Optimizing Sensor Arrays for Detecting Dirty Bombs

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1 Abstract

Professor Ryan McLean and others at Caltech have developed a new, cheaper radiation sensor using CdZnTe materials. Professor K. Mani Chandy and the Infospheres research group have developed algorithms for aggregating the data collected by many of these sensors working in concert. This paper considers the optimal placement for such sensors. This paper concludes that stationary sensors are far inferior to mobile sensors.

2 Background

Professor Ryan McLean at Caltech has successfully developed inexpensive radiation detectors that are less accurate than existing high-quality expensive detectors[1]. Said detectors rely on a 20 mm x 20 mm x 5 mm slab of CdZnTe to detect gamma rays emitted by the radioactive materials in the dirty bomb being transported by the terrorist[1].

3 Spherical sensors

As a base case, Concetta Pilotto examined the implications of using sensors that are perfectly spherical. This makes the calculations easier, as the cross sectional area of the sensor is the same, no matter what direction is facing the radiation source. Pilotto developed the following formula to calculate the probability that a radiation source is in a specific area:

$$f(\lambda, k, T) = \frac{(\lambda * T)^n * e^{-\lambda*T}}{n!}$$

Pilotto showed that a grid arrangement of detectors was advantageous for lowering interdiction times.

4 Plate sensors

Next, we have been examining the implications of the fact that the detector is a plate and not a sphere. If we ignore edge effects, the cross sectional area
presented to the radiation source should go as

\[ A \ast \cos(\theta) \]

5 Ground Truth

The actual sensors manufactured by the physics department contain three 20 mm x 20 mm x 5 mm plates of CdZnTe: one plate oriented forward, and two side plates angled 30 degrees to the left and right.

For high energy radiation, detection is independent of orientation. This is because, for high energies, the probability of detection goes as cross-sectional volume, which is the same regardless of orientation.

For low energy radiation, this arrangement affords some measure of directionality. The difference in the number of particles detected by each plate gives some additional information as to the probable location of the source.

6 Experiments

For all of these experiments, interdiction is considered to be accomplished when 50 % of the total probability in the heat map is concentrated in 1 % of the area. For example, for a 100 m x 100 m field, 50 % of the probability would have to be within 100m².

6.1 Line experiment

Consider a line of nine spherical sensors, each 30 meters apart, on one side of a 300 m x 300 m field, 30 meters from each edge. Consider a terrorist located a distance L perpendicularly away from the center of the line. As L increases, how does the interdiction time change? This seems to go exponentially. This indicates that groups of sensors in a single location are much, much worse than spread out sensors, which fits with what is expected.

6.2 Expanding field experiment

Consider a square field with sides of length L with four idealized spherical detectors at the four corners and a terrorist in the exact center. As L increases, how does the interdiction time change? As predicted, interdiction time goes at L squared.

6.3 Expanding sensor grid

Consider a square field with sides of length 300 meters, with four idealized spherical sensors forming a square with sides of length L in the middle of the field, surround a terrorist in the exact center. As L increases, how does the interdiction time change? Especially intriguing is the local minima apparently present at L=200 m. The experiment was run on different size fields, and this same local minima was always present. There is a consistent local minima at L
= 2/3 S, where S is the field side length. I theorize that this is because the edges quickly eliminated by the algorithm as very improbable, improving interdiction time.

7 Conclusions

I conclude that interdiction times increase rapidly when the sensors are far from the source and that none of the configurations examined adequately corrects for this shortcoming. I conclude that any array of immobile sensors will suffer from this flaw and will have blind spots, where interdiction is much slower. I conclude that mobile sensors are the only feasible solution in situations where interdiction must be accomplished quickly.

8 Further Work

In situations with sources emitting large amounts of radiation and with little to no background radiation, it may be advantageous to add collimators to the sensor plates. Such collimators would be formed by using a cylinder of some non-permeable material to limit the radiation striking the plate to a narrow range. Then, by aiming the collimator at possible radiation source locations, it might reduce interdiction time by allowing the user to concentrate on possible location at a time. Further research on this topic is needed.

A more accurate model of the existing sensor device is also required. Currently, the model does not distinguish between high- and low-energy radiation, nor does it take into account the increase directionality afforded by the two side plates. More work in this area is required.
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References

