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Move Over X-ray:
Millimeter is Wave of the Future for Homeland Security

Millimeter wave stand-off detection systems currently being developed under a contract from the Department of Homeland Security are designed to detect suicide bombers at a distance

There is a growing and critical need for the detection of person-borne improvised explosive devices (PBIEDS). A favored tactic due to its simplicity and low cost, suicide bombing creates maximum fear because the victims are randomly chosen, and in public areas such as schools, churches, hospitals, sports stadiums, bus or train stations, or other populated areas.

Unfortunately, person-borne IEDS are often shaped from a variety of metals and concealed under clothing so are extremely difficult to detect. With a typical blast ratio of 50 meters or more, close-up detection methods such as airport-style scanning booths and pat-downs are of limited value, given that detonation would still claim many innocent victims.

Instead, improving the ability to detect explosives at a distance demands sophisticated stand-off detection systems that are capable of scanning individuals in a crowd at a distance in mere milliseconds.

Such systems are already in development under the guidance and support of the Department of Homeland Security, including by the ALERT Center, a partnership of academic, industrial and government entities dedicated to improving the detection, mitigation and response to explosives-related threats facing the country and the world.

The Concept

The concept currently being developed by ALERT (an acronym that stands for Awareness and Localization of Explosives Related Threats) involves multiple radar units that can be pointed in the direction of crowds of people that are approaching a venue, checkpoint, or other area of entry.

The system would scan each individual at a distance of 50 meters or more to identify suicide bombers who appear to be dressed normally, but are concealing IEDs strapped to their chest or limbs.

Fulfilling the need for detection in large gathering areas, such as concerts in the park, parades, political rallies, protests, and sporting events, the portability of the equipment is another key component. For this, the ALERT radar is expected to be mountable to a van or truck for wide-ranging field use. Permanently mounted solutions would also be available for high security buildings, checkpoints or border crossings.

"For the suicide bomber problem we need a high performance radar system that can send out very specific types of signals a half a football field away and identify specific features under clothing," says Carey Rappaport, Distinguished Professor of Electrical and Computer Engineering at Northeastern University.

In 2008, the Department of Homeland Security (DHS) selected Northeastern as one of 11 universities nationwide for a DHS Center of Excellence. The $12 million grant established the ALERT Center at Northeastern.

Wave Technology

According to Rappaport, various methods of wave detection systems including X-ray and Black-body radiation were initially researched and investigated, before he ultimately selected a millimeter wave based system.

X-rays

Although X-ray based systems are widely used for passenger screening at airports, an X-ray based system for stand-off detection presents many challenges and concerns.

Traditional transmission X-ray images like those used by the medical industry result when X-rays pass through an object to a detector located on the other side. Objects with greater X-ray density block or absorb more X-rays than objects with lesser density, creating an image.

Although X-rays can be beamed effectively at a distance of 50 meters, they produce ionizing radiation, which is a known carcinogen and the dangerous dose level is hard to quantify. Even though the public accepts the health risks from X-rays for medically necessary procedures, acceptance of routine exposure is unlikely by the general public and could lead to lawsuits.

There are ways to minimize the danger of X-rays at a stand-off distance of 50 meters, but there are legitimate concerns about employing such a system in what would typically be an uncontrolled environment where an individual might get excessive exposure walking in front of the beam only a couple meters from its source.

In addition, transmission X-ray sensing isn't very effective for stand-off detection because it requires a transmitter with a separate detector on the other side of the target, in the distance.

The other option was X-ray backscatter scanners like those used for passenger screening. This type of scanning uses high-energy X-rays, which instead of passing through reflect (scatter back) from objects.

The amount of backscatter is picked up by detectors from the same general direction as the source to yield a high-resolution image designed to reveal concealed objects. In addition to the health concerns, X-ray backscatter units have come under intense scrutiny over concerns of lack of privacy as they reveal much of the human anatomy.

Concerns over the use of X-rays have already impacted the Department of Homeland Security and the U.S. Transportation Security Administration (TSA). On November, 2011, the European Union announces it was banning the use of backscatter X-ray machines for passenger screening from all EU airports.

This is a particular concern for the TSA because incoming international flights must use TSA-approved security measures at the airport of departure. Fortunately, the alternative employed by the EU using a different type of electromagnetic energy, the millimeter wave, is also accepted and utilized by the TSA for such screening.

Millimeter Wave Technology

The ALERT Center's research eventually led it to select a millimeter wave based system design approach. Millimeter waves are a subset of the Microwave band, which in turn is part of the larger radio wave band. These waves operate within a frequency range of 30-300 GHz. Unlike X-rays, millimeter-waves are non-ionizing and universally considered non-carcinogenic.

Until recently, millimeter wave technology has largely been used by the military until plummeting hardware costs have opened up this band to more commercial applications.

The TSA is already on board with some 260- millimeter-wave scanners already installed throughout the U.S. along with its approximately 250 backscatter X-ray machines. However, these "close-up" detectors are not capable of stand-off detection.

Collaboration with Industry

In early research, the ALERT Center has already successful demonstrated stand-off detection of person-borne IEDs concealed under clothing can be accomplished with millimeter-wave radar and advanced synthetic aperature radar processing techniques (the technique used by NASA spacecraft to take photos of a planet's surface as it flies by).

However, the next phase in the testing required development of a complete radar sensor, one that involved a number of components including multiple millimeter wave transmitters, receivers and antennas.

"Our expertise is in developing the algorithms and the computer programs to interpret measured radar signals, but we needed help with the actual hardware," says Rappaport.

According to Rappaport, HXI, a leading supplier of millimeter-wave products, components and sub-systems for commercial and government applications, learned of the ALERT Center's mission and proposed to develop and provide all the necessary "proof-of-principle" radar modules for the project.

HXI is a subsidiary of Renaissance Electronics & Communications, a company that is already developing commercial products utilizing millimeter wave technology. Products already introduced to the market include high bandwidth wireless and cellular backhaul communications links that deliver fiber-optic level speeds.

"HXI wanted to collaborate because they realized the advantage of combining our algorithm expertise with their hardware expertise," says Rappaport. "There is a great synergy between our groups. They are fantastic engineers and their millimeter wave technology is first-rate."

System Design

To increase the field of view and pick out fine depth features, the millimeter wave radar sensor needed to be multistatic. A multistatic system contains multiple radar components located in separate locations with a shared area of coverage. The spatial diversity allows for different aspects of a target to be viewed simultaneously, and the data fused together to generate an image with high resolution.

However, the concept of multiple radars in different locations far apart creates challenging triangulation issues when attempting to focus on a single individual within a crowd.

Instead, the multistatic system would involve multiple radars mounted with as much distance as possible, but still designed to fit on a single vehicle roughly the size of a delivery truck. With even several meters of separation between antennas, the system could effectively distinguish features on people at a range of 50 meters.

"For the highest resolution and best definition, the larger the distance between antennas the better, but it's got to be small enough to be practical so there are trade- offs," says Rappaport.

Image Resolution

The strength of the millimeter band is its unique set of properties, many of which lend themselves to improved resolution for multistatic radar systems using advanced synthetic aperature radar processing techniques such as this one.

Imaging resolution is based on the cross-range and range measurement resolution that can be achieved by the system, both of which are tied to the bandwidth of the signal. In other words the greater the bandwidth, the higher the resolution of the image.

Fortunately, there is a tremendous amount of available bandwidth in the millimeter wave spectrum – much more than at lower frequencies. Transmission of large volumes of data is possible at lower frequencies, but they lack the continuous bandwidth allocations. At lower frequencies, for example, typical allocations are 2-5 MHz only.

In the millimeter wave spectrum there are 5, 7, 10, 15, even 20 GHz of allocation with a total potential up to 250 GHz. This bandwidth availability means that a very short pulse can be used to interrogate a target. Measuring the time it takes for this pulse to echo back from the target lets one accurately determine how far away it is.

For this project, HXI is delivering the multistatic radar system that operates in the 70-77 GHz range.

“That frequency range gives you a wide bandwidth and you can resolve things much more effectively,” says Rappaport.

To illustrate its relationship with signal bandwidth, range resolution is measured as the speed of light divided by twice the signal bandwidth.

“The larger bandwidth means you can get narrower slices of distance and this is irrespective of how far the target is from you,” says Rappaport. “So, for example, at a higher bandwidth you can distinguish something that is 2 centimeters in front or behind another object. If you are looking for a one inch diameter pipe bomb strapped to a human body that would be sufficient.”

The cross-range resolution is also improved based on the high frequency of the millimeter wave, because the width of the aperture is measured in wavelengths.

“A higher frequency [such as millimeter waves provide] means shorter wavelengths so for the same physical size aperture you have more wavelengths across, so you have better cross range resolution,” says Rappaport.

Rappaport explains that such a system would not be able to take high resolution images such as those produced by security scanners at airports due to the distance, nor does it capture a 360 degree field of view.

However, through sophisticated signal processing, the system would be able to collect enough information in the radar signal to delineate an object that doesn’t meet the smooth contours and characteristics of skin, for example, is metallic, or otherwise meets other characteristics of person-borne IEDs.

If such inconsistencies were flagged, the individual could be detained and searched before reaching more populated areas.

With its phased array, the system will be able to focus in on specific small scene area of one person or a crowd of people.

“By adjusting how much signal goes to each antennae, you can electronically ‘steer’ a beam back and forth,” explains Rappaport. “In doing so, you can bounce between an individual, the person next to him and maybe three or four people off to the side.”

Ultimately, the ALERT Center’s mission is to partner closely with industry, companies such as HXI, in order to ultimately transition this research into a fieldable system.

Agencies that could benefit from a stand-off millimeter wave detection system include the TSA, the military, security companies, and other agencies involved in Homeland Security.

For more information, contact Renaissance Electronics at phone (978) 772-7774 or on the web at www.rec-usa.com. They are located at 12 Lancaster County Road, Harvard MA 01451.