Quick Response Airborne Deployment of Viper Muzzle Flash Detection and Location System During DC Sniper Attacks (*)

M. C. Ertem[1], E. Heidhausen[1], M. Pauli[2]
[1] *University Research Foundation MADL,* [2] *Naval Research Laboratory*
madl@ertem.com, cheeks@urf.com, pauli@ninja.nrl.navy.mil

Abstract

The VIPER infrared muzzle flash detection system was deployed from a helicopter and an airship in response to the Washington, DC area sniper attacks in October 2002. The system consisted of a midwave IR camera which was used to detect muzzle flash and cue a visible light camera on a gimbal to the detected event. The helicopter installation was done to prove that a manned airborne installation of the VIPER detection system would work. Within 36 hours of the request to deploy the system, it had been modified, approved by an FAA inspector and flown. Testing at the Ft. Meade rifle range showed that in a helicopter installation the system worked at least as well as a ground based system. Because of the limited endurance that a helicopter allows, the system was then installed aboard a Navy leased airship. It was flown at Elizabeth City, NC and was tested against live fire.

In response to the Washington, DC sniper shootings, the OSD had tasked a parallel effort to deploy a 20" WesCam gyro stabilized gimbal on the same airship. Software was developed in the field to interface the WesCam gimbal to the VIPER system so that it could automatically slew over to a detection event. The airship installation also added GPS based moving map display capability. That was completed within four days of the first request to deploy. The next four days were spent trying to coordinate a concept of operations for working with law enforcement agencies and getting flight clearances to bring the airship into the DC-Richmond corridor. After the sniper suspects were caught, the airship was taken to Patuxent River Naval Air Station and the muzzle flash detection system was tested there against live rifle fire.

These were the first flights of the airborne VIPER payload. It has since been flown numerous times on helicopters and tested against various guns, mortars, and artillery. Multiple identical payloads, each of which flew in a piloted helicopter, and all simultaneously controlled from a single ground station have since been demonstrated.

1. Introduction

The VIPER infrared muzzle flash detection system [1][2] uses a midwave infrared camera to detect and locate the discharge of firearms. Work on this system has been carried out by the Naval Research Laboratory and the Maryland Advanced Development Laboratory of University Research Foundation [3]. The system has been in continuous development since 1995, and has gone through many configuration changes. This paper describes the configuration as used during the October 2002 period.

1.1. Sensor and Optics

Several midwave IR camera / lens configurations have been used as the sensor for the VIPER system. The configuration used in the events described here consisted of an Indigo Phoenix 320 x 256 InSb midwave camera with an anamorphic lens that resulted in an approximately 140 x 17 degree field of view. This camera has a 14 bit digital output that gives it a high dynamic range that allows operation at a fixed gain. This makes it easier to operate the system in a 'NUC and forget' mode, where once a non-uniformity correction has been done on the

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focal plane array / lens configuration the system can be used with no further sensor adjustment. Earlier configurations of the system had used cameras with analog video output which required continuous control of pedestal and gain settings to keep the scene levels within the small dynamic range of the sensor. Because such a wide field of view anamorphic lens is used, and hence there is a large difference in optical gain between the lens axis and pixels around the edges of the image, the nonuniformity correction becomes important. This is especially true for a camera that is installed on a moving platform, since any spatial nonuniformity will appear as a temporal signal when the camera moves. For a stationary camera the quality of the NUC is of much less concern.

1.2. Detection Algorithms

The detection system in VIPER consists of spectral, temporal, spatial and morphological filters to discriminate IR flashes due to gunfire from background noise and clutter. Spectral filtering increases the signal to background ratio in the video collected from the IR camera. Temporal filtering is done by a matched FIR filter that has taps optimized for detecting the signature of a typical muzzle flash. The spatial filters include a low pass adaptive background estimator that tracks the localized signal energy at each pixel to account for dynamic activity in the scene, and a high pass filter that is used to discriminate small flashes. (At the ranges of interest and with the fields of view used, the muzzle flash signal typically has a spatial extent of at most a few pixels.) These filters are followed by morphological filters. The first one of these is a selectable global background filter. When this filter is on, it implements an IIR low pass threshold adjustment based on the entire scene. It acts to raise the detection threshold if there is excessive signal energy at the output of the preceding detection stages. Hard upper and lower bounds are used to limit how much the threshold can change. The global background filter was developed to reduce false alarms in cases where the camera makes sudden or high rate turns, or when there is activity in the near field. This filter is usually turned off. Another morphological filter detects and rejects tracks. This is normally on, and is used to reject false alarms due to far field objects transitioning the scene at high speed. The system can be set to display those events rejected by the track filter, since they would presumably be from activity in the scene that although is not due to muzzle flash, is still of interest to the operator.

The detection algorithms were implemented on a computer equipped with a Datacube MaxPCI image processor. The temporal and spatial filters were run on the image processing card, while the morphological filters were executed using the host processor. The Datacube card also had the camera interface on board.

The entire suite of detection algorithms run at a rate of 120 frames per second. With the fixed number of taps in the temporal filter, this allows the system to declare a detection in under 100 mS of the gun flash. (This means that a detection occurs before a supersonic bullet has traveled 50 meters from the weapon.)

1.3. Response to Detections

The system declares a detection in several ways. An operator alarm consisting of a 'ding' sound is initiated. It has been observed that if the shooter is at a range of more than about 300 meters from the system, the audio alarm gives enough warning for a trained user to duck before the round arrives. (The system does not require that the shot be fired in its direction. It works at all aspect angles, as long as there is a line of sight to the muzzle flash or to the flash reflection, e.g., from inside walls.) The typical sequence of events is 'ding, bang, boom' with a supersonic round at

The x,y pixel coordinates of the alarm, and the calculated azimuth and elevation angles in canera coordinates are displayed in numeric form and graphically.

The system is attached to a gimbal with a visible light video camera installed. When a detection occurs, this camera can be set to automatically slew to and zoom in on the bearing of the target. The operator then sees where the declared target is, and the video is recorded for intelligence or judicial use later.

2. The BOUNCE Project

The original VIPER system was developed for ground use with a stationary camera. A follow on project called Battlespace Ordnance Understanding - Net Centric Environment (BOUNCE) was under way in 2002. The goal of BOUNCE was to extend the VIPER technology to detect and locate ordnance from a low flying unmanned air vehicle (UAV). The reasoning was that a low cost low flying UAV would be able to fly under the clouds to detect and locate targets such as mortars, artillery, and even rifles and get this information to the warfighter in real time.

A data collection and feasibility anaysis was done in 1998 by flying an early version of VIPER aboard an experimental NRL UAV [4]. The recorded data was postprocessed and it was shown that reliable detection of gunfire could be performed in an airborne system. An airborne system was also seen as a logical next step in the development of motion control algorithms for muzzle flash detection. The fact that for a camera installed on an aircraft all objects in the scene are in the far field means that image motion is constrained to translation and rotations. Even for the very wide field of view anamorphic lenses used, it would be easier to determine the optical flow vectors as the aircraft moved. In a ground system, on the other hand, since there are so many object in the foreground, it is a much more complex task to estimate camera motion, and to predict the next image given a sequence of images. BOUNCE would be a good intermediate project to work on developing motion algorithms.

The BOUNCE project also involved algorithms for geolocating a target once it was detected. This would be done by using an inertial measurement unit (IMU) on board the UAV, and tracking the attitude and position of the aircraft. Upon detection it would be a simple geometric transformation to draw a bearing line from the UAV position to target. BOUNCE had a gimbal on the aircraft with a laser rangefinder. Geolocation is done in several ways. One uses a digital terrain map to calculate where the detection bearing line intersects the surface of the earth. This is immediate, but is potentially the least accurate method, depending on the grazing angle and accuracy of the terrain data available. The second method uses the laser rangefinder to geolocate the target. The third method is to get multiple lines of bearing to the target. The second and third methods are more accurate, but require the operator to visually identify and track the target using gimbal video. (All three methods have since been implemented and tested [5].)

3. Washington, DC Sniper Emergency

In October 2002, the area around Washington DC was affected by a series of sniper shootings. The immediate reaction to this was to evaluate how this technology and assets at hand could be used to aid in the invstigation.

Implementing the detection algorithms for a moving airborne camera, for slewing a gimbal to detection, and for calibrating camera and gimbal coordinated had just been finished. There was one system for software development and a single available camera with a wide field of view lens. The system had been deployed in a vehicle but airborne tests had not yet started. The UAV's that BOUNCE would use had not yet been flown or certified. It seemed that the only option would be to deploy from the ground. Considering the area under potential threat (roughly a triangle between Frederick, MD, Baltimore, and Richmond) it was realized that chances of being at the same neighborhood and within line of sight of the snipers at the time of a shot was infinitesimally small.

On the afternoon of Wednesday October 16, 2002 MADL was asked by NRL whether a quick response deployment from an aircraft was possible. A trip to Tipton airfield, at Ft. Meade, MD was made to determine if the system could be installed on a JetRanger helicopter. It was required to fly both the system and the operator, as data links for ground operation in BOUNCE had not yet been implemented. That night and Thursday was spent building the mechanical interface (consisting of 2x4 lumber and plywood) resolving the power supply issue, and working to get emergency FAA certification (the unit flew as tie-down cargo in the cabin of the helicopter.) On the morning of Friday, October 18, 2002 the system was ready to operate. It was powered by two automobile batteries and an inverter strapped to the floor. The IR camera and a visible light camcorder were mounted to look out the left side of the helicopter with the left door removed. The operator squeezed in to the right of the rack of equipment. [Fig 1]

The helicopter had FAA clearance to operate over the Fort Meade rifle range, which is immediately adjacent to Tipton airfield. Detection tests were carried out at the rifle range against .223 caliber sniper rifles [Fig 2]. The helicopter orbited the shooter at altitudes of up to 1000 feet and detections were obtained. It was noticed that above approximately 100' altitude the false alarm rate was acceptably low at several per hour. Below this altitude objects on the ground blowing about because of rotor downwash caused false alarms. However any operational aircraft would have to fly at a minimum of 1000' altitude due to FAA restrictions and reliable detections from that altitude were demonstrated on this flight.

Late that day the system was taken to Elizabeth City, NC to deploy on the US Navy leased airship. On the morning of Saturday October 19, 2003 the system was installed on the Airship 600 [Fig 3]. Because of the much better space, power, and weight capabilities on the airship it was possible to install the visible camera verification gimbal as well. The system was installed to look out the left side of the airship [Fig 4].

In addition to this system, a WesCam stabilized gimbal was installed by another contractor in response to the OSD request for quick response to the sniper emergency. That gimbal had much better optics than Viper's gimbal and was stabilized. It was normally manually controlled by an operator, but in discussion with the WesCam engineers it was discovered that the their gimbal would take positioning commands over a standard RS-232 port. Modifications were made to the Viper software to issue WesCam gimbal commands so that, in addition to its gimbal, it could also autoslew the WesCam gimbal to the detection bearing. [Fig 5]

No known concept of operations had ever been developed for an airship outfitted with a sniper detector. A quick CONOPS that dealt with contingencies such as how to communicate a detection, procedures for geolocation and even scenarios such as what to do if the airship was fired on was written that day.

On Sunday October 20, 2003 the first detection was performed test from the airship while still tethered. This was also done to calibrate the visible light gimbals to IR camera coordinates. The system worked as expected and had satisfactory detection and false alarm rates.

On Monday, October 21, 2003 the the code to interface to the WesCam gimbal was finished. Also a separate processor and GPS receiver to run a moving map display to assist in geolocating any detections was added. (The geolocation capability in BOUNCE had not yet been coded.)

At this point, the system was fully operational, five days after the initial request. Coordination for a full up flight test with the Elizabeth City Coast Guard Station at the Pasquotank Sheriff's Department shooting range was made. The system was flight tested and showed that it could detect and locate rifle fire from operational altitudes.

It proved to be more challenging to coordinate the operation of the airship in the threat region, especially since it meant flying inside the Washington, DC Temporary Flight Restriction Area [Fig] Tuesday October 22, 2003 was spent working on procedures and clearances. Clearence to depart Elizabeth City, NC for Manassas, VA was obtained. That night sniper suspects were caught, before the airship was deployed.

The airship was subsequently flown to Patuxent River NAS and another test flight was conducted. The experience obtained during this week in October 2002 allowed transition to the airborne testing of the BOUNCE system. [5]

4. References

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Figure 1 - First flight. Processor is strapped down in yellow rack, IR and visible cameras are on stand, and batteries are on floor under plywood frame.

Figure 2 - Fort Meade rifle range from helicopter at 1000' with video captured at time of detections.

Figure 3 - Airship 600 at Weeksville, NC

Figure 4 - Installation in airship.

Figure 5 - IR detection suite on left, consisting of visible camera on gimbal, operator station, detection camera. WesCam operator station on right.

Figure 6 - Test flight with IR detection suite, moving map geolocation on laptop.