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Detection and Localization with an Acoustic Array on a Small Robotic Platform in Urban Environments

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1. Introduction

The U.S. Army is currently engaged in a dramatic transformation leading to an objective force that is more lethal, survivable, sustainable, and responsive to worldwide threats. In order to meet this objective, robotic systems will populate the battlefield and will exhibit a range of sizes and capabilities[1]. Unmanned systems will greatly enhance the soldiers of the objective force and are critical to keeping soldiers out of harm's way. The U.S. Army Research Laboratory (ARL) is developing technology that supports the Objective Force Warrior (OFW) and the Future Combat Systems (FCS) initiative which is the highest priority science and technology initiative for the Army[2]. The use of acoustic sensors on robotic platforms, as shown in this report, will greatly aid the FCS in performing numerous types of missions, including reconnaissance, surveillance, and target acquisition (RSTA).

This report discusses experiments in which the scenario was for a small mobile robotic vehicle to move throughout an urban environment in search of an acoustic event, namely, gunshots and other loud acoustic events, and to determine the location from the robot. Results from field experiments conducted at Ft. Sam Houston, Texas, the McKenna Military Operations in Urban Terrain (MOUT) facility at Ft. Benning, Georgia, and in Rockville, Maryland, are presented.

2. Procedure

Sophisticated robotic platforms with diverse sensor suites are quickly replacing the eyes and ears of soldiers on the complex battlefield. ARL in Adelphi, Maryland, has developed a robot-based acoustic detection system that will detect an impulsive noise event, such as a sniper's weapon firing or a door slamming, and will activate a pan tilt to orient a visible and infrared (IR) camera toward the detected sound. Once the cameras are cued to the target, on-board image processing can then track the target and/or transmit the imagery to a remote operator for navigation, situational awareness, and target detection. Such a vehicle can provide reconnaissance, surveillance, and target acquisition for soldiers, law enforcement, and rescue personnel and can remove these people from hazardous environments. ARL's primary robotic platforms contain 16-inch diameter, eight-element acoustic arrays. Additionally, a 9-inch array is being developed in support of the Defense Advanced Research Projects Agency's (DARPA's) Tactical Mobile Robots (TMR) program. The robots have been tested in both urban and open terrain. Figure 1 shows the robot with acoustic array and other RSTA sensors. Figure 2 shows the smaller 9-inch diameter array with small windscreens on seven of the eight miniature microphones positioned on an iRobot (formerly IS Robotics) urban robot.

Figure 1. iRobot ATRV-2 robot with RSTA sensors.

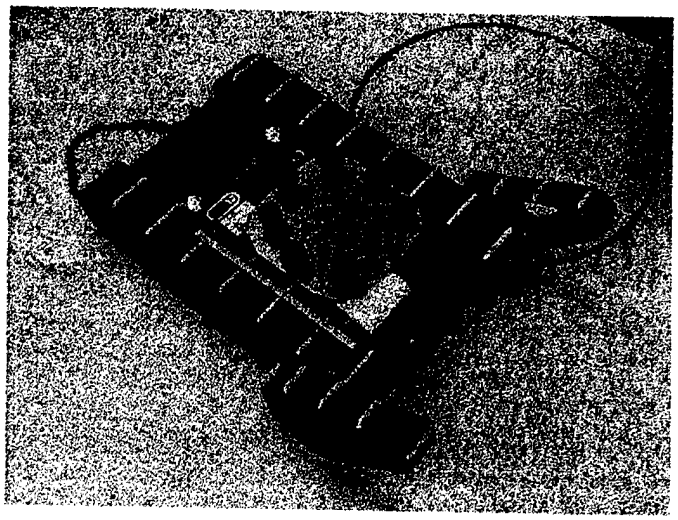

Figure 2. iRobot Urban Robot with 9-inch diameter array.

The current acoustic processing algorithm has been optimized to detect the muzzle blast from a sniper's weapon and reject many interfering noise sources such as wind gusts, generators, and self-noise. However, other detection algorithms for speech and vehicle detection/tracking are being developed for implementation on this and smaller robotic platforms[3].

The collaboration between two robots, both with known positions and orientations, can provide useful triangulation information for more precise localization of the acoustic events. These robots can be mobile sensor nodes in a larger, more expansive, sensor network that may include stationary ground sensors, unmanned aerial vehicles, and other command and control assets.

ARL's robotic vehicle uses acoustic microphones to detect and locate impulsive noise sources and steer a pan-tilt with both visible and IR cameras toward the noise. Transmitting thermal and visible imagery can help find the sniper or obscured person for interdiction, rescue, or training. Data fusion from robot, other battlefield sensors, and intelligence assets provides commanders with overall situational awareness. The robot can be remotely driven into dangerous environments while soldiers as well as fire, rescue, and law enforcement personnel are kept out of harm's way. One benefit of using acoustics is that the sounds travel through smoke or fog, around objects, and through foliage. The IR camera (Indigo Alpha) also provides the ability to drive in obscurants such as smoke, fog, or total darkness. ARL's acoustic sensor array consists of eight Knowles BL-1994 electret microphones in a 16-inch diameter array with 3-inch diameter windscreens. The windscreens reduce the effects of wind- and motion-induced turbulence detected by the microphones. An eight-channel preamplifier with anti-aliasing filters inside the robot body is matched to the microphones. An eight-channel PC card data acquisition card from National Instruments (DAQ-1200) is placed inside a PC card slot of a Toshiba Libretto hand-held computer. This small computer processes the acoustic data using algorithms developed at ARL with LabView software and provides the serial interface for the pan-tilt controller.

The algorithm calculates the azimuth and elevation to an impulsive noise source. The equations rely on timing of wavefront precession through three microphone combinations. With an eight-microphone array, 56 different three-microphone combinations are possible. The geometry is precisely known for each microphone triad. Equations from "Fundamentals of Sound Ranging"[4] are used to calculate an azimuth and an elevation solution for each of the 56 triads with the appropriate arrival times and geometry. The relationship between geometry and wavefront arrival direction is very predictable. If the acoustic wavefront arrival timing at a certain sound speed matches the calculated microphone separation, then the signal is coming from a direction in the plane of microphones. If the calculated distance is shorter than the actual geometry, that implies an elevated arrival direction—a decrease in path length by cosine(theta). The current algorithm assumes that no targets are coming from a negative elevation (below the horizontal) since the robot would be on the ground in a MOUT situation and most of the targets would be superelevated. This can be changed in future software revisions. Of the 56 solutions, a median value in both azimuth (AZ) and elevation (EL) is taken to remove any outliers that could be the result of extraneous noise, waveform modification because of defraction around the pan-tilt (in the center of the microphone array), multipath or reflection off the vehicle body itself. The resulting solution (a single AZ and EL) is compared to the "1st microphone hit," and logic within the algorithm determines a final solution to be sent to the pan-tilt server. Using a LabView-to-serial virtual interface, the code writes the final AZ and EL solution to the serial port of the Libretto, which goes to the pan-tilt controller box, and the camera turns. While the camera is turning to point in the direction of the impulsive source, the algorithm does not permit another capture in the current configuration, since the self-noise of the pan-tilt movement may be of a significant amplitude to create false alarms. The algorithm maintains the same look direction until another impulse triggers the capture algorithm or until a preset time-out sends the cameras

back to the vehicle front and level position. It still can be triggered while at the home position or at a previous look angle. An alternate mode of capture is to plot multiple lines of bearing (occurring in rapid succession, not simultaneously) on an operator's map display without cueing the pan-tilt. This allows for multiple shots to be captured and viewed with an omni-directional camera currently being integrated on the robot.

The current algorithm uses a predetermined threshold crossing to initiate capture and then cross-correlates the data captured slightly before and after the trigger to calculate times of arrival for all eight microphones. Previous versions of the algorithm merely used the peaks from the first impulse, but noise in the vicinity of the robot occasionally caused the algorithm to choose the wrong peak and give erroneous times for the azimuth and elevation calculations. The correlation approach uses the entire impulsive waveform in the cross-correlation to reduce the correlation effects of noises on the microphones.

The primary robot used during ARL's experiments (shown in Figure 3) was a commercially available ATRV-2 from iRobot. The vehicle was powered by four batteries and driven by four large direct current motors. The platform noise at rest came primarily from cooling fans. While the vehicle was in motion, the platform noise was primarily generated by the motors, the cooling fans, and the four pneumatically inflated rubber "knobby" tires. This relatively large vehicle was used for this experiment for several reasons. First, the large platform allows for much flexibility for implementing processing, sensor fusion, meteorology (MET) and communication options. The technique developed for this array will be used on reduced scale arrays that can be placed on smaller robots in the future, both wheeled and tracked (see future work section). Another reason that a relatively large robot was used was that we were also experimenting with concepts in which "daughter" ships deploy from the larger "mother ship"[1,5].

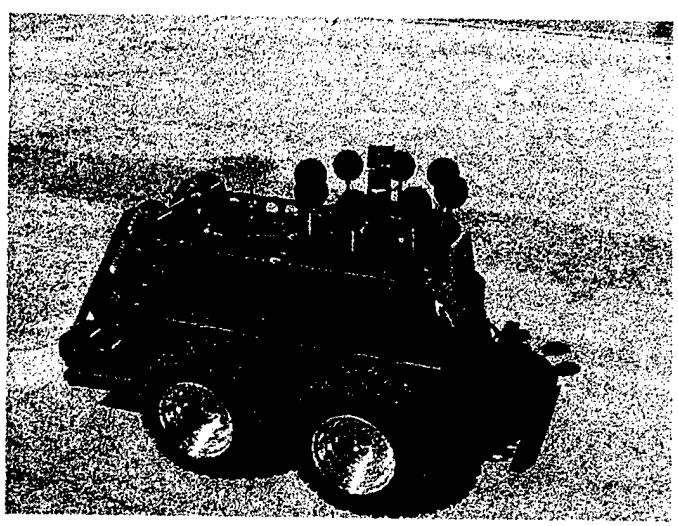

Figure 3. iRobot ATRV-2 with urban robot on dock.

3. Results

In this report, we discuss three experiments in which the robot was used to detect the location, in azimuth and elevation, of a sniper firing blanks in an urban environment. Once the sniper's location was determined by the acoustic array, the pan tilt and imaging sensors were cued.

3.1 Fort Sam Houston

The first experiment that we discuss took place in October 1999 at the old hospital (Bldg. 1000) at Ft Sam Houston, Texas, during an experiment with DARPA's Tactical Mobile Robotics (TMR) program. In this scenario, the robot was deployed to an alley behind the hospital where a sniper had shot a couple of soldiers (see Figure 3). Once the robot was in the alley, it was able to acoustically identify the location of the sniper on the rooftop of the hospital. During this experiment, the acoustic array successfully cued the visible camera to the location of the sniper. The robot's localization objective was for the sniper to at least be within the field of view (FOV) of the camera (25-degree FOV) and transmit the video to the soldiers who were waiting out of harm's way. Additionally, once the location of the sniper was determined, an iRobot Urban Robot was deployed from a dock on the back of the larger robot (see Figures 3 and 4). Once the information from both robots was used to determine the location of the rooftop sniper, the squad was able to conduct their counter sniper assault and continue with the rest of their intended mission.

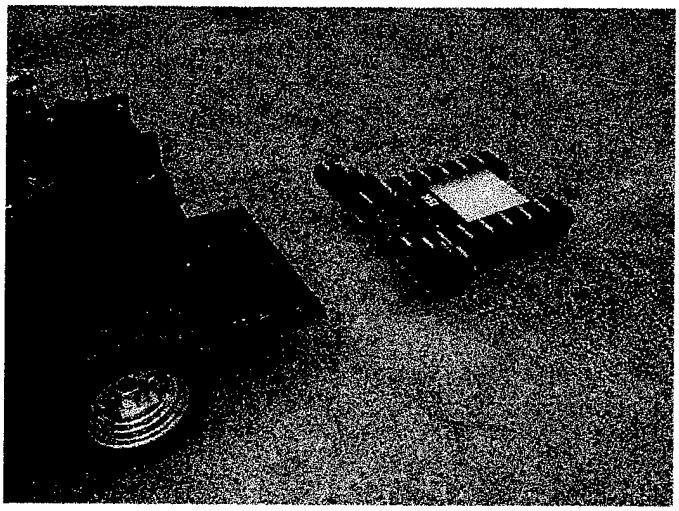

Figure 4. iRobot ATRV-2 with urban robot deployed.

3.2 McKenna MOUT facility, Fort Benning

The second experiment that we discuss took place in August 2000 at the McKenna MOUT facility at Ft Benning, Georgia. In this scenario, the robot was deployed from the woodline toward the MOUT city (see Figures 5 and 6). During the robot's approach, a sniper fired from a second story window. The visible and IR cameras on the robot were cued to the direction of the sniper. The IR image of the sniper was then transmitted to the squad leader, identifying the building from which the sniper fired. The squad leader then conducted his assault on the building. The IR camera that was used had a 15-degree horizontal FOV and an 11-degree vertical FOV. Because the sniper in some cases was no longer visible in the window by the time the IR camera slewed into position by the pan tilt, the squad leader at least had the building identified and was pleased with that amount of information to conduct his assault.

Figures 6 and 7 show photos of the experiment at the McKenna MOUT site.

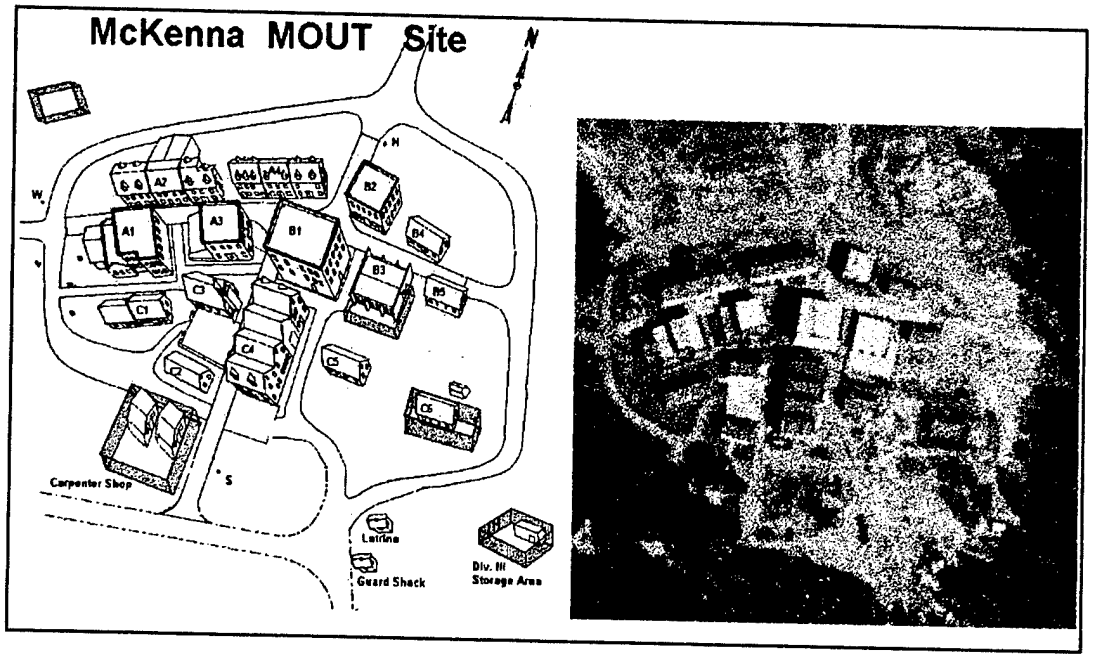

Figure 5. Map and overhead image of McKenna MOUT facility.

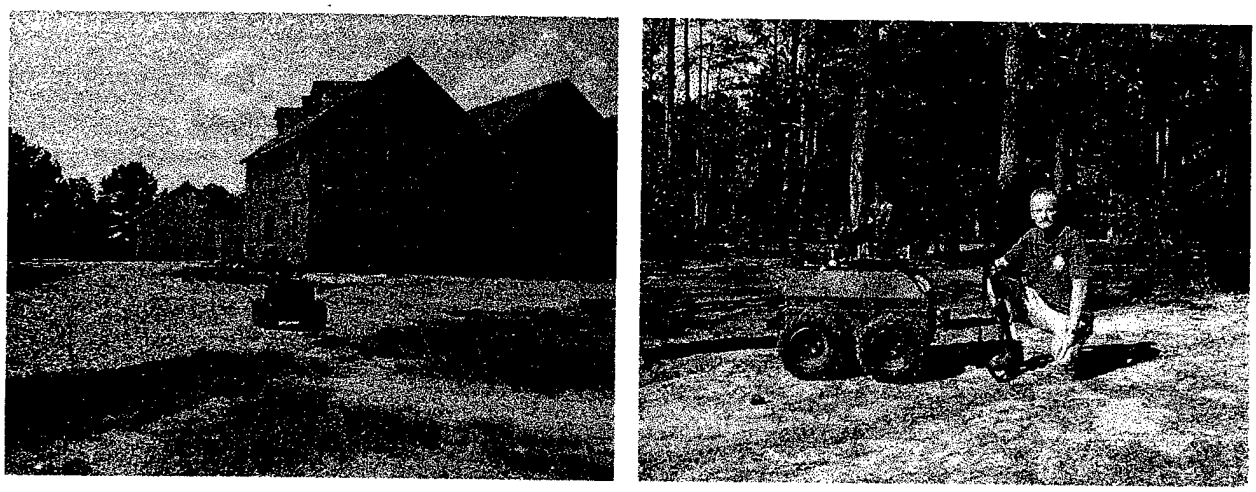

Figure 6. Photos of robot at McKenna MOUT facility.

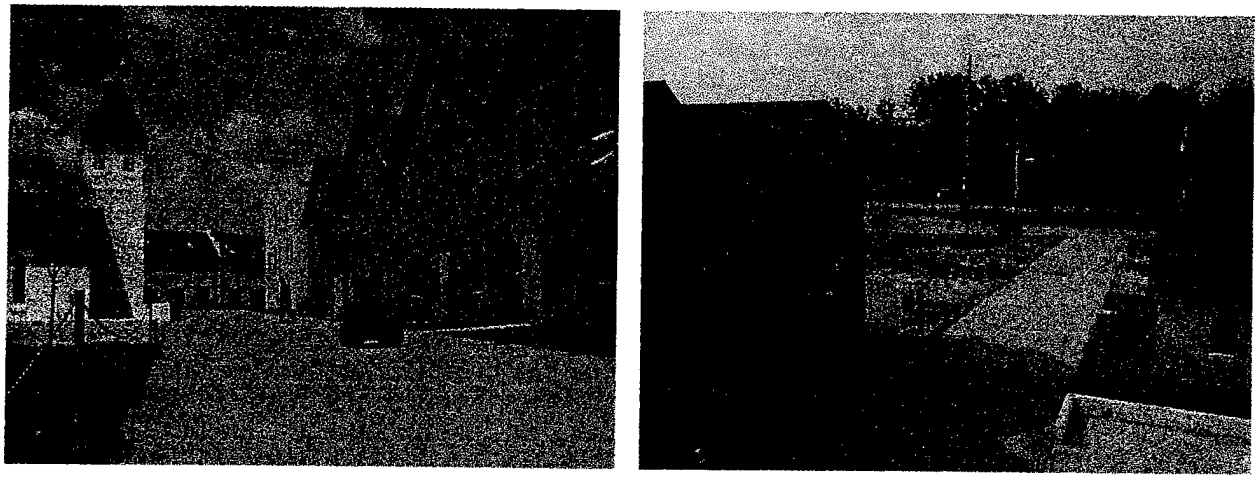

Figure 7. Photos of robot at McKenna MOUT facility.

3.3 Rockville, Maryland

The third experiment discussed in this report took place in September 2000 at the Montgomery County Public Service Training Academy in Rockville, Maryland, at the DARPA TMR experiment[6]. In this scenario, the robot was deployed from the woodline toward a six-story building (see Figure 8). During the robot's approach, a sniper fired from the top of the six-story building. Figure 9 shows the sniper's view. The visible and IR cameras on the robot were cued to the direction of the sniper. Both the IR and visible images were sent to the on-board RSTA processor (running the image-processing algorithm)[7]. Once the pan-tilt stopped at the position where the gunshot was identified, the image processing algorithm sent a single background frame to the operator, followed by image "chips" caused by any subsequent motion in the FOV. This approach of on-board RSTA processing greatly reduces the communications bandwidth required by the robot to alert the operator that it has detected a gunshot and the corresponding image.

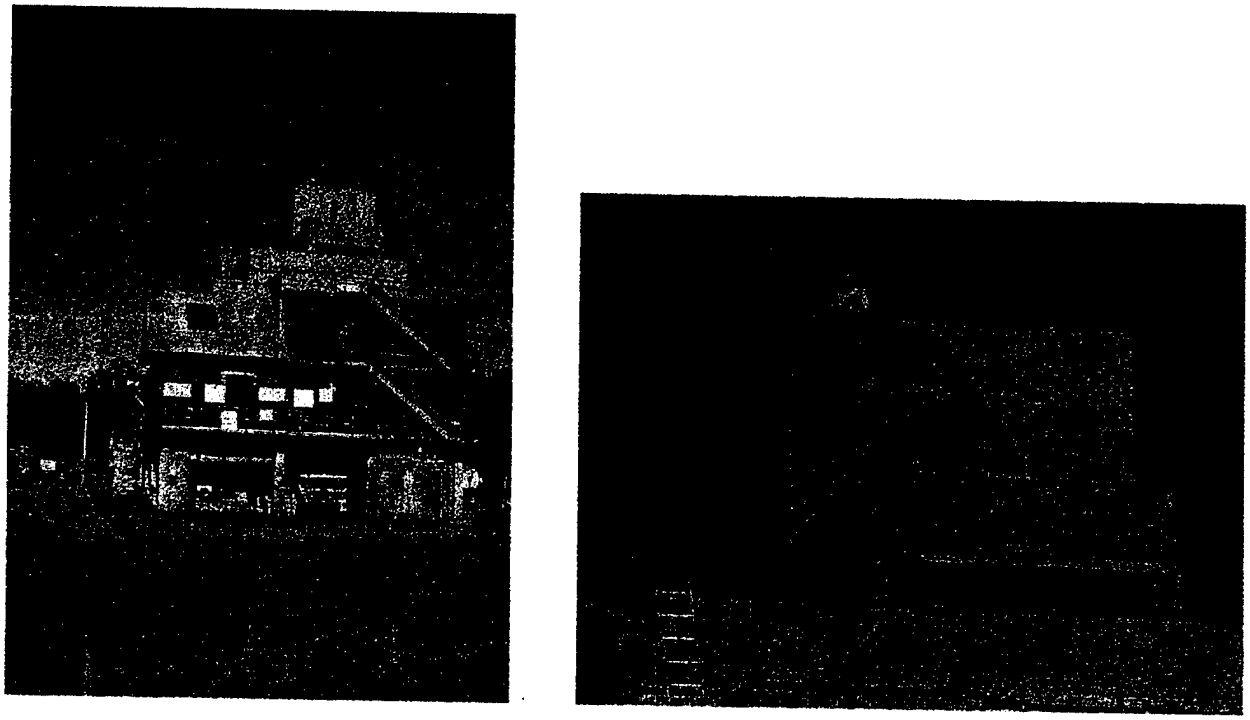

Figure 8. Police and fire training academy, Rockville.

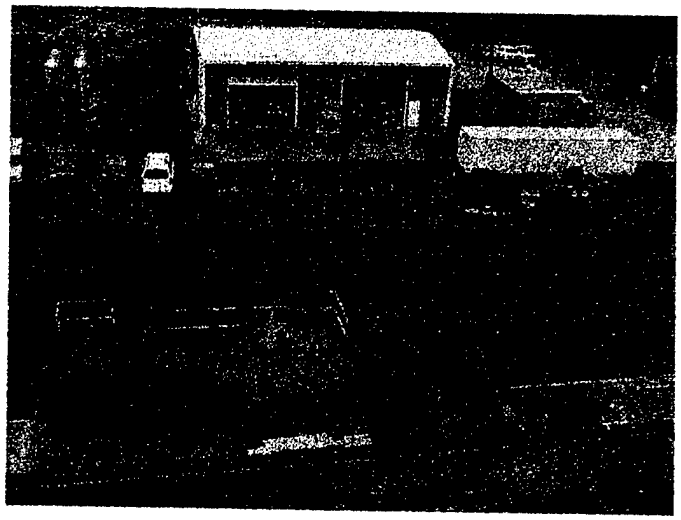

Figure 9. Sniper's view of alley, Rockville.

The IR camera that was used had a 15-degree horizontal FOV and an 11-degree vertical FOV. Once the camera was slewed to the direction of the sniper, the image-processing algorithm was able to continue tracking movement of the sniper. This experiment was also run at night, where the acoustic algorithm was unaffected, and similarly, the IR camera provided tremendously successful results that the visible camera was not able to duplicate.

During daylight experiments, approximately 30 shots were fired from the top of the six-story building in Figure 8. The temperature was 82° F with calm winds to 10-mph gusts. Both an M-16 and .30 caliber rifle were used with equally successful results. The robot was surveyed into

position with the sniper at exactly the 90-degree position at a range of 50 meters. The results were collected and statistical results were calculated, which yielded the following results: Average of 90.6 degrees; median of 90 degrees; standard deviation of 1.58; and a 95% confidence interval of between 89.6 degrees and 91.5 degrees.

The 95% confidence interval is well within our 15-degree horizontal FOV of the IR camera. During the data collection, two false alarms occurred in 27 shots. An elevated noise level or other ambient acoustic events (such as car doors slamming in the background) caused these false alarms. Eliminating these types of false alarms is one of the many refinements that are being worked on to develop a more robust algorithm.

In addition to the azimuth, the algorithm calculated the elevation. During the same test, elevation data were collected. The actual elevation from the robot to the sniper was 23 degrees (up from horizontal). The following are the results for elevation: Average of 19.8 degrees; median of 19.7 degrees; standard deviation of 2.76; and a 95% confidence interval of between 17.6 degrees and 22.0 degrees. This indicates that the elevation is consistently a couple of degrees low. This area requires more work in order to address the smaller vertical baseline of microphones. The current robot has the microphones mounted in a staggered pattern, creating a volumetric array, but more work is required to refine the elevation solution. However, even though the solutions were consistently low, the solutions were generally good enough to capture the sniper in the FOV of the IR camera.

Figure 10 shows the result from the IR image processing algorithm's detection of a walking human target and his thermal reflection off the floor. This indicates that although a person might be totally concealed from direct view, a reflection off a wall, floor, or object might reveal his position. Additionally, latent heat from where a person stood or lay for a short time can also provide useful data. Figures 11 and 12 give a comparison of the visible and IR images from the robot.

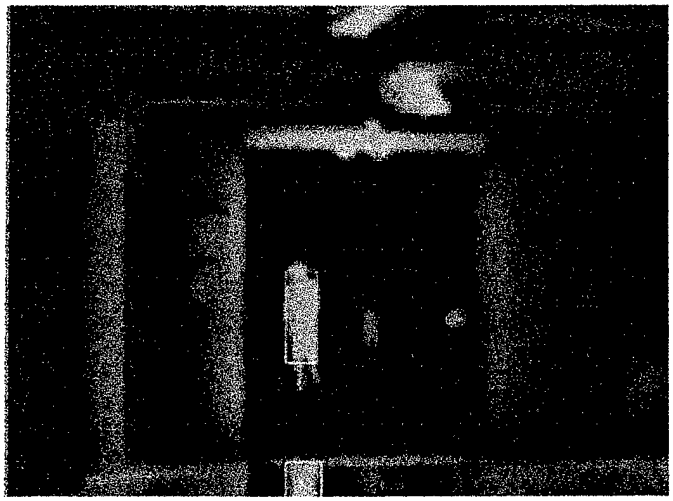

Figure 10. Image processing results.

4. Conclusion and Future Work

This report shows that the use of acoustic sensors on robotic platforms can provide tremendous benefits in the detection of targets, and when fused with other sensors, can be a powerful method for detecting targets and performing reconnaissance missions. While the results shown in this report demonstrate the usefulness of acoustics on small robotic platforms, the robustness of the algorithms must be improved in order for the system to be usable by soldiers.

In order to handle multiple shots from multiple locations, ARL is refining the algorithm to address multiple LOBs at nearly the same time. ARL is also incorporating more robust graphical displays for the operator to track multiple LOBs even though the current system is limited by the speed of the pan-tilt mechanism in slewing the cameras. ARL is also trying to use the same acoustic array presented in this report for speech detection inside an urban environment, to determine the direction to tanks, wheeled vehicles, and helicopters, and to further reduce the size of the arrays in support of the DARPA TMR program.

ARL is currently designing a 16-channel array that will perform similar functions on the iRobot "Packbot" platform. This array, undergoing development, will have 16 microphones flush mounted with the surface of the robot's body, which will not affect the mobility or cross section of the robot.

Additionally, ARL is working to eliminate and reduce the platform self-noise in an effort to detect and resolve a line of bearing to human speech by applying the improved quality target data to existing algorithms to detect the speech[8,3] and other acoustic events of interest[9,10]. Also, ARL is working to apply other acoustic identification, tracking and detection algorithms already in development for battlefield sensor arrays[11,12].

The algorithm presented in this report was meant to look at any impulsive noise crossing a threshold. These impulses could be door slams, a loud voice, or gunfire. The algorithm does not have the ability (at this point) to discriminate between a shock wave and a muzzle blast. If real bullets were shot at the robot, it would detect the conical shock wave and point normal to the shock cone. More than likely, it would miss the muzzle blast while the camera is moving. Future work can capture larger files that would contain both muzzle blast and shock and process it accordingly. Recent experiments in June 2002 at the small arms shooter performance research facility, Aberdeen Proving Ground, Maryland, have collected data and tested a refined algorithm that discriminates the shock wave impulse from the muzzle blast in an effort to identify a line of bearing to a target with live rounds.

The 16-inch array has been demonstrated at MOUT facilities and has detected muzzle blasts extremely well in both azimuth and elevation. Obviously, there is much to be gained in using smaller, more mobile robots. However, going to the smaller 9-inch array will require better

Figure 11. Comparison of visible image versus IR image of soldier with gun.

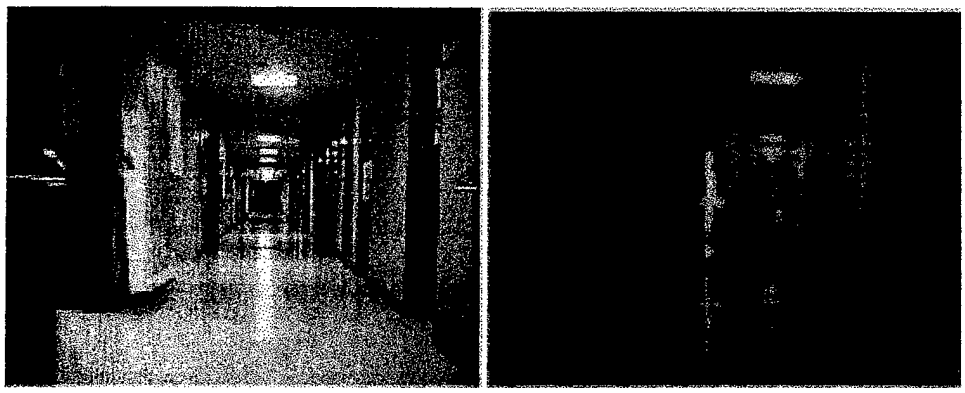

Figure 12. Comparison of visible image versus IR image of soldier hiding in hall.

The Rockville experiment also demonstrated the collaboration between two robots with known locations (surveyed locations for this experiment, but global positioning system [GPS] or differential GPS in the future) to triangulate the lines of bearing from each robot and determine the exact location of the sniper with just acoustic sensors. In this experiment, we took some measurements from two robots simultaneously in an effort to triangulate the location of the sniper. For this experiment, the range from the first robot to the sniper was 40 meters horizontally and the range from the second robot to the sniper was 46 meters horizontally. The elevation of the sniper from the ground was 20 meters. The distance between the two robots was 63 meters. Using the localization accuracy values shown so far, one could expect an area of approximately 1 square meter (using a 95% confidence interval) for the location of the sniper during the best conditions at a range of 40 to 50 meters from each robot. However, this is assuming that the exact location and orientation of the robots are known and the lines of bearing (LOBs) are nearly orthogonal; the estimated area will be larger at longer ranges. If one assumes that the LOB from each robot is a conservative ±5 degrees, then at a range of 40 meters, the estimated target area would be 16 square meters, with further results pending. Nevertheless, this approach shows great potential, which we plan to continue pursuing, including errors in the baseline between robots from GPS.

accuracy of timing for wavefront arrival to maintain good localization. It also will provide a smaller baseline for detection and localization of low frequency targets such as tanks, vehicles, and facilities.

In addition to using only robots for acoustic detection, ARL has conducted experiments using a ground-based distributed sensor network to detect and track vehicles such as tanks and wheeled vehicles. Once the vehicles are tracked, the robots can be sent to verify the target via their acoustic and imaging sensors, and the results can be passed to an operator with a 2D or 3D map display or to a Land Warrior or Objective Force Warrior outfitted soldier. The integration of distributed sensor networks[11,12], soldier/robot teaming, 2D/3D visualization interaction with robots, and collaborative robots is the focus of current and future research at ARL[13].

References

1. P. Emmerman, S. Young, P. Budulas, and R. Winkler, "Mother Ship and Physical Agents Collaboration Concept," Proc. Advanced Manufacturing in the Automotive Industry, 32nd ISATA, pp. 35–42, June 1999.
2. A. Michael Andrews and T. Killion, "Accelerating the pace of Transformation," Army A.L.&T. Journal, Ft. Belvoir, VA, pp. 13–16, March-April 2000.
3. S. Young and M. Scanlon, "Robotic Vehicle uses Acoustic Sensors for Voice Detection and Diagnostics," Unmanned Ground Vehicle Technology, Proc. of SPIE 4024-10, April 2000.
4. COL (Ret) Arthur R. Hercz, "Fundamentals of Sound Ranging", U.S. Army Field Artillery.
5. S. Young, P. Budulas, and P. Emmerman, "Mother Ship and Physical Agents Collaboration," Unmanned Ground Vehicle Technology, Proc. of SPIE, pp. 224–232, April 1999.
6. R. Lopez, "DARPA Develops Tactical Robots for Dirty and Dangerous Missions," Unmanned Systems, Vol. 19, No.1, pp. 12–13, Jan/Feb 2001.
7. P. David, "Real-Time target Acquisition for the Army's Scout Mission," Proc. SPIE, Acquisition, Tracking, and Pointing X, Vol. 2739, April 1996.
8. S. Young, et. al., "RSTA for Small Rovers in Urban Warfare," ARL-TR-1678, May 1999.
9. M. Scanlon, "Long-Range Hearing," Proc. Tactical Technologies and Wide Area Surveillance International Symposium, Chicago, IL, pp. 327–339, November 1993.
10. S. Young, P. Budulas, P. Emmerman, and M. Scanlon, "RSTA Sensing on Small Rovers in Urban Environments," Proc. IRIS Acoustics and Seismic Sensing, 1998, Vol. 2, pp. 79–98, March 1999.

11. N. Srour and J. Robertson, "Remote Netted Acoustic Detection System," ARL-TR-706, May 1995.

12. T. Pham and B. Sadler, "Adaptive wideband aeroacoustic array processing," 8th IEEE Statistical and Signal Processing Workshop, June 1996.

13. S. Young, P. Budulas, and P. Emmerman, "Reconnaissance, Surveillance, and Target Acquisition (RSTA) Using Small Physical Agents," Proceedings for Association of Unmanned Vehicle Systems 27th Annual Symposium and Exposition, July 2000.

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13. ABSTRACT (Maximum 200 words)

Sophisticated robotic platforms with diverse sensor suites are quickly replacing the eyes and ears of soliders on the complex battlefield. The U.S. Army Research Laboratory (ARL) in Adelphi, Maryland, has developed a robot-based acoustic detection system that will detect an impulsive noise event, such as a sniper's weapon firing or a door slamming, and will activate a pan tilt to orient a visible and infrared camera toward the detected sound. Once the cameras are cued to the target, on-board image processing can then track the target and/or transmit the imagery to a remote operator for navigation, situational awareness, and target detection. Such a vehicle can provide reconnaissance, surveillance, and target acquisition for soldiers, law enforcement, and rescue personnel and can remove these people from hazardous environments. ARL's primary robotic platforms contain 16-inch diameter, eight-element acoustic arrays. Additionally, a 9-inch array is being developed in support of the Defense Advanced Research Project Agency tactical mobile robot program. The robots have been tested in both urban and open terrain. The current acoustic processing algorithm has been optimized to detect the muzzle blast from a sniper's weapon and to reject many interfering noise sources such as wind gusts, generators, and self-noise. However, other

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