SAND2011-4089C

Detection of Suicide Bomber Threat Using a Dual Radar System

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Abstract

Detection of threat targets, which consist of different types of shrapnel, has been evaluated for a dual radar system designed and manufactured by Safe Zone Systems, New Mexico. The Safe Zone product consists of two spread-spectrum, interrupted continuous-wave (CW) radars operating around 10 GHz. The radars are able to detect anomalies on the human body that would be associated with suicide bombers. Suicide bombers generally hide a small explosive device on their body, along with several pounds of shrapnel; it is generally accepted that the shrapnel is what causes the majority of the deaths and injuries to bystanders. The Safe Zone device was tested by Sandia National Laboratories using the following targets: nails, random nuts and bolts, glass marbles, broken glass shards, ball bearings, ceramic shards, and rocks. The test results indicated that the Safe Zone system correctly identified, approximately 95% of the time, when a subject was carrying targets on Side A and/or Side B of their body.

The purpose of this paper is to present the results of the "Design of Experiments" (DoE) tests used to assess the detection quality of this radar system and to provide details on the detection capability of the radar system. Designed experiments were used to

- minimize the number of tests required to characterize the Safe Zone system;
- provide a more structured approach to data gathering; and
- maximize the data generated

Human subjects varying in height and weight donned a vest that accommodated the insertion of a shrapnel-threat target. For the 10+ distinct trials run for each subject in these tests, a randomly-generated table designated whether a target was inserted into the vest or not, what that target was, and at what level of the body it was placed. Detection was monitored at both Side A and Side B of the subject, often with differing shrapnel targets.

Although the detection of false negatives, i.e. missed targets, was higher on one side than on the other side, the combined detection was relatively high. This system has potential impact for the protection of government buildings, embassies, or any type of public location where attendees can be screened before entering.

Introduction

Detection of suicide bombers is a critical threat in many parts of the world. As a result, many researchers and businesses have been trying to develop technologies to detect a suicide bomber ranging from smart video sensors to sensors to detect the actual explosive being carried by the suicide bomber [1-3]. This development, though, has not been straightforward or easy [1-4].

Safe Zone® Systems in Albuquerque, NM, has been working for over 12 years in the development of their Concealed Threat Detection system. The Safe Zone® system consists of a dual spread spectrum interrupted CW radar pair operating in the range of 10 GHz system and designed to identify the shrapnel carried by suicide bombers. The CTD is intended to be applied at controlled locations, rather than random pedestrian locations.

Detection of the suicide bomber by the system requires the person to step between the two radars for less than 6 sec to enable the system to sense the shrapnel. Since the exposure to the 10 GHz occurs for only a few seconds, the harm to humans is judged to be negligible.

In 2010, Sandia National Laboratories was tasked to perform an independent performance assessment of the Safe Zone® System. Funding was arranged by the state of New Mexico, which has a program designed to access the expertise of the labs in support local small businesses. A statistically designed experiment (DoE), coupled with human test subjects, was used to assess the ability of the system to detect a wide variety of shrapnel targets on human test subjects. The shrapnel selected for testing included ceramics, glass shards, rocks, and glass marbles. A total of 8 different types of shrapnel targets were tested, along with the "safe" condition, for which no target was present. The weight of the various shrapnel targets ranged from 2.5 lbs up to 10 lbs, well below the limits found in real-world examples. The testing targeted threats with lower weights to ensure that the test results would have broad applicability to the targets tested.

This paper will discuss the results of the independent performance assessment done by Sandia National Laboratories. In particular, the paper will focus on the conditions under which false negatives and false positives occurred during the testing and will include recommendations for future work.

Experimental Procedure

Safe Zone's® Concealed Threat Detector (CTD) consists of two spread spectrum, interrupted CW radars operating in the range of 10 GHz. The term "interrupted CW" is used as the time that the signal is ON is long compared to the over-the-air transit time for the signal to propagate to the target and return. The signal is ON for about 37% of the time, yielding a power density at 3 meters away of 7×10^{-3} milliwatts/cm^2. The safety margin for the subject being screened is 34 dB (decibels). This device requires the test subject to be exposed for 5 to 6 seconds to yield a reading, which is below the ANSI C95.1-1982 standard of 6 minutes.

The CTD dual radar units were set-up at an angle of 45 deg above the test subject at a distance of 3 meters in front and 3 meters in back of the human test subject. Figure 1 shows the test setup.

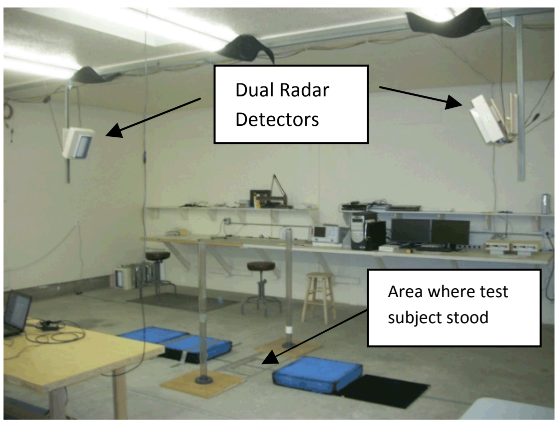


Figure 1 Experimental Setup for Concealed Threat Detection (CTD) Dual Radar Setup

The return signals were analyzed by an artificial neural net contained in a small, self-contained instrument, which renders an automatic decision without human intervention. The system only reads and shows the frequencies returned off the subject, not an actual body image.

To ensure uniformity in the testing, a test procedure was strictly followed. When the test subjects arrived, they were asked to empty their pockets of cell phones and typical pocket debris, and to remove any jewelry. Jackets and other outer wear were not removed. A specially designed denim vest was donned by the test subject prior to entering the field of detection. This vest contained numerous pockets on the front and back to allow placement of the targets at varying positions on the test subject.

For the tests, a particular target was placed into a particular pocket of the front and/or back of the vest or no target placed into the front and/or back of the vest, i.e., a "safe" condition, which was then worn by each of the human tests subjects. The target positions were the same on the front and the back for each particular test. The next step was to have the human test subject step into the area shown in Figure 1, extend their arms to be parallel to the floor, and wait for the signal to step out of the test zone. Exposure time of the subject to the radar beam was less than 6 seconds. The human subjects recruited for these tests consisted of 16 individuals, 9 women and 7 men, of varying heights, weights, and body types. Weights for the individuals ranged from 98 lbs. to 350 lbs. Heights ranged from 4 ft. 11 in. to 6 ft. 6 in. Figure 2 provides examples of some of the body shapes.

Figure 2 Examples of some of the Body Types used in the testing

Due to the number and complexity of the independent test variables, Design of Experiments (DoE) was used to generate the test matrix. The matrix consisted of six independent variables and 4 dependent response factors. The design used was a custom designed fractional factorial matrix, generated using the statistical software JMP9®. The six independent variables were:

- Height (3 levels)
- Weight (3 levels)
- Gender (2 levels)
- Position of target (3 levels)
- Type of target (8 targets and one safe condition [9 levels]) on Side A
- Type of target (8 targets and one safe condition [9 levels]) on Side B

The 4 dependent response factors were:

- False Negatives on the Side A (conditions where a target was missed by the radar)
- False Positives on the Side A (conditions where an alarm sounded when no target was present)
- False Negatives on the Side B
- False Positives on the Side B

From the response factors, two other factors were calculated:

- Combined False Negatives
- Combined False Positives

By using DoE, it was possible to minimize the number of tests that had to be performed and to maximize the information gained from this smaller number of tests. The resultant fractional factorial test matrix, using the number of levels for each independent variable noted above, resulted in 560 tests, which included 3 - 6 repetitions per test condition. Table 1 shows an excerpt from the test matrix and includes repetitions. A total of 595 tests were conducted to assess the performance of Safe Zone's CTD dual radar system. Some of the additional tests examined the foam and duct tape used in the packaging of the targets to make sure they were not contributing to detection; other tests were conducted at positions not specified in the original test matrix.

Table 1 Excerpt from the DoE designed Fractional Factorial test matrix

Weight	Height	Sex	Position	Front	Back	ft	wt	F False neg	F False positive	B False neg	B False positive	Combined FN	Combined FP
aboveavg	medium	Female	none	Safe	Safe	5.45	200	0	1	0	1	0	2
aboveavg	medium	Male	none	Safe	Safe	5.7	350	0	1	0	1	0	2
avg	tall	Female	bottom	Safe	Safe	6	150	0	1	0	1	0	2
aboveavg	medium	Female	bottom	Safe	Glass/hvy	5.45	200	0	1	1	0	1	1
aboveavg	medium	Female	bottom	Safe	Glass/hvy	5.45	200	0	1	1	0	1	1
aboveavg	medium	Female	bottom	Safe	Glass/hvy	5.45	200	0	1	1	0	1	1
avg	tall	Male	bottom	Safe	Rocks	5.95	185	0	1	1	0	1	1
aboveavg	medium	Female	bottom	Ceramic	Safe	5.45	200	0	0	0	1	0	1
aboveavg	short	Female	middle	Glass/lt	Safe	5.1	140	0	0	0	1	0	1

Figure 3 shows photos of seven of the actual shrapnel targets.   The eighth target, glass/light target is not shown. The glass shards shown below are termed glass/hvy (heavy) in the experiment. It consists of pieces of tempered glass.

Figure 3 The seven shrapnel targets used in the threat detection testing

The actual shrapnel targets ranged in weight from 2.5 lbs for the "light glass shards", which consisted of shards of light bulbs, to 10 lbs for the "ball bearings (BB)". The average weight of the targets was 4 lbs. The shrapnel material was encased in rigid foam and, in some cases, wrapped with duct tape. Targets consisting only of the foam and only of the duct tape were tested as well to ensure that the foam or duct tape was not contributing to detection or the lack thereof.

Results and Discussion

The performance of the CTD system was measured by recording the number of false negatives, which occurred when a target went undetected and false positives, which occurred when the system detected a target but no target was present. Figure 4 shows plots of the positive indications of a target (82%) vs. the false negatives on Side A or Side B(18%) vs. the combined Side A and Side B. (<1%).

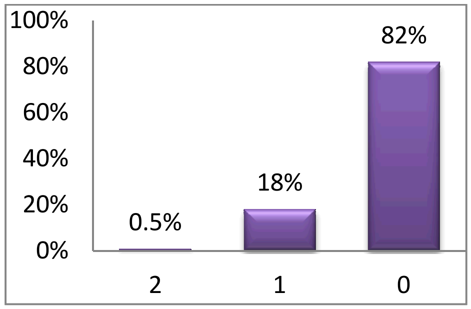


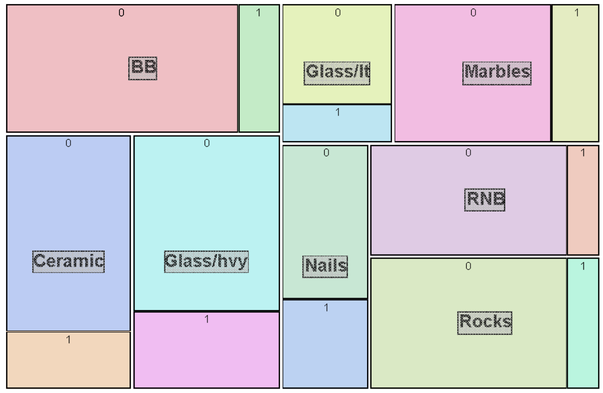
Figure 4 Comparison of the number of correct target id's (0's) vs. the number oftotal false negatives (either Side A or Side B - 1's) and the number of combined Side A and Side B false negatives (2's)

The CTD system is designed such that an "alarm condition" occurs when detection is triggered on Side A, Side B, or both Side A and Side B. Following this logic, the performance of the CTD is measured by the number of double (Side A and Side B) false negative tests, which were 3. For this number, the percentage of actual misses by the CTD system was 0.5%, compared to the 18% false negatives generated on either Side B or Side A of the person.

The data from the test matrix was examined by generating a tree map. A tree map shows the proportions of tests performed in each main category by differences in size and shows the percentages of the false negatives (1's) within each category. For the shrapnel targets, using a tree map configuration, it is possible to determine which of the shrapnel targets has the highest likelihood to go undetected.

Figure 5a shows the tree map for the Side A false negatives;

a.



b.

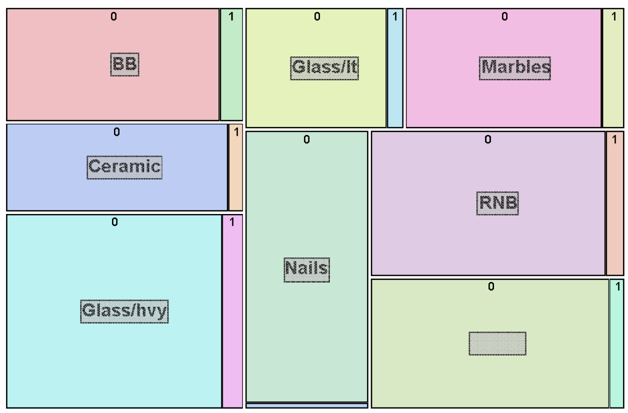


Figure 5 Comparison of the percentages of false negatives generated by the various shrapnel targets on a) the Side A and b) the Side B.

Figure 5b shows the tree map for the Side B false negatives. What the maps indicate is that for the tuning conditions tested by Sandia National Laboratories, Side A was tuned differently from Side Band hence the likelihood of false negatives on Side B was less.

In looking at the effect of body type on the detection of the shrapnel targets, it appears from the tree map that height had little effect on whether false negatives were generated on the Side A, as shown in Figure 6.

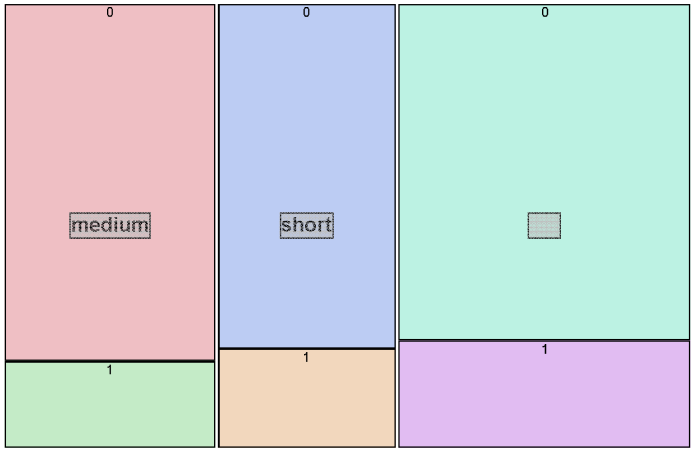


Figure 6 Comparison of the number of false negatives generated on the Side A as a function of height.

Similarly, there is little difference between the likelihood of females vs. males to go undetected, as shown in Figure 7. The area containing the female statistics is larger than the male as there were 9 female and 7 male test subjects in the test. .

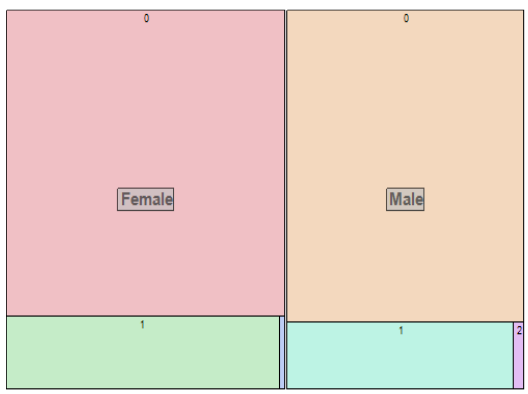


Figure 7 Comparison of the number of combined false negatives on Side A and on Side B for females and for males

In contrast to the tree map in Figure 7, Figure 8a shows the number of false negatives generated as a function of weight differs considerably with category. Interestingly enough, the majority of false negatives were generated by under-average weight individuals and average weight individuals. Figure 8b shows the percentage of individuals in each weight category. Although there are considerably fewer under-average weight people in the category, this is taken into account in the tree map, so that the percentage of Side A false negatives for those two categories is about equal between average and under-average weight individuals.

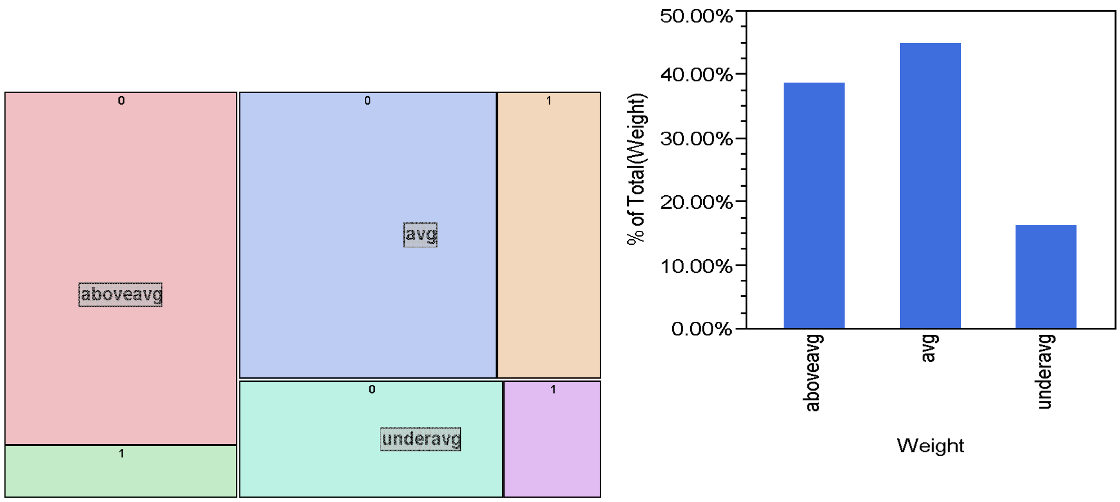


Figure 8 Comparison of the number of Side A false negatives generated as a function of a) body weight and b) a comparison of the percentage of individuals in each weight category.

One additional issue addressed was the effect of position and target weight on the generation of false negatives. Figure 9 indicates that chest level was more likely to generate false negatives on Side A, which is counterintuitive. The "none" category indicates tests for which no target was in place.

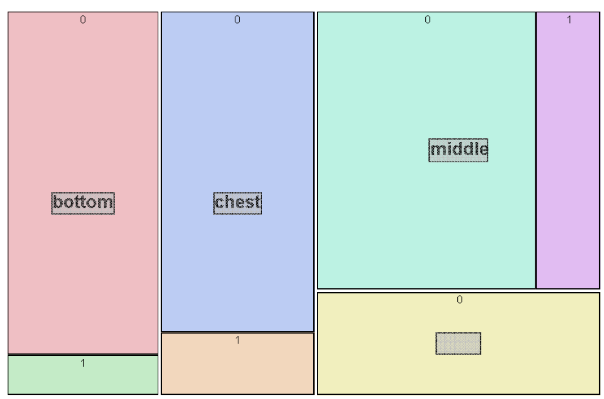


Figure 59 Comparison of the percentages of false negatives on Side A as a function of target position.

Looking now at the false positives, i.e. the times at which a target was indicated when no target was present, the total combined false positives are shown in Figure 12. There were only 3 instances in which both sides were "safe", i.e. no targets were in the vest, but the system alarmed for both sides, indicating it detected the presence of a threat on both sides. Otherwise, the percentage of false positives on either Side A or Side B was small, 8%, and occurred only when no target was present.

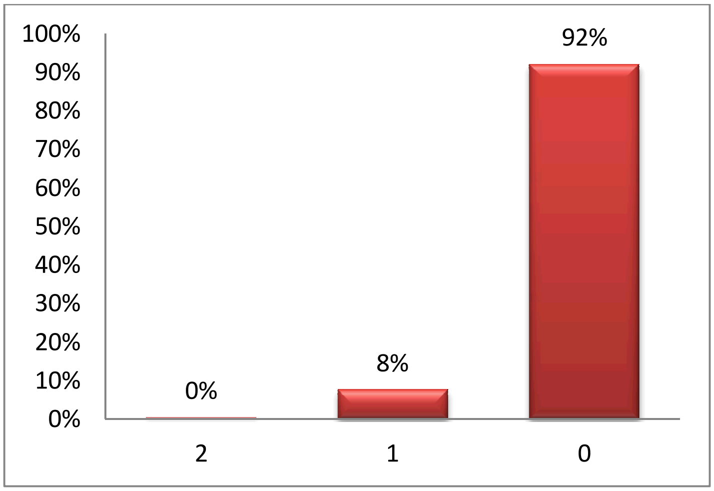


Figure 6 Comparison of the percentages of false positives, 2's or 1's, i.e. 0% or 8% vs. the percentage of times the system correctly identified the target, 92%.

Conclusions

A Concealed Threat Detection (CTD) system, developed by Safe Zone® Systems of Albuquerque, NM, was independently tested by Sandia National Laboratories to assess its performance capability in the detection of various shrapnel targets. The system consisted of dual radars operating in the 10 GHz region. To test the system, Sandia National Laboratories designed a statistical test matrix using Design of Experiments (DoE) to incorporate a wide range of independent input variables and dependent responses. A total of 595 tests, which included 3 or more repetitions per test, were conducted for 9 shrapnel types (including one “no target” condition) and a variety of body types. The 595 tests included 35 additional tests performed on the rigid foam matrix and the duct tape used in the shrapnel targets. Human test subjects wore a specially designed denim vest to hold the targets at various positions on Side A and Side B of the person.

After examining the data produced in testing Safe Zone’s Concealed Threat Detector, it appears that this system offers significant detection capabilities against a wide range of threat targets. It also appears that gender, weight, height, and target position for the test subjects did not significantly impact this detection capability. In addition, the type of target did not have a significant influence on the accuracy of the radar detection.

Acknowledgements

I want to acknowledge some of the key people, who supported this work and helped in the testing. Mary Wilson Green of Sandia National Laboratories, who provided significant support for the testing and was the principal investigator on the project; Robby Robertson and Coda Robertson, owners of Safe Zone® Systems of Albuquerque, NM, who provided their time, their equipment and their laboratory for the testing; Jerry Hausner, consultant to Safe Zone® Systems, who provided insight into previous testing and tuning of the system; and the Small Business Initiative people at Sandia National Laboratories, who provided funding for this project. I'd also like to thank all of the test subjects, who shall remain anonymous, for their time and their patience. Without all of these people, this project would not have been possible.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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