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Standoff Through the Wall Imaging Sensor User Evaluation, FCC Certification and Performance Improvement

OJP NIJ Cooperative Agreement 2011-IJ-CX-K005

AKELA National Institute of Justice

Final Report Revision

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This AKELA Revised Final Report is submitted to the DOJ NIJ describing Cooperative Agreement 2011-IJ-CX-K005 research findings, 1 Oct 2011-Dec 31 2012, in response to Special Conditions 15 and RPPA reporting requirements

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ABSTRACT

Through grant and Cooperative Agreement support from the National Institute of Justice (NIJ), AKELA Inc. developed a sense through-the wall standoff radar imaging system for law enforcement use. The underlying technology of the imaging system is multiple antenna, continuous wave, frequency stepping radar in a portable case that can be positioned at standoff distances of up to 30 m (98 ft) away from a building of interest. Radar information is processed in real time on a laptop computer to allow detection and tracking of stationary or moving individuals within a building structure.

AKELA leveraged radar technology being developed for military platforms, adapting it to specifically fulfill the needs of law enforcement (LE), and at the same time, navigating the technical constraints and requirements particular to FCC approved operation in an urban environment. Initially, a prototype system operating between 500 MHz and 2000 MHz was tested both in the laboratory and on a challenging (realistic) structure with 26.7 cm thick double-reinforced concrete walls and metallic clutter objects located within the structure. Both stationary and moving individuals were successfully detected and tracked within the structure. Additionally, it has been demonstrated that the use of multiple systems can provide significant situational awareness information to LE in resolving detected personnel within groups and concealed individuals behind metallic barriers.

Obtaining an FCC license to operate the radar in this band has proven challenging task, even when use of the device was to be restricted to law enforcement agencies and first responder units. To satisfy FCC constraints, the AKELA prototype radar was modified to operate in the 2900 MHz to 3600 MHz band. In addition, AKELA requested a waiver for LE operation in emergency operations in this band and received FCC waiver approval. However, final FCC certification is required prior to sale for LE application of the ASTIR (AKELA Standoff Through-the-Wall Imaging Radar) system for field evaluation and operational deployment.

This report documents 1) the successful FCC certification effort by AKELA and 2) AKELA user test and evaluation of the NIJ ASTIR system. At the conclusion of this NIJ Cooperative effort, the ASTIR system received final FCC Certification. The FCC certification allows the availability of the ASTIR for LE emergency operations. Its effectiveness will be a function of the building wall material makeup, line-of-site metallic and moving obstructions, and complexity of the building structure. Due to limited user operational testing on complex structures and wall construction materials, it is anticipated that image display information and associated interpretation will require signal processing product improvement. Product improvements will be limited to signal processing and imaging display software - no modifications are required for radar hardware and/or the physical system.

1.0 Executive Summary

NIJ and DOD have sponsored AKELA's development of ultra-wide band radar technology that has resulted in the capability to produce an imaging sensor that can both map the internal structure of building, and locate personnel inside the structure. This capability provides increased situational awareness, in both peace keeping and law enforcement operations, where there is a need not only to determine if there is someone inside a building, but also determine their location and movement within the building. These situations arise during searches for suspects, hostage and barricade incidents, post event building clearance, and tactical surveillance. While, in many cases, the object is to make contact with a suspect to defuse a potentially violent situation, unfortunately, most operations conclude with a physical search further exposing LE personnel are subject to a possibility of physical harm.

Using this radar imaging technology, AKELA has built for NIJ a sense through-the-wall standoff imaging radar system, ASTIR, that has been tailored for use during law enforcement operations. The system transmits and receives on single frequencies over a selected frequency range. Analysis of the returned signals provides information to determine the presence, location, and tracking of personnel movement behind building walls. Real time processing of personnel movement information provides the capability to detect and track moving individuals within a building structure. Unlike existing through-the-wall systems which must be placed in direct contact or close proximity to a wall, AKELA's ASTIR system provides the ability to place the system at a standoff distance up to 30 meters. The standoff distance significantly decreases the likelihood that system operator and law enforcement personnel will place themselves in harm's way when positioning and using the system. Additionally, the standoff radar provides a wide viewing angle, allowing personnel movement detection on multi-level structures from a single position.

Through NIJ grants 2007-RG-CX-K016 and 2009-SQ-B9-K113, AKELA demonstrated the capability to image the interior of a building, and detect the motion of both stationary and moving individuals through multiple internal walls and reinforced concrete exterior walls. Under AKELA's current NIJ grant, a small, portable imaging system based on this technology has been configured that is lightweight**,** can be operated remotely through either a wired or wireless Ethernet link and can operate under battery power for two hours. This standoff detection system has demonstrated detection ranges of 30 meters through concrete block and steel reinforced concrete walls. The sensor control and display functions are performed by an off-the shelf laptop computer. The system is portable, quickly deployed, produces real time personnel movement detection behind building walls.

Throughout the development of the ASTIR, numerous development and performance test series were conducted and documented in References 1 and 2. Initial testing was executed with a moving plate behind cinder block walls to simulate a person breathing and associated chest movement. After IRB review and upon NIJ approval, subsequent testing was conducted with human subjects as targets. An evaluation comparing the plate simulation to human breathing body movement was conducted and the human breathing motion was significantly easier to detect than the breathing machine. This verified early breathing machine simulation test data and represents a worst case for personnel movement detection.

The primary goal for the development of the ASTIR radar system was to establish a baseline of technical performance for a standoff STTW system. A simple detection and imaging algorithm for both small (standing still) and large motion and movement (walking) was applied. The baseline motion detection algorithms use change detection so that stationary objects are removed from the image. However, it is often useful to determine the location of stationary objects so the baseline ASTIR system superimposes both the change detection and stationary images to give a more complete picture of the observed situation. The presence of stationary objects or “clutter” will often result in false detections when there are moving individuals in the scene resulting in a display that is more complicated to interpret. However, algorithms to reduce the effect of clutter are more complicated and difficult to implement and were out of scope for the level of effort of the current grant. It was always anticipated that such algorithms would be investigated post baseline performance establishment.

The ASTIR system shown in Figure 1, is a small (22”Lx17”W x 9”H), light-weight (18 lbs.) , portable package. It is deployed by placing the system in front of a building on a stationary object such as tripod, table or vehicle roof, and orienting towards the building of interest. Control of the system is accomplished using software running on a laptop computer, connected to the device through either a wireless or hard wired connection. The control software allows full control of the system operation, signal processing, and user graphical display. Upon ASTIR setup and power turn on, the system imaging display produces detection results within a few seconds. The use of multiple antennas provides the ability to not only detect individuals, but to also determine an individual’s approximate location in both range and cross-range without the need to move the system to other locations. In addition to the ability to resolve individual detection of personnel within groups, multiple ASTIR system deployment, at 90 degrees, can detect personnel concealed behind metallic barriers (e.g., a Refrigerator).

The ASTIR system is capable of running for up to 2 hours on standard double AA batteries or continuously when connected to a power source (e.g., vehicle cigarette lighter). AKELA’s radar sensor operates in a stepped frequency, continuous wave (CW) mode. All operating parameters are digitally controlled and configurable through the software interface. The radar has a maximum operational frequency range of 380 – 3600 MHz, however, the ASTIR system configured to meet FCC requirements operates in a range from 3100 to 3500MHz.

Figure 1 ASTIR (**A**KELA **S**tandoff **T**hrough the Wall **I**maging **R**adar) system

Throughout the course of AKELA's NIJ efforts to remotely locate and track individuals through walls, compliance with FCC regulations for AKELA's radar technology has proven to be a challenging technical, schedule, and scope risk, even when use of the device is restricted to law enforcement agencies and first responders in emergency operations. To address FCC regulatory constraints, the original NIJ prototype radar was modified to operate in the 2900 MHz to 3600 MHz band. AKELA requested a waiver for operation in this band and the FCC approved the waiver request. However, a final FCC certification is required prior to sale and use of the ASTIR unit for field evaluation and operational deployment. Due to delays in obtaining FCC experimental licensing, waiver approval, and final Certification, user and field test evaluation and subsequent test results feedback were delayed and limited in scope.

Certification testing has been completed and final FCC approval granted on January 9 2013 FCC Identifier: ZZM-ASTIR3300. As final LASP user test and evaluation was dependent on FCC certification, the scope of user testing reported in this Final Report is limited to development testing and ASTIR training tests at both AKELA and the LASD test facilities. Developmental tests were conducted at the Los Angeles Sheriff Department's (LASD) tactical training facility and test training conducted with the ASTIR unit to ManTech, NIJ's Sensor and Surveillance Center of Excellence (COE). At the conclusion of the COE personnel training, the NIJ ASTIR unit was delivered to COE personnel, for continued device performance assessment and user evaluation in various LE operational scenarios.

Please note this Revised Final Report was submitted to NIJ to update program documentation after post Final Report submission. The Final Report was revised to: 1) update the FCC ASTIR Certification approval and associated ASTIR LE use, 2) include NIJ Practitioner Review suggestions and respond to comments received on the Draft Final Report post December 31 Final Report submission, and 3) identify references that provide additional FCC information and technical descriptions of ASTIR technology development and performance assessment testing.
This Revised Final Report describes: 1) the AKELA developmental and calibration tests at the LASD tactical training site, 2) COE ASTIR operator test training at the AKELA's laboratory facility, 3) FCC Certification efforts and associated documentation, and references providing pointers to previous NIJ reports ASTIR technology development, and the required IRB (Independent Review Board) documentation.

2.0 Background

Current U.S. military operations in the Middle East have served to reinforce the importance of being able to conduct surveillance and reconnaissance on combatants in urban settings with the goal being to recapture the situational awareness advantage by denying adversaries the use of cover. Law enforcement faces the same kind of disadvantage while conducting operations for hostage rescue, building surveillance, building clearance, and building search. While early development of through-the-wall detection and imaging systems was supported by the intelligence community, most of the recent technology development has been supported by the National Institute of Justice (NIJ), U.S. Army, DARPA, ONR, and JIEDDO.

The ability to detect and locate stationary and moving individuals through building walls from significant standoff distances provides a tactical advantage to law enforcement personnel. Knowing that there are one or more individuals inside a building, their location, and what the internal layout of the building is, can completely change the operational tactics used thereby increasing the probability that an operation will successfully conclude without casualties. However, because law enforcement agencies have limited budgets for hi-tech equipment, practical implementation of through the wall technology for law enforcement application requires that careful attention be paid to design to make this capability affordable for all levels of law enforcement.

The major objectives of AKELA's ASTIR development were to develop a system package to:

- meet operational law enforcement needs
- perform system evaluations in concert with law enforcement agencies to define

limitations and identify improvements
- incorporate identified improvements into the system design
- resolve issues to ensure system can be certified by the FCC for law enforcement application.

FCC certification was the final program task prior to law enforcement sales and emergency field use application. Certification testing has been completed and FCC documentation submitted. As user test and evaluation was dependent on FCC certification, the remaining scope of user testing was limited to two series of development tests at the LASD SWAT training facility, and training and handover of the ASTIR unit to the NIJ Center of Excellence (COE) team for continued device performance assessment and user evaluation.

3.0 Introduction

This document is the Final Report on AKELA's OJP NIJ Cooperative Agreement 2011-IJ-CX-K005. This effort builds on prior AKELA NIJ and DOD technology efforts to develop Standoff Sense Through-the-Wall and building interrogation radar sensor systems. This NIJ report documents accomplishments of the program tasks that include: 1) ASTIR FCC Certification, 2) LASD (Los Angeles Sheriff Department) tactical training facility ASTIR development testing, and 3) operator test training of COE (NIJ Center of Excellence) personnel for user evaluation of the ASTIR system. Each of these three efforts will be described in separate sections of this report.

AKELA NIJ project goals and objectives were to develop a standoff, high performance, portable, see-through-the-wall imaging radar system. The system provides the ability to detect and track the presence of both moving and stationary individuals within a building structure. The AKELA effort is a continuation of the development of a FCC compliant system and law enforcement (LE) field evaluation of the AKELA through-the-wall standoff surveillance system (ASTIR). Project tasks associated with achieving project goals and objectives included:

1) FCC AKELA radar device certification (Test certification at a FCC designated / accredited laboratory and FCC certification documentation submission)
2) LE User test and evaluation of the AKELA ASTIR sense through-the-wall device on a range of operational scenarios for personnel detection and location behind building walls. These system evaluations were to be conducted in cooperation with the Los Angeles Sheriff's Department (LASD) and the NIJ's Sensor and Surveillance Center of Excellence (S&S COE) support contractor ManTech
3) Evaluate user test results for subsequent system design "product improvement" efforts, and assess value added from multiple ASTIR sensor systems.

The third goal and objective, to assess the value added by multiple ASTIR sensors, was a result of discussions with LE emergency response team personnel, after they observed the benefits of using multiple sensors to reduce cross range detection. They pointed out that, currently one of the most dangerous situations after emergency operations was building clearance. , Many of these structures have lofts /attics and crawlspaces requiring LE personnel access. The probability of having to enter these areas without knowledge of any hidden armed assailants behind barriers (many times metallic) is high. With a single ASTIR, it is possible that a direct view may be blocked and not detect, an assailant behind a barrier (e.g. metal refrigerator). A second ASTIR system positioned at 90 degrees to the first ASTIR could identify the assailant behind metallic barriers. However, due to funding limitations, this objective of the use of multiple ASTIR systems was only addressed in the ability to correlate multiple ASTIR data from a user interface perspective. It was determined that with knowledge of operational ASTIR location parameters relative to their placement, multiple ASTIR data could be correlated and displayed at a user interface with minor modifications to existing data processing software.

Under this AKELA effort a prototype portable ASTIR system has been delivered to NIJ through it S&S COE ManTech. The ASTIR provides personnel detection and tracking sense through the wall imaging radar sensor system prototype for LE field development evaluation and emergency event application. .

The report consists of an abstract and eight sections. Section 1 is the Executive Summary, followed by Background and Introduction, Sections 2 and 3 respectively. Section 4 describes the Technical Approach, followed by three sections discussing ASTIR FCC Certification, User development tests, and ASTIR operator test training, Sections 5, 6, and 7, respectively. Section 8 discusses project conclusions, and the final Section 9 presents AKELA recommendations.

4.0 Technical Approach

This program had three major tasks, ASTIR FCC certification, continued ASTIR user evaluation, and ASTIR test training. Certification of the ASTIR was the critical task, since both user evaluation efforts and final prototype product delivery to NIJ were dependent on successful FCC certification. It was recognized early in the program as the FCC certification activities progressed, that certification would require most of the NIJ Cooperative Agreement funding. As the certification task continued, testing was conducted at the LASD tactical training facility. Test objectives were to assess the ASTIR performance on realistic complex structures representative to what LASD personnel might encounter. From these test results, it was determined that modifications to the user interface and signal processing were required to improve personnel detection and user display interpretation. As the program had no funds to make these signal processing and user display modifications, AKELA committed internal resources to make these modifications and support continued user evaluations with the new user interface. When further user testing had to be curtailed, NIJ requested that the prototype ASTIR be provided to the NIJ's COE ManTech for evaluation of the performance of the device against an array of LE scenarios.

This provided an opportunity to train COE personnel on ASTIR operation, and potentially leverage COE testing results to obtain ASTIR user performance data. Additionally, it provides a source of feedback to AKELA for signal processing and user interface display product performance assessment for product improvements. On 28 August 2012 two ManTech engineers received a day of hands-on training on ASTIR operation and interpretation of radar data displays. Operator training included a series of tests of ever increasing complexity, in which the test objectives were to provide hands on experience of the ASTIR device operation, user interface familiarity, and interpretation of resultant data images and monitor displays. Test configurations, and resultant test results, are presented in Section 6 and 7 of this report.

5.0 FCC ASTIR Certification

FCC certification and compliance tasks included certification testing of the AKELA ASTIR system in a FCC approved laboratory, and the submission of radar device documentation. Test planning included AKELA in-house laboratory acceptance testing of the device and preparation for FCC lab testing. During AKELA lab tests, device unintentional emissions exceeded FCC Part 15 specifications. Upon subsequent FCC laboratory device calibration, radar tuning and shielding was added to the enclosure interior, reducing unintentional emissions to meet or comply with acceptable FCC Part 15 levels. Two days of FCC laboratory tests were conducted successfully in Aug 2012. All FCC test requirements were met and a FCC Certification Laboratory report issued documenting all test results and their compliance with FCC test requirements. This report is the keystone component of the required FCC documentation for final ASTIR certification approval.

A significant documentation effort was required to comply with the FCC certification process. All documentation submission is required prior to final FCC certification. A summary check list of required FCC certification documentation is listed below.

FCC Check List

- FCC Agency Agreement
- Confidentiality Request
- Cover Letter
- FCC Waiver Submission and Approval Documents
- External photos (Provided by FCC Lab)
- Device Label information
- Internal Photos (Provided by FCC Lab)
- RF Exposure levels
- Test Report (Provided by FCC Lab)

- Test Setup Photos (Provided by FCC Lab)
- Operation Manual
- Schematics (Confidential)
- Block Diagram (Confidential)
- Theory of Operation (Confidential)

All FCC documentation was submitted, including the FCC certification laboratory report as a package to the FCC for formal approval. Final official approval is expected in February 2013, depending on FCC headquarters work load.

6.0 User Evaluation Testing at LASD's Castaic Site

Figure 2 LA Sheriff's Department Castaic Site

As part of the ASTIR system evaluation activities, AKELA performed prototype testing at three separate buildings at Los Angeles Sheriff Department's Castaic Site in April and May of 2012. Figure 2 shows a satellite image of the site as well as specific locations of five buildings. Three of these buildings were chosen for ease of accessibility to their rooms and the availability of additional space for experimental setups.

For the first test series performed in April 2012, Buildings One and Two were surveyed and selected for use. Figure 3 shows pictures of the front of Building One, as well as views from the front door of the living room, from inside Room Two and a close up of the cinder block wall construction. Over the course of performing initial system testing, the first interior wall exhibited unexpectedly strong reflectivity. Upon investigation, it was discovered that two layers of expanded metal were used to anchor the plaster for the construction overcoats of several interior cinder block walls of Building One, as shown in the close up in Figure 3. Such interior walls imbedded with metallic anchoring screens effectively block through-the-wall radar signals.

Figure 3 Details of Building One

Figure 4 shows a floor plan of Building One. Data files were collected with the system surveying the building from Position 1, and the same series of tests were later duplicated from Position 2. The standoff distance in each test case was approximately 18 meters. The figure also highlights the walls that were identified to be blocked during testing. In addition to this problem, most of the pantries and cabinets lining the walls of the kitchen area were found to be lined with metal. As a consequence, for experiments conducted in Building 1, an adjustment of expectations was reduced to a successful detection of an individual standing or moving around Room 1 (living room), and walking down the hallway to the other rooms. Because of the presence of double layered expanded metal in walls and the metal lined cabinets, we would expect low to zero detection of individuals in other rooms. Figure 5 shows examples of some of the other rooms in Building 1.

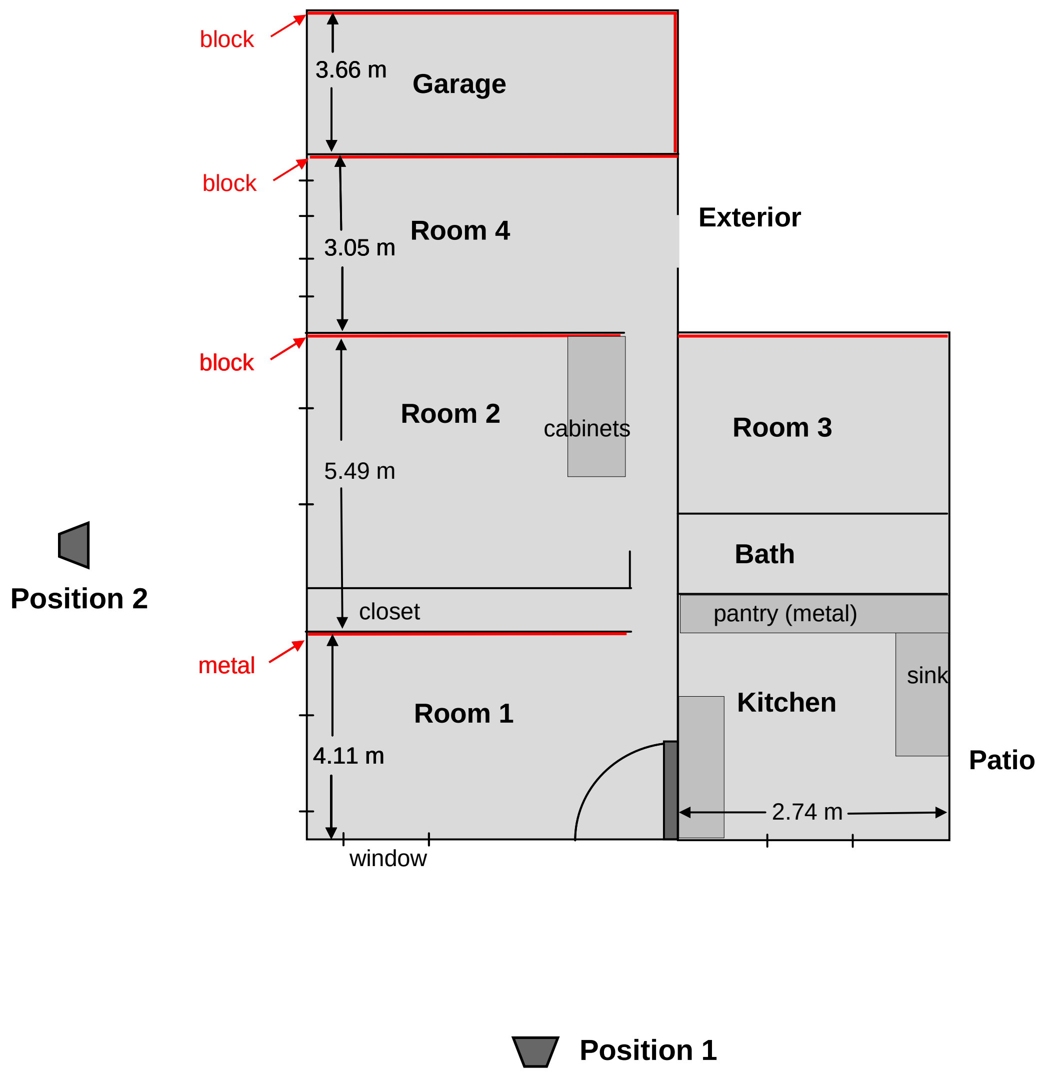

Figure 4 Floor plan Building One

Kitchen and cabinets **Bathroom**

Figure 5 Additional rooms in Building One

Test results from Building One verified expectations. Detection of an individual was successful in Room One (living room) and when the individual was moving in the hallway, but proved mostly unsuccessful in other areas of Building One. On a few occasions, movement could be detected in Rooms Two, Three, or Four, but these were analyzed and later attributed to radar multipath signals reflected down the hallway into and out of these rooms. Detection performance from multipath signals was severely degraded from the extensive use of metal in structures and fixtures.

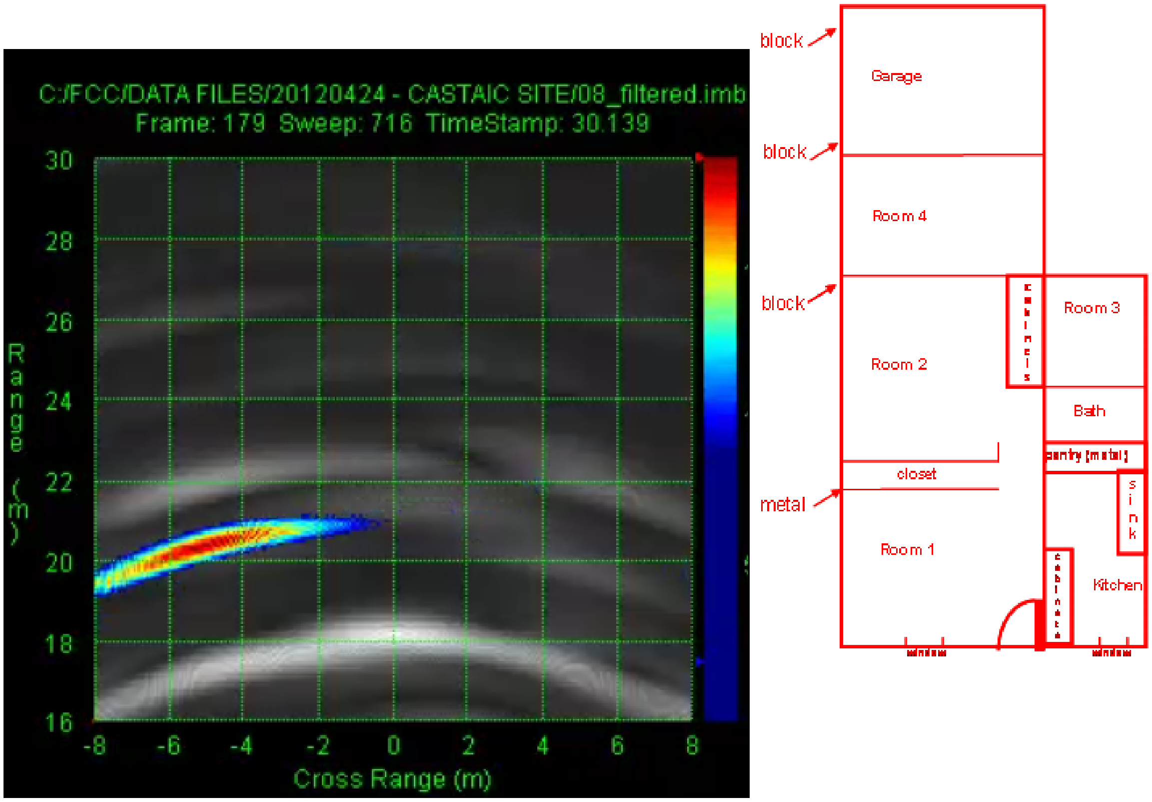

Figure 6 Image reconstruction for Building One

Figure 6 shows an example of the image reconstruction results demonstrating successful detection performance in Room One. The building layout is displayed side by side and approximately to scale for comparison. The walls of Building One show up in the image at the correct ranges as determined by measurements and a survey of the building conducted by AKELA. While this example only shows successful detection in Room One, the overall routine followed by the test subject across several test runs is detailed as follows:

1) The individual enters the building through the front door

2) Turns left into Room One and walks around

3) Crosses the hallway and into the kitchen

4) Enters hallway and crosses into Room Two

5) Crosses hallway and enters bathroom

6) Enters hallway and into Room Three

7) Crosses hallway and enters Room Four

8) Walls down hallway and exits through front door

Additional tests were performed with two people walking inside Building One. After entering the front door of the building, one person stood stationary in Room One while the second person walked around the room. At the end of the test, both individuals exited from the front of the building. While image reconstruction of this test series with multiple individuals was slightly more difficult to interpret, an alternative method of examining the data allowed a successful detection of people inside the building.

Figure 7 shows the time history chart of the data file with two people inside Building One. The time history chart is a new display window that AKELA developed and is currently integrating into the law enforcement user interface, to provide an alternative method of analyzing data and to provide additional useful detection information. This proves to be especially useful in challenging and complex environments such as the buildings surveyed at the LASD Castaic site, where the presence of blocked walls with double layers of expanded metal and cabinets with metal sheet backing made detection extremely difficult.

The X-axis represents the progression of time while the Y-axis represents distance in range. The figure shows the two individuals entering the building through the front door, and one person standing still inside the room while the second person stands or walks around in random patterns. Near the far right of the figure, both individuals exit the building together at the end of the test. As demonstrated, the time history chart helps the operator use pattern recognition to detect individuals that might otherwise be lost in the clutter of a challenging environment such as the Castaic site.

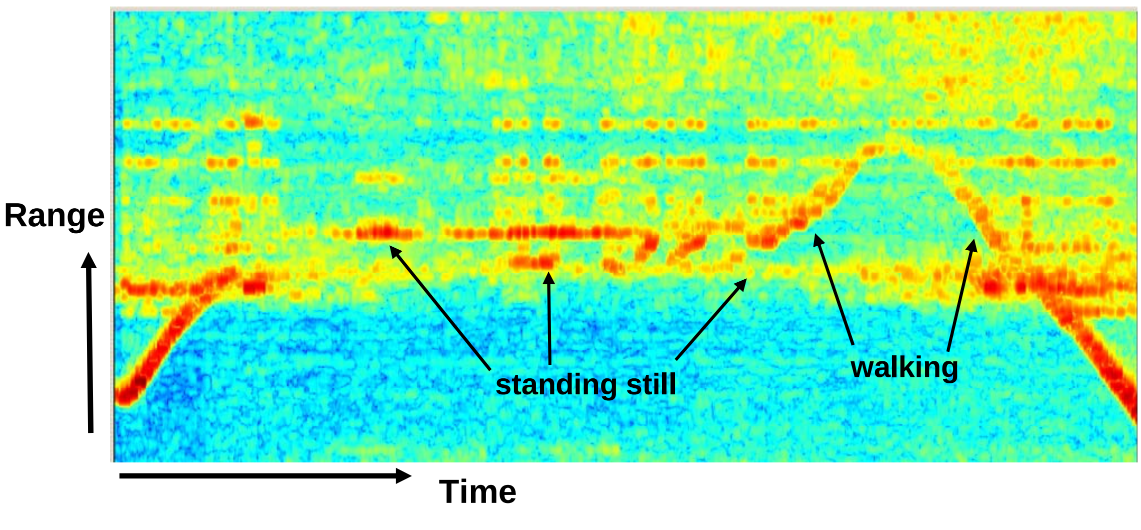

Figure 7 Time history display of two individuals walking in Building One

To provide a different but equally complex environment for comparison, system testing was subsequently performed at Building Two, with location shown in the satellite image. Figure 8 shows the front and side views of Building Two, as well as the initial and final system locations with respect to the building. The system was moved in cross range, along the concrete courtyard wall, to determine if not having the front door on antenna boresight would improve detection performance. Data files with personnel walking inside the building in the same routines were taken at both system locations.

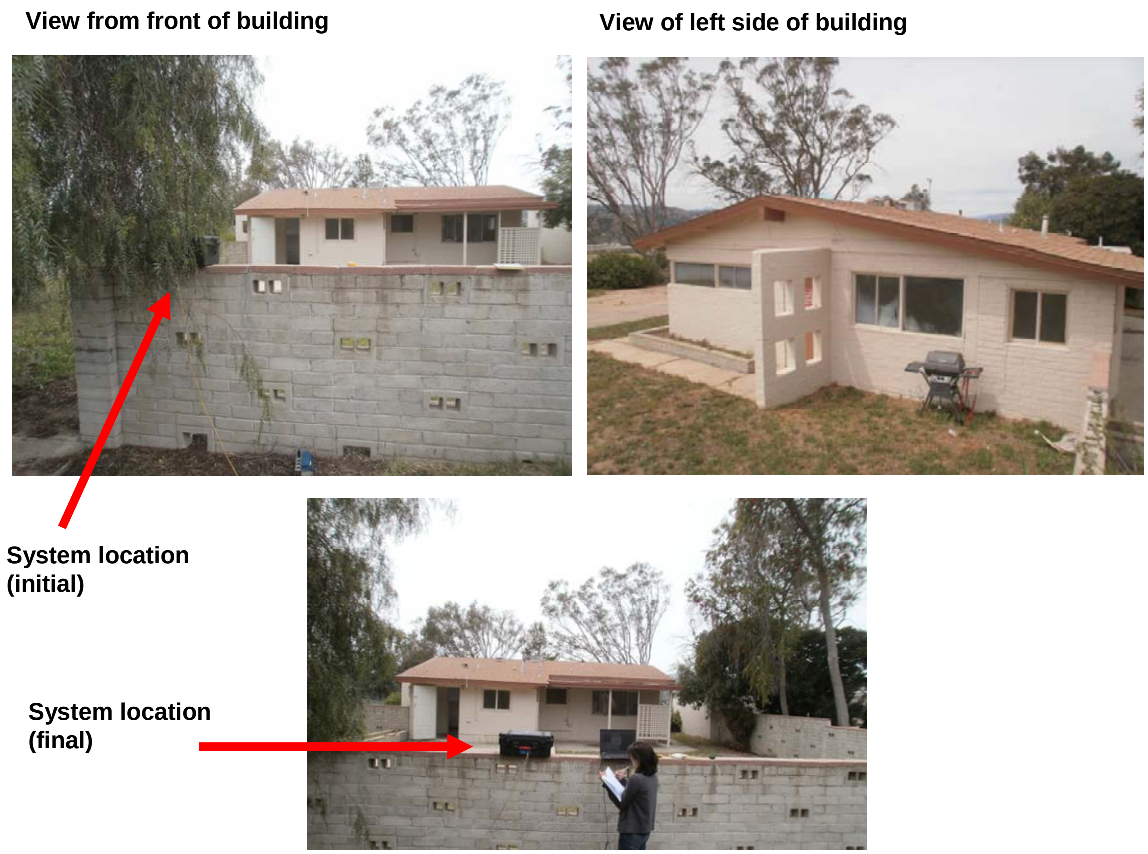

Figure 8 Views of Building Two and system placement

Figure 9 depicts the layout of Building Two with respect to the courtyard wall, and the location where the system was positioned. The initial and final placements of the radar system on the courtyard wall are also indicated. Placing the system on the wall translated to a standoff distance of approximately 12.5 meters from the protruding back section of the building. For the first few tests performed at Building Two, an individual walks from the courtyard and in through the back metal door, closes the door, then stands or moves around the laundry room as directed.

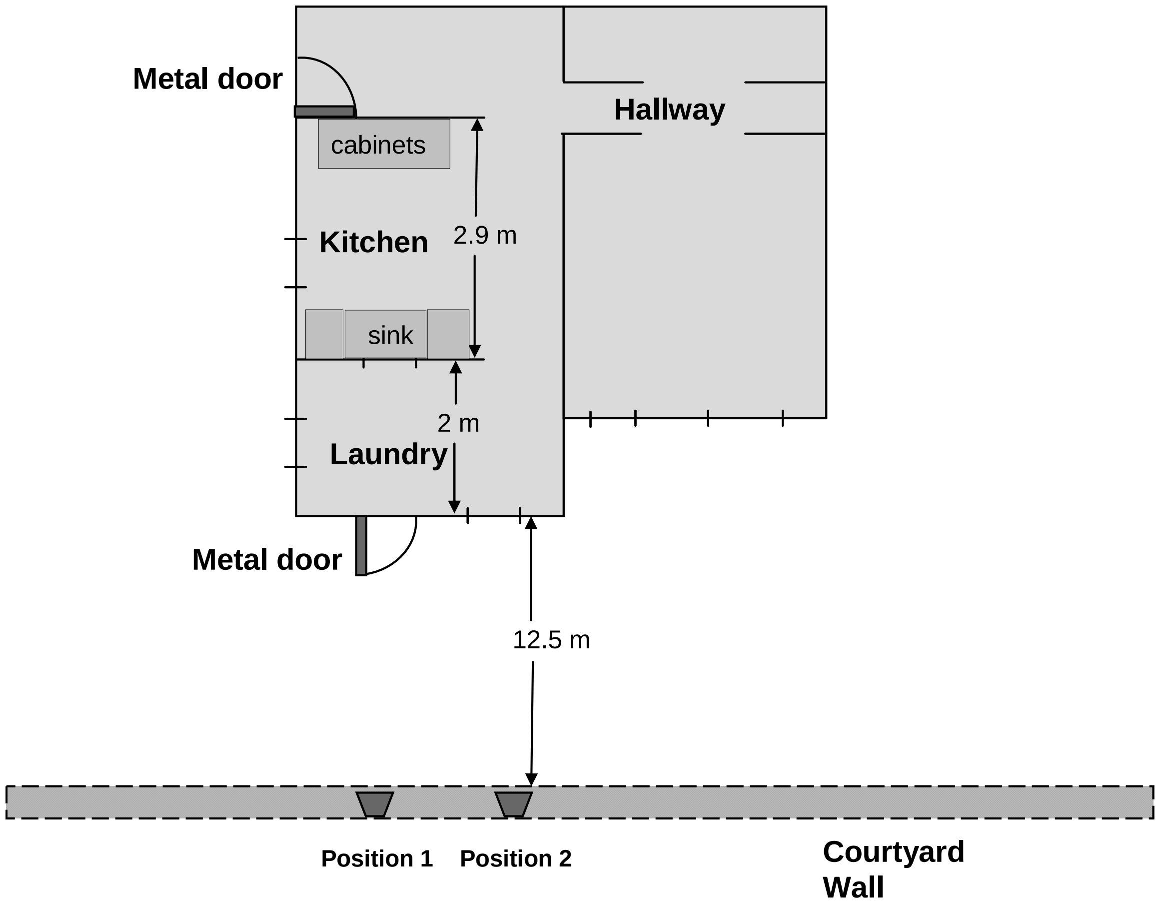

Figure 9 Floor plan Building Two

Similar to Building 1, Building Two's walls were also found to be constructed with double layers of metal mesh, essentially blocking any line of sight through-the-wall systems. In addition, most of the cabinets in the kitchen were constructed with sheet metal backed doors, making detection in these rooms very difficult. A number of data files were subsequently taken with the individual walking inside the building to the second metal door and swinging the door open and shut. These files were used to test the functioning of the system when the presence of blocked walls prevented the successful detection of an individual standing behind them. Results verified that the system was functioning correctly, and the location of the second door showed up at the correct range in the reconstructed image.

The ASTIR radar system was able to successfully detect the individual walking in cross range, down the unblocked hallway in a direction parallel to the courtyard wall. Figure 10 shows the detection results of the person as the subject person traverses the hallway to the right side of the building. The protruding section of the building shows up at approximately 12 meters from the system's position on the courtyard wall, and the blocked wall separating the laundry room from the kitchen shows up 2 meters behind the exterior wall, as expected. The person walking in the hallway shows up at around 18 meters in range from the system, and traverses the screen in cross range when not moving behind blocked walls.

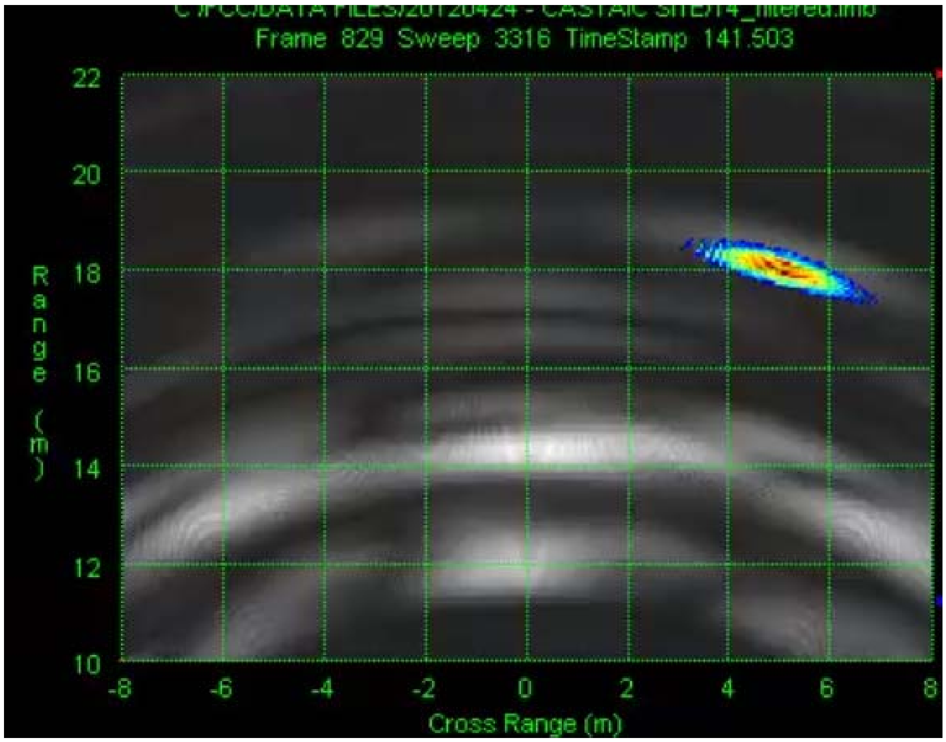

Figure 10 Image reconstruction for Building Two

In May 2012, AKELA returned to the Los Angeles Sheriff Department's Castaic Site to obtain further measurements of the two buildings. On this subsequent trip Building One and Two had both been barricaded for training purposes, and filled with various clutter objects, and inaccessible for follow up testing involving moving individuals. Figure 11 shows the state of Buildings One and Two on the subsequent visit. Note in particular, the blocked off entrance to Building One, as well as the clutter blocking hallways and doors inside the building.

Figure 11 Buildings One and Two inaccessible due to LASD training exercises

In lieu of obtaining data for tracking moving individuals in either of the barricaded buildings, used for training, a third building was chosen to perform additional testing. Its location within the Castaic test site is marked on Figure 2, shown earlier. Figure 12 shows the positioning of the radar system looking into Building Three.

Figure 12 Radar system position viewing Building Three

Figure 13 shows the floor plan of Building Three. The location of the radar system is also drawn relative to the building. The standoff distance was approximately 8 meters, constrained by the physical layout of the site and proximity to the other buildings. Building Three was surveyed and found to be essentially a mirror image of the main section of Building One. As before, the presence of blocked walls posed the same challenges to successful detection.

Figure 13 Floor plan Building Three

Figure 14 demonstrates the successful detection of a person standing in the kitchen, behind two walls, in Building Three. Both the time history display and the traditional image reconstruction are shown for reference. The first wall appears at approximately 8 meters from the front of the system, as expected from the standoff distance, while the second wall appears at 13 meters. Since the individual is standing still, the subject individual appears at the same range over the progression of time. The bright streak around 17 meters across the time history display demonstrates the detection of the individual.

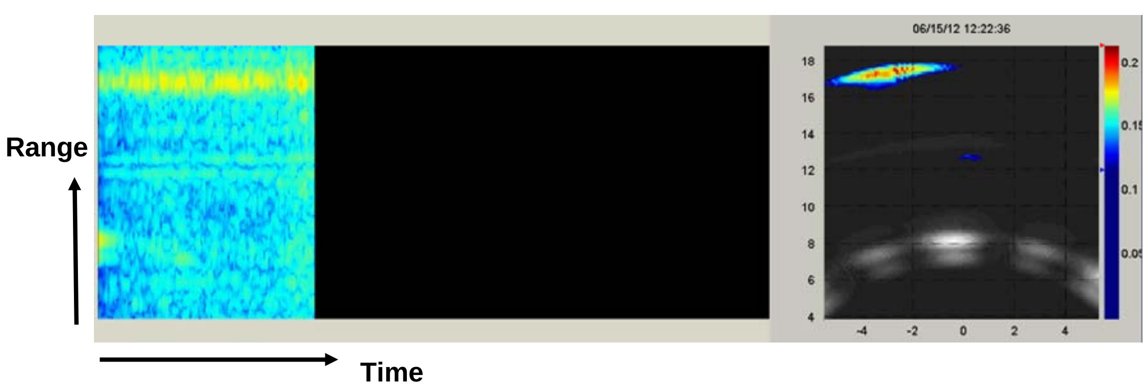

Figure 14 – Successful detection of stationary individual through two walls

7.0 NIJ ASTIR COE ManTech Test Training

To provide ASTIR hands-on training, data display interpretation, and tutorial material for ManTech operators, AKELA conducted a series of experiments using the pre-production prototype unit in both open area testing (no wall) and complex building (one wall) situations. All video data and radar data files were saved for playback and training. During ManTech's visit, several experiments were repeated to allow ManTech operators hands on experience with the unit and demonstrate the capabilities of the user interface in real time.

<u>Test Series 1: Open Area Testing</u>

Figure 15 Camera view from camera positioned at ASTIR system location

Figure 15 shows the view of the parking lot as recorded from a camera positioned at the ASTIR unit's location. The unit was set up approximately 20 meters away from the parking lot concrete wall. Two individuals walked back and forth between the wall and the radar system at a steady pace. Video files and radar system files were taken at the same time, allowing new users of the system to learn to interpret the user interface with knowledge of ground truth.

The test objective of this first test series was to demonstrate the radar and the imaging algorithms were performing as expected in the least challenging environment (open air, no wall in front of individuals). In addition, this set of clean data made it easier to train new users to recognize patterns in the Time History Chart and Image Window to assess whether there are individual breathing or moving in the target area.

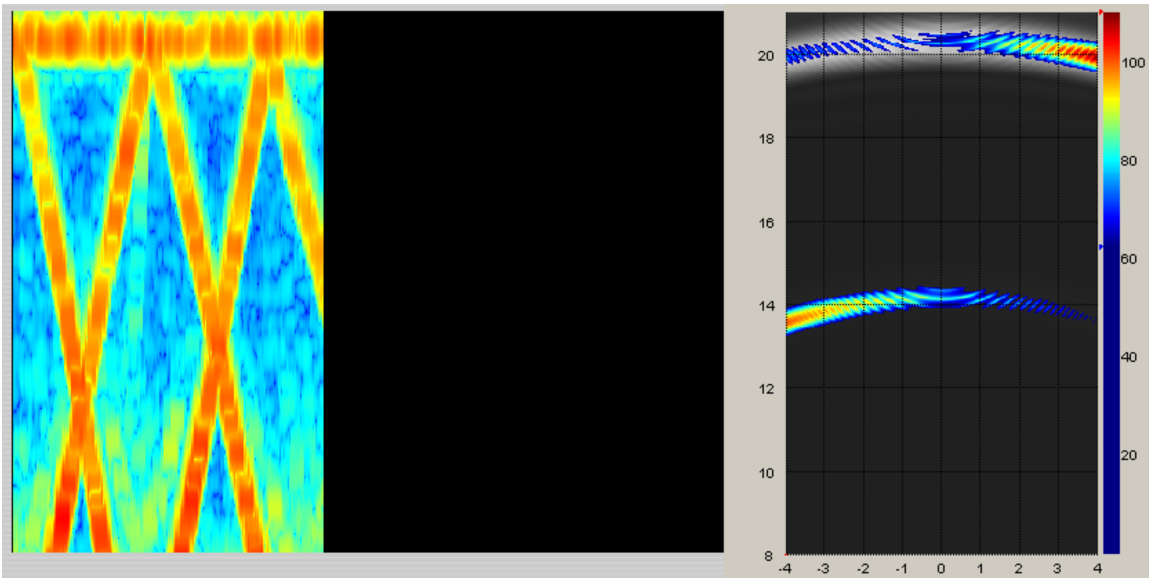

Figure 16 Detection results from parking lot tests

The detection results from the open area tests are shown in Figure 16. The Time History display, on the left of the figure, and the grey structure in the background of the Image Window, on the right of the figure, both verify that the wall is located at 20 meters from the front of the system. The tracks of the two individuals are clearly shown to cross paths over time, as they head in opposite directions back and forth between system and wall. This data file, although an ideal case, made it easier for operators to recognize similar movements of individuals in more complex environments, behind reinforced walls or in cluttered rooms.

While the wall at 20 meters is a stationary feature that doesn't move over time, it shows up in the Image Window with occasional flashes of color because the movement of the individuals in front of a wall effectively 'casts' a shadow on the wall and changes its radar returns. The Image Window is designed to display all breathing or moving objects in color, with static objects in grey scale. Cross referencing with the Time History display, where the wall remains at the same range throughout the course of the experiment, allows the user to determine that the wall is indeed a stationary environment feature.

Test Series 2: Building Tests (1 wall)

Figure 17 Exterior photo view of test room wall

After the open area testing was completed, AKELA relocated the radar system to survey a wall of AKELA's office building. The stand-off distance was approximately 14 meters. Figure 17 shows the exterior view of the building, from the approximate location of the unit. The area of surveillance was a room with significant metal clutter which included computer desks, monitors, chairs, metal filing cabinets, and a metallic backed whiteboard. A breathing machine was placed approximately 2 meters behind the wall. This breathing machine was operative for about half of the tests. In addition to the breathing machine, an individual was instructed to pace back and forth in the office, first in range and then cross range. Figure 18 is a screenshot from the video capture taken during one of the experiments, showing the individual moving in the room with the breathing machine on.

Figure 18 Video capture of individual walking inside room (breathing machine on)

Figure 19 shows the detection results from a test with the breathing machine on and the individual moving back and forth in range. In the Time History display, the amount of noise that appeared beyond 16 meters was attributed to the tree, identified at the right in Figure 17. The tree was located at approximately the same distance in range as the room itself, and any slight winds caused it to dominate the Time History display. In the midst of the noise, it's possible to barely detect the breathing machine appearing at 16 meters in range with a set periodicity. The V-shaped tracks in the Time History display of Figure 19 are the individual's movements when the subject crosses in front of the breathing machine.

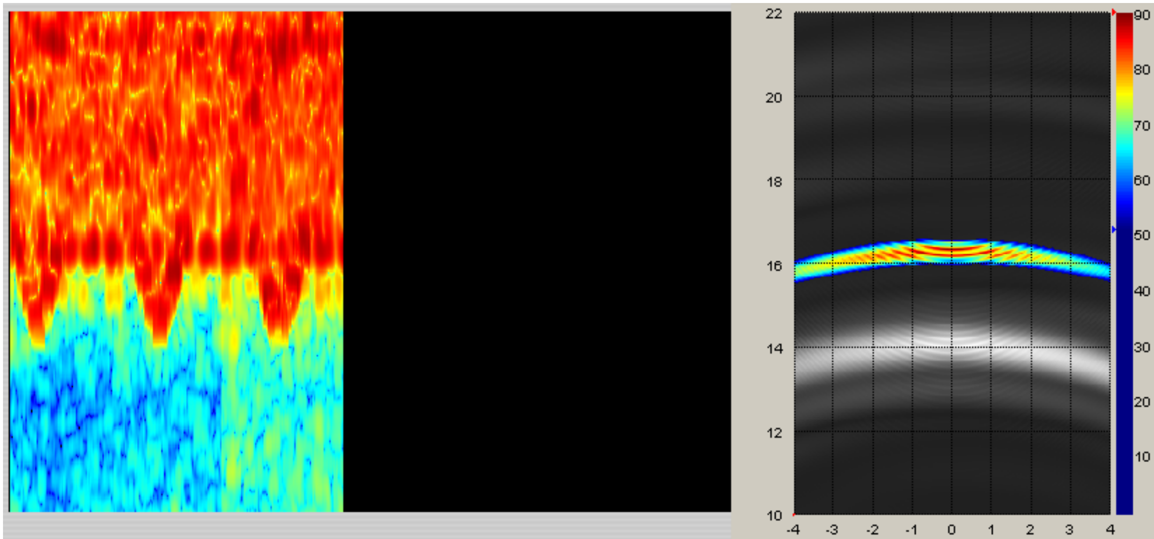

Figure 19 Detection results of individual walking inside room (breathing machine on)

In a subsequent experiment where the breathing machine was turned off, tracking personnel movement as the individual moved in range was clearer. Figure 20 shows the detection results with the breathing machine turned off. As shown below, the noise due to the location of the tree still dominates the Time History display. Since the breathing machine is a larger reflector than a person, with the machine turned off, the individual tracks can be traced for longer durations before they too are lost in the noise.

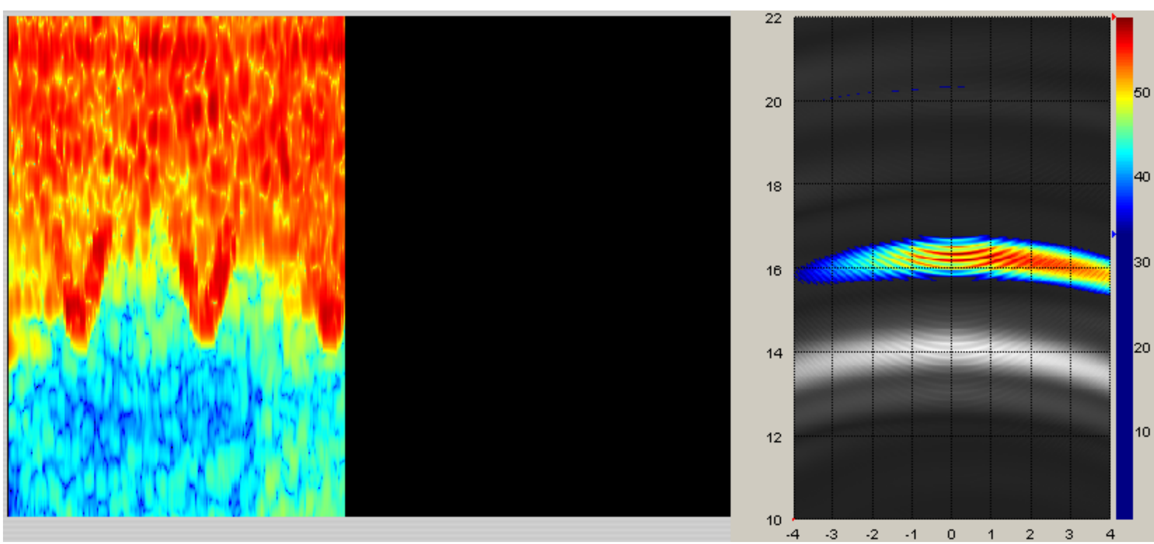

Figure 20 Detection results of individual walking inside room (breathing machine off)

Data was also taken with the breathing machine turned off and the individual walking in cross range. The detection performance was affected by the same problems as previously observed. In order to mitigate the noise contribution from the tree, in the subsequent test series, the system was moved off-angle with respect to the front wall and also moved back to survey the same office building obliquely.

Test series 3: Building tests (1 wall), oblique view

The list of experiments varying breathing machine and individual motions were repeated for the test series at the new system location. When the radar is viewing into the building obliquely the tree no longer appears at the same distance as the interior of the room. Figure 21 shows a screen capture from the video feed of the interior of the office as a test is in progress. The setup is similar to Figure 18, with one adjustment made for the new radar system position. The breathing machine is now angled towards the true location of the radar.

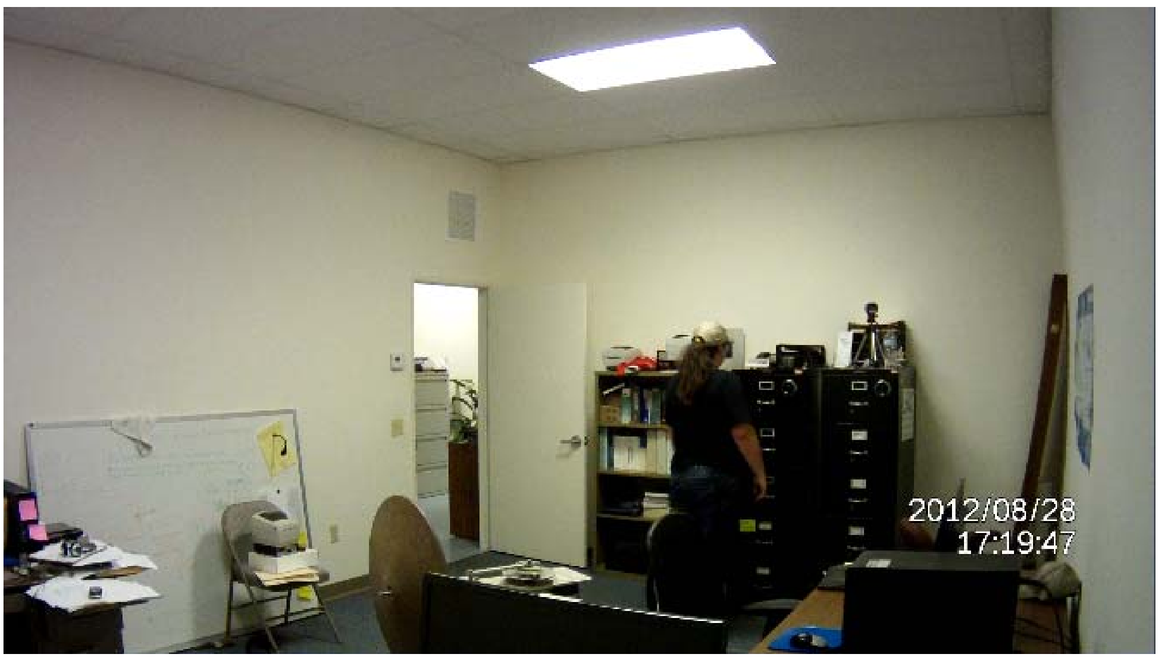

Figure 21 Video capture of individual walking inside room (breathing machine on)

Figure 22 shows the detection results with the individual walking in the room in range, and with the breathing machine on. As can be observed from the Time History display, the noise contribution due to the tree is significantly reduced. The breathing machine can be clearly located at approximately 18 meters, showing up with its typical periodicity in the Time History display. As before, the V-shaped tracks are due to the individual showing up most clearly when the target individual is walking in front of the breathing machine, which would otherwise tend to be the most significant reflector in the room. Behind the breathing machine, the individual's tracks are less clear.

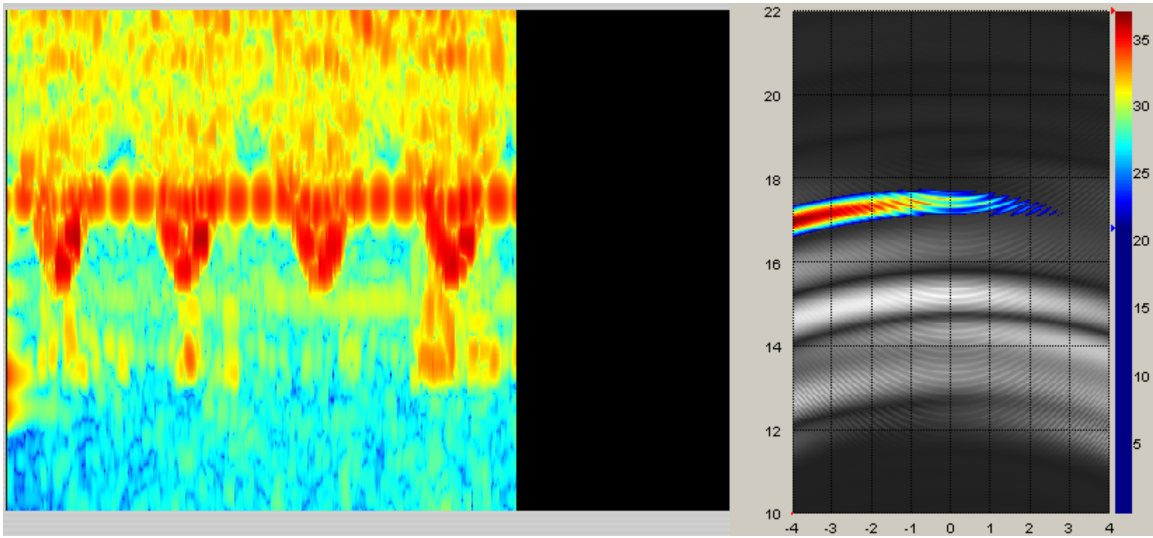

Figure 22 Individual walking results inside room (breathing machine on)

The experiment was repeated at the same location with the breathing machine turned off. Detection results are shown in Figure 23. With the machine off and with the clutter due to the tree significantly mitigated, the individual's tracks appear quite clearly as the target individual approaches the front wall.

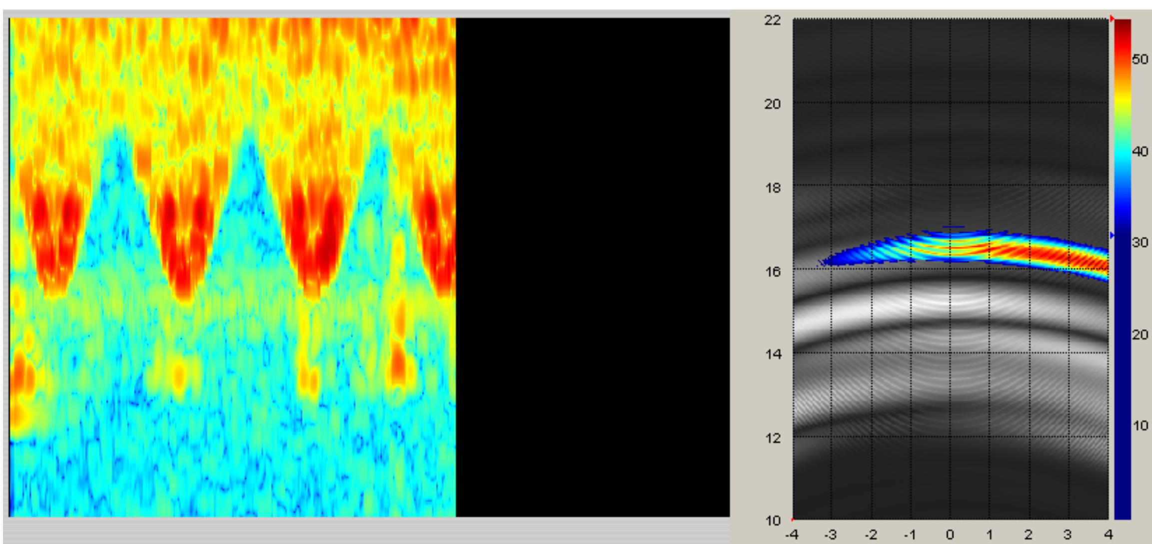

Figure 23 Individual walking results of inside room (breathing machine off)

At the conclusion of this third test series, and with the ASTIR in this test configuration, building wall and device calibration measurements were conducted as part of a training exercise. With a corner reflector located inside the building room, wall radar attenuation measurements were made using two way transit time and signal amplitude data.

8.0 Conclusions

A portable standoff sense-through-the-wall (STTW) imaging system prototype for civilian law enforcement use has been developed, and has demonstrated the ability to detect stationary individuals from standoff ranges in excess of 25 m through 26.7 cm (10.5 in) thick steel-reinforced concrete walls. The prototype commercial name is **ASTIR** (**A**KELA **S**tandoff **T**hrough the Wall **I**maging **R**adar) and is Certified by the FCC for emergency use by LE. Compliance restrictions imposed by FCC requirements for system operation in the frequency band of 500 MHz to 2000 MHz have necessitated modification of a previously developed NIJ laboratory radar prototype to a frequency band between 2900 and 3600 MHz.

Engineering prototypes have been designed and have demonstrated the ability to detect personnel movement through cinder block reinforced and concrete walls at distances up to 30 meters. The engineering prototype weighs approximately 18 lbs., operates for two hours on internal batteries, and is controlled with a wired or wireless Ethernet connection. A pre-production ASTIR system has been designed to meet FCC requirements, and Certification was granted on 9 January 2013 (Reference 4) for Law Enforcement application. With this certification the AKELA device is available for first responder and Law Enforcement evaluation, operational application, and product acquisition. The ASTIR pre-production system was delivered to ManTech (NIJ COE) for further user evaluation. It is expected that feedback from ManTech will provide ASTIR user performance data and identify imaging, display, and user interface product improvements. All product improvements are expected to be software related, requiring no baseline hardware modifications.

The ASTIR radar sensor has met the performance goal of 30 meter standoff detection of personnel through reinforced concrete walls. Additional conclusions are:

- An FCC compliant, hermetically sealed pre-production system has been manufactured and delivered to NIJ agents for further user evaluation.
- A radar system protocol has been modified along with software to support asynchronous mode for wireless communication, virtual data storage, and user display interface.
- NIJ program SWAP goals have been met, the pre-production system weighs approximately 18 lbs, is powered continuously with AC or eight AA batteries (2 hours), and has a peak instantaneous power of at approximately 50 mW.
- The present pre-production system will cost approximately $10-12K in a production lot of 20 units. Without a substantial electronic redesign effort, unit costs may not be substantially reduced. A small unit cost may be realized with multiple unit buys; however, the anticipated number produced is too small for appreciable cost reduction.
- LE practitioners' participation from the Los Angeles Sheriff’s Department (LASD) and other LE organizations and their feedback provided key information to AKELA for product

evaluation and improvement efforts. This feedback aided several improvements to the graphical user interface, operations and maintenance improvements, and critical input for future test planning and execution. Additionally, the availability of the LASD tactical training facility to provide realistic complex structures often encountered by LASD Emergency Response Teams, has proved to be invaluable in the performance assessment and identification of ASTIR software modifications for signal processing and user interface image display interpretation.

- The time and resources required to define and respond to FCC compliance surpassed AKELA's scope, risk, and schedule expectations. Identifying FCC test requirements and obtaining FCC experimental licensing and waiver approval caused: 1) prototype radar system design modification, new component system integration, retest, and re-verification, 2) delays in user test evaluation schedules, 3) increased program risks (technical, cost, and schedule), and 4) replan of major engineering tasks.
- Leveraging prior and concurrent AKELA DOD radar sensor contracts has been invaluable for technology transfer to this and previous NIJ efforts. This technology transfer and maturation has aided in reducing design and test technical and schedule risks, as well as providing significant cost reduction opportunities.
- A primary end goal of this NIJ Cooperative Agreement was initial commercialization and production of the NIJ AKELA's first generation standoff radar system product for LE field application. Product operational user evaluation and redesign modifications to meet FCC compliance requirements were major factors in task schedule delays; task replans, and associated resource reallocation.
- The NIJ COE LE evaluation and suggested product improvements of the ASTIR performance may be critical to the acceptance by LE.
- Results from current (FY12-14) AKELA DOD contractual efforts, may provide significant improvements in detection algorithms, image interpretation, and multiple radar/optical signal integration that can be directly integrated into the LE ASTIR system to enhance performance.

The current AKELA ASTIR system can detect personnel behind non-metallic building walls of simple structures. Current capabilities are limited as a result of lack of device data on structures that may be encountered in LE operational scenarios. This limitation is also reflected in the interpretation of device display data with no operator prior knowledge and associated training.

9.0 Recommendations

The NIJ AKELA ASTIR System represents a first generation product available for LE and First Responder application. Future product improvements should focus on:

1) collecting additional LE ASTIR user sense-through-the-wall personnel detection data in operational scenarios, 2) continual user training with updated user interface data interpretation, 3) integration of an adjunct optical (video) sensor, 4) deployment and synchronization of multiple ASTIR systems, and 5) evaluation of mobile and overhead ASTIR systems. Additional specific recommendations include:

- Several NIJ AKELA grant key objectives were not fully realized due to FCC certification schedule and scope requirements. This caused limited testing feedback and interaction with LE practitioners. This feedback and interaction was expected to play a key role in the ASTIR performance effectiveness and user operational deployment and field acceptance.
- Imaging data from complex targets suggest that further data analysis and signal processing software modifications could provide additional information on personnel detection and tracking. These efforts could provide valuable data and warrant further investigation.
- An optical adjunct sensor should be considered for integration into the current ASTIR system pre-production prototype. Real time video data has proved to provide significant value added in interpreting external building information in concert with internal radar sensor data.
- Multiple radar system deployment provides better cross range resolution for personnel detection in groups and concealed behind barriers. Multiple ASTIR deployments may also address personnel detection in multiple story structures. Additional development efforts and testing should be conducted to investigate performance characteristic and increased situational awareness with the use of integrated multiple ASTIR systems.
- AKELA's ASTIR has the ability to be used by both minimally trained and highly experienced personnel. This can be accomplished with the same hardware and software operating in a dual operational mode with a simple switch.
- DOJ should continue to leverage DOD technology (e.g., sensor systems and signal processing) investments for LE application. A significant amount of synergy is evident, and to that end NIJ and AKELA's DOD customers should interact for sense through-the-wall surveillance technology transfer and updates. Specifically, results from current (FY12-14) AKELA DOD contractual efforts, may provide significant improvements in detection algorithms, image interpretation, and multiple radar/optical signal integration that can be directly integrated into the LE ASTIR system to enhance performance. Additionally, the military development of multiple integrated sensor methodologies (e.g. radar, optical, IR, nuclear, and magnetic) to address complex LE and First Responders building interrogation should be evaluated and tracked.
- The LASD tactical training facilities provided significant ASTIR data for LE system performance evaluation. Additional complex building structure testing representing

operational encountered scenarios with the NIJ AKELA standoff system configurations should be conducted with continual user feedback.

- For program information dissemination, in addition to 6 month progress reports, AKELA and NIJ POCs conducted monthly telephone conferences to discuss program status and technical and programmatic issues and possible resolutions. The brief prepared by AKELA for these telecoms was provided to NIJ for redistribution. Due to NIJ programmatic issues, AKELA did not receive any on site visits by NIJ personnel for all NIJ efforts over all three grants and cooperative agreements FY07-CY12, (with the exception of an auditing person with the DOJ auditing team). This retarded face to face discussions and full disclosure of AKELA capabilities and hands on demonstrations of the ASTIR prototype and its performance capabilities. An NIJ visit would have increased program information dissemination to both NIJ technical monitors and management and served as an indication to AKELA staff supporting the challenging NIJ effort that NIJ management was supportive of AKELA's grant activities.

10.0 References

1 AKELA NIJ RRA Final Report <u>Through the Wall Standoff Detection and Tracking of Individuals</u>, 30 April 2012, DOJ NIJ Cooperative Agreement No. 2009-SQ-B9-K113, Period of Performance (Aug 2009- Apr 2012), NIJ POC Dr. Frances Scott.

2 AKELA NIJ Final Report Standoff through the Wall Imaging Sensor, 31 December 2009, Grant 2007-RG-CX-K016, Period of Performance (Dec 2007-Dec 2009), NIJ POC Dr. Frances Scott.

3 FCC Certification FCC IDENTIFIER: **ZZM-ASTIR3300** Name of Grantee: **AKELA Inc. Equipment class: Licensed Non-Broadcast Station Transmitter, Notes: Standoff trough-the-Wall Imaging Radar** FCC Waiver application confirmation No.2010920376580

Grant Notes **20 All electrical and mechanical devices employed for spurious radiation suppression, including any modifications made during certification testing, must be incorporated in each unit marketed;** FCC Rule Parts **90;** Frequency Range (MHZ) **3101.0 - 3499.0;** Output Watts **0.0316;** Frequency Tolerance **50.0 PM;** Emission Designator **NON**

<u>Power Output listed is EIRP. The Grant of Equipment Authorization is issued pursuant to Waiver issued per **ORDER DA 11-8170** issued November 9, 2011.</u>

<u>Device use is limited to state and local police and firefighters, and use is limited to actual emergencies involving threats to safety of life, and necessary training . Device may not be mounted on a fixed outdoor structure.</u>

3 Portable Through-The-Wall Imaging Radar For Urban Applications presented at the DOD Radar Technology Conference, Monterey CA, June 2011, AKELA authors: Allan Hunt, Mei Su Wu, and Patton Gregg. (NIJ approved for Conference Public Release)