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Urban Operations, The New Frontier for Radar

While Electro-Optical systems can bring revolutionary tactical surveillance to the urban battlespace, they have limitations. We need to sense when EO systems are denied line of sight due to urban canyons around buildings—and particularly inside them. This is the new frontier for radar: urban operations.

Radar has historically provided broad-area coverage in all weather and lighting conditions and provided powerful reconnaissance and tracking capabilities. Now that our battles have moved to dense urban environments, is radar really ready to make this change—or is it only useful on the traditional battlefield?

Conventional radar systems are designed for open environments. They run into trouble even in mountainous or forested terrain. They run into bigger problems when facing man-made environments with large discretes from power lines and buildings, as well as dense road networks. Is there a way around these problems?

SPO believes there is. Our Knowledge-Aided Sensor Signal Processing and Expert Reasoning program (KASSPER) addresses these limitations for detection of ground targets in difficult terrain. KASSPER architectures remove the effects of heterogeneous clutter, large discretes, similar targets in the background, and nonstationary clutter to significantly improve overall radar performance. In short, KASSPER allows radar systems to become smarter about real-world effects.

Of course, to call an urban environment a "complicated" area is a huge understatement. Line-of-sight blockage creates innumerable hiding places in urban canyons—the very antithesis of the open environments for which radar was designed. A city also gives you a quagmire of large-clutter returns, obscuration, multipath, and competition for scarce RF spectrum.

We know RF energy fills the nooks and crannies of the urban space. Your cell-phone reception is proof of that. You can receive calls around and inside buildings without direct line of sight to base stations. Can RF multipath in and around buildings do the same for radar?

SPO believes radar can, in fact, use multipath to extend reconnaissance into two new frontiers: urban canyons and the interiors of buildings. In short, we believe we can transform "Can you hear me now?" into "We can see you now."

These applications may strike you as fanciful, but the whole history of radar suggests the path from the fantastic to the fundamental can be quite short. Until the mid-1930s, the radar effect was little more than an interesting anomaly. A few short years later, radar allowed England to survive the Battle of Britain and to turn the tables on the Axis by breaking the U-boat fleet.

In this age of asymmetric warfare, is it possible urban radar could bring about a stunning new advantage?

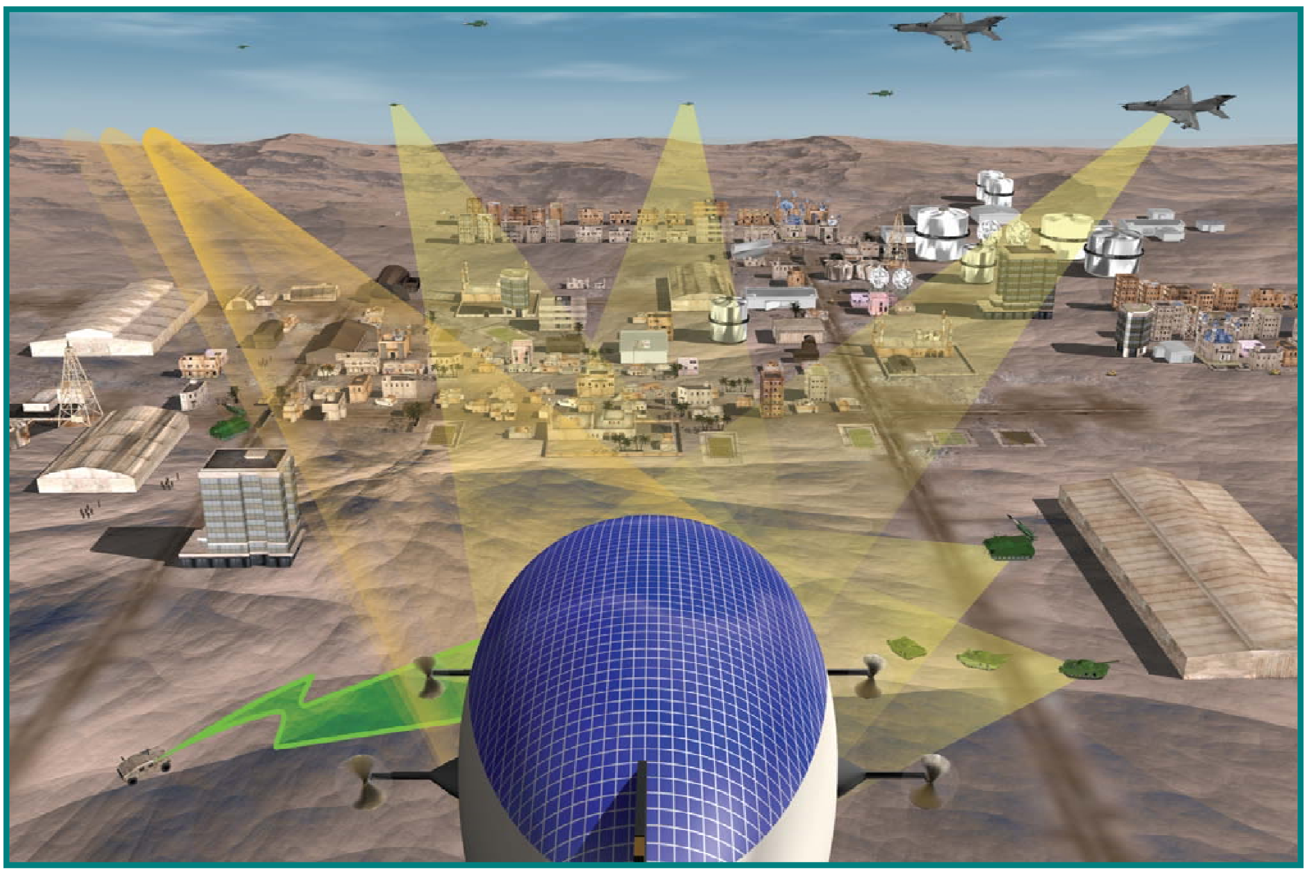
Suppose a key insurgent target has left a building by driving away in a car—could we follow that car to his destination with a cradle-to-grave capability? Or consider a vehicle-borne IED that has detonated in front of a crowded hotel, killing scores of people. Could a grave-to-cradle capability rewind history to find targets? The first requirement to fulfill this mission is persistence. UAVs have played a key role in Afghanistan and Iraq, and offer long-duration reconnaissance capabilities on the order of days.

SPO is developing the integrated sensor is structure (ISIS) program to offer duration of a year using a large airship. ISIS will provide long time on station with a mixture of RF sensors to build important track histories. ISIS can be the bedrock on which we can build urban reconnaissance. However, to track targets through the urban domain, we need to unravel multipath reflections off buildings. We know that RF energy can reach targets between buildings by indirect reflection. That's our opportunity. New signal and knowledge-aided processing will not only allow us to co-exist with multipath; these technologies will allow us to exploit it. This is a game of RF pinball. It will require integrated signal processing, tracking, and detection. By solving severe multipath ambiguities and developing indirect information about the targets, the game can be won.

Knowledge-aided reasoning, directly applied, can turn vague information into near-certainties. We know how city streets constrain the movement of vehicles. We have visual imagery of city layouts, so we can predict the obscurations we will encounter. Intelligent radar systems can use this information to correctly localize and track targets. This creates new opportunities for researchers to tackle advanced target acquisition. New ideas will be needed in fast propagation modeling to build the knowledge necessary to unravel target threads.

By looking at areas from multiple directions, radar's knowledge of the environment and targets can be further increased. Multiplatform or multistatic radar solutions can provide the extra information needed to develop physical tracks from ambiguous radar backscatter. Different vantage points can provide spatial diversity to fill in multipath fades. Multiple frequencies and waveforms can be exploited to our advantage.

As it happens, the urban domain is rich in RF sources. Consider all the uncontrolled transmission sources we might use: television and radio broadcasts, cell phone transmissions, and other RF



signals—all these might be used as “transmitters of opportunity” to give us more information on targets.

Intelligent integration over the whole RF spectrum can give us diversity of frequency and angle. Signals that previously presented barriers to our use of spectrum may now be exploitable emitters. They can become a piece of an integrated RF-sensing puzzle. A full spectrum solution can provide enhanced performance, from detection to resolution, tracking, and maybe even classification using optimal cross-mode integration. In short, signal density, once a foe, can eventually become a valuable weapon in urban sensing.

Radar will be an important piece of a multilayer urban sensing architecture. Radar tracks through urban canyons can help us connect the dots of detection and vehicle ID provided by other systems. Track information can provide the glue to hold together optical track snippets or disambiguate target tracks between waypoints provided by observers or sporadic image captures. It can make sparse eyes-on data more valuable without covering the skies in sensors. Of course, we’ll need to assemble the pieces in affordable ways.

We’ll want to explore architectures of all sensor types and how they best complement each other.

We’ll want to integrate existing airborne radars, UAVs, small distributed sensors scattered throughout the city, as well as existing transmitters like radio, televisions, and cell phones.

If we can do these things, we will have the ability to dominate in urban combat.

This is a major change in thinking for radar systems. It is embracing the challenges of the urban domain to turn what were once insurmountable obstacles into integral parts of the solution. Your ideas and insights can help us take radar into this brave new world. We want to hear your thoughts on intelligent radar processing, multistatic radar, multi-input/multi-output (MIMO) radar, waveform diversity, frequency integration, urban propagation modeling, new detection and tracking approaches, and overall architecture integration that revel in using multipath as an asset instead of an obstacle.

So far, the focus has been about vehicles moving around urban buildings. What about sensing inside those buildings, for example, to look for weapon caches or to locate factories for vehicle-borne explosives? This leads us to the second frontier—radar that can see inside buildings.

Make no mistake: if exterior urban multipath is DARPA-hard, interior multipath is DARPA-harder.

Our current sensor systems are blind inside the vast 3D space of building interiors. A vehicle-borne IED may take only a few minutes to drive to its destination, but it may take weeks for a bomb-maker to construct it in his garage. Detection of threats during this period can be our best defense. We need ways to peer inside buildings to determine layouts, localize personnel, and detect weapons caches.

We know RF energy can do this—actually penetrate into buildings. There have been ample demonstrations of radar systems that can detect a movement as subtle as breathing even through a concrete wall.

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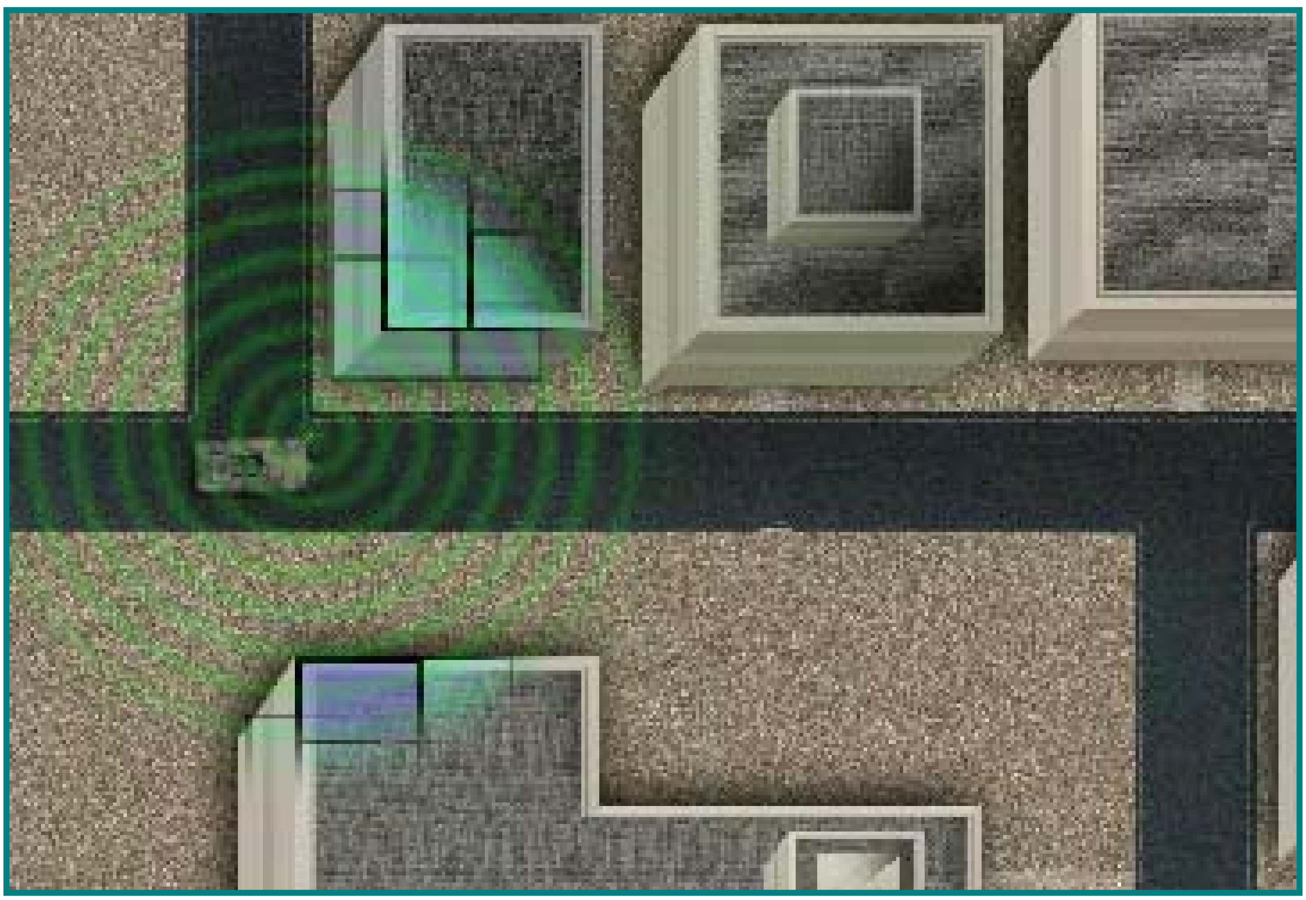
As a first step, our Radar Scope program aims to provide such a light-weight, low-cost, through-wall personnel detector for our warfighter. This innovative device uses stepped-frequency radar to detect subtle changes in Doppler signature of the returned signal. Put more simply, it is a motion detector that can see through walls. A warfighter searching a building will now be able to hold the Radar Scope up to a wall and detect in seconds whether someone is in the next room. It doesn't matter if that someone plays possum; just as long as he is breathing, he will make a detectable movement.

In the future, the Radar Scope could be extended to sensor arrays that yield 3D imagery of a room. Taking this further, we would like to image through multiple walls and even penetrate whole buildings using distributed sensors on or around buildings, carried by Soldiers, vehicles, even UAVs. Imagine a commander being able to drive or fly down a city block and monitor buildings on both sides of the street, to find occupants inside, determine the layouts of the buildings, and locate weapon caches. We will be developing capabilities in advanced multistatic sensors and signal processing to create urban radar systems that will allow reconnaissance over whole city blocks.

Again, though, this is DARPA harder. RF signals will reflect and refract at every interface—floors, ceilings, stairways, furniture, doors, windows, wiring, and plumbing—you name it. Getting the energy inside is only the starting point. We have to get the energy back outside and interpret it to remove the distortion.

As Radar Scope shows, the most straightforward see-through radar task is motion detection. We would like to build approaches that can extend motion detection inside a building into methods that allow us to trace paths of motion. We can then build information on walkways, stairwells, and room boundaries. Even occupants' RF shadows will have detectable signatures, allowing us to build information about background walls.



Of course, the problem gets harder if we cannot exploit movement inside the building. Static sensing would require the discernment of individual building components. Just like Synthetic Aperture Radar (SAR), we need to mathematically refocus phase fronts to specific points in space. Unlike SAR, however, we need to do this in a high-multipath, highly refractive environment. We need to follow the bouncing rays as they move through the building and then invert their effects on imaging algorithms. Just as with urban reconnaissance outside of buildings, multistatic integration of multipath signals may provide the answer. One way to extract this information is to peel back the building one wall at a time. When the locations of exterior walls are found, they can be used to build propagation models that show the wave diffraction and reflection through them. This can help focus imaging results on the inner walls. With each pass through, we use our growing knowledge of a structure to see deeper into it.

This feedback loop iterates between the likely building structure, the electromagnetic propagation modeling, and RF sensing to develop a constraint-based model to explain the multipath. We need to exploit information on building practices and the characteristics of materials. We need new concepts in fast electromagnetic propagation modeling and signal-processing deconvolution techniques to unravel the 3D multipath and refraction.

Once developed, these capabilities will let our warfighters identify which buildings are potential threats and go into them armed with layouts, knowing where our adversaries are. In addition, anomalous amounts of materials can be tagged as potential areas to be examined. This might allow our troops to find weapons caches and munitions without having to do an exhaustive room-by-room search.

This sounds incredible, but there is something about radar that evokes the incredible. Believe it or not, radar research began in the 1930s as a quest to build a death ray. That weapon was never feasible, but the path of inquiry led to stunning advantages in warfare. While I believe the applications discussed are real-world, we should expect our inquiry to lead to directions yet unimagined.

New capabilities for radar will be possible only with advances in multisensor radar integration and creative ways to unravel urban multipath, both inside and outside of buildings. Sorting through the ambiguities, ghosting, and multipath of the urban environment, and the insides of buildings, all present a huge challenge. They also offer great opportunity for revolutionary new ideas. SPO encourages you to accept these challenges and help us move radar into the new frontier of urban operations.