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Intelligent Targeting for a Remotely Operated, Rapid Aiming Weapon Platform

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Abstract

Sandia National Laboratories has been investigating the use of remotely operated weapon platforms in Department of Energy (DOE) facilities. These platforms offer significant force multiplication and enhancement by enabling near instantaneous response to attackers, increasing targeting accuracy, removing personnel from direct weapon fire, providing immunity to suppressive fire, and reducing security force size needed to effectively respond. Test results of the Telepresent Rapid Aiming Platform (TRAP) from Precision Remotes, Inc. have been exceptional and response from DOE sites and the U.S. Air Force is enthusiastic. Although this platform performs comparably to a trained marksman, the target acquisition speeds are up to three times longer. TRAP is currently enslaved to a remote operator's joystick. Tracking moving targets with a joystick is difficult; it dependent upon target range, movement patterns, and operator skill. Even well-trained operators encounter difficulty tracking moving targets. Adding intelligent targeting capabilities on a weapon platform such as TRAP would significantly improve security force response in terms of effectiveness and numbers of responders. The initial goal of this project was to integrate intelligent targeting with TRAP. However, the unavailability of a TRAP for laboratory purposes drove the development of a new platform that simulates TRAP but has a greater operating range and is significantly faster to reposition.

Intelligent Targeting for a Remotely Operated, Rapid Aiming Weapon Platform

1 Background

This report discusses the development of automated, intelligent targeting capabilities for the weapon platform that integrates machine-vision-based tracking with sensor- and model-based control. These developments off-load low-level targeting details, allowing an operator to focus on the immediate threat before deciding whether or not to issue firing commands. The results of processed video images are used in lieu of a joystick to automatically manipulate the platform's pointing angle and keep the target within the weapon's sights. Video from the system provides immediate assessment capabilities for the operator to determine the appropriate response.

2 Weapon Platform Development

A laboratory setup of a weapon platform was designed and built for algorithm development. The laboratory setup is shown in the Figure 1 below. A specially designed shooting bench was constructed to mount the platform. The shooting bench simplifies calibration and allows for consistent and repeatable operation of the targeting platform. A high-speed pan and tilt assembly is used as the basis of the platform. Mounting hardware was added to the pan and tilt and limit switches were installed to provide safety limits on the rotational movement of the gimbal. A paintball gun was modified for mounting on the pan and tilt. A frame grabber is used to acquire live video from a small CCD camera that is mounted on the gun barrel. A solenoid was also added to the gun to control the trigger mechanism. The pan and tilt movement, the video processing, and the trigger action of the gun are controlled through our software on a single PC. Also shown in the picture to the right is the chronograph that was used in the determination of the ballistic model. The gun is pointing through the chronograph at a target backdrop that was specially built to trap paintballs. A PHS was written to support this setup and a weapons safety class was given by the Central Training Academy to all individuals involved in the project.

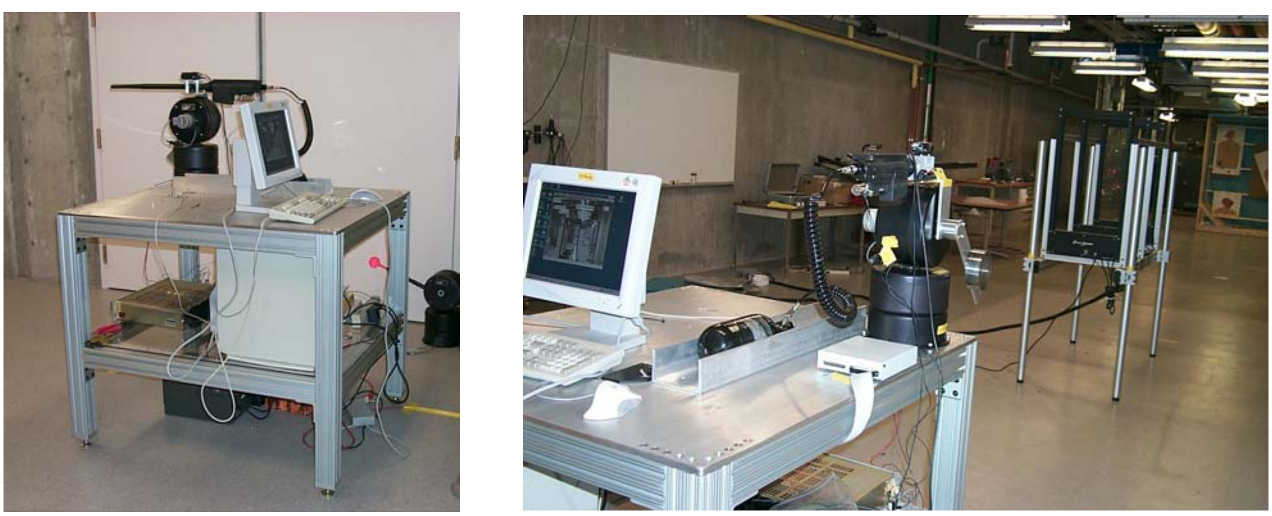

Figure 1. Laboratory setup of weapon platform used for algorithm development

2.1 Weapon Calibration and Target Acquisition

One of the first problems for intelligent targeting to be solved was to find the optimal sighting distance of the gun. This is necessary to accurately locate the line-of-sight pixel that is required to calibrate the system and to determine the pixel position of the target at the instant of fire to guarantee an accurate hit. A representation of the problem is shown in Figure 2.

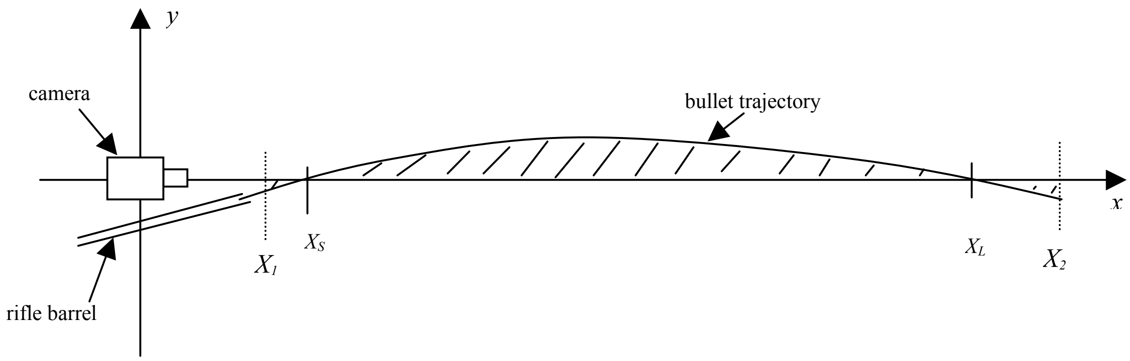

Figure 2. Calibration of the system to determine a line-of-sight pixel

The *x* axis is the line-of-sight of the camera mounted on the gun barrel and the *y* axis is the distance above or below the line-of-sight. The bullet chamber is defined at $x = 0$. The short range sighting distance is given by X_S and the long range sighting distance is given by X_L. The optimal sighting distances minimize the hashed area between the bullet trajectory and the line-of-sight over the designated range of fire, which is defined between X_1 and X_2. The kinematic models for the bullet under the influence of air resistance were selected to be the following:

$$x = x_0 + v_{0x}t + \tfrac{1}{2}a_xt^2 \qquad \text{and} \qquad y = y_0 + v_{0y}t + \tfrac{1}{2}a_yt^2 \tag{1}$$

where x_0 is assigned at $x = 0$, y_0 is the distance from the bore center to the line-of-sight at $x = 0$, v_{0x} and v_{0y} are the horizontal and vertical components of muzzle velocity, a_x is the acceleration of the bullet, a_y is the acceleration of gravity, and *t* is time in seconds. Using a substitution of *t* in terms of velocity, the *x* model can be written as an equation of a line that is a function of *x*:

$$v^2 = 2a_xx + v_{0x}^2 \tag{2}$$

A chronograph was used to find the unknowns v_{0x} and a_x. Data was acquired for the speed of the paintballs, *v*, at varying distances from the platform, *x*. The data was plotted as a straight line indicating that the model over the projective range was good. The parameter values were determined to be v_{0x} = 283 feet/second and a_x = -284 feet/second^2. The unknown parameters in the *y* model are v_{0y} and a_y. The acceleration due to gravity, -32 feet/second^2, is assigned to a_y and v_{0y} was optimized to provide the flattest trajectory in a least squares sense. The optimal sighting distance for the paintball gun was found to be 5 yards at the short range and 20 yards at the long range.

One of the most important issues that affects the performance, accuracy, and practicality of the intelligent targeting system is the calibration of the platform. The calibration parameters incorporate scaling, rotation, and translation between the sensor and the platform coordinate systems. A mathematical model was selected to represent the change in azimuth and elevation positions of the pan and tilt with respect to the x and y pixel coordinates of the video screen. This model assumes that the camera axis is oriented at the zero position of the tan and tilt. With this assumption, the line-of-sight of the camera accounts for the roll, pitch, and yaw angles (θ, Φ, Ψ) of the camera in relation to the barrel of the gun. Figure 3 illustrates this relationship.

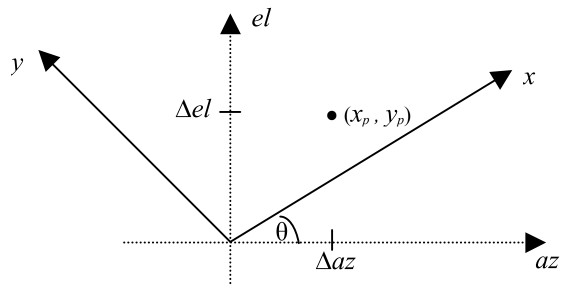

Figure 3. Mathematical model of parameter selection

Here, Φ and Ψ are 0 and (x_p , y_p) is the target pixel position. The change in azimuth, Δ*az*, and the change is elevation, Δ*el*, from the line-of-sight position can then be derived to be as follows:

$$\Delta az = ax_p + b\,y_p \quad \text{and} \quad \Delta el = ay_p - bx_p \tag{3}$$

To select the parameters of the model, *a* and *b*, the line-of-sight pixel was located by shooting a target at the optimal sighting distance derived earlier. Several targets were selected and the (*x, y*) pixel locations and azimuth and elevation positions to each target from the line-of-sight were measured. A least-squares solution was found to assign the parameters of the calibration model. The resulting assignments are *a* = 4.579669 and *b* = 0.004545. The pictures in Figure 4 show an example of a validation of the calibration procedure. The image on the left shows the view from the on-board camera with red crosshair over the line-of-sight position. The selected target location is shown on the image with a blue circle. The second image shows the view from the on-board camera after the command to move the pan and tilt to the target location was executed. Note that the line-of-sight crosshair is now over the selected target location. Although this illustration shows the execution of a relatively small movement of the pan and tilt, the system is capable of moving the gun over a 180º azimuth range and a 90º elevation range. Switches were added to the pan and tilt assembly as a safety precaution to limit these ranges.

Figure 4. Validation of the calibration procedure

The capability of tracking a moving target is being integrated into the system. An off-board sensing system, based on video motion detection technology is used to provide site monitoring and position estimates concerning the location of detected targets. It provides sub-second updates necessary for monitoring humans and moving targets. Tracking algorithms provide target velocity information that is used in the kinematic model of a moving target with respect to time. This model is as follows:

$$x_t = x_{t0} + v_t t \quad (4)$$

where x_t is the target position at the time that the bullet is fired, or $t = 0$, and v_t is the target velocity in feet/second. With the appropriate translation, the model of the target can be expressed in terms of pixel coordinates as follows:

$$xp = xp0 + vpt \quad (5)$$

where x_{p0} is the pixel position of the target the firing instant, and v_p is the target velocity in pixels/sec. The target model and the x and y models of a projectile described previously are used to derive the target position in pixels at the instant of fire:

$$xp0 = - vp*d / vb \quad (6)$$

where v_p is the target velocity in pixels/sec, v_b is the average velocity of the bullet over the range of fire and d is the distance to the target as it crosses the line of sight. The value of v_p comes from the onboard sensor (i.e., camera on the weapon) and v_b is derived from the projectile model. The video motion detection algorithms provide the value of d. With these equations, we can accurately hit a moving target.

The acquisition of a target is based on the processed video from the on-board and/or off-board cameras. Motion detection and tracking are performed on the video images and a command to shoot is sent to the weapon at the calculated time to hit the target. There are two approaches taken for controlling the weapon when an object is tracked. First, the line of sight of the weapon is fixed. When a moving target enters the field of view and is tracked, the weapon is fired only if the target moves in the line of sight position. Second, the weapon is commanded to move with the moving target, keeping the target in the line of sight of the weapon at all times. A command to fire the weapon is provided according to the application.

2.2 Intelligent Targeting Demonstrations

The developed algorithms provide the basis for the intelligent targeting software. The laboratory system currently has several modes of operation. The first is a “point and shoot” mode in which the operator views live video input from the on-board camera (mounted on top of the weapon) through the computer monitor. The left mouse button is used to select and shoot a target. When the operator clicks on a location in the image, the platform will rapidly move to the position in which the selected target location is lined up with the weapon’s line-of-sight. Once the platform completes its move, the weapon will shoot. The two screen shots in Figure 5 show the current system user interface and illustrate the point and shoot mode of operation. The red crosshair in the pictures indicates the current line-of-sight position of the weapon. A green crosshair reflects the movement of the mouse. In the top picture, the operator has placed a target crosshair (green) on a target position in the image (upper right pop-up target) by moving the mouse. Once the operator “clicks” the left mouse button, the platform immediately positions itself to place the selected crosshair position in the weapon’s line-of-sight and the weapon fires. The picture on the right shows the image after the weapon has fired and the target is falling. Notice that the new line-of-sight crosshair (red) is positioned at the location selected by the operator.

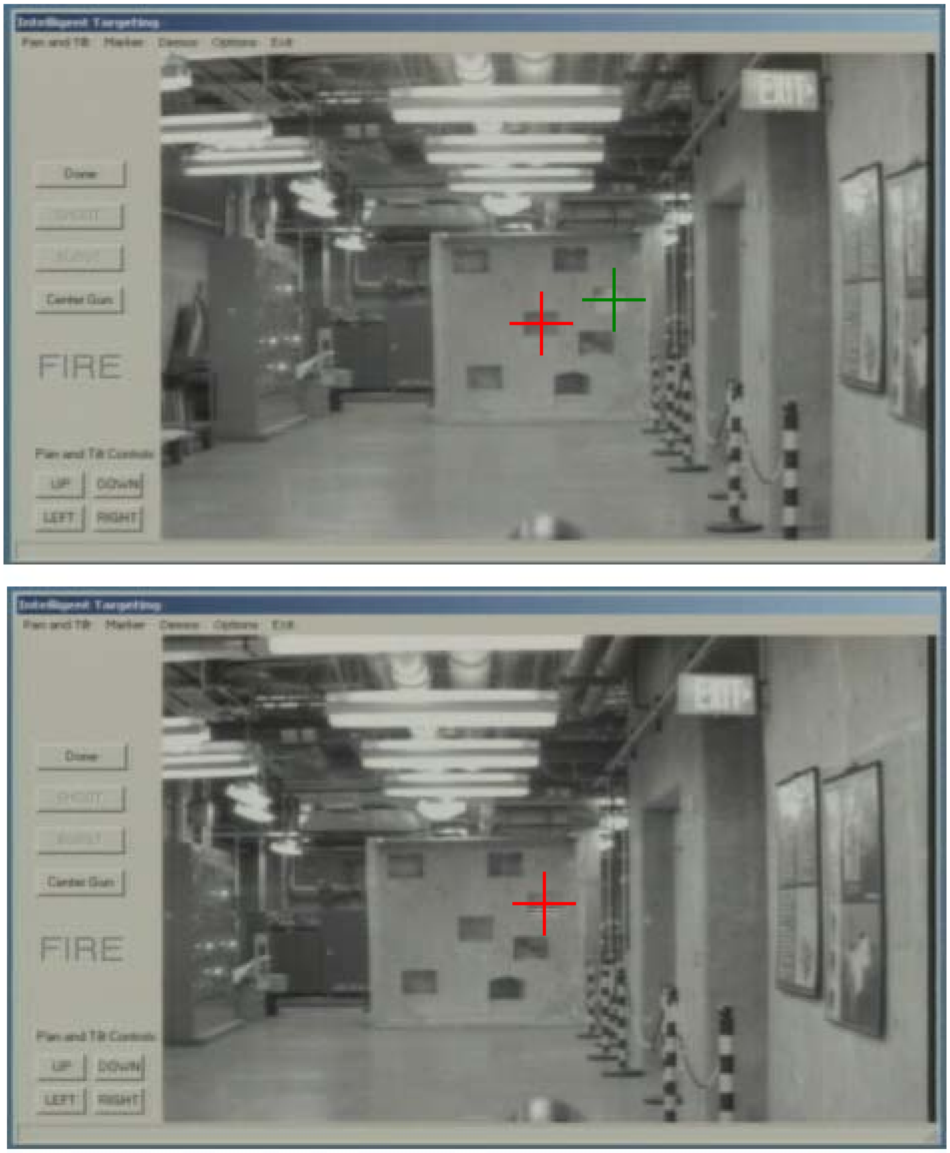

Figure 5. Screen shots of the point-and-shoot demonstration

The weapon platform also works in an "ambush" mode. In this scenario, a target aim point is selected using the left mouse button. The platform moves until the target aim point is lined up with the weapon's line-of-sight. When an intruder enters the field of view of the weapon's camera, the distance of the intruder from the platform and the speed of the intruder are estimated. These results are used to calculate the necessary lead-time to hit the target once it crosses the line-of-sight of the weapon. The weapon will shoot when the target reaches the calculated position.

The ambush mode of operation was modified for an application in which specific vehicles are tagged as they travel along a road. The actual tag has not yet been developed and, hence, paintballs are currently being used. An off-board camera that is about 150 yards from the road is used to target the vehicle and calculate the required lead-time of the paintball. The image in Figure 6 is from the off-board camera. The location of the vehicle that is to be tagged is indicated in the image. The other vehicle in the image is a "HUMVEE", which currently is used to store the processing equipment and weapon platform. The platform is located about 30 yards from the road and is too small to be seen in the image.

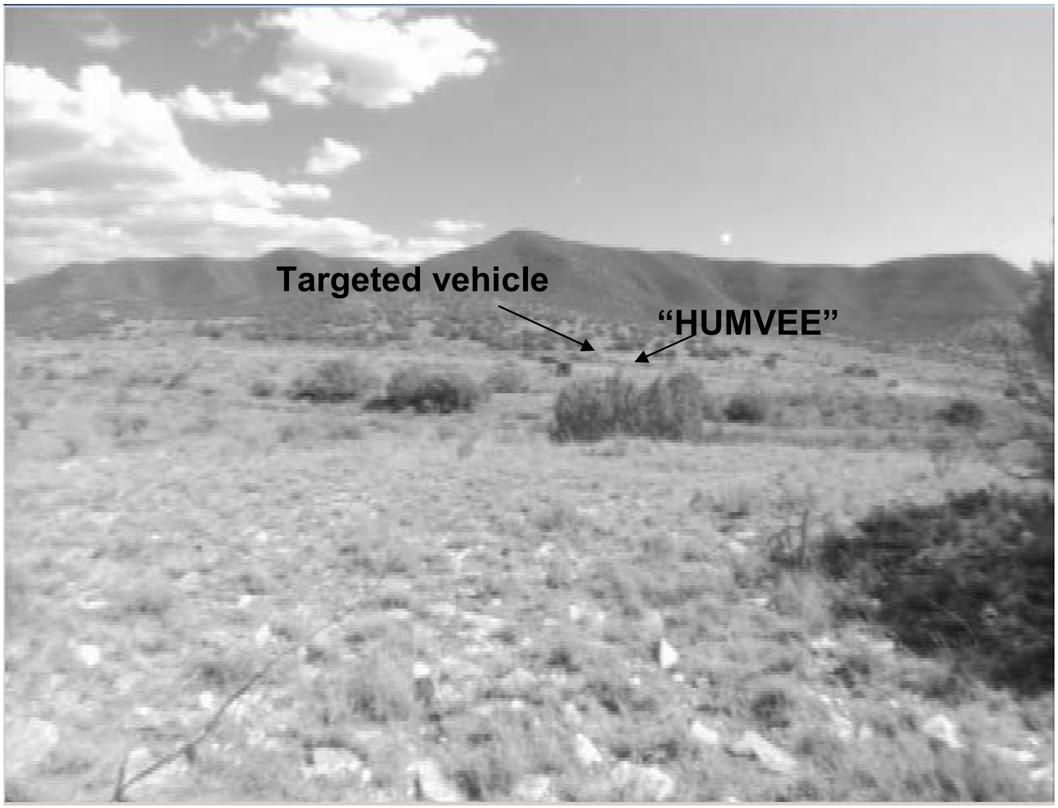

Figure 6. Image view in tagging application in which targets are detected and tracked

When the vehicle travels along the road and approaches the aim point, the target is validated (as being a vehicle) and the lead-time is estimated. A command is sent to the gun to fire when the vehicle is in the calculated location. The series of images in Figure 7 are from the on-board camera. The first two images show the paintball in its trajectory to the vehicle. The third image shows the results of the paintball hitting the vehicle. Note that in this application, all processing, tracking, and weapon control is performed using images from the off-board camera. The on-board camera is used to verify a hit.

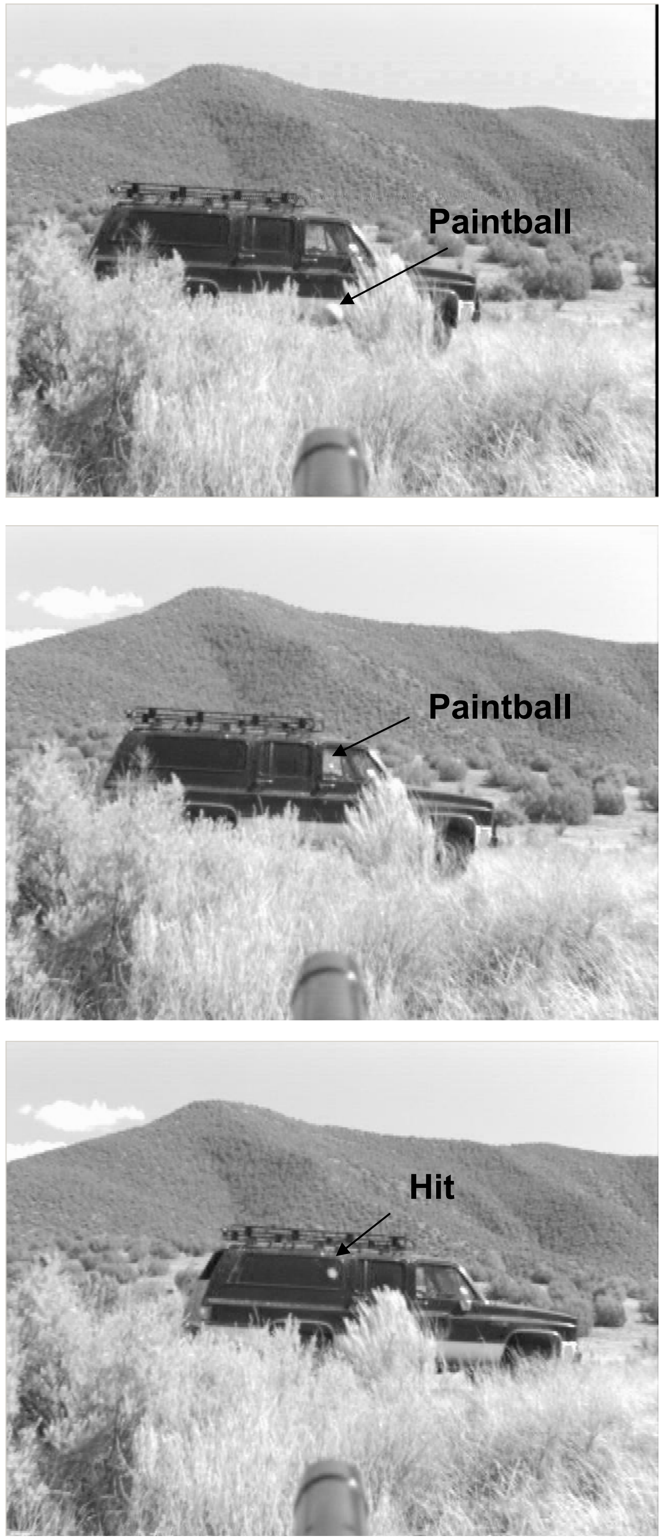

Figure 7. Image sequence from tagging demonstration

An “automated targeting” mode is used to track intruders that are within the field of view of the off-board camera. Once an intruder is detected, the platform will continually reposition itself to keep the moving intruder within the weapon’s line-of-sight. This mode can be set up to either automatically shoot at the moving target or to simply track the target and shoot when the operator provides a “fire” command. Image processing techniques are implemented to identify a valid moving target (e.g., minimum size constraints). The images below illustrate the weapon tracking a moving person from the point of view of an observer. As the person moves, he is kept within the line-of-sight of the weapon. With the high speed of the pan and tilt, it is extremely difficult for a moving target to avoid being the aim point of the weapon until the target leaves the field of view of the off-board camera. In these still images, the motion of the weapon is best noted by observing the position of the barrel as the person moves.

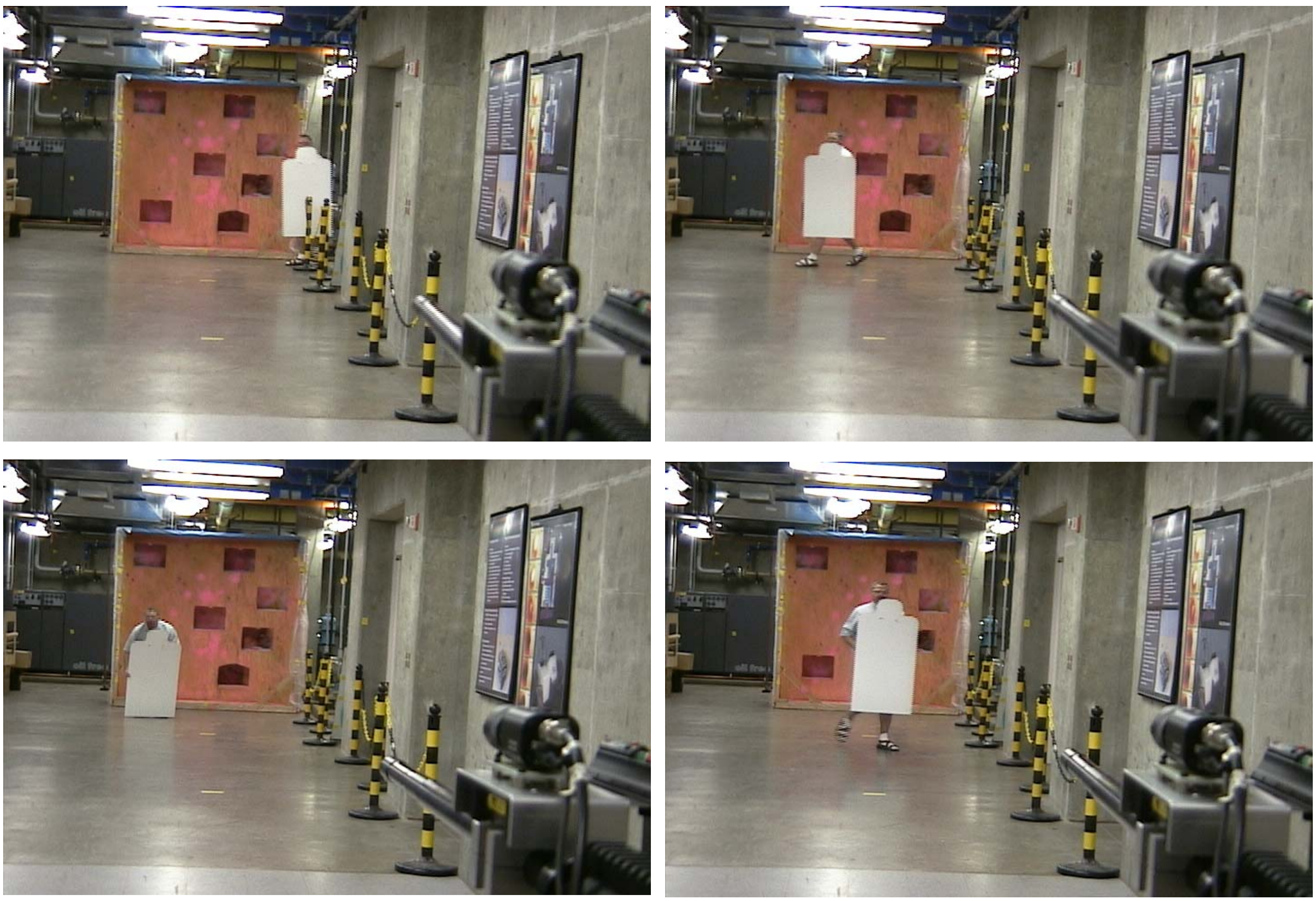

Figure 8. Tracking demonstration

An application using the coordinated control of two weapons platforms was also developed. In this system, both weapons have an on-board camera, but used the input from a shared off-board camera to detect and track targets. A single processor controls both weapons. This setup can currently operate in a couple of modes. In the first mode, both weapons can shoot at any target, resulting in some targets being hit by both. In the second mode, each weapon is assigned different areas of the field of view. Each weapon targets only those objects moving in its assigned area.

Algorithms were also developed to target and track multiple objects. The initial application of these algorithms involved low level recognition in which only selected objects were targeted and fired upon.

3 Summary

The intelligent targeting algorithms developed under this LDRD form a solid basis for additional development. A next step could include targeting and shooting multiple intruders in a closed quarter environment. This would involve prioritization of targets such that the greatest threat is eliminated first. Another area for development could include more sophisticated targeting between multiple weapon platforms. This could also include prioritization of targets as well as control over adjacent, but non-overlapping areas. An additional SAND report on this topic will be written in the near future to further discuss algorithm development and application areas.

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