Automated Recognition and Tracking of Aerosol Threat Plumes with an IR Camera Pod

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ABSTRACT

Protection of fixed sites from chemical, biological, or radiological aerosol plume attacks depends on early warning so that there is time to take mitigating actions. Early warning requires continuous, autonomous, and rapid coverage of large surrounding areas; however, this must be done at an affordable cost. Once a potential threat plume is detected though, a different type of sensor (e.g., a more expensive, slower sensor) may be cued for identification purposes, but the problem is to quickly identify all of the potential threats around the fixed site of interest. To address this problem of low cost, persistent, wide area surveillance, an IR camera pod and multi-image stitching and processing algorithms have been developed for automatic recognition and tracking of aerosol plumes. A rugged, modular, static pod design, which accommodates as many as four micro-bolometer IR cameras for 45deg to 180deg of azimuth coverage, is presented. Various OpenCV[1] based image-processing algorithms, including stitching of multiple adjacent FOVs, recognition of aerosol plume objects, and the tracking of aerosol plumes, are presented using process block diagrams and sample field test results, including chemical and biological simulant plumes. Methods for dealing with the background removal, brightness equalization between images, and focus quality for optimal plume tracking are also discussed.

Keywords: microbolometer, standoff, passive, aerosol, tracking

1. INTRODUCTION

Protection of fixed sites from chemical, biological, or radiological (CBR) aerosol plume attacks depends on early warning to provide time to take mitigating actions. An effective early warning system requires continuous, autonomous, and rapid coverage of large surrounding areas. Most qualitative CBR sensors used for identification purposes are too expensive or too slow to deploy in the quantities needed to continuous coverage of an area large enough to provide a sufficient early warning. A low cost, continuous scan, wide-angle IR camera pod has been developed along with an aerosol plume detection algorithm to address this problem. The rugged, modular, multi-camera pod was designed to house up to four uncooled micro-bolometer IR cameras to provide continuous coverage for 45 degrees to 180 degrees.

The individual camera images are stitched together to provide a panoramic view of the field of view. This image, collected multiple times a second, is analyzed using Open Source Computer Vision[1] (OpenCV) computer vision algorithms to detect and track aerosol plumes. These plume results can then be used to cue additional resources to confirm the presence of a threat.

Problems that were overcome during this project include:

- Methods for alignment and stitching of images from multiple cameras
- Background removal process to increase detection capability
- Brightness equalization between camera images
- Aerosol plume detection and tracking algorithm
- Triangulation of data from multiple cameras to produce a 3D plot of the plume location

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An overview of the system is provided in section 2 followed by a discussion of the above-mentioned problems and solutions in section 3. Section 4 contains results from sample field trials using simulated biological and chemical aerosol plumes.

2. AEROSOL PLUME DETECTION SYSTEM OVERVIEW

2.1 Underlying Theory

Aerosol plume detection using micro-bolometer IR cameras is possible due to an atmospheric effect called Mie scattering. Down-welling radiation from the atmosphere is scattered off aerosol particles, causing an aerosol plume to appear as a cold object against the surrounding background. Figure 1 shows an aerosol plume, which appears as a darker object when compared to the warmer mountain background. Although there is scattering of radiation from other directions (e.g. the ground), the dominant thermal contrast is between the cold sky and the detector. This colder aerosol plume can then be detected and tracked using aerosol plume tracking software.

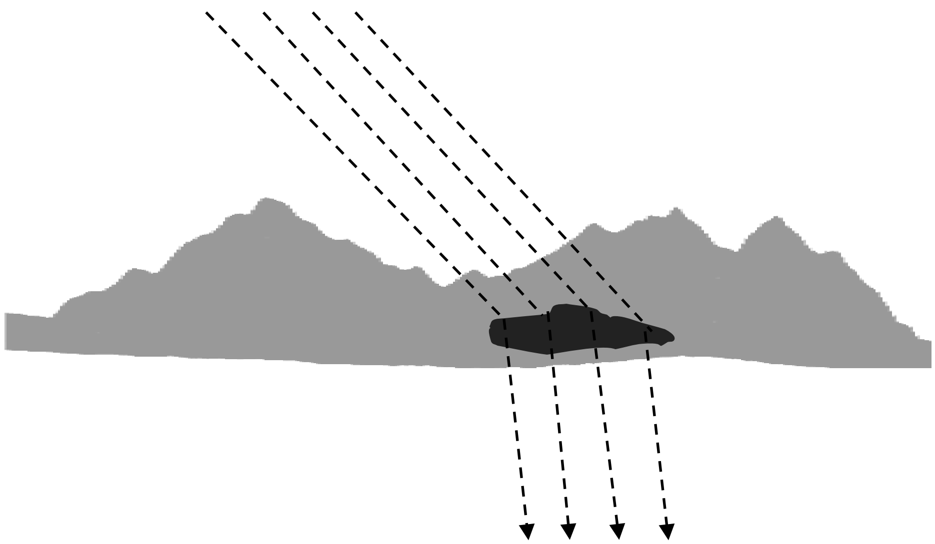

Figure 1. Aerosol plumes appear as a cold object due to the Mie scattering effect. This occurs from down-welling radiation reflecting off the aerosol particles, giving it a colder appearance (darker) than the surrounding background.

2.2 Hardware Description

Rugged, multi-camera enclosures with a 180-degree field-of-view design and a 45-degree field-of-view design are shown in Figure 2. These pods contain FLIR Tau microbolometers cameras, which are sensitive to the thermal IR range of 7.5 to 13.5 µm. The camera pods contain no moving parts making them rugged, lightweight, and easily portable. The cameras inside the pods are positioned to provide a several degree overlap between adjacent images that allows the images to be stitched together (Discussed in more detail in section 3.1)

A separate enclosure (not shown) contains an embedded PC104 processor running embedded Linux, GPS receiver, hard drive, and Ethernet switch. IR images are collected, analyzed, relayed over a network, and stored to disk in this enclosure. The hard drive allows many days worth of data to be collected without user intervention. GPS receiver data is processed on the embedded processor and is used to automatically locate and time sync the system. The GPS coordinates and synchronized time are included in the IR image data files.

Aerosol plume detection results along with a live image from the cameras are viewed using a web browser. All processing occurs at the IR camera pod site. Only results are transmitted via a network connection, allowing remote viewing of the sensor results using a low-bandwidth network connection.

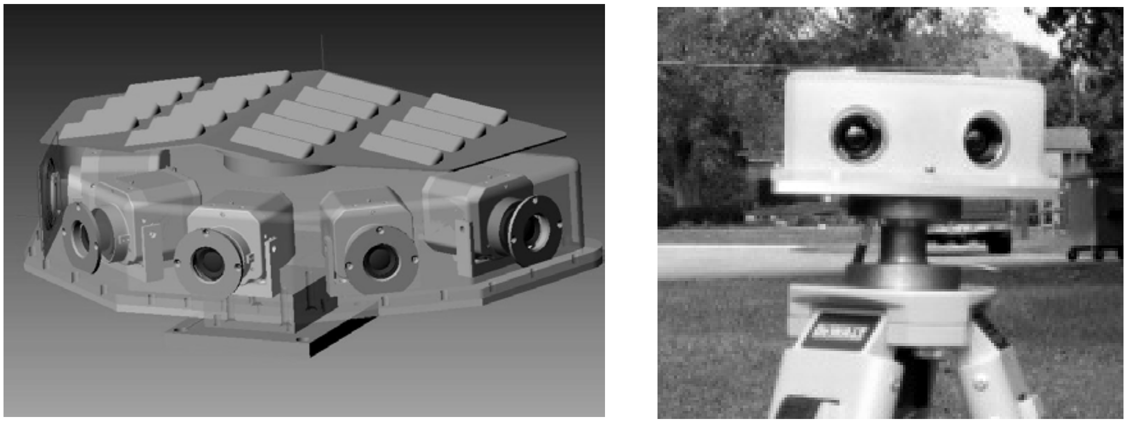

Figure 2. Five-camera pod design (left) for 180-degree coverage and a two-camera pod design (right) for 45-degree coverage, which was used to collect test data presented in this paper.

3. AEROSOL CLOUD DETECTION AND TRACKING ALGORITHM

An algorithm to detect and track aerosol plumes was developed as shown in Figure 3. The process begins with a stitching process where images from multiple cameras are aligned and merged together to form one panoramic view of the scene. A balancing process is then run to equalize brightness temperatures between cameras. This combined, balanced image is then used in a moving window background subtraction process to remove background features. The result of these processes is a stitched, equalized, difference image that can be analyzed using OpenCV[1] algorithms to acquire and track clouds. Details for each step in the process are discussed in the sub-sections that follow.

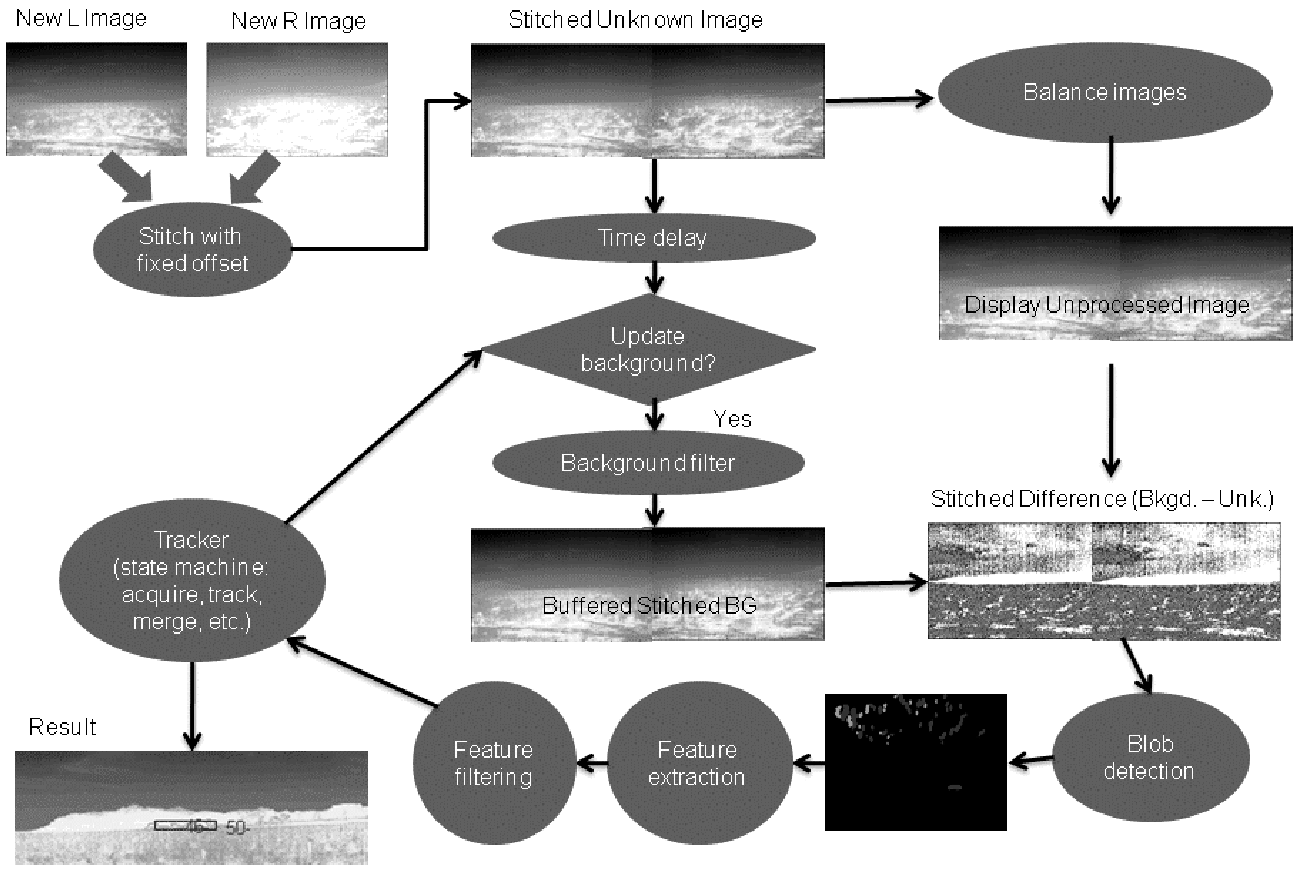

Figure3. Aerosol Cloud Detection and Tracking Algorithm Block Diagram

3.1 Raw Image Stitching

Images from multiple cameras are first combined using a stitching process. To determine the offset between two cameras images, an OpenCV[1] library method called CvMatchTemplate was used. CvMatchTemplate uses 2-D correlation to best match a small subset image from the right image to a specific location in the left image. This process produces an x-axis and y-axis offset that can be used to stitch the images together by overlaying the right image on top of the left image at the measured offset values, as shown in Figure 4. This process is repeated for each set of neighboring cameras.

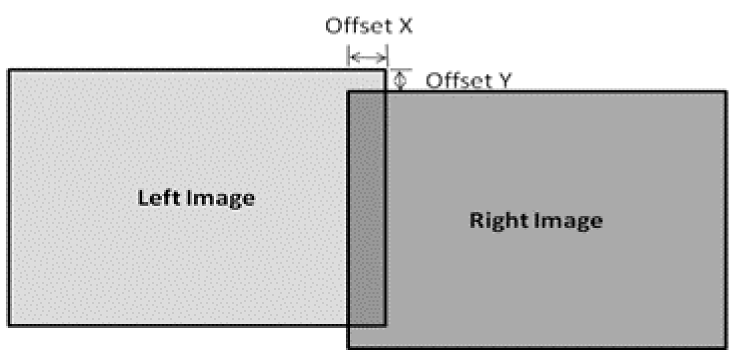

Figure 4. Raw image stitching method used to combine multiple images to produce one continuous panoramic image.

3.2 Brightness Equalization

For display purposes only, camera images are balanced to remove differences in brightness and contrast. This is done by taking the mean temperature value of the foreground region near the matching region of each camera, and then applying the difference to one side. A histogram equalization is then applied to the image for display. This process is repeated for each set of neighboring cameras. Figure 5 shows the area of the image that is used mean value measurements. A stitched and balanced image from two cameras is shown in Figure 6.

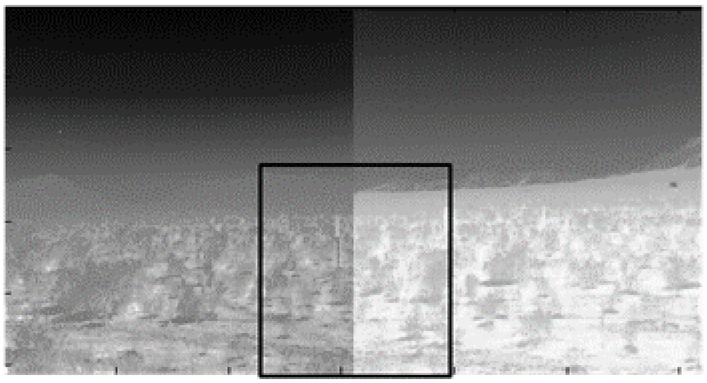

Figure 5. Area of dual camera images used to calculate mean values needed for the best balancing the scene.

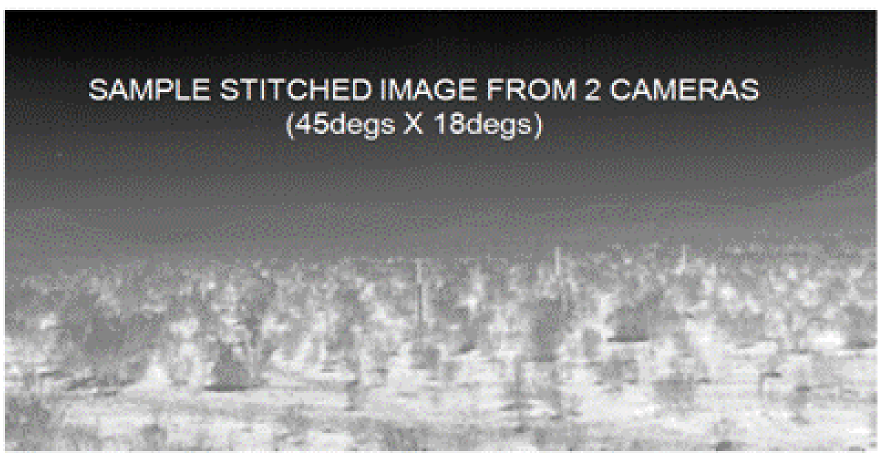

Figure 6. Sample stitched and balanced image of a mountainous desert environment using two 24deg x 18deg FOV cameras. The several degree overlap of the two cameras creates a 45deg x 18deg stitched image.

3.3 Background Subtraction Methods

Depending on the environmental conditions, an aerosol plume can be too close to ambient temperature or too small to be seen by the naked eye and thus difficult to detect using image processing software. To improve detection capabilities, background subtraction is used. The method used involves a moving background subtraction window to subtract background effects. This method was shown to greatly increase detection capabilities of aerosol plumes. From the example in Figure 7, the plume is difficult to be seen in the upper left “Unknown” image. When the “Background” image collected several seconds prior is subtracted from the “Unknown” image, the difference is the lower left “Subtraction” image where the plume can clearly be seen. The lower right “Detection” image shows the algorithm detection result as a line drawn around the plume.

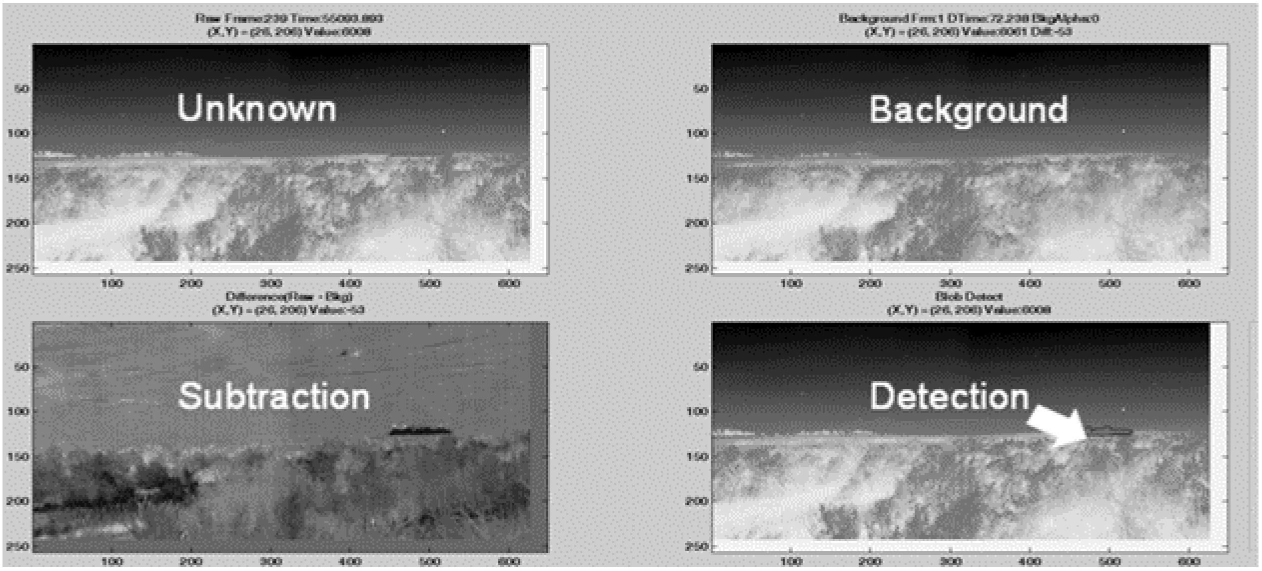

Figure 7. Background subtraction applied to scene image. The aerosol plume cannot be seen by eye in the raw image (upper left) but can clearly be seen in the background-subtracted image (lower left) as a dark, cold object.

In addition to having a low signal to noise, there is a challenge detecting and tracking the plume due to temperature changes in the background scene. Temperature variations occur due to wind, clouds and other environmental conditions, as well as drift due to camera electronics. Various algorithms have been employed in an attempt to correct for these changes and extend the length of time that a plume can be detected. The methods used include background filtering techniques, and an adaptive bias shift to the foreground image based on statistical measurements of the background scene.

3.4 Aerosol Plume Detection and Tracking Method

The result of the processing steps in the preceding sections is a stitched, equalized, difference image. An Aerosol Plume Detection and Tracking Algorithm was developed to use this difference image to detect and track aerosol plumes. First, a region boundary tracing method is used on each image to trace the boundaries of all objects, or blobs, in the image. Blobs that do not meet minimal size criteria for aerosol plumes are eliminated. Any remaining blobs are considered potential plumes and are sent on to the tracking routine.

In the tracking routine, a new plume "track" is started to follow the track of the plume. The following steps are performed with each new image:

- Update predicted edges of the plume tracking path based on the elapsed time since the last update
- Find all new blobs that fall within the predicted edges of the plume track. These blobs are merged into the existing track.
- Resolve blob conflict (multiple blobs may fall within the edges of multiple tracks)
- Find new edges for tracks based on an outline of all associated blobs

If a track is not updated with new blobs over several images, the plume is declared lost and the track discarded.

3.5 Triangulation of Aerosol Cloud Using Multiple Camera Pods

Using tracking data from camera pods at multiple vantage points, a 3D representation of an aerosol plume can be calculated and displayed on a map, providing location and size of the plume. This is accomplished by combining the boundary points of a plume from multiple camera pods to triangulate the location of the cloud. A 3D binary grid is produced providing GPS coordinates, length, and width of the plume, as shown in Figure 8.

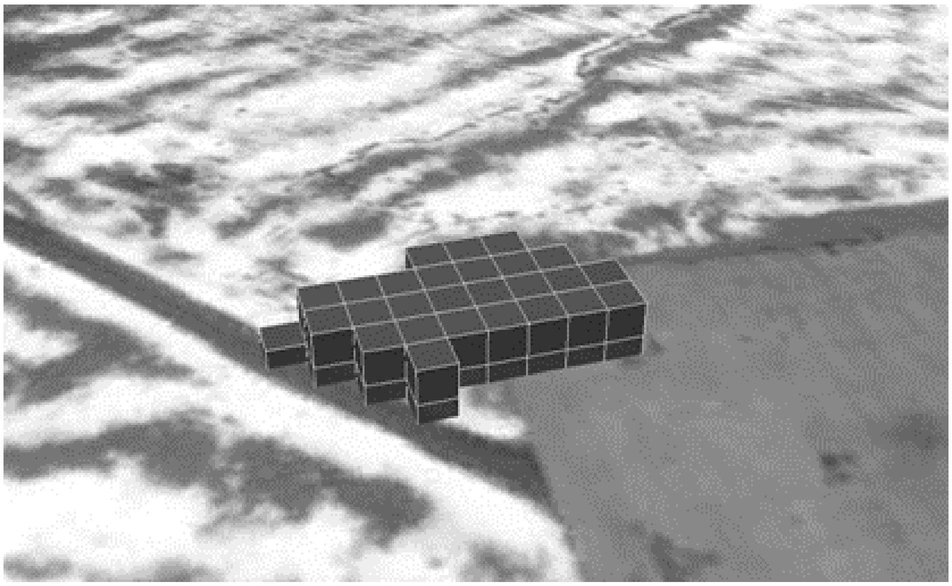

Figure 8. 3D binary grid of an aerosol plume from a 100-gram release, shown in 3D mapping software. Tracking results from multiple camera pods are combined and triangulated to provide size and location of the plume.

4. TEST DATA ANALYSIS

Several camera pods have been deployed at multiple biological and chemical simulant release events to evaluate performance of the equipment and tracking algorithm. Two sample trials were selected to demonstrate performance. The first is a 100-kg chemical simulant release observed from a 2km standoff distance. The second is a 100-gram biological particle release observed from a 250-meter standoff distance. The results are shown in the following sections.

4.1 Sample Detection, Tracking, and 3D map results

The first sample trial was a 100-kg chemical simulant release conducted in a desert environment. Camera pods were positioned around the release site at 2 km standoff distances. The highlighted area in Figure 9 shows the tracking results where the plume has been detected and can be tracked through the field of view. Data from multiple vantage points of the plume was combined to produce a 3D binary grid of the plume. Figure 10 shows the location and size of the aerosol cloud viewed with 3D mapping software.

The second sample trial was a 100-gram biological release with a wooded background. A biological plume was released and tracked from a 250-meter standoff distance. Figure 11 shows the tracking results where the plume can be seen as it travels through the field of view.

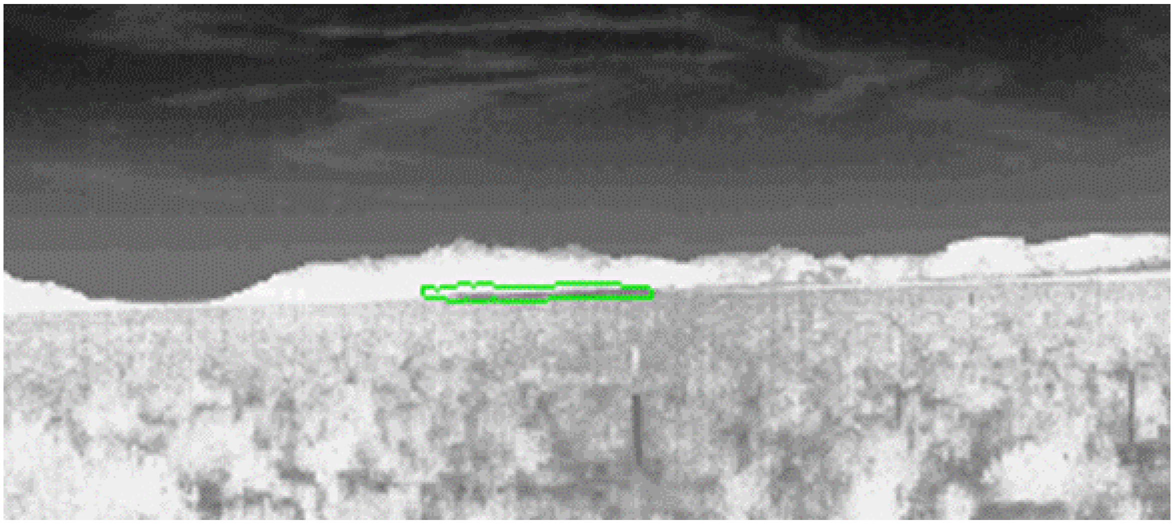

Figure 9. Tracking algorithm results for a 100kg chemical simulant cloud in a desert environment at a 2km standoff distance.

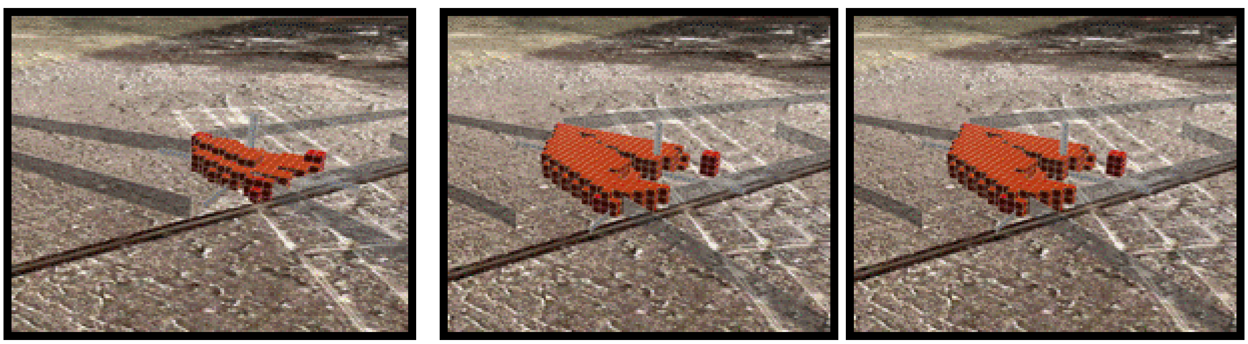

Figure 10. 3D plot sequence created by combing data from multiple camera pods at different vantage points.

Figure 11. Tracking algorithm results for a 100-gram release of a bio simulant at a 250-meter standoff distance.

4.2 Observed Detection Range

Several chemical and biological simulant release tests have been supported with IR camera pods over the past several years. Test data shows that the release amount and standoff distance play a large role in the aerosol detection capability. The selection of an appropriate microbolometers lens size could greatly improve detection capabilities. Figure 10 shows detection results, using a lens with a 19mm focal length. The results show that for small releases of 100 grams or less, a larger camera lens is required to detect the plume from distances greater than 500 meters.

Detection capability could also be improved by utilizing a more sensitive camera lens. For these experiments a 19 mm F/1.4 lens could be replaced with a F/1.0 lens, and effectively improve the temperature sensitivity by a factor of two.

Table 1. Detection result summary at varying standoff distances and release amounts for a 19mm, 24x18deg FOV F/1.4 lens mounted on a 324x256-detector array.

	Distance from release (meters)					
Release amount (kg)	**250**	**500**	**750**	**1000**	**1500**	**2000**
0.1	**X**	**X**	**Camera pod too far away to detect plume**			
0.4				**X**	**X**	**X**
60				**X**	**X**	**X**
90				**X**	**X**	**X**
100				**X**	**X**	**X**
120				**X**	**X**	**X**

5. CONCLUSIONS

An analysis of test results indicates that the following performance objectives have been met:

- Alignment and stitching of images from multiple cameras
- Brightness equalization between camera images
- Background removal process to enhance detection capability
- Aerosol plume detection tracking algorithm
- Display of plume on a 3D plot using multiple cameras

Test data results show that aerosol plumes can be detected and tracked using low cost IR micro-bolometer cameras. Potential applications include:

- Ground Truth: detection and tracking of a release from a known location
- Cueing Device: continuous qualitative monitoring to provide cueing for more costly quantitative sensors

REFERENCES

[1] http://code.opencv.org/