AN INTERACTIVE SOFTWARE FOR REAL-TIME SIMULATION OF THROUGH-THE-WALL IMAGING RADAR

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ABSTRACT

An interactive software written in Visual C# has been developed to provide real-time simulation capabilities for imaging behind the wall scenes. The software implements algorithms and techniques developed by the researchers at the Center for Advanced Communications in Villanova University, but is also amenable to house other imaging approaches. The software features a user friendly and flexible graphical interface that permits easy and interactive scene construction, from specification of the wall and array element locations to placement of objects at various locations behind the wall. All operations are performed using comprehensible dialog boxes and mouse drag-and-drop actions. For illustration, we present an example that demonstrates the usage of the real-time through-the-wall imaging radar simulator. The software serves as an educational tool for courses on radar imaging, introducing the students to the important emerging technology of through-the-wall imaging.

1. INTRODUCTION

With recent advances in both algorithm and component technologies, Through-the-Wall Radar Imaging (TWRI) is emerging as an affordable sensor technology supporting a variety of applications. “Seeing” the targets behind obstacles such as walls, doors, and other visually opaque materials, using microwave signals is considered as a powerful tool for a variety of applications in both military and commercial paradigms.

The TWRI is a complex and difficult problem that requires cross-disciplinary research in electrical engineering. Fundamentally, it is a hybrid between two main areas of image, statistical signal, and array processing on one hand and antennas and electromagnetics on the other. There are many technical challenges facing a TWRI system development, namely, the system should be reliable, portable, light weight, small-size, and has both short acquisition time and set-up time. The system performance should be robust to ambiguities in wall parameters and can properly function under non-uniform wall, multiple walls, and operator motion. Ultimately, the system should have high range and cross range resolution. Finally, the TWRI system must be able to detect and classify motions in a populated scene and in the presence of heavy clutter, which may include interior back and side walls, water pipes, electrical cords, and various types of furniture items.

Differences in construction techniques, available materials and expertise, and personal and cultural preferences can lead to substantially different EM environments. As such, performance can vary substantially from one building / region to another, rendering through-the-wall imaging and sensing a difficult and challenging problem.

Researchers at the Center for Advanced Communications (CAC) at Villanova University have developed and successfully applied algorithms and techniques to detect targets behind both known walls as well as walls with unknown characteristics, such as wall thickness and dielectric constant [1-2]. At Villanova, a comprehensive series of experiments on different behind the wall settings have also been successfully conducted and real data has been collected using an integrated state-of-the-art RF instrumentation suite [3].

In this paper, we describe an interactive software that has been recently developed at the CAC. The purpose of the software is dual-fold. On one hand, it is intended to be used as a tool for both pictorial and descriptive representations of the existing and new radar imaging algorithms and for displaying the respective images based on real experimental data. On the other hand, it provides a real-time TWRI simulator that allows the user to build a complete scene, starting with specifying the wall location and the antenna array size via dialog boxes, followed by a drag-and-drop

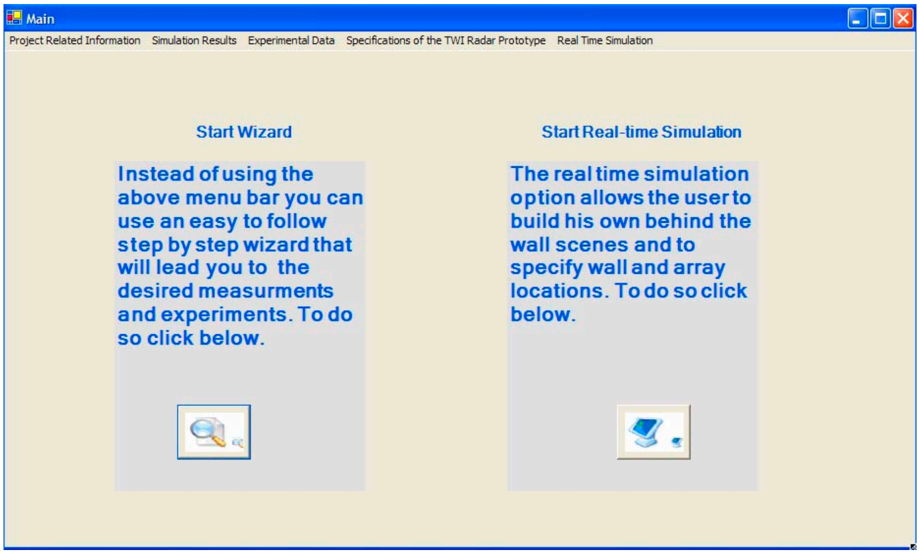

Fig. 1. Main Window

placement of the targets behind the wall. Finally, an image of the user specified scene using wideband through-the-wall beamforming is generated [1]. The data viewer and real time simulator not only provide the user various algorithms and techniques for through-the-wall imaging applications, but also allow the user to learn about the various trade-offs between array aperture size, imaging quality, standoff distance from the wall, and imaging performance. As such, this software can be used as an educational tool in courses on radar imaging, introducing students to the emerging technology of TWRI. We also envision it as a forum to support senior projects and graduate theses.

The software was developed in Visual C#, which is a relatively new programming language that inherits its syntax mainly from java and C++ [4]. It is the programming language of choice for designing Graphical User Interface (GUI), since it is simple to use and offers flexibility and quick algorithm development.

The paper is organized as follows. Section 2 presents a detailed description of the software and includes a flowchart of the display tool section of the software. It also includes an illustrative example of the usage of the real-time simulator. Section 3 contains concluding remarks.

2. DESCRIPTION OF THE SOFTWARE

This application has two main characteristics, user friendliness and modularity. User friendliness is assured through the comprehensible dialog boxes, buttons and icons. The object oriented nature of C# makes it easy to accommodate new updates, as everything is encapsulated into classes and methods. Thus, updating existing features or adding totally new ones can be easily accomplished by either editing few lines of the code within a method or class, or adding a new method or class within that code.

The software consists of two main parts: the "display tool" and the "real-time simulator". The former can be thought of as an archiving software; it provides the user with a full description of the project and provides access to the real data made available for download from a central repository on the Villanova University website (http://www.engineering.villanova.edu/research/cac/TWRI-experiments/index.htm). These options reside in the main menu of the main dialog box, namely under the *project related information* menu item. This tool is also used as means for viewing description and simulation results of various coherent and noncoherent techniques for TWRI. Photos of the experimental setup and the scene layouts for real data collection as well as the corresponding images can also be displayed. All of these features can be accessed either by navigating the main menu or through a wizard that loads as soon as the user clicks on the button under "Start Wizard" of the main dialog box, shown in Fig. 1. Figure 2 shows a flow chart, listing the different techniques to which the wizard provides a shortcut.

The Second part of this software is the real time simulator. The main window displays a large rectangular area representing a 12ft x 20ft room that is divided into a virtual grid with 154 vertical pixels and 97 horizontal ones, each pixel is a square with dimensions 0.126ft x 0.126ft. When the real time simulator starts, a window prompts the user to choose a wall location. The wall can be placed at either zero, three or six feet in front of the antenna array. The size of the antenna array needs to be specified next. The antenna array can be a uniformly spaced line array consisting of a minimum of four elements up to a maximum of 64 elements. Once this is done, the user can then select a target from the toolbar, shown in Fig. 3, which contains different icons representing a variety of targets one would typically find indoors. The user can select any of these

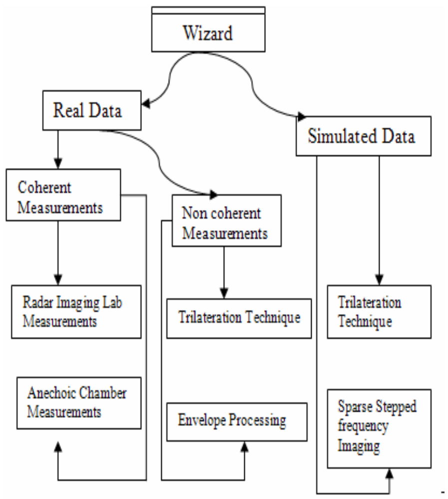

Fig. 2. Wizard's Flowchart

Fig. 3. Real-time Simulator toolbar

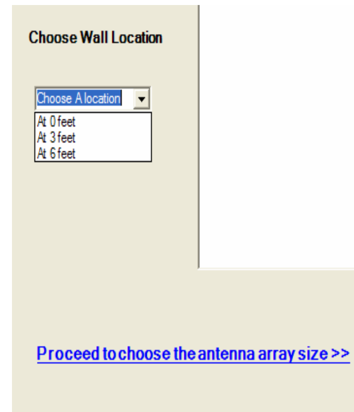

Fig. 4. Specify Wall Location

targets to be part of the scene; each chosen target can be specified to be either a point target or an extended target, in which case it will occupy more than one pixel in the grid. The targets can only be placed in the section of the room behind the wall. A warning message will appear if an attempt is made to violate this rule or if the user proceeds to build a scene consisting of a total of 80 or more target pixels. Each target will be assigned a location whose coordinates are determined by the screen coordinates of the drop location of the mouse. Once the scene is set up, the user can click the 'simulate' button. This will trigger the beamforming algorithm and generate the real and imaginary matrices corresponding to the complex image pixel values. The matrices will be saved to an Excel sheet, and MATLAB will then run and load the corresponding spreadsheet, compute the dB value corresponding to each pixel and finally display the image using our predefined function "*viewimage( )*".

The simulator provides the user with the opportunity to gain hands-on experience by varying certain system parameters and observing their effects on the imaging performance. For example, the size of the antenna array aperture can be varied to observe its effect on the cross-range resolution of the imaging system. Also, the simulator allows the user to study how the performance of the radar imaging system significantly changes as a function of the standoff distance of the array from the wall. Moreover, the user can also observe the difference in the images that result from considering an object as a point reflector or as an extended target. These features render the real-time simulator an excellent tool for learning about through-the-wall radar imaging.

2.1. Demonstrative Example

We now demonstrate the use of the real-time simulator. We describe the steps involved in building a scene and obtaining its through-the-wall radar image. To load the real-time simulator at startup, we click the button under *Start Real Time Simulation* in the main window. The first pop-up dialog box, shown in Fig. 4, asks the user to specify the wall location. It is noted that the wall can only be placed at specific locations in front of the antenna array. Next, the user will be asked to specify the size of the antenna array using a track bar, as shown in Fig. 5. The array size can vary from four to sixty four elements in increments of two. Once the wall location and the size of the array have been specified, the user can begin placing objects, chosen from the toolbar, in the specified rectangular area behind the wall. For illustration, we build the simple scene, depicted in Fig. 6, which consists of a chair at (4.8 ft, 19.5ft), a computer monitor at (-4.8ft, 16ft) and a sphere at (0ft, 18ft), all treated as point targets. We placed the wall at zero feet and we chose the antenna array to be an 18-element array. The beamformer output, generated by the real-time simulator, is displayed as a downrange vs. crossrange image in Matlab, as shown in Fig. 7. We can clearly see the three targets in the image at the expected locations.

3. CONCLUSIONS

In this paper, we have described the development and the functionalities of a software intended to be used as an educational and demonstration tool for through-the-wall radar imaging (TWRI). The TWRI is an emerging

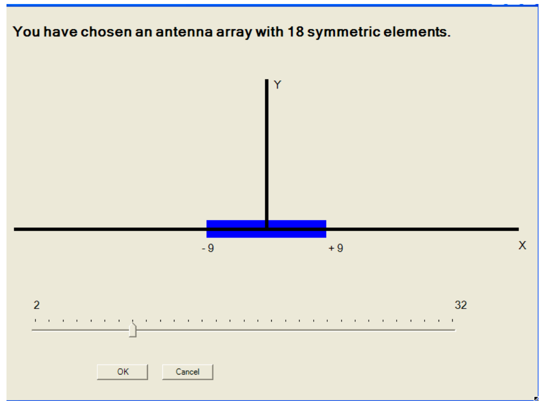

Fig. 5. Specify Antenna array size

technology, finding wide applications in the commercial, homeland security, and defense sectors. The software has an intuitive and user-friendly interface that allows the user to either simulate imaging of a scene using a radar system with certain parameters and to learn the effect of the chosen system parameters on the imaging performance or to use the display aspect of the software to learn more about the techniques and algorithms for TWRI under both known and less-than-cooperative propagation environments being developed at CAC radar imaging lab in Villanova University.

4. ACKNOWLEDGMENT

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5. REFERENCES

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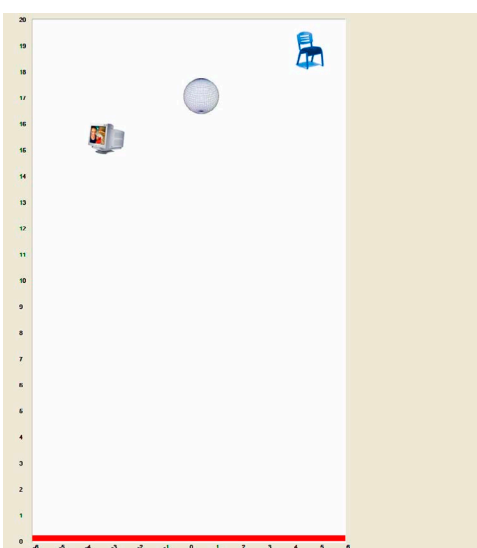

Fig. 6. Sample Scene

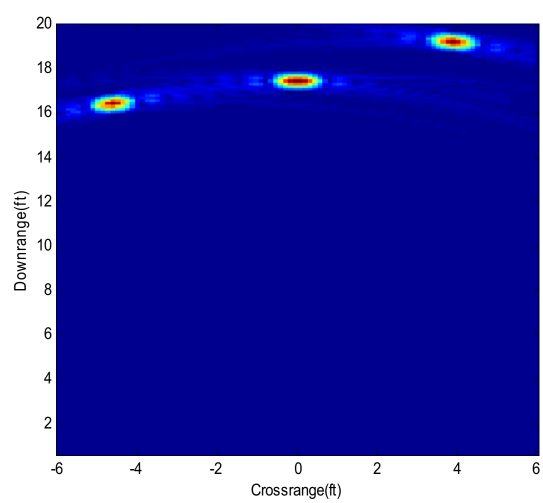

Fig. 7. Simulated Radar image