Optimization of an Array of Antenna Elements for Millimeter Wave Imaging

Ben Berkowitz, Borja Gonzalez-Valdes, Jose Martinez-Lorenzo, Carey Rappaport
Northeastern University, Boston, MA 02115 Contact Information:, Berkowitz.Be@husky.neu.edu

Northeastern University

Abstract

The aim of this project is to improve the performance and efficiency of airport security technology. It utilizes Synthetic Aperture Radar (SAR) and Millimeter Waves to map the surface of a passenger's body. Our scanner uses multiple frequencies from a single transmitter to create an image obtained by an array of receivers. Anomalies on the surface of a person's body may correspond to concealed objects.

Airport passengers are subject to multiple methods of security scanning which may be unreliable, unsafe or invasive. Pat-downs are uncomfortable, slow and subject to human error. Backscatter X-Ray machines quickly produce reliable images, but are feared for their use of potentially harmful ionizing radiation. Millimeter Wave Scanners are being developed to meet the need for fast, reliable and safe scanners.

This project focuses on manipulating the layout of the virtual receiving elements within the scanner's array, while decreasing the number necessary to create a clear image. This was done using a proven optimization algorithm and was quite successful. As this research continues to develop, the number of elements needed to form a clear image has decreased to fewer than 8% of the number of elements used in the original design.

Relevance

The project advances the state of personnel security scanning. Reducing the number of elements needed to drive each scanner lowers the computational cost during operation and shrinks the overall cost of the technology. The more efficient scanner is, the likelier it is to be implemented.

MMW Scanning is newer than the classic X-Ray scanning technology, but is developing rapidly. MMW-Radar has already been developed for use scanning subjects from a standoff distance of 7-15 meters. Our project takes some elements from the design of the standoff scanner and incorporates them into a body portal scanner.

Security Chiefs in high-traffic hubs such as airports and train terminals can utilize the scanners in order create checkpoints that have advantages over the standard. Millimeter Wave Scanners are safer and less invasive than X-Rays or pat downs, respectively, leading to a potential increase in the willingness of the passenger to be scanned. Optimization performed in this project decreases scanning time and reduces overall scanner cost.

Technical Approach

What is Millimeter Wave Imaging?

Millimeter Wave Imaging uses Synthetic Aperture Radar (SAR) to map surfaces without ionizing radiation. Our project adapts MMW Scanning into an airport body portal scanner seen in Figure 1.It uses frequencies around 65GHz and an array of receptors (Fig. 2) to map the surface of a passenger's body. If any anomalies on the body surface are found, they may correspond to concealed objects.

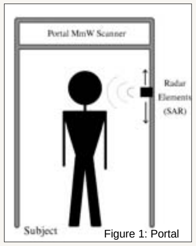

Figure 1: Portal

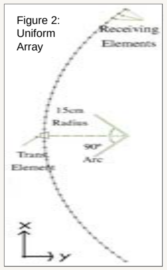

Figure 2: Uniform Array

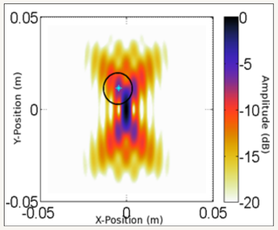

Figure 3: Side Lobe on a Field

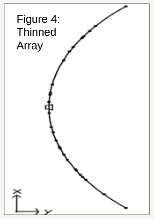
Figure 4: Thinned Array

Array Optimization

The goal of the project was to develop arrays with few elements that could generate clear images. Spaced more than one wavelength apart, a uniformly distributed array's images will have Side Lobes (SLL), circled in Fig. 3. SLLs create phantom surfaces, reducing the quality of a surface map. However, a non-uniformly spaced "thinned" array (Fig. 4) can generate clear images with a small number of elements spaced widely apart. Our optimization was based around a "Cost" function with evaluated the SLL generated by each array, and iteratively located the best distributions.

Simulated Annealing Optimization

The distributions were optimized using Simulated Annealing Optimization [1]. This technique is dependent on the "Cost" function and is depicted below in Figure 5.

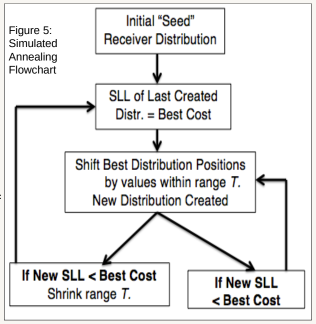

Figure 5: Simulated Annealing Flowchart

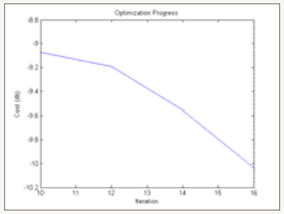

Figure 6: Progress Chart (evolution of the cost function)

Optimization Results

Figure 6 displays an example of the progress of Simulated Annealing Optimization. The more iterations of the algorithm performed, the lower the SLL.

Figure 7 is a chart comparing the SLL of uniform land optimized distributions with the same number of elements. The fewer the elements, the larger the disparity in SLL between the optimized and uniform distributions. Optimized distributions with 23 or fewer elements were often over 10 orders of magnitude better than their uniform counterparts.

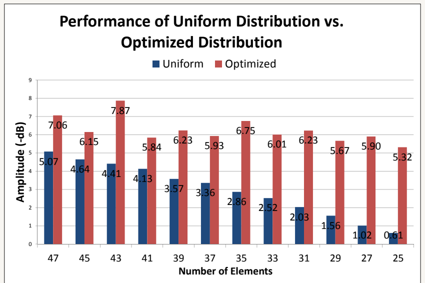

Figure 7: Performance Comparison Chart

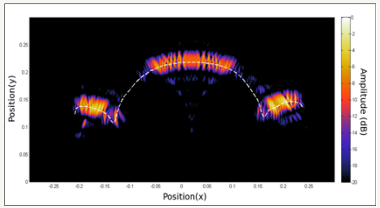

Figure 8: 519 Element Inversion Image

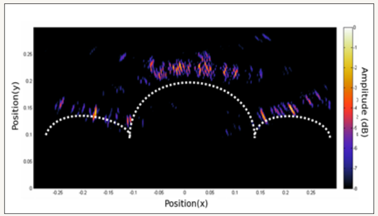

Figure 9: 23 Element Inversion Image

Conclusion

Figures 8and 9 are inversion algorithm images of a cross section of human arms and a torso. The white outlines were added to illustrate the position of the body. In both images, the body is clearly detected by the radar, however Fig 9 contains the image generated by an optimized distribution of just 23 elements, where Fig 8 was generated by and array of 519 elements.

Our optimization was successful. We were able to match the performance of a uniformly spaced array of 47 elements with a thin array of only 11 elements, less than ¼ of its original size. If optimization continues, we will create high performance arrays with fewer than 50 elements.

Accomplishments Through Current Year

This year we have accomplished the following:

- Transmission Phase Synchronization
- Array Performance Evaluation Algorithm in terms of SLL
- Successful Simulated Annealing Optimization
- Improved on Initial Distributions by up to 15 orders of magnitude
- Greatly reduced computational cost.

Future Work

We will continue this project by:

- Further Optimizing the receiver distribution to approach the best possible performance from the fewest number of elements
- Begin to optimize the frequencies used by the scanner to further improve performance.

Opportunities for Transition to Customer

The improvements in efficiency presented here are important in facilitating the implementation and ultimate performance of the MMW radar whole body imaging system being developed with ALERT funding. The production and computational costs will be decrease, and the overall performance may improve.

Publications Acknowledging DHS Support

1. Fernandes, J., et al. "FMCW SAR imaging of body worn explosives from FDFD modeled scattered field data," *PIERS*, Cambridge, MA, July 2010, pp. 350.
2. Fernandes, J., et al. "Simulation results for standoff detection of suicide bombers at millimeter-wave frequencies using a full wave numerical analysis," *Homeland Security Summit*, Washington, DC, March, 2010,.
3. Martinez-Lorenzo, J., et al. "SAR imaging of suicide bombers wearing concealed dielectric structures," *IEEE Homeland Security Technology*, Waltham MA, Nov 2010.
4. Fernandes, J., et al. "A comparison of experimental and simulated millimeter wave imaging system for standoff detection of person-borne improvised explosive devices," *IEEE Homeland Security Technology*, Waltham MA, Nov 2010

Other References

1. *S. Kirkpatrick, J. Gelatt, and M. Vecci. Optimization by simulated annealing.Science, vol. 220, pp. 671-680, 1983.*

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied of the U.S. Department of Homeland Security.