Image formation through walls using a distributed radar sensor network†

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ABSTRACT

Interest in methods for obtaining surveillance information through walls has been increasing for both domestic and military security applications. While our previous through wall sensor development activities have demonstrated acceptable imaging performance by synthesizing a large antenna aperture from a portable, collapsible antenna array, these operational constraints have driven AKELA to a concept of operation where images are created by a distributed array of individual sensors. Each sensor is a high range resolution radar that can be either fixed in place or carried by an individual. The sensors are connected with a wireless communication network that distributes timing and control information, receives data, determines sensor location, and fuses the data from each sensor to generate imaging and motion detection information.

We have developed a frequency agile radar operating between 500 MHz and 2 GHz that is the sensor element in our networked concept. Its performance has been tested on a variety of wall materials. Results of these tests show that this new radar has the capability to detect the breathing response of a stationary individual through a reinforced concrete wall at a distance of 6.5 meters.

Keywords: Through the wall surveillance, stepped-frequency radar

1.0 INTRODUCTION

Military and law enforcement operations in urban terrain are difficult. Most applications of through wall sensing technology occur in building clearing or search operations and involve teams of people. For the military, the smallest unit of maneuver is a rifle squad containing a leader and 8 men organized into two fire teams of 4 men each. The two teams work as a unit with one providing cover while the other maneuvers.

Most current through wall system development is aimed at handheld sensors designed for use by a single individual. This type of implementation changes the way fire teams work as coordinated units, limiting situational awareness to a single individual, and requiring that the individual using the sensor lose control of his weapon during operation. Since the teams work in concert to achieve objectives, it makes sense to consider options where the sensor is distributed among the team members allowing each to have the same situational awareness and hands free for self protection.

With the support of NIJ/AFRL, AKELA has been developing a network centric through wall imaging sensor system that can be used for both small and large unit operations. The elements of our system are described in Figure 1. It consists of a distributed network of sensors that 1) enables small or large units to “see” through building walls and foliage, 2) provides individual and command elements individually tailored views of the battlespace, 3) provides command flexibility to deploy sensors as desired, and 4) allows sensing on the move.

Each sensor is a small, low cost, frequency agile radar that can be carried by an individual, mounted on a vehicle, or set in place. All sensors are connected with a wireless communication network that distributes timing and control information, receives data, determines sensor location, fuses the data from each sensor to generate imaging and motion detection

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information, sends processed results to both command element and individual displays, and allows sensors to be added or removed from the network. Frequency agility provides low probability of intercept, enhanced jam resistance, tailored range resolution, optimized material penetration capabilities, and the ability to avoid transmitting in critical operational frequency bands. Coherent detection preserves phase information that is useful for determining the presence of metal and the breathing response of a stationary individual. Moving sensors and random sensor array configurations enhance the ability to reduce ghost images and improve image resolution where needed. There is no single point of failure and loss of a sensor results in graceful degradation of performance. In this approach, the self organizing network IS the sensor.

Testing of our developmental system has confirmed its ability to detect both stationary and moving individuals through all types of common building walls in real time, and demonstrated the ability to implement a low cost, low weight, sensor using existing electronics technology.

2.0 DEVELOPMENT SYSTEM HARDWARE

The imaging sensor that AKELA has developed during the past several years has evolved from a portable fixed in place sensor, to its current form as a distributed radar imaging system as shown in Figure 2. The major elements of the system are 1) small, portable radar sensors carried by individuals, deployed on vehicles, and/or set in place, 2) a processing and fusion network, and 3) command and display computer.

The radar sensor is completely digitally controlled, hops at 10 μsec per frequency point, and can generate any frequency arbitrarily between 500 and 2000 MHz. This provides a low probability of intercept waveform, good jam immunity, user selectable range resolution, and a speed sufficient to generate coherent images suitable for using signal averaging to improve static imaging capability, and for detecting fast movement by coherent scene subtraction. Using the entire bandwidth of the radar provides a range resolution of 0.1 meter.

All of the sensor, processing, and display elements are connected through a wireless network. This network is used to provide timing and control to the radar sensors to preserve coherent detection, to allow sensor movement, to transmit data to the processing units, and to receive processed image information. Using wireless network technology allows sensors to be added or removed from the network giving it flexibility for use in different types of field operations.

Processing is performed by specialized nodes that determine sensor location, fuse sensor data into coherent images, and perform other signal processing functions. As fusion points, these nodes have the information necessary to enable command elements to reconfigure the sensor network, generate selectable views of the operations space, and deal with lost or unavailable sensor nodes. Figure 3 shows photos of a laptop computer used as both the display and fusion node, and a single wireless radar sensor node. Figure 4 shows the individual elements of the radar sensor node. It consists of a

Concept Elements	Characteristics	Enables
Distributed sensor nodes on individuals on vehicles set in place	Frequency agile radar Coherent detection Random array Stationary or mobile	Dismounted operations Standoff surveillance Resolution where needed
Processing (fusion) network timing and control sensor location data and results	Imaging and motion 3 dimensions Weapons detection	Sensing through walls Sensing on the move Hostile ID
Command and Display individual mounted operation control command	Global views Local views	Situational awareness individual command elements

Figure 1 - Characteristics of AKELA’s distributed sensor network.

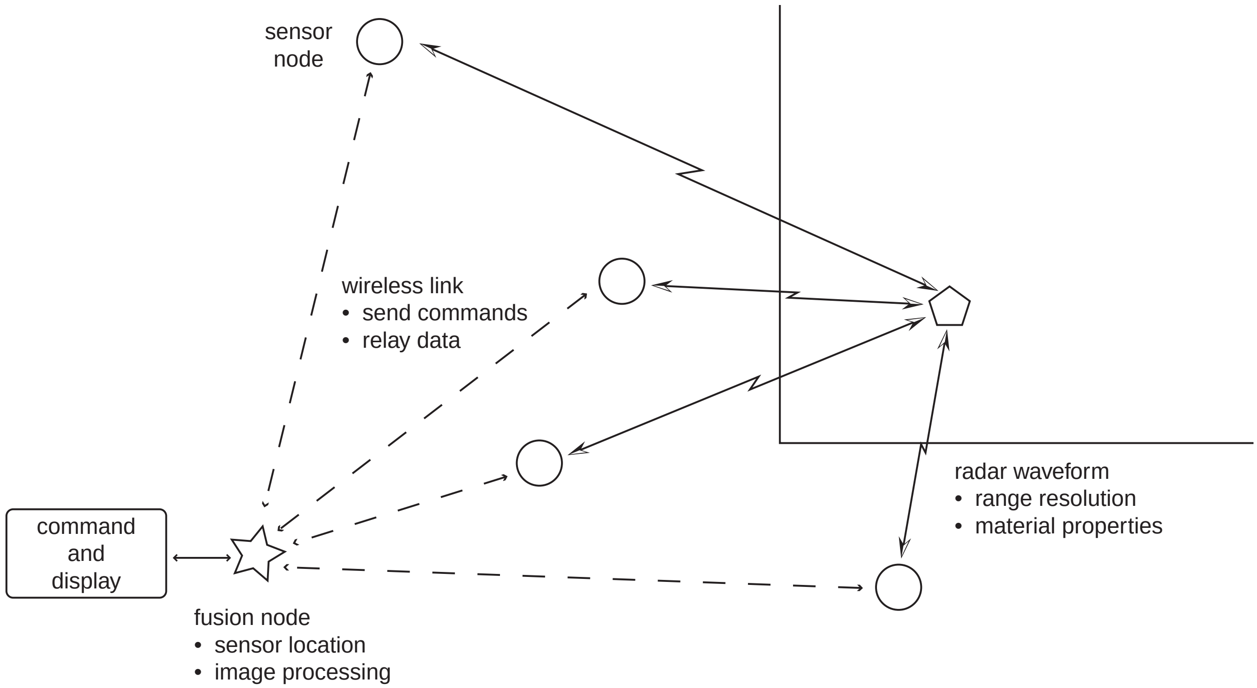

Figure 2 - Distributed radar imaging system diagram.

set of circuit boards that are 4” in diameter assembled into a stack that, including space for a battery capable of sustaining operation for 4 hours, is about 8” tall and weighs 2.5 pounds. The radar has been designed so that it is modular, isolating the radar to a single board and providing power conditioning and control interfaces separately. The control interface receives commands and sends back data over an Ethernet link at a rate of 4.096 Mbps. Special interfaces have been developed to enable wireless communication and different types of antenna configurations.

Figure 3 - Display/fusion node and wireless radar sensor node.

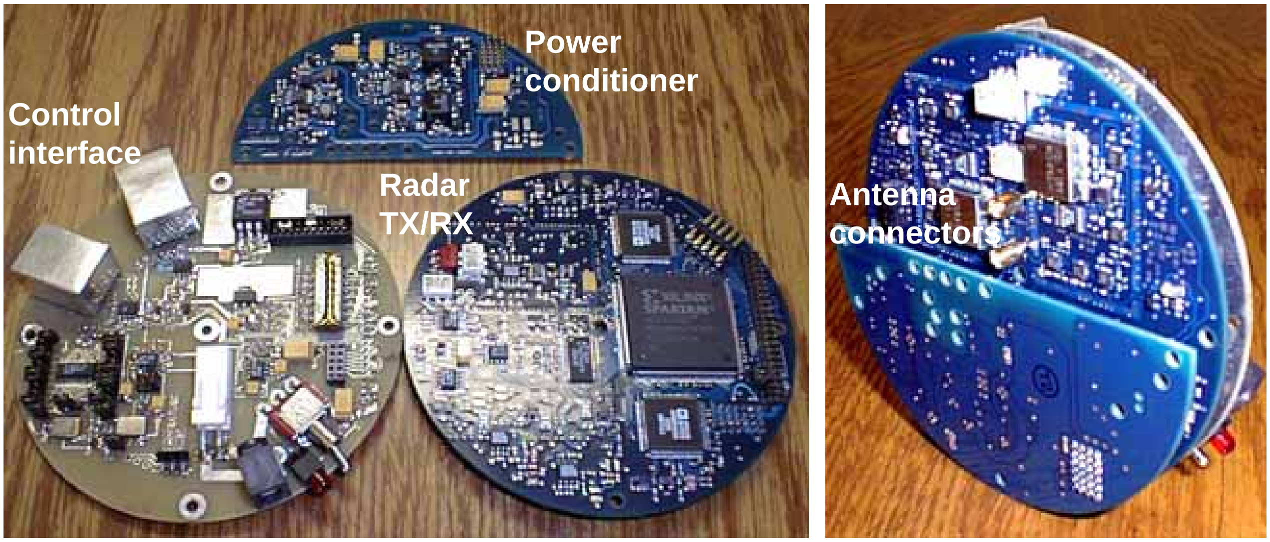

Figure 4 - Radar sensor node elements.

3.0 EXPERIMENTAL DATA

Recent experimental activities have been performed to explore the capabilities of our radar to detect large and small motions through wall types of operational interest at significant standoff distances. We performed extensive testing at a government wall facility and at various locations in the Santa Barbara area. Static tests were performed to characterize the electromagnetic material properties of the walls, and in an open field environment to provide data that was used to theoretically determine the detectability range of the radar and to determine the sensitivity of different motion detection algorithms. Analysis of the static data resulted in the generation of frequency dependent attenuation and dielectric constant curves for each of the wall types. Figure 5 shows a comparison of the frequency dependent attenuation characteristics for the five walls measured over the band of .5 to 2 GHz. The attenuation through the reinforced concrete wall was found to be more severe than earlier measurements made by Frazier[1].

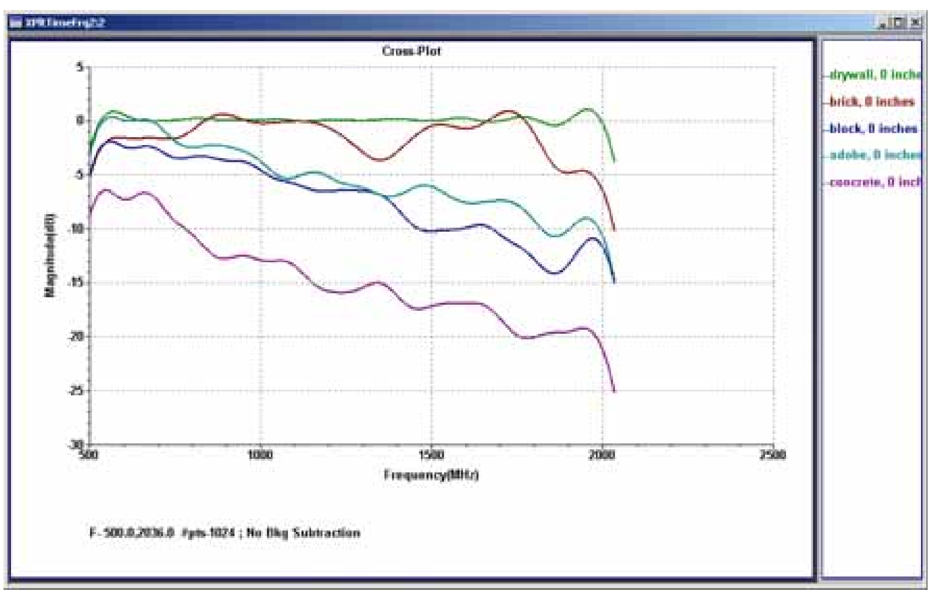

Figure 5 - Attenuation characteristics of different wall materials.

1. L. Frazier, “MDR for Law Enforcement”, IEEE Potentials, Vol. 16, No. 5, pp. 23 - 26, 1998

Dynamic testing was performed to test both large and small motion detection algorithms. It was found that both large and small motions could be detected at significant ranges through the walls of interest. Figure 6 shows a frame from a test where a person was sitting in a chair 12' behind a concrete wall with the antennas at a standoff distance of 10 feet. Even though the person was sitting as still as possible they are still clearly detected through their breathing. We have used the static and dynamic results from these tests to perform calculations of the expected performance of our development radar. Figure 7 shows a plot of the predicted probability of detection as a function of range for a person behind a 12" thick reinforced concrete wall.

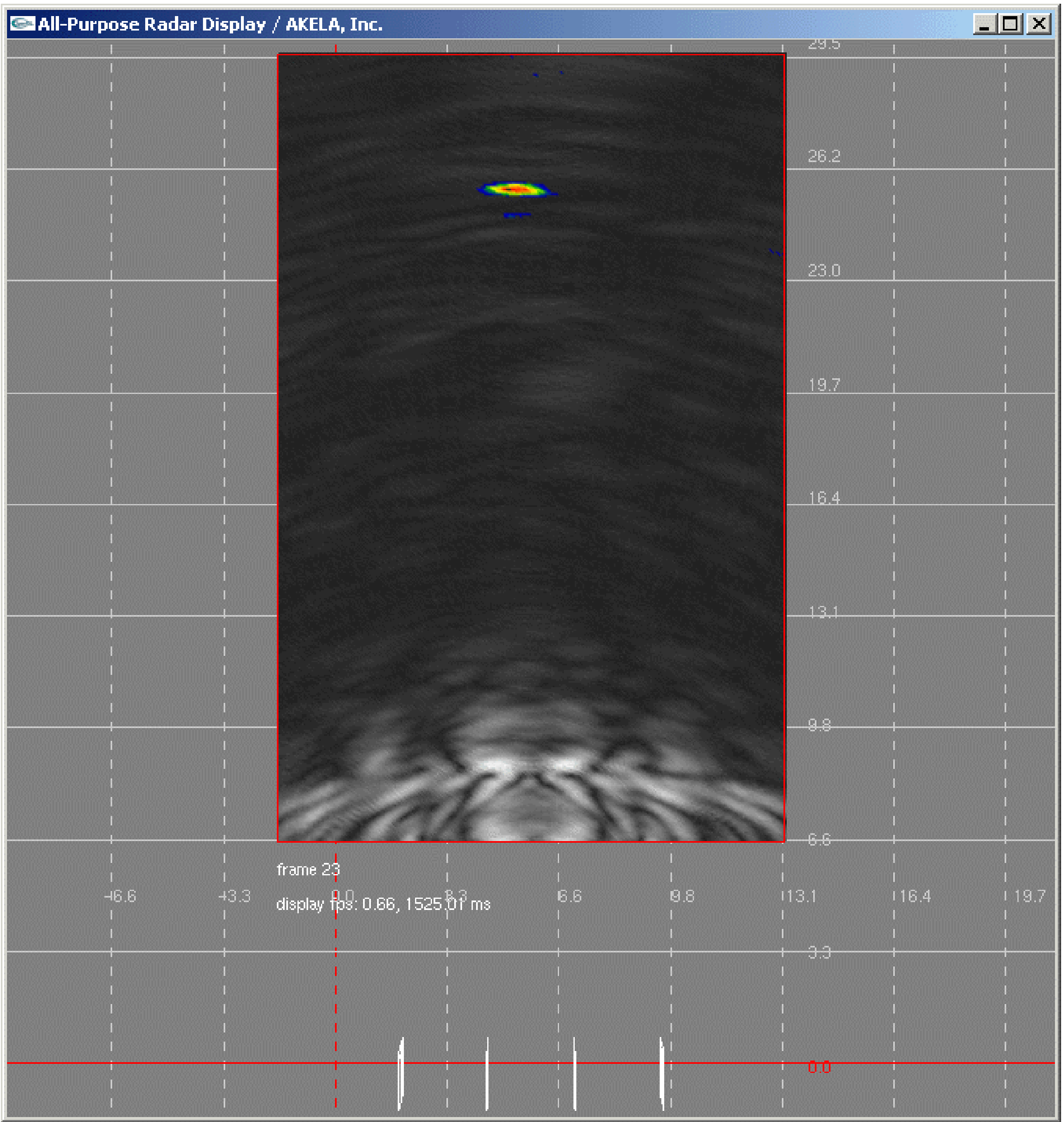

Figure 6 - Breathing signature of a person sitting 12' behind a concrete wall.

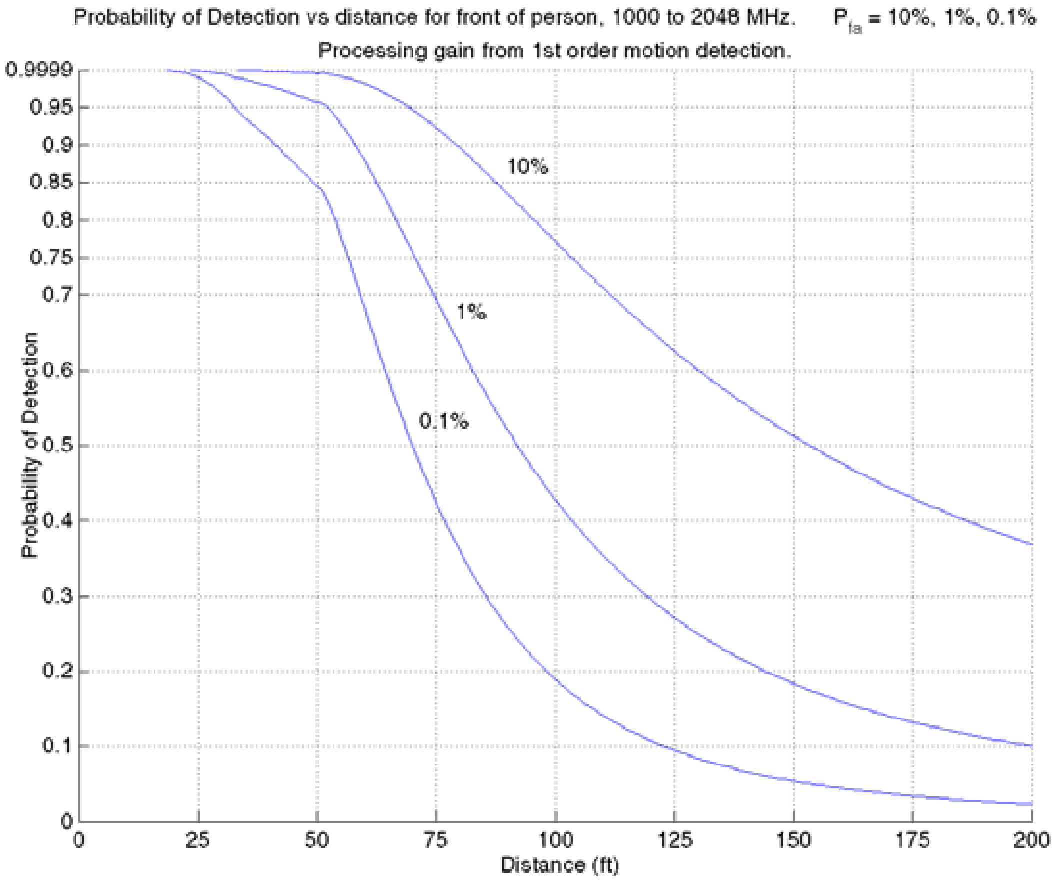

Figure 7 - Probability of detection of a person through a 12" reinforced concrete wall.

4.0 CONCLUSION

The data and images from our experimental activities have demonstrated that our radar sensor has the ability to image and detect both large and small motions through walls of operational interest at significant standoff distances. We have shown that it is possible to do this in real time using cost effective, commercial technology. And we have identified limitations in our current radar that can be changed to significantly enhance its performance. There are no fundamental physical principles that limit its success. The major technical issues are well understood. Commercial technology exists for implementing a robust system. The next significant milestone in our development will be integrating this radar sensor into our distributed imaging concept.