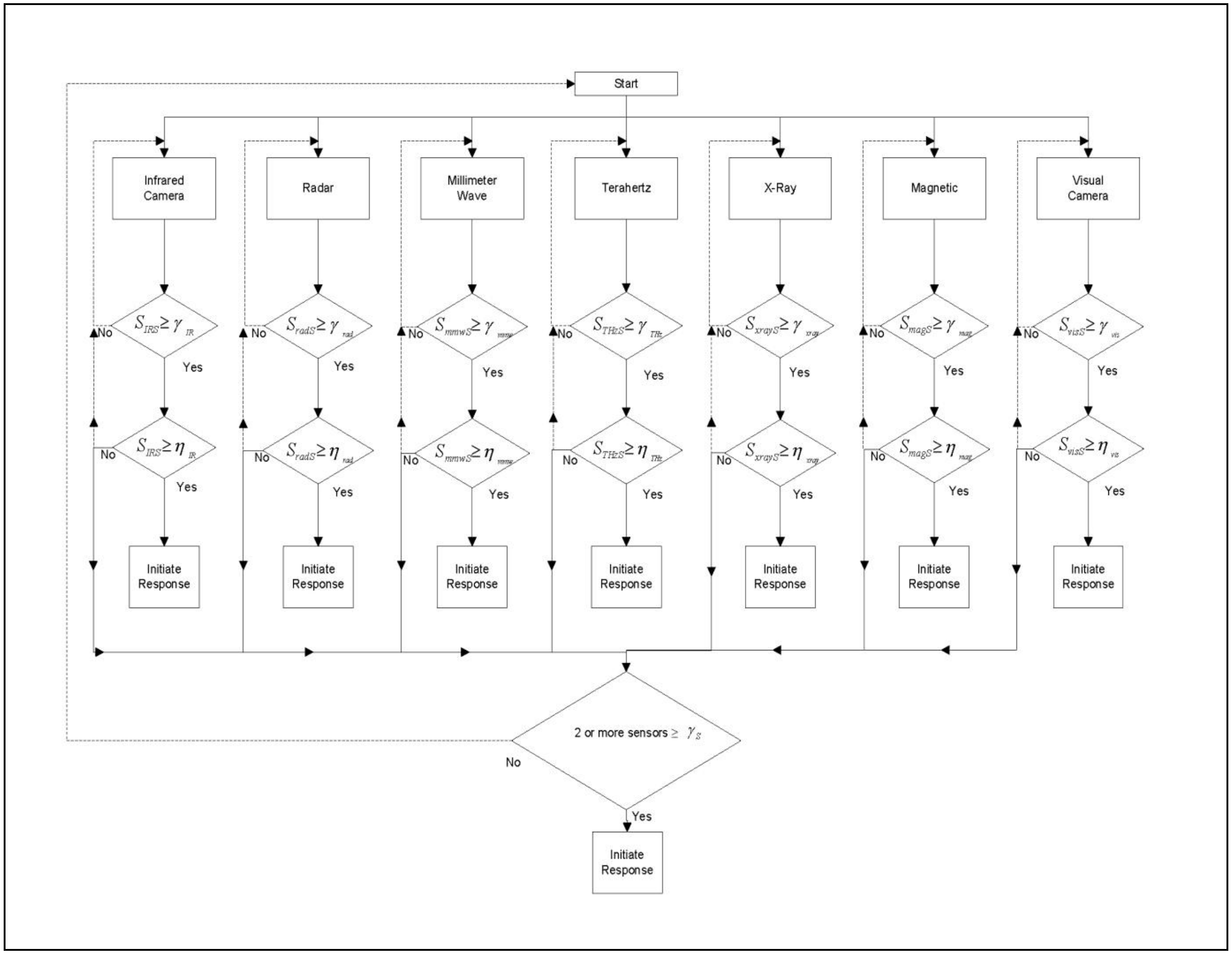

Figure 45. Marketplace detection flowchart.

IV. METHODOLOGY TESTING

A. CONCEPT FOR TESTING

The focus of this thesis is to propose a suicide bomber standoff detection methodology that can be incorporated in multiple military environments to increase the probability of detecting a human born IED prior to detonation. Since there is currently no standoff detection system being actively used by the military to detect a human born IED prior to detonation, the only method for detecting a suicide bomber is with the human eye, which is dependent on the IED being visible. Using this as the current baseline, our goal is to identify current technologies that when fused together with other technologies in an orthogonal system can identify a possible suicide bomber at a standoff distance adequate for a response that prevents the detonation or reduces the number of casualties.

The conception of this thesis was based on previous research using radar to identifying people carrying wires on their body for IED detonation conducted by Professor William Fox, Naval Postgraduate School, and Professor John Vesecky and Kenneth Laws from the University of California at Santa Cruz. We expanded on their research by incorporating the capabilities of X-ray, infrared, terahertz, and passive millimeter wave technologies. Our goal for this research is to incorporate the capabilities of these five technologies into an orthogonal system that fuses the data from each sensor to determine if an individual wearing an IED is present in the crowd and identify that individual to the security forces.

B. MODEL DESIGN

We were unable to obtain the technologies used in our proposed standoff detection system for field-testing and data collection, so we relied on a software model to test the probability of detecting a suicide bomber in a crowd of people given the stated capabilities of the various technologies. The original model was created by Fox et al. for their research using radar cross sections to identify people carrying wires on their body. The model used for this thesis expands on the original model by adding the comparison of an individual's speed calculated by radar and thermal temperatures calculated by infrared to determine if the combination of more than one sensor reading increases the probability of detecting a human wearing a suicide vest compared to a single technology. The detailed algorithm for our model is seen in Figure 46. Of the five technologies incorporated in our proposed system, only radar and infrared have quantitative values that can be incorporated into a model. X-ray, terahertz and millimeter wave technologies all produce images that are qualitative and require either an automated imaging comparison program or a man-in-the-loop to compare real-time images to previously established images of typical suicide bomber characteristics.

INPUTS: N, number of runs, assumed distribution for the number of suicide bombers in a crowd, distributions for probability metric for radar detections, threshold value
OUTPUTS: the number of positive detections, the number of false detections

Step 1. Initialize all counters: detections = 0, false alarms=0, suicide bombers =0

Step 2. For i = 1,2,…, N trials do

Step 3. Generate a random number from an integer interval [a,b].

Step 4. Obtain an event of a suicide bomber based upon our hypothesized distribution of the number of suicide bombers in a crowd of size X. Basically if random number $\leq$ *a specified small value* then we have a suicide bomber, otherwise we do not.
For example, we might generate random numbers between [1,300] and if the random number is $\leq$ *2* then they are a suicide bomber.

Step 5. Generate a random number from the distribution of |VV-HH| differences depending on whether the target is a suicide bomber with a vest and wires or not a suicide bomber. These distributions are described previously in Table 2.

Step 6. Compare results from step 5 to threshold value using the following:
Target present: $y(t) > Y \rightarrow$ correct detection
Target present: $y(t) < Y \rightarrow$ missed detection
Target not present: $y(t) > Y \rightarrow$ false alarm
Target not present: $y(t) < Y \rightarrow$ no action

Step 7. Generate a random speed for each of the N trials above based upon
Speed normal about 1 m/sec for a non-suicide bomber and
Speed is 1-.5(rand()) or 1=.5+rand() for a bomber on drugs

Step 8. Compare for detection with speed.
Target present: $z(t) > Z \rightarrow$ correct detection
Target present: $z(t) < Z \rightarrow$ missed detection

Target not present: *z(t) > Z*→ false alarm
Target not present: *z(t) < Z*→ no action

Step 9. Generate a random number for thermal imaging for temperature difference based upon

$$\frac{100\% \cdot (temperature_h - temperture_l)}{temperature_h}$$

Thermal difference for a normal person temperature percent differential of $\frac{100\% \cdot (temperature_h - temperture_l)}{temperature_h}$ using $temperature_h$= 98.6 and $temperture_l$ = 95

Thermal difference for a normal person temperature percent differential of $\frac{100\% \cdot (temperature_h - temperture_l)}{temperature_h}$ using $temperature_h$= 98.6 and $temperture_l$ = a random number between 70-95 degrees)

Step 10. Compare for detection by thermal imagining

Target present: *w(t) > W*→ correct detection
Target present: *w(t) < W*→ missed detection
Target not present: *w(t) > W*→ false alarm
Target not present: *w(t) < W*→ no action

Step 11. Increase all Counters as necessary

Step 12. Output statistics under the assumption of independence

$P(A \cup B) = P(A) + P(B) - P(A) \cdot P(B)$ for two events or

$P(A \cup B \cup C) = P(A) + P(B) + P(C) - P(A) \cdot P(B) - P(A) \cdot P(C) - P(B) \cdot P(C) + P(A) \cdot P(B) \cdot P(C)$

END

Figure 46. Simulation for Methodology Model for RCS, Radar, and Thermal (After Fox et al., 2009).

Prior to running the model, we established the threshold range (high-level and low-level) for an individual human's radar cross-section, speed, and thermal reading. Since we did not conduct field tests, we used the real data for radar cross sections collected by Fox et al. and made assumptions for speed values and thermal values based on our research. For speed values we assumed that an average person walks at a rate of 1 m/s and that a variance from that could be a sign of abnormal behavior. This assumption is based on research conducted by the Bornstein's in 1977, where they found that people in a region walk at about the same speed. If a crowd is moving at a certain speed and a person in that crowd is walking at a speed that is significantly faster or slower than our specified threshold, then that person might be a suspect.

The person's speed might vary as a result of drugs, or a result of carrying the excessive weight of an IED. The thermal temperature difference threshold is based on an average surface temperature for a human being approximately 100 degrees Fahrenheit. If the difference in temperature between an object in the torso area and the average surface temperature of the individual is between 3% to 7%, there might be an object under the clothing. Again, we think the combination of these threshold values in the model should improve the statistics on detecting the target as well as further decreasing the false positives even further.

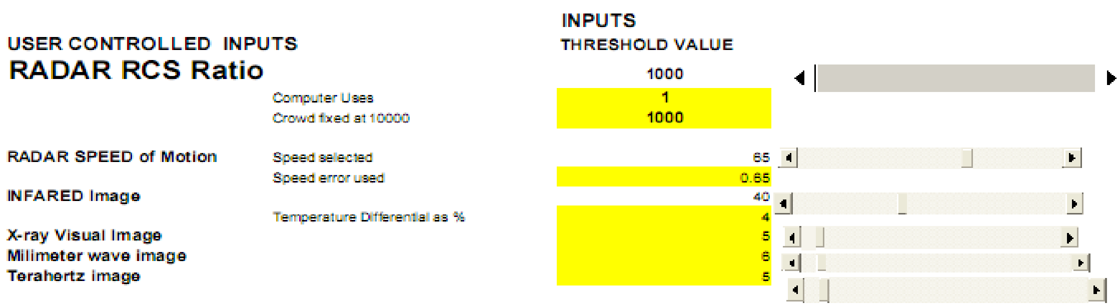

Figure 47. The Model controls showing the tool bars to vary the threshold values.

C. DISCRIPTION OF MODEL

The model runs through 1000 iterations 10 sequential times for each execution. In each iteration, the model randomly generates a crowd size and values for radar cross-section, speed, and thermal temperature for each individual in the crowd. The randomly generated values created for each individual are compared to the preselected threshold values identified before each execution of the model. The model compares the threshold values with the randomly generated values to determine if a bomber is present. Depending on the threshold values, the model can identify a true detection, false detection, or a miss. The model only identifies if a bomber is or is not present in a crowd buy using a binary 0 or 1 to represent no or yes. However, it does not identify how many bombers are in the crowd. After each execution of the model, the conditional probabilities listed in Table 3 were averaged from the 10K iterations.

Threshold measured	Detect	False Detect
RCS, speed, thermal	P[Detect|bomber]	P[Detect|no bomber]
RCS, speed	P[Detect|bomber]	P[Detect|no bomber]
RCS, Thermal	P[Detect|bomber]	P[Detect|no bomber]
Speed, Thermal	P[Detect|bomber]	P[Detect|no bomber]

Table 3. Conditional probabilities calculated by model.

There are three threshold values (RCS, Speed, and thermal) that can be adjusted with any combination of the three. Once the threshold values were selected, we ran the model multiple times with the same threshold values, which allowed us to average the average probabilities and establish a normal distribution of the data. We classified the threshold values as low, medium, or high and changed them in various combinations to determine which threshold combination produces the highest probability of detection with the lowest probability of false detection.

D. TESTING METHOD

Following the methodology identified in Chapter III, we ran the model to test each threshold value independently, then as a combination of two thresholds, and finally with all three thresholds. Although the only real data we had from previous research field testing was the radar data, we were still able to determine if there is an increase in the probability of detecting a bomber while reducing the probability of false positives.

E. TESTING USING INDIVIDUAL THRESHOLD VALUES

The probability of identifying a bomber in a crowd using only the RCS of an individual to determine if wires are present decreased as the threshold value increased.

This shows us that that the smaller the individual RCS ratio, the higher the probability of detecting an actual bomber. As the probability of detecting an actual bomber goes up, so does the probability of a false detection. When using only RCS as a detection system, we found that a medium threshold value produced the highest probability of detection with the lowest probability of a false detection. The challenge for decision makers is to determine what is an acceptable ratio between the probability of detection and the probability of a false detection.

	Probabiilty of:	
Threshold value	**Detection**	**False Detection**
RCS(.2)	100%	94.4
STD	0	0.0103
RCS(.3)	86.70%	58.3
STD	0.0126	0.1179
RCS (.4)	59.50%	0
STD	0.3703	0
RCS(.5)	33.30%	0
STD	0	0
RCS(.7)	11.30%	0
STD	0	0
RCS(.9)	16.70%	0
STD	0	0

Table 4. Calculated probability of detecting a bomber and false detection for increasing RCS thresholds.

After running the model to determine the optimal speed and thermal threshold values, we found that the resulting change in probability of detecting a bomber was not consistent with the change in threshold values. As the threshold values were increased from low to high, the probability values for detecting a bomber were initially high with low threshold values. But, as the threshold values were adjusted within the medium range, those probability values dropped, spiked, and dropped again. This spiking characteristic in the probability values shows us that within the medium threshold range, there is also an optimal threshold. Overall, threshold values on the extreme low edge of the threshold range are the optimal values to produce the highest probability of detection for speed and thermal sensors run independently. The probability of false detection for both the speed and thermal testing provided no valuable insight due to the assumption implemented in the model. With future research and field testing, real data can be implemented into the model, which will present a more accurate representation for the speed and thermal readings.

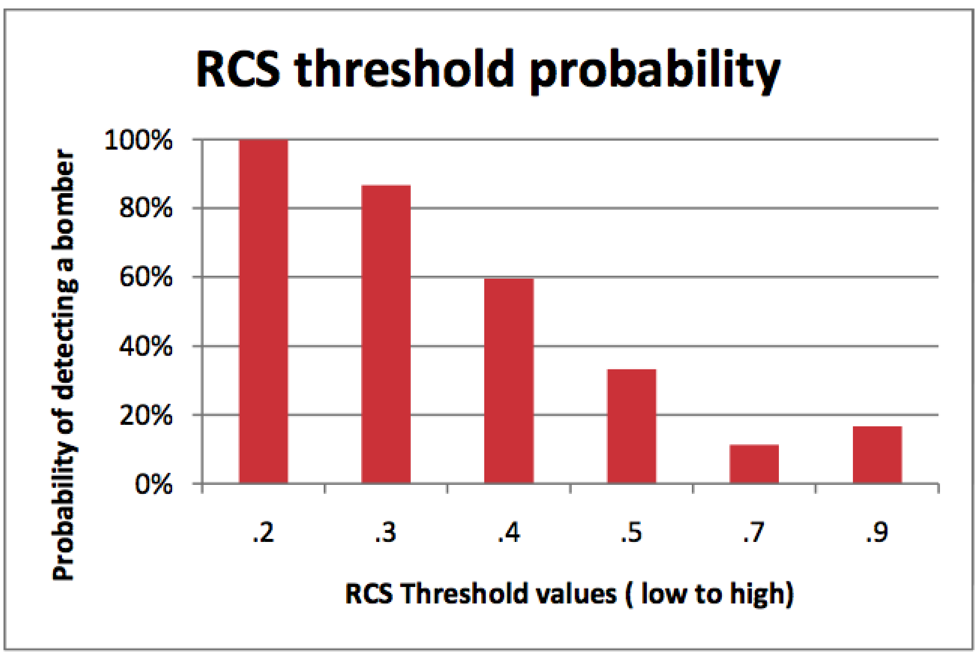

Figure 48. Single sensor probability using only RCS.

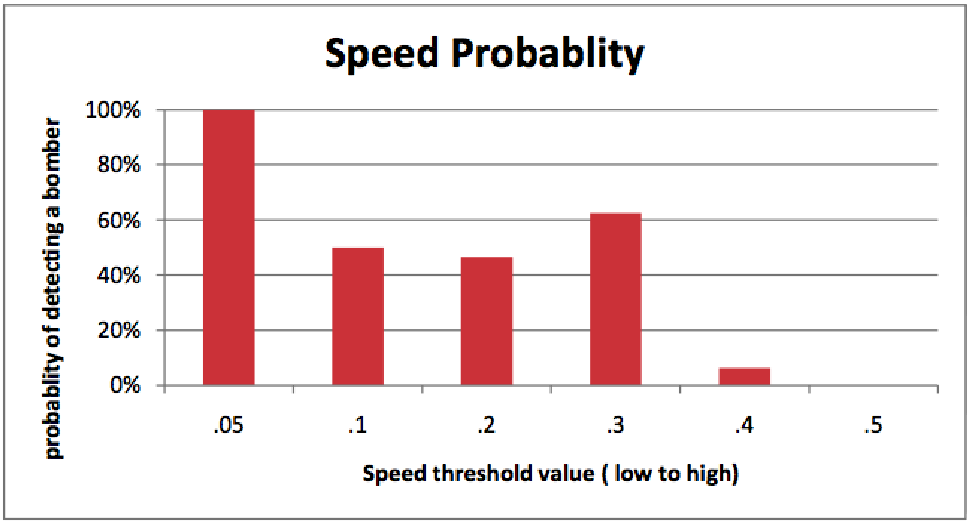

Figure 49. Single sensor probability using only speed.

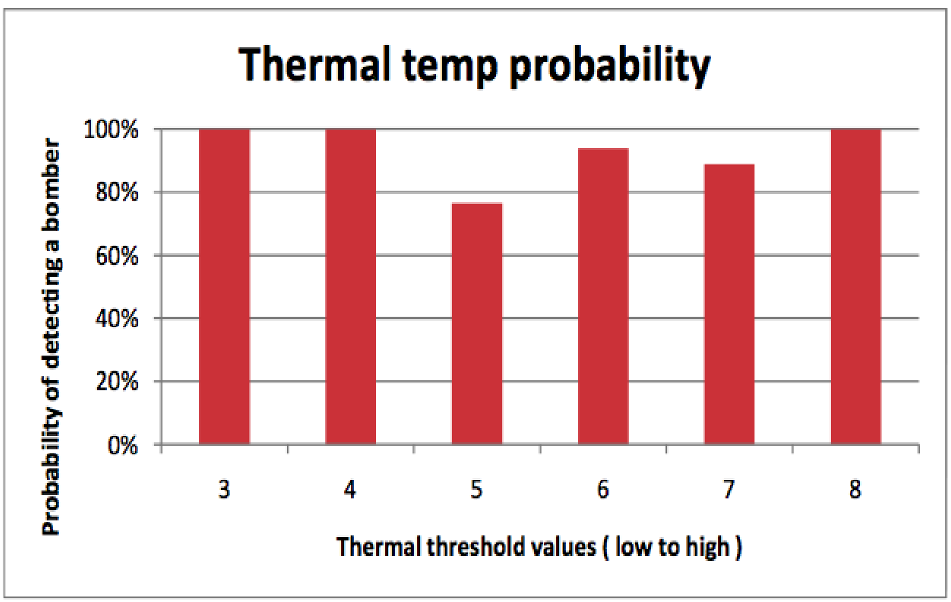

Figure 50. Single sensor probability using only thermal temperature.

F. TESTING USING TWO THRESHOLD VALUES

As we progressed the testing through our methodology described in Chapter III, we ran the model with multiples of two threshold values to determine if the probability increased as we added additional sensors. The first test with the model was done with RCS and speed threshold values, then RCS and thermal values, and finally speed and thermal values. The testing of RCS with speed and RCS with thermal threshold values had similar resulting. For both combinations of testing, the probabilities were inconsistent and fluctuated throughout the low, med, and high threshold values. As the probability of detecting a bomber went up, so did the probability of a false detection. Compared to an individual threshold being testing independently, the probability of a false detection dropped within these combinations. The test consisting of speed and thermal threshold values combined showed that the probability of detecting a bomber increased throughout all threshold values. However, as the threshold values increased from medium to high values, the probability of a false detection also increased.

G. TESTING USING THREE THRESHOLD VALUES

The final test with the model was performed with all three-threshold values combined and measured orthogonally. The resulting values were the most consistent of all the tests performed with the model. We tried multiple combinations of threshold values while changing the individual threshold values from low, low, low to high, high, high to determine what combination of threshold values produced the highest probability of detection. As we changed the individual sensor's threshold values, we noticed that the probability for detecting a bomber fluctuated very little, while the probability of a false detection remained consistently around 10% for all combinations of threshold values.

Since the model generates random values, we ran the model multiple times with the same values to calculate the average of the average probabilities. This allowed us to establish a normal distribution of values and eliminate any outliers created from the random values. After running the model, with varying combinations of threshold values and sensors, to follow our methodology, we found that the overall probability of detecting a bomber increased as the probability of a false detection decreased.

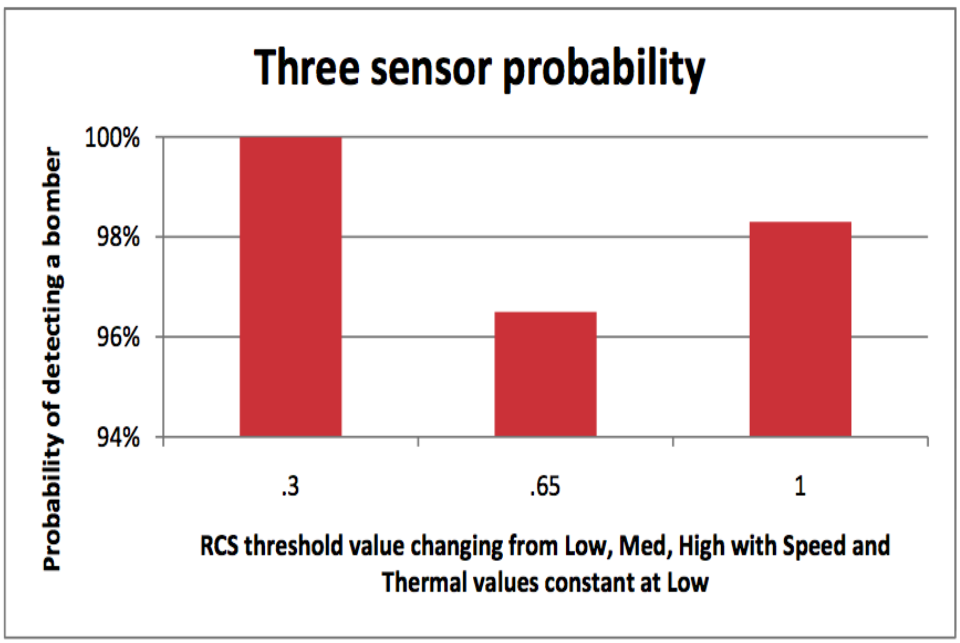

Figure 51. Multiple sensor probability using a varying RCS threshold and constant speed and thermal threshold.

V. CONCLUSION

A. RESEARCH SUMMARY

Suicide attacks will continue to pose a significant threat to the United States and its allies. Organizations will continue to employ suicide bombers both as tactical and strategic weapons. Preventing suicide attacks in the planning stages has proven to be an effective method from stopping attacks and should remain as the primary countermeasure. However, standoff detection sensors can be a useful tool in deterring attacks and indentifying suicide bombers at checkpoints and public areas. There is no one sensor that can detect all types or characteristics of a suicide bomber or explosive vest. Integrating multiple sensors and fusing the data into a single system is a continuing challenge but will be the most effective way to best detect suicide bombers at a standoff distance.

It is extremely difficult to identify a suicide bomber without the use of sensors, especially since historically, nearly all suicide bombers concealed their explosive device prior to detonation. Therefore, the current baseline detection probability of visual identification is nearly zero. Using the data from our model, we can conclude that compared to the current detection method of relying on visual identification of a suicide bomber, our methodology of incorporating multiple sensors with specific threshold values produces a higher probability of detecting a bomber. By running multiple tests through the model, we were able to determine that the combination of three sensors vice one sensor produced a higher probability of detecting a bomber while reducing the probability of a false detection.

B. FOLLOW-ON RESEARCH

Research and experimentation must continue in order to develop sensors with increased sensitivity and specificity. Increasing both the sensitivity and specificity will lead to improved detection rates and fewer false alarms. Identifying common characteristics of a suicide bomber will continue to be a major challenge for image sensors, and as such, sensors must be able to find a minute signal within a dynamic environment full of white noise. As image comparison technology continues to improve, further research must be conducted in the area of data fusion.

Our proposed methodology uses both high and low threshold values, η and γ. These threshold values were used in a simulation model to determine if there is a specific sequence or operation for the highest detection probabilities. For the purpose of our research, the threshold values we used were taken from past research and experimentations conducted by other individuals. We were able to adjust the threshold values in the model to determine the best probability of detection while reducing the probability of a false detection. However, future research must be conducted in each technology field to determine the optimal threshold for each sensor. As the fidelity and accuracy of the threshold values become more precise, the detection system will produce a higher detection probability while continuing to reduce false detections.

The detection ranges and standoff distances of the sensors will continue to be a challenge. Many of the sensors have a maximum detection range around 10 meters, therefore, further research needs to be conducted to increase standoff detection distance. As the detection ranges and standoff distances increase, the resolution and accuracy of the sensors must also increase.

In order to determine the threshold values for image-producing sensors, our proposed methodology assumed that imaging software was capable of comparing the image received from the sensor to images stored in databases at real-time speeds. There needs be continued research in automated image-comparison software in order to increase the probability of detecting a bomber.

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