Detection and Tracking with a Hemispherical Optical Sensor Tracker (HOST)

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ABSTRACT

Detection and tracking algorithms for a Hemispherical Optical Sensor Tracker (HOST) are described. The HOST unit provides simultaneous and continuous viewing of a region spanning 360° of azimuth and -7° to zenith in elevation. Maximum likelihood derived, multi-frame detection algorithms are described for use with a stationary HOST surveillance sensor. A multi-target tracking architecture is also described. Due to the nature of the optical system, tracking in Line Of Sight (LOS) angular coordinates is much easier than using pixel coordinate tracking. This in turn provides an opportunity for multi-HOST unit triangulation to obtain 3D position estimates. This paper provides a brief overview of the HOST optical system, describes the multi-frame detection algorithm, the pixel to LOS conversion, and the multi-target track algorithm.

Keywords: Surveillance, acquisition, optical electro-optical, hemispherical, maximum likelihood, detection, multi-target tracking

1. INTRODUCTION

A Hemispherical Optical Sensor Tracker (HOST) has been developed providing in excess of 2π steradian simultaneous and continuous coverage, from -7 degree through zenith elevation and 360 degree azimuth. The entire hemisphere is imaged onto a single, rectangular Focal Plane Array (FPA). The optical system is composed of two optical paths, a panoramic optical path for low elevation angles and a fisheye optical path for higher elevation objects. This provides improved resolution and radiometric throughput at low elevation angles, as compared to a single fisheye optical design. Both optical systems are imaged onto a single focal plane, with the result that a target moving through the overall sensor Field Of View (FOV) from one optical system to the other, will exhibit non-linear and discontinuous motion on the focal plane.

While the sensor may be employed on aircraft or moving platforms, one particular application is for the HOST sensor to be mounted in a fixed location in order to observe moving targets. The sensor will observe complex terrain and sky backgrounds, including slowly changing features such as clouds and shadows. In order to detect moving targets, the background must be eliminated through clutter suppression techniques. Since multiple targets may be present, a multi-target tracker capable of handling large numbers of targets is required. The background suppression technique is a multi-frame technique derived from maximum likelihood principals. In order to handle the non-linear and discontinuous movement of a target on the focal plane, tracking is performed in azimuth and elevation coordinates. This requires the use of a unique pixel to Line Of Sight (LOS) conversion technique which accounts for the variable IFOV characteristics of this imaging system.

The HOST sensor uses an embedded Field Programmable Gate Array (FPGA) processor architecture. The processing includes focal plane non-uniformity correction, background suppression and target detection, pixel to LOS conversion, and multi-target tracking.

Like other passive electro-optic sensors, the HOST is an angles only sensor which does not provide range to targets. However, the HOST system has been designed to be used in pairs to support LOS triangulation in order to obtain 3D target coordinates.

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This paper will give a brief description of the HOST optical system and then concentrate on describing the processing algorithms, including the triangulation function. This is followed by a brief description of the FPGA hardware implementation.

2. OPTICAL SYSTEM

The Hemispherical Optical Sensor Tracker (HOST) provides in excess of 2π steradians of coverage. The sensor provides 360° of azimuth and 97° of elevation coverage. Thus it has a viewing area extending from -7° in elevation to zenith, and complete coverage in azimuth. The optical system views this entire space simultaneously so that there are no drop outs in coverage as would occur with a scanning sensor.

In the visible band, it is possible to buy COTS fisheye lenses which provide hemispherical viewing. However, at low elevation angles the radiometric efficiency degrades dramatically making the sensor less sensitive. At the same time, the Incremental Field Of View (IFOV), the solid angle seen by a single pixel and hence a measure of the minimum resolvable feature size, increases dramatically at these low elevation angles. In order to provide improved low elevation angle performance, the HOST sensor uses two different optical paths, imaged onto a single Focal Plane Array (FPA). A fisheye lens is used for higher elevation angles, while a panoramic optical system is used for lower elevation angles. The footprint on the FPA is shown in Figure 1. Since the focus of this paper is on the detection and tracking algorithms, a discussion of the trade-offs leading to the exact division between the fisheye lens and the panoramic optical system is beyond the scope of the current paper.

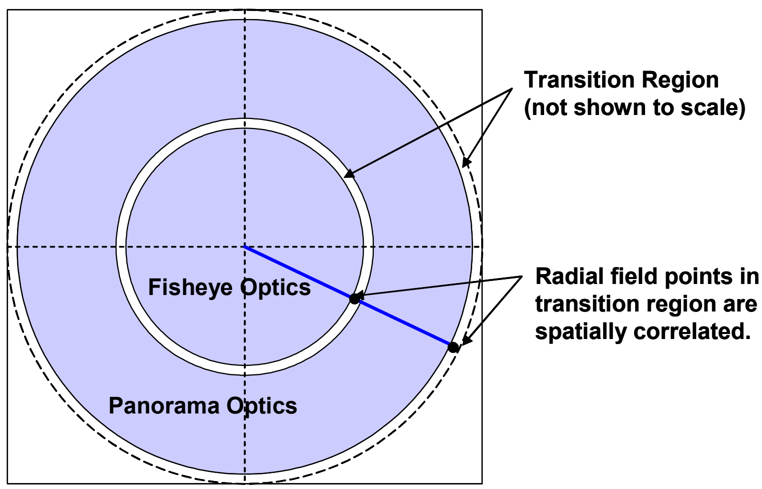

Figure 1. Panoramic & Fisheye optical paths imaged onto common focal plane

The panoramic sensor provides substantially improved radiometric efficiency and improved (reduced) IFOV at low elevation angles, compared to a fisheye lens. The two optical paths are aligned so that their respective boresights are separated by less than a single pixel.

As a result of the dual optical paths, the image of moving targets on the focal plane of moving targets, exhibits unusual behavior which must be accounted for in the tracking system. An object which approaches the HOST sensor from a great distance, passes over the sensor, and then recedes in the distance will be imaged on the focal plane as follows. The object will first appear at the fisheye / panoramic sensor boundary and will be observed to move outward toward the edge of the FPA. Upon reaching the edge, the target will jump back to the fisheye / panoramic boundary, invert, and move across the center of the FPA until it reaches the fish-eye / panoramic boundary on the other side. Then it will jump to the outer edge of the FPA, invert, and move inward until it again reaches the fisheye / panoramic boundary.

The transition region between the two optical systems has another implication for the tracker. An object moving from the panoramic optical system to the fisheye system will be imaged at two different locations on the focal plane: at the outer edge of the panoramic sensor region and at the outer edge of the fisheye region. Furthermore, two objects at different locations can be imaged onto the same region of the FPA. An object slightly below the horizon (-7°) and one on the lower edge of the fisheye lens, that appear simultaneously along the same radial line, would both be imaged at the same point of the transition region on the FPA.

Prior to detection processing and tracking, the HOST system performs a number of standard focal plane corrections, including a 2 point non-uniformity correction and bad pixel replacement. However, this correction is strictly for the FPA and does not correct for the elevation angle optical efficiency of the system.

The entire HOST sensor consists two major subsystems: (a) the Opto-Mechanical Assembly (OMA) which is comprised of the dual optical system previously described and cryogenic dewar that maintains the FPA at its nominal operating temperature, and (b) the Sensor Tracker Electronics Unit (STEU) which houses the Field Programmable Gate Array (FPGA) advanced re-configurable tracker processor. The system described in this paper is a second-generation prototype, principally designed to be a ground-based, initial acquisition sensor. HOST can be easily re-designed to reduce both size and weight, and enhance performance for a number of applications including based on ground-mobile and flight platforms.

3. DETECTION PROCESSING

3.1. Scene Description

In its initial applications, the HOST sensor will be on a fixed and stationary mounting. In this configuration, immobile objects in the FOV will be imaged onto fixed locations on the focal plane. Thus a static background will form a static image. The sensor provides hemispherical viewing coverage and as such will see the local landscape, birds, sky, clouds, and sun. The local landscape may include moving vehicles, people and wildlife, terrain, including vegetation (possibly moving in the wind), and airborne debris such as leaves and dust. In an urban environment, other scene background effects will occur which may be both temporally and spatially abrupt. These range from lights turning on/off, to welding torches at construction sites. In a maritime environment, waves will be visible at very low elevation angles and will provide substantial flicker as the waves slopes align to allow specular reflections of sun light.

Due to the large Field Of View (FOV) coverage, each pixel will have a large IFOV, meaning that unless they are extremely close, things such as moving vegetation and airborne debris will provide negligible temporal variation. Changing solar illumination will provide temporal differences in the background and the solar illumination will in turn depend on cloud cover, with the result that moving clouds may lead to large, rapidly changing illumination levels on the terrain.

In most applications of a fixed HOST sensor, terrain backgrounds will be confined to low elevation angles, with sky representing the bulk of the scene. The sky consists of a (spatially and temporally) slowly varying component, clouds, and celestial objects (sun, moon, stars). While the sun will saturate the pixel(s) on which it is imaged, it will not damage these pixels nor will it result in blooming beyond these pixels. The sun will provide not only saturated pixels, but also very large intensity gradients, meaning that both simple threshold detection and edge enhanced detection will probably detect the sun. Celestial objects (sun, moon, stars), while potentially extremely bright (the sun) will vary only slowly with time due to their motion (1 pixel per minute).

Clear sky will have an elevation angle dependent radiance, decreasing from low elevation angles to a minimum at zenith. Clouds will provide additional, time varying background structure. The optical system non-uniformity (described in the sensor section) may be considered an additional static background effect. Clouds however may contain spatially abrupt transitions and may move across the scene at a substantial rate.

The net effect of the above background effects is that there will be substantial background structure visible in the imagery, and this structure will change over time. While most of the changes will occur slowly (on the order of many minutes), a few of the effects may occur rapidly, on the order of a few seconds.

Targets are defined as moving objects, primarily ground or air vehicles. Most of these will not only be moving but will exhibit an elevated IR signature. In the ideal case, moving targets will be the brightest objects in the scene and a simple threshold detection will separate targets from background. However, due to range, perspective, self-obscuration, and other effects, the desired targets may in fact result in lower focal plane irradiance than background items, such as sun baked rocks, specular solar reflections, lights, and torches. Velocity cannot be used to discriminate using a single HOST sensor, since it is an angles only sensor. A real target may be moving on a radial vector with respect to the sensor, and hence exhibit no motion on the focal plane (no angular motion). However, most targets of interest will in fact be moving rapidly, and will only be present for a short period of time (at most 10s of seconds). As a result, change detection is a valid detection technique, even for targets moving on a radial vector from the sensor which do not exhibit any focal plane motion.

The detection problem may be summarized as detecting sudden large, localized changes in the scene radiance. Bright, slowly varying objects, such as the sun are to be ignored, as are extended objects such as cloud edges.

3.2. Algorithm Description

3.2.1. Overview

The detection algorithm is based on maximum likelihood detection theory [1], but is adapted in a variety of ways to address the particular detection problem facing the HOST sensor, and the constraints of real-time operation. Multiple frame maximum likelihood detection for moving targets consists of a multiple frame clutter suppression operation (data normalizer) designed to provide a uniform, clutter free scene. This is followed by a multi-frame signal enhancement operation (assumed velocity filter or binary M out of N tests) to aide in the detection of faint targets which may be buried in noise. These two operations are separable and in our case, we expect to have bright targets, so the signal enhancement portion of the algorithm is dropped. Focal plane non-uniformity correction and bad pixel replacement is performed in a separate processing block prior to the detection algorithm described in this section.

The HOST detection algorithm shown in the diagram below (figure 2) consists of background removal, limiting the region of interest (to eliminate ground traffic), edge enhancement, and thresholding. The steps are discussed in detail in the following sections.

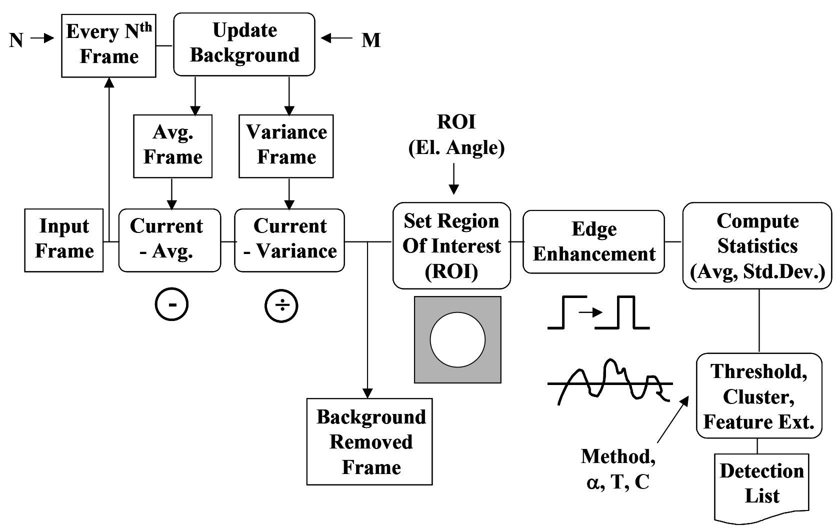

Figure 2. HOST Detection Algorithm

3.2.2. Background Removal

The data normalizer computes a temporal average and standard deviation for each pixel, resulting in average and standard deviation "image" frames. As each new image frame arrives, the average frame is subtracted from this frame and the resulting difference frame is divided by the variance frame. The difference operation removes the average value at each pixel location. However, some pixels will have higher variance than other pixels, so we normalize this temporal variance by dividing by the variance frame. Think of three pixels, one imaging a dark region, one imaging a bright region, and one imaging a light which is flickering on and off. The first pixel will have a low average value and a low variance, the second pixel will have a high average value but will also have a low variance. The third pixel will have a medium average value but a high variance. Subtraction of the average values will reduce the first and second pixels to approximately zero value, with very little deviation from zero. However, the third pixel will have a substantially non-zero value: If the light is on, the pixel will be above the average value resulting in a positive difference, if the light is off, the pixel will be below the average value, resulting in a negative difference. Division by the variance will bring the statistics for this pixel in line with the first two. Mathematically, this operation can be written as follows:

$$n_i = \frac{p_i - \mu_i}{\sigma_i^2} \quad . \tag{1}$$

where n_i is the normalized pixel value, p_i is the original pixel value, μ_i is the average value of the i^{th} pixel, and σ_i is the standard deviation of the i^{th} pixel.

Since the system is expected to operate in continuous mode while the background changes over time, it is necessary to continually update the background average and variance estimates. While targets of interest may be quite bright, we need to minimize their contribution to the background estimates or we may end up suppressing them.

Since we assume that targets of interest are moving and only present for a short time, we employ a two part strategy. First, we select only every N^{th} frame. We select N so that targets will probably have moved several pixels since the last sample, thus ensuring that any given target contributes no more than one sample in a given background pixel (even targets on a radial trajectory, if they are short lived, will not contribute many samples). A nominal initial value for a 30 frame per second imager is N = 30 (one sample per second).

We now want to use this sample frame to update our existing background mean and standard deviation estimates. If for the i^{th} pixel we have M samples, $s_{i,j}$ where j=1 to M, the mean and variance of the i^{th} pixel are:

$$\mu_i = \frac{1}{M}\sum s_{i,j} \qquad \sigma_i^2 = \frac{1}{M}\sum s_{i,j}^2 - \mu_i^2 = v_i - \mu_i^2 \quad . \tag{2}$$

Since we are continually updating our statistics, we do not want to keep a large buffer of past image frames. Instead, we employ a decaying average technique by apply a weighting factor M to each incoming sample. Our updated values may now be written:

$$\mu_i = \frac{\mu_i M + s_i}{M+1} \qquad v_i = \frac{v_i M + s_i^2}{M+1} \quad . \tag{3}$$

The μ_i and v_i frames are stored, and the variance values $\sigma^2 = v - \mu^2$ are computed on the fly.

A larger value of M creates a longer time constant in the background estimates. At one extreme, a value of M=0 replaces the current background estimate with the current sample value. A good initial value of M is M=60 which essentially replaces the background estimate once per minute.

This portion of the algorithm requires two input parameters, N, and M, as well as the input images. It requires storage for two additional "image frames", the average and variance frames.

3.2.3. Region Of Interest (ROI)

The purpose of the ROI is to place a limit on the Field Of View (FOV) to eliminate ground targets from processing. We have implemented a simple software ROI which excludes any targets below a given elevation angle. In future versions it is easy to envision using an azimuth dependent elevation angle in order to exclude high terrain in one direction while retaining sensitivity at lower elevation angles in other directions. In the current implementation, the input elevation angle is mapped to a radius on the focal plane. Any pixels outside this region are ignored in further processing.

The ROI is implemented following background suppression but before computation of image statistics and thresholding. By placing the ROI limit prior to computation of threshold statistics, any large leakage of ground targets through the background suppression will not affect detection of airborne targets.

3.2.4. Edge Enhancement

The use of edge enhancement, followed by thresholding, clustering, and size thresholding provides future options for handling extended targets. Alternatively, an impulse response filter could be used for unresolved targets only. The basic assumption is that targets will have sharper edges than background features, and this will serve to enhance targets over any background leakage from the clutter suppression.

The edge enhancement is a Sobel edge enhancement [2], implemented using two kernels, S_1 and S_2:

$$S_1 = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad S_2 = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad . \tag{4}$$

results are added in quadrature so that the Sobel image, S, may be written as:

$$S = \sqrt{(I * S_1)^2 + (I * S_2)^2} \quad , \tag{5}$$

where $I * S_i$ represents the convolution of the image input image I with the Sobel kernel S_i.

3.2.5. Compute Statistics

Various detection thresholds may be applied to the edge enhanced image. One popular type of threshold is a Constant False Alarm Rate (CFAR) threshold. A CFAR threshold assumes that the form of image statistics will remain constant over time, even while actual statistical values vary. In this section of the algorithm we wish to estimate the background (spatial) mean and standard deviation (of the background subtracted, edge enhanced image). The arithmetic mean and standard deviation can be distorted by the presence of large targets. Estimating the mean and standard deviation from a histogram of the image are found to be more robust.

First we form a histogram of the image values (number of occurrences as a function of pixel grey scale level) . Next the histogram is scanned for the peak value. The pixel value corresponding to the peak of the histogram is used as the estimate of the background mean, μ. The standard deviation is estimated from the width of the largest peak. If the background follows gaussian statistics, one should scan away from the peak in both directions until finding the value closest to $1/e^2$ of the peak value. The width at this point corresponds to 4σ.

Only pixels which lie within the region of interest are included in the histogram.

3.2.6. Threshold, Cluster, Feature Extraction, & Size Threshold

Once the background statistics have been estimated, a threshold is determined and applied to the (ROI of the) image. All pixels above the threshold are considered detections. We use two alternative types of threshold for detection. The simplest form is an absolute value, T of the threshold. The CFAR threshold requires a user supplied parameter, α which specifies the threshold as that number of standard deviations above the mean.

$$T = \alpha\sigma + \mu \quad . \tag{6}$$

In either case, all detected pixels must now be clumped into targets. Since we have assumed we are dealing with unresolved targets, a simple clustering algorithm is sufficient. Essentially, we grow a rectangular box around each detection pixel, adding any other detection pixels which fall within the box and growing the box to include the current detection pixel. A more complex clustering algorithm which allows separate detection of inter-digitated targets is described in [3].

As we are clustering, we also maintain various statistics for each cluster. Specifically, we keep count of the number of detected pixels in this object, the minimum and maximum extents of the cluster (in the x and y focal plane directions), the centroid location of the target, and the total intensity of the target. To compute the total intensity, the pixel location (x,y) is used to look up the pixel value in the original input image (prior to background subtraction). The total intensity is the sum of the intensities of all pixels in the target. The centroid location (x_0,y_0) is computed as the sum of pixel location times pixel intensity, divided by the sum of pixel intensities:

$$x_0 = \frac{\sum Ix}{\sum I} \quad y_0 = \frac{\sum Iy}{\sum I} \quad . \tag{7}$$

A silhouette centroid could be computed by setting the pixel intensity I to unity.

A size threshold can be applied to detections to eliminate leakage of large background structures. The size threshold is a "not to exceed" number of pixels. It can be implemented as a total number of pixels or as extents in the x and y directions. For this implementation we use a total number of pixels size threshold. The parameter C is the pixel count threshold. A typical value of C = 6 was used. Any targets having more than C pixels are eliminated from the detection list.

Remaining detections are placed in a "Sighting Message" structure. The sighting message structure is placed in shared memory for the tracker. Note that the sighting message contains a time stamp. This should be the time the frame was acquired, the start of frame integration.

This portion of the algorithm requires three input parameters, one is a flag indicating whether to use an absolute or CFAR threshold. The second parameter is either the absolute threshold or the α value, depending on the threshold type flag. The final input is the pixel count threshold value C. This module produces the Sighting Message output for the entire detection algorithm.

4. PIXEL TO LINE OF SIGHT

Development of target histories and tracking in focal plane coordinates is difficult because of the effects described in section 2: non-linear and discontinuous motion on the focal plane, single objects imaged at two simultaneous locations on the focal plane, and multiple objects at different real space locations imaged to the same location on the focal plane. The natural solution is to convert detected target pixel locations into angular Line Of Sight (LOS) coordinates and develop track histories in LOS coordinates. The natural LOS coordinates for a stationary HOST system are azimuth and elevation.

Most tracking sensors have a limited Field Of View (FOV) in which each pixel has the same Incremental Field Of View (IFOV), such that one can multiply the IFOV by the number of pixels to obtain the total FOV. In the case of the HOST sensor, the IFOV varies with elevation angle, and hence the LOS is not a simple conversion as described in [4].

In order to determine the azimuth of a target, we use the target pixel location relative to the point where the optical axis intersects the focal plane, the boresight pixel. If the target is located at pixel location (x,y), and the boresight pixel location is (x_b,y_b), then the x and y distance from the boresight is (dx,dy) and the radial distance from the boresight to the target is r:

$$dx = x - x_b; \quad dy = y - y_b; \quad r = \sqrt{dx^2 - dy^2} \quad . \tag{8}$$

In general, this calculation requires determining whether the object lies in the fisheye or panoramic sensor portion of the focal plane, in order to determine which boresight pixel to use (fisheye or panoramic). In practice, since the two optical axes are well aligned, there will be little error introduced by using a single common value for the boresight location.

We define 0° azimuth as dx = 0 and dy > 0. Then, the azimuth (az) is given by:

$$az = \tan^{-1}(dy/dx) \tag{9}$$

where we use the C language atan2() function in order to get the correct 4 quadrant result. We can add an arbitrary offset to this value, to account for HOST unit rotation so that the computed azimuth is relative to true north. The IFOV in the azimuth direction (in radians) is 2π radians divided by the number of pixels in a circle of radius r ($2\pi r$):

$$IFOV_{az} = 1/r \tag{10}$$

We considered two approaches for mapping HOST pixel location to elevation angle: 1) Develop analytic equations which convert pixel radius from the boresight location into elevation angle, or 2) Use a Look Up Table (LUT) of elevation angle versus radius from boresight. To develop this mapping algorithm, we began with measured elevation angle as a function of radius (in pixels) from the boresight location.

We determined that a third degree polynomial gave a good match to the measured data for the fisheye portion of the focal plane, while a fourth degree polynomial was needed for the panoramic portion. Thus we needed two different polynomials. A nice feature of the analytic equation approach is that it automatically provides sub-pixel mapping to elevation angles.

The maximum radius achievable with our NxN pixel focal plane array, is N/2 pixels from the boresight. We decided to utilize an N/2 position LUT resulting in single pixel quantization. It is of course possible to interpolate from the LUT to obtain sub-pixel mapping accuracy.

After comparing the two approaches, we decided to implement the LUT approach in the HOST system. We felt this gave the most flexibility in the processing to accommodate future changes in the optical system. Further, we felt we could achieve sub-pixel accuracy if required through interpolation. Elevation angle versus pixel distance from boresight is shown in figure 3.

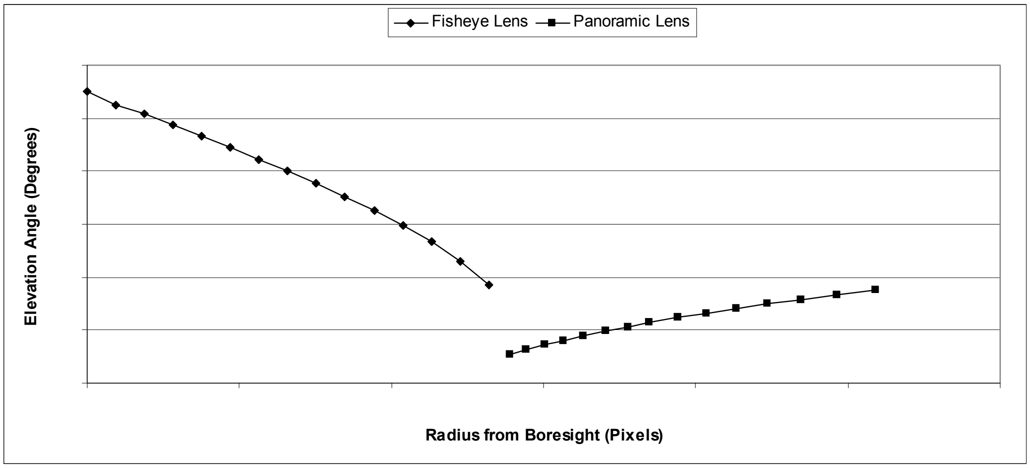

Figure 3. Elevation Angle versus radius from boresight

The IFOV in the elevation direction is estimated by taking the difference in elevation angle between two adjacent pixels at the target location. Thus if the radius to a target is 15.3 pixels, the IFOV would be the elevation angle at 15 pixels minus the elevation angle at 16 pixels.

The IFOV mapping also combines targets which are split across the fisheye / panoramic sensor boundary. The algorithm looks for targets with the same azimuth and elevation angles just above and below the fisheye / panoramic boundary. Targets satisfying these criteria are combined into a single target before passing to the track function.

5. TRACKING & TRIANGULATION

A multi-target global nearest neighbor detection to track assignment algorithm [4] is used to develop track histories for individual targets. This algorithm assigns detections to tracks using a unique detection to track assignment algorithm (no detection can be assigned to more than one track and no track can have more than one detection assigned to it). Unused detections are used to initiate new tracks. The tracker develops time histories of each physical target, including LOS and intensity. This data is output from the HOST unit for use in higher level processing.

Since the HOST is a LOS angles only sensor, it does not generate range information. Since targets may be moving in any direction, a single HOST sensor cannot distinguish a distant fast moving target on a radial vector, from a stationary target. By combining the LOS track data from multiple sensors, it is possible to perform a triangulation operation [5,6] to develop 3D position versus time. With this information, it is possible to apply velocity thresholds to eliminate targets which are not of interest.

In general, the multi-sensor data association problem is difficult. For narrow FOV sensors there is no assurance that both sensors are seeing the same targets. Since the HOST sensor has a hemispherical FOV, two HOST sensors will see approximately the same region of space and hence the same targets. Since our targets are assumed to be radiometrically bright sources, we do not anticipate a situation where targets seen by one sensor are unobservable by a second HOST sensor. Thus we assume that both sensors see the same set of targets. Sensor to sensor correlation can be accomplished primarily based on time of origin, and secondarily by features such as radiometric intensity.

Once the sensor to sensor correlation has been performed, it is possible to triangulate and determine the 3D position of each target. From this it is possible to determine the velocity. The 3D velocity and radiometric signature can be used to perform target classification.

6. VALIDATION AND TEST

To test the pixel to LOS conversion routine, three trajectories were generated: a low-angle trajectory, high-angle trajectory, and an overhead trajectory. The trajectories were then fed to the HOST tracker code to test accuracy of the resulting az/el values as well as the track history function.

The low angle trajectory simulates an object flying at low elevation angles. The target is detected and tracked by the only panoramic system. The target is detected near the horizon to the left of the FPA's "North" line. The target gradually rises, peaking around 12º before falling back to the horizon. This trajectory crosses the 0º/360º line, testing the pixel to LOS conversion. The azimuth angles correctly progressed from 359º to 0º when this trajectory was tested with the tracker code.

The high angle ballistic trajectory simulates an object flying from the horizon, to near zenith, returning to the horizon. The trajectory crosses the fisheye and panoramic boundary. In reference to the FPA, the target is first detected near the horizon line to the left of "North". The target progresses to the outer edge of the panoramic image space and then appears to jump to the inner circle near the dotted boundary line marking the transition from panoramic to fisheye field of views. The target moves inward, approaching zenith, before falling toward the boundary line and jumping to the outer edge of the panoramic image space, moving inward toward horizon.

The overhead trajectory simulates an object flying a ballistic path from horizon through zenith and back to the horizon. Similarly to the high angle trajectory, the target is first detected near the horizon to the left of "North". The target progresses toward the outer edge of the panoramic image space. It is then detected near the boundary of the panoramic and fisheye image spaces where it proceeds through zenith toward the right of the FPA toward the boundary line. Detection continues on the outer edge of the panoramic space to the right of "North", where it progresses inward to the horizon line.

For all these test cases, the pixel location maps were created, input in to the tracking program, and the resultant azimuth and elevation for each object of interest were produced. The resultant output from the tracking program were then compared to the expected azimuth and elevation values, and were found to be correct.

Recently, the optical subsystem of HOST was field tested at the intersection of three active runways at a local international airport. During two separate experiments, conducted during the early evening and mid day, HOST observed normal commercial and military flight operations of a variety of fixed wing and rotary aircraft. Target distance was measured out to 30 kilometers using a passive optical ranging device.

7. SUMMARY

A Hemispherical Optical Sensor Tracker provides unique capability for large area, continuous and simultaneous surveillance. However, it also introduces a number of challenges for target detection and tracking. These challenges include the presence of extremely bright, high gradient background objects such as the sun, moving background features such as clouds and cloud edges, non-linear and discontinuous movement of objects on the focal plane, and the presence of multiple objects to be tracked simultaneously. This paper has described how maximum likelihood multi-frame detection techniques can be adapted to solve the detection problem, and how tracking in Line Of Sight (LOS) coordinates can simply the tracking problem caused by the optical system discontinuities. We have also briefly discussed how multiple HOST units can be used to triangulate 3D position of objects, and hence apply velocity thresholds to improve discrimination. The result is a highly capable surveillance and target acquisition sensor.

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REFERENCES

1. J.N. Sanders-Reed, "Maximum Likelihood of Unresolved Moving Targets", *IEEE Trans AES*, **34 (3)**, July, 1998.
2. W.K. Pratt, "Digital Image Processing", Wiley-Interscience, 1991.
3. J.N. Sanders-Reed, "Transportable Algorithm TestBed (TATB)", *Proc SPIE*, **2468**, April, 1995.
4. J.N. Sanders-Reed, "Multi-Target, Multi-Sensor, Closed Loop Tracking", *Proc SPIE*, **5430**, April, 2004.
5. J.N. Sanders-Reed, "Error propagation in two-sensor 3D position estimation", *Opt Eng*, **40 (4)**, April, 2001
6. J.N. Sanders-Reed, "Impact of tracking system knowledge on multi-sensor 3D triangulation". *Proc SPIE*, **4714**, April, 2002.