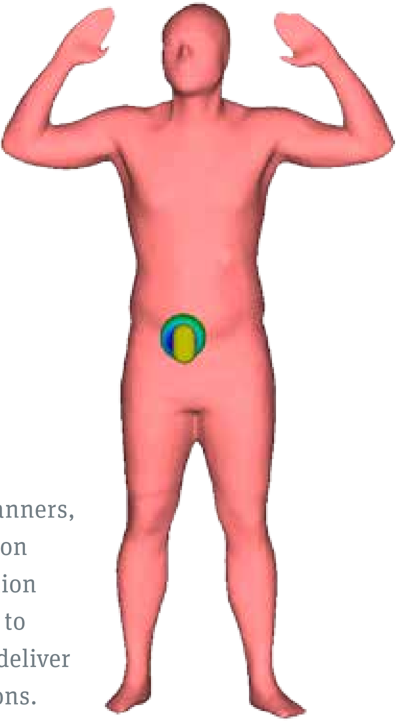
Enhanced Detection of **Concealed Weapons**

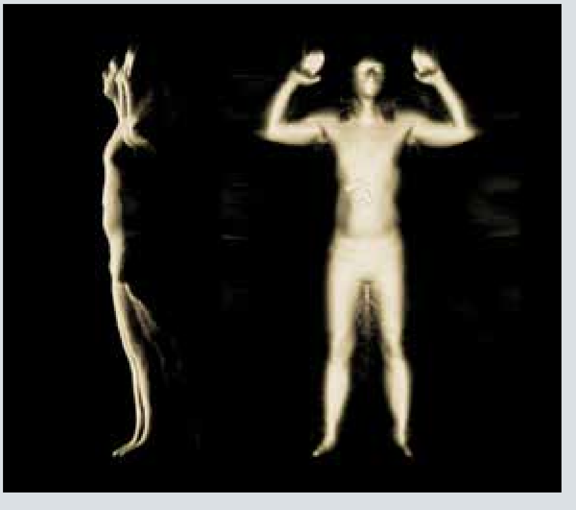


To develop next-generation full-body millimeter-wave airport scanners, Pacific Northwest National Laboratory researchers used simulation models of the electromagnetic systems to reduce design exploration times compared to experimental-based methods. They were able to easily investigate factors required to improve the technology and deliver higher-resolution images for better detection of concealed weapons.

By **Mark Jones**, Senior Research Engineer; **David Sheen**, Technical Team Leader; and **Thomas Hall**, Staff Engineer; Pacific Northwest National Laboratory, Richland, USA

If you have flown within the past five to 10 years, you are familiar with the millimeter-wave (mm-wave) imaging portals that scan passengers for concealed weapons. The scenario is probably familiar to even nonfrequent flyers: You step inside a cylindrical booth, are asked to place your arms over your head, and wait as antenna array masts sweep around the booth to scan for concealed weapons.

Researchers at the Pacific Northwest National Laboratory (PNNL) in the U.S. developed this technology more than a decade ago and have licensed it for commercial use. Now, PNNL is working to optimize the image quality and resolution of next-generation mm-wave imaging systems for enhanced threat detection. Engineers leverage ANSYS software to simulate the antenna performance and ANSYS high-performance computing to explore the design space using realistic 3-D images.



Use of 30 GHz bandwidth and 60-degree beamwidth showed excellent depth resolution and body illumination.

Improving Scanner Performance

An active mm-wave scanner forms an image of the human body by transmitting electromagnetic waves that harmlessly penetrate clothing and reflect off the body, sending signals back to a transceiver; the transceiver then sends the signals to a computer that reconstructs the signals from various positions as the scanner's antenna arrays rotate to create a 3-D holographic image.

PNNL is conducting studies that examine three methods to enhance the capabilities of mm-wave imaging for concealed weapon detection: wide-frequency bandwidth of up to two octaves of bandwidth for high depth resolution; wide antenna beamwidth to increase lateral resolution and improve the capture of

> “ANSYS HFSS SBR+ provided simulation results to 3-D mm-wave imaging challenges that enabled rapid development and refinement of antenna designs.”

specular reflections from the imaging target, which improves the visual quality of the image; and circular polarization to reduce artifacts caused by multipath signal propagation.

To understand how these design parameters impact the mm-wave imaging system performance, PNNL engineers simulated the effects of various bandwidths, beamwidths and polarizations on images captured via a virtual scanner modeled using ANSYS HFSS SBR+. The resulting datasets helped them study design requirement trade-offs for enhanced next-generation systems without the need to fabricate and test a full prototype or perform time-consuming measurements.

Before the use of advanced simulation tools, the researchers did not possess the capability to conduct advanced digital design studies for these imaging systems. Instead, the team relied upon simplistic simulations of point scatterers or measurement-based data collected using rectilinear scanners. Although researchers were able to get information from the simulated point scatterer scenarios, they could not obtain images that accurately represent a scanned person in order to determine quality of illumination, clarity and other objectives.

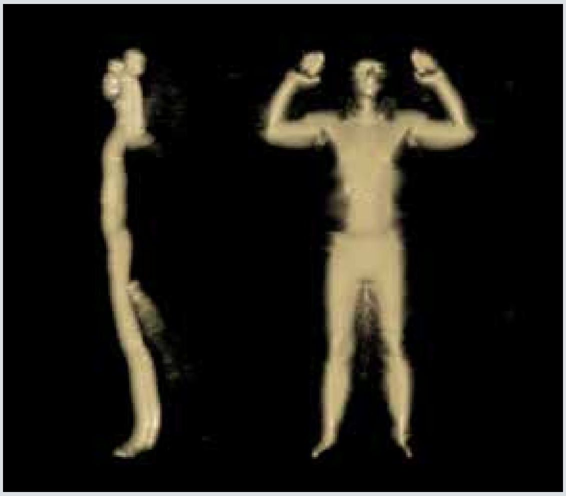
Security Scanner Simulation

Previously, researchers created a physical experiment using a rectilinear laboratory scanner and a mannequin coated with a reflective paint. A transceiver raster-scanned the mannequin and transferred the measurement information to a software package that used an algorithm to mathematically focus the image.

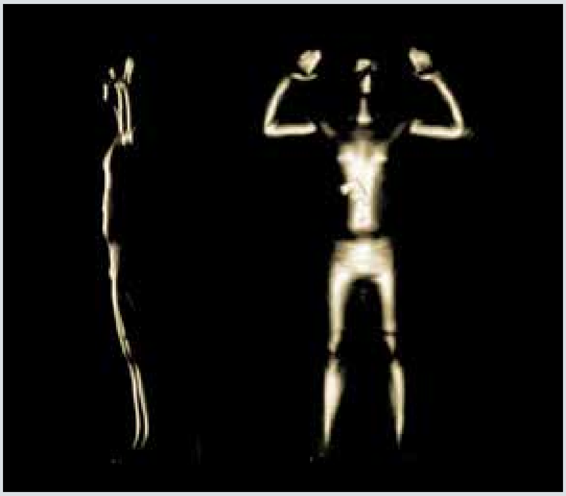
To avoid the need for this type of physical system, the researchers turned to ANSYS HFSS SBR+ to simulate the antennas, define their patterns and simulate the target to be scanned. The simulations were configured to import and determine results based upon the realistic complex geometries required for this application. ANSYS HFSS SBR+ provided simulation results to 3-D mm-wave imaging challenges that enabled rapid development and refinement of antenna designs. Researchers dramatically reduced overall system development time by using high-performance computing to explore and validate designs.

The researchers first raster-scanned a pair of co-located transmit and receive antennas across the aperture defined in the simulation model.

Solve Large-Scale Problems in a Connected World with HFSS SBR
ansys.com/large-scale



Use of 5 GHz bandwidth and 60-degree beamwidth showed impact of reduced depth resolution on image quality.



Use of 30 GHz bandwidth and 20-degree beamwidth revealed impact of reduced body illumination on image quality.

> “This technology will be able to detect concealed weapons with even greater accuracy to increase security while reducing false alarms.”

At each location, they performed a frequency sweep and evaluated the complex-valued signal at the receiving antenna. A typical scan used approximately 500 discrete frequency point samples at each antenna position during approximately 10,000 individual simulations. A complete simulation dataset was processed to produce a single fully focused 3-D image.

Airport mm-wave scanner. *Courtesy TSA.*

While the measurement process is semi-automated, simulation offers the advantage of investigating scenarios researchers cannot easily replicate or for which a physical measurement test may be difficult to perform. This removes limitations on design studies which can be performed for a given application.

To accelerate throughput for this large amount of simulation data, researchers ran 10 simulations simultaneously using ANSYS high-performance computing. ANSYS HFSS SBR+ paired with high-performance computing was able to yield realistic simulated image datasets in less than one day.

Better Image Quality

After the simulation model was created and solved using ANSYS HFSS SBR+, the data was manipulated via proprietary mathematical algorithms. Researchers were able to study a number of simulation scenarios to examine the effects of beamwidth, bandwidth and polarization on image quality.

To determine the effect of bandwidth on image quality, the researchers simulated 5 GHz and 30 GHz bandwidths using the same antenna beamwidth in both scenarios. The resulting data was used to study the impact of better depth resolution on image quality when larger bandwidths were used.

The use of extremely wide bandwidths — up to 30 GHz — can result in depth resolution as fine as 5 mm. This wider bandwidth operation may allow for improved detection techniques based upon high-range resolution. Because designing systems for high bandwidths becomes difficult and expensive, simulation allows researchers to evaluate the bandwidth performance to choose the lowest bandwidth that corresponds to the required image quality.

The ANSYS software also helped the researchers explore the effects of antenna beamwidth. To determine how antenna beamwidth would affect imagery, they simulated different beamwidths over a 10 to 40 GHz range. They found that the images constructed from a 60-degree half-power beamwidth offered significantly better illumination of the body than those that used a 20-degree half-power beamwidth. Additionally, a wide antenna beamwidth can allow for operation at a lower center frequency, resulting in less scattering and attenuation from the clothing.

For the third parameter, the researchers studied the effect of polarization on the simulated imagery. Polarization diversity can be used to eliminate artifacts from even-bounce “corner traps” on the body or to highlight features on the body. The images created using cross-circular polarization antenna pairs were brighter and contained fewer artifacts than those using vertical polarization antennas.

With this information in hand, future generations of mm-wave scanning systems can be efficiently designed to produce superior images for use by automated threat detection algorithms. This technology, which is widely deployed at airports and other areas, will be able to detect concealed weapons with even greater accuracy to increase security while reducing false alarms.

How High-Performance Compute Can Accelerate Your Simulation Throughput
ansys.com/throughput