# THE VECTORIAL 3D BIRD FLIGHT MONITORING SYSTEM: A NEW TOOL TO TRACK AND MANAGE BIRDS ON AIRPORTS,”


By:
Raoul Tommasi Crudeli
Tommasi & Tommasi America LLC
West Joppa Road, 1106
Baltimore MD 21204
USA
raoulamerica@yahoo.com



PRESENTED FOR THE
2007 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2007

## ABSTRACT

Among the many sensors available to detect and track bird movement on airports, few provide a satisfactory capacity to both monitor bird flight to rapidly review, update, and improve monitoring capabilities. The patent pending Vectorial Three Dimension Bird Flight (V3DBF) Monitoring System has been developed to provide detection and analysis of bird movement leveraging digital images and advanced image analysis technology. The sensor system is capable of identifying bird targets and, using geometric relationships between sensors and the targets, to localize three dimensionally birds and flocks, providing native WGS84 output data, and therefore it is also possible to integrate measurements with existing GIS. The rapid refresh rate of the system allows three dimensional tracking of bird targets, as well as measurement of their speed and direction.

The detailed output data can be further compared with a pattern library, both in an automatic or supervised way, to determine the species for ethological studies. The library will comprise the most frequent species found near US airports, therefore enabling the system to provide not only counting and positional information, but also an adequate classification in terms of species.

Because the original data are retained, a complete record of detection and corresponding data processing is available to check accuracy and evaluate the performance of the system in a given airport setting. The system can be extended to integrate multiple sensors and provide coverage of large areas. Present V3DBF system capabilities have been expanded beyond detection and tracking to include birdstrike hazard assessment and hazard warning based on track intersection with critical airspace.

## INTRODUCTION

This system will calculate the dynamic 3D position of flying birds by taking advantage of the stereovision method. Not only does this method allows us to detect the presence of flying objects in a given zone; it also allows their coordinates and movements to be tracked when they are within the field of vision of the system. The system consists of two appropriately calibrated video cameras that are connected to a PC.

## BASIC INFORMATION ABOUT STEREOVISION

Stereovision is a methodology the permits 3D measuring for $n>=2$ images from the same scene. When $n=2$ we speak of epipolar geometry.

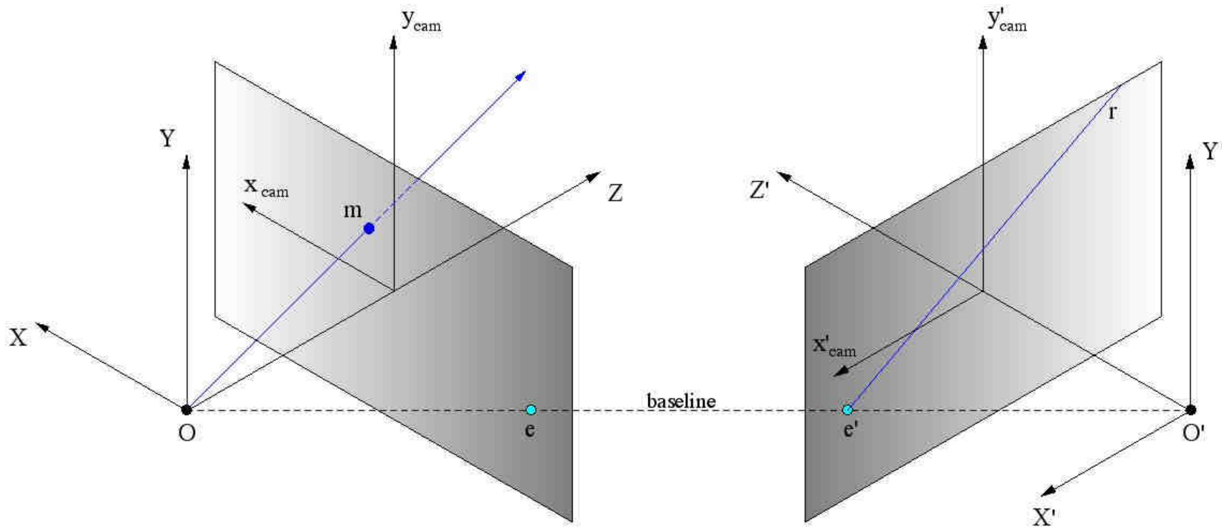


Figure 1. A scheme of the epipolar planes and lines.

If we consider two cameras C1 and C2 posted at points O and O' we see how a point *m* on the image plane of camera C1 corresponds to a point which lies on line *r* which is traced on the image plane of camera C2. This line is called the epipolar line.

All epipolar lines pass through a point called the epipole (*e* and *e'*) which is the point at which the line connecting the two optical centers (the baseline) meets the image plane. Given a set of corresponding points in the two images (*Pi*,*Qi*), each point lies on the epipolar line generated by its correspondent. Epipolar geometry depends uniquely on the parameters and geometry of the two cameras and not on the geometry of the scene. In particular, an epipolar line on the image is described by $ax+by+c=0$ where the coefficients of the *i*-th line can be represented as $r_i=[a_i, b_i, c_i]^T$.

A matrix called the "*fundamental matrix*", F, exists which is the algebraic representation of the epipolar geometry and which therefore relates an epipolar line to the point it has generated. For each pair of valid points *x* and *x'*, a 3x3 matrix exists for which $\mathbf{x}'^T F \mathbf{x}=0$ and this matrix is therefore called the "*fundamental matrix*".

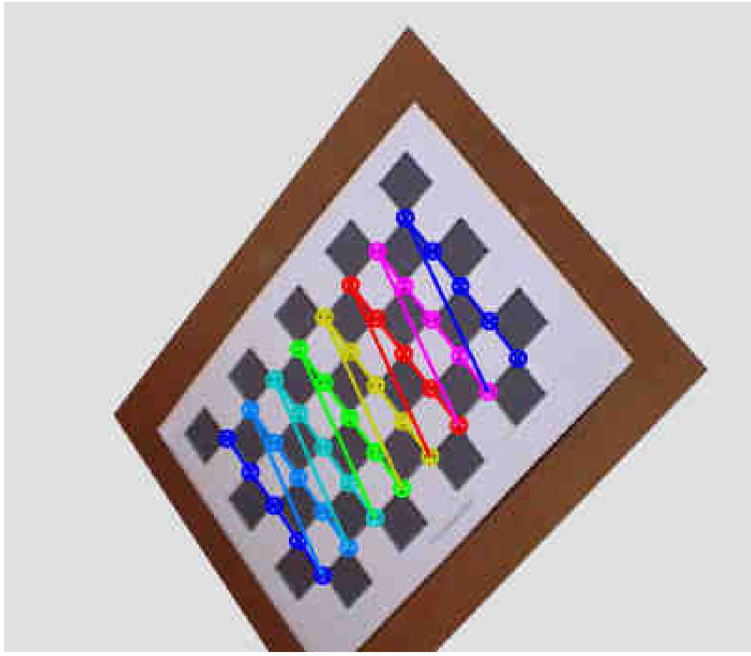

Figure 2. An example calibration checkboard with the automatically detected points and the interconnecting lines.

For simplicity, let's assume that the coordinate system defined by the first camera is the coordinate system of our space. The projection matrix of the first camera is therefore $\boldsymbol{P} = \boldsymbol{K} [\boldsymbol{I_{3x3}} | \boldsymbol{0}]$ and the matrix of the second camera is $\boldsymbol{P'} = \boldsymbol{K'} [\boldsymbol{R} | \boldsymbol{t}]$, where ***R*** and ***t*** describe a rotation and a translation of the second camera with respect to the first and where ***K*** and ***K'*** represent the calibration matrices of the two cameras. The "*fundamental matrix*" depends only on the position of the cameras in relation to each other and on their calibration. Given ***R*** and ***t*** (the rotation and translation matrices) a matrix E exists called the *essential matrix* which is $\boldsymbol{E} = [\boldsymbol{t}]_{\boldsymbol{x}} \boldsymbol{R}$ and from which it follows that $\mathbf{E}=\mathbf{K}^T\mathbf{F}\mathbf{K}'$. Thus we see that we can have the 3D coordinates of the point in the real world, because the intrinsic calibration matrices of the two cameras generate the "*fundamental matrix*" and the two homologous points on the relative images have been defined.

## CALIBRATION OF THE VIDEO CAMERAS

We have seen how it is possible to create the 3D positioning of a point starting with a pair of 2D images. To be able to perform this calculation, however, we must first obtain the intrinsic and extrinsic calibration matrices of our videocameras. We use the algorithm described in [1] to calculate the intrinsic and extrinsic parameters of a videocamera. The implementation of this algorithm has been made possible using the libraries of OpenCV from Intel. In particular, to obtain the intrinsic calibration values of a videocamera, a large checkboard is used. Given a series of images of the checkboard acquired with the videocamera to be calibrated, an automatic calculation procedure takes place which allows us to obtain the intrinsic calibration values.

These values are used to determine the position in space of the videocamera and the 3D coordinates of points which can be seen in the two homologous images. We use the checkboard because the OpenCV library contains a whole series of functions that facilitate the automatic recognition of the vertices in checkboards. This allows automatic calibration to proceed very easily.

Table 1.
Example of the parameters gathered during the calibration of a videocamera.

| | |
|---|---|
| Number of images | 231 |
| Square Size | 40.000 (mm) |
| Checkboard Dims | 9 x 6 |
| Principal Point | [362.007 281.433] |
| Distorsion | [-0.243676 0.033767 8.536094 -0.001556] |
| Pixel Error | [0.13 0.18] |

Once the calibration parameters have been defined for the individual videocameras involved, it's necessary to determine the position of the videocameras with respect to each other in such a way as to be able to define the position of a given point in 3D space. Given the intrinsic calibration parameters of the videocameras and given two images of the same checkboard along with the parameters that define that same checkboard (dimensions and number of squares) a function in OpenCV called "cv3dTrackerCalibrateCameras" can provide the matrices that define the positions of the two videocameras in the space that we are considering. Since in the proposed system distances are too large to create a real size calibration checkboard, we had to modify the calibration function of cv3dTrackerCalibrateCameras. This had to be done in order to let it use some points with known 3D coordinates instead of the automatic checkboard-based calibration. Using the coordinates relative to the two images taken from the videocameras, the new function delivers precise calibration even considering large actual distances.

Table 2.
Example of the matrices that result from the calibration of two videocameras using the "cv3dTrackerCalibrateCameras" function from OpenCV.

Camera 1

| | | | |
|---:|---:|---:|---:|
| -0.000917 | -2.14e-005 | -0.000244 | 0.000 |
| -1.69e-005 | 0.000876 | -1.33e-005 | 0.000 |
| -0.258 | 0.00965 | 0.966 | 0.000 |
| -845.0 | 307.0 | 2.67e+003 | 1.00 |

Camera 2

| | | | |
|---:|---:|---:|---:|
| -0.000946 | -9.85e-006 | 2.23e-005 | 0.000 |
| -9.37e-006 | 0.000878 | -9.55e-006 | 0.000 |
| 0.0235 | 0.0111 | 1.00 | 0.000 |
| -102.0 | 366.0 | 2.63e+003 | 1.00 |

## SYSTEM STRUCTURE AND SETUP

The V3DBF system is composed of a pair of videocameras for acquiring synchronized images. This detail is very important since analyses must be made from images simultaneously. To acquire synchronized images, we turn to certain acquisition boards that allow the acquired images to be in sync. Some videocameras even have synchronization ports that are built in for use in stereovision systems where synchronization of images is of fundamental importance. Another important element to keep in mind is the frequency of acquisition, which must by greater than five frames per second to allow the movements of flying objects to be **tracked** with enough time-resolution.

Before being deployed in the field, videocameras get calibrated using the software provided, to generate the intrinsic calibration parameters that then get inserted into the survey software. The intrinsic calibration is made using a high number of images of the calibration checkboard taken from various angles in such a way as to cover all the possible angles and have parameters that are as precise as possible.

The parameters that get entered into the software and are then used to build the calibriation matrix are:

- Principal Point
- Focal Length
- Distortion

At this point, once the videocameras are located on site and are oriented as needed to cover the zone in which the presence of birds is to be detected, the cameras must be calibrated so as to obtain the positioning matrices of the videocameras and to permit the definition of the coordinates (x,y,z) of a detected point in 3D space.

To externally calibrate the videocameras, we insert a series of points in the image of the first camera, in the image of the second camera, and their real world coordinates. These are defined with respect to a pre-established origin whose coordinates are known.

This way of calibrating, is more laborious with respect to the automatic detection of a checkboard, but allows two distant videocameras to be externally calibrated, and was developed to take into account the large distances among the objects to be detected (birds flying in the whole viewfield of the cameras). In fact, since the dimension of the calibration checkboard should be as close as possible to the maximum common viewfield, in order to use the automatic calibration, a checkboard of some hundreds meters would be needed, which is obviously unfeasible. If the calibration procedure is successful, the system will be ready to survey objects in space by detecting the coordinates of the point in the defined system of reference. The image acquisition systems and calculation systems can also be located in separate structures, also to distribute the computational requirements.

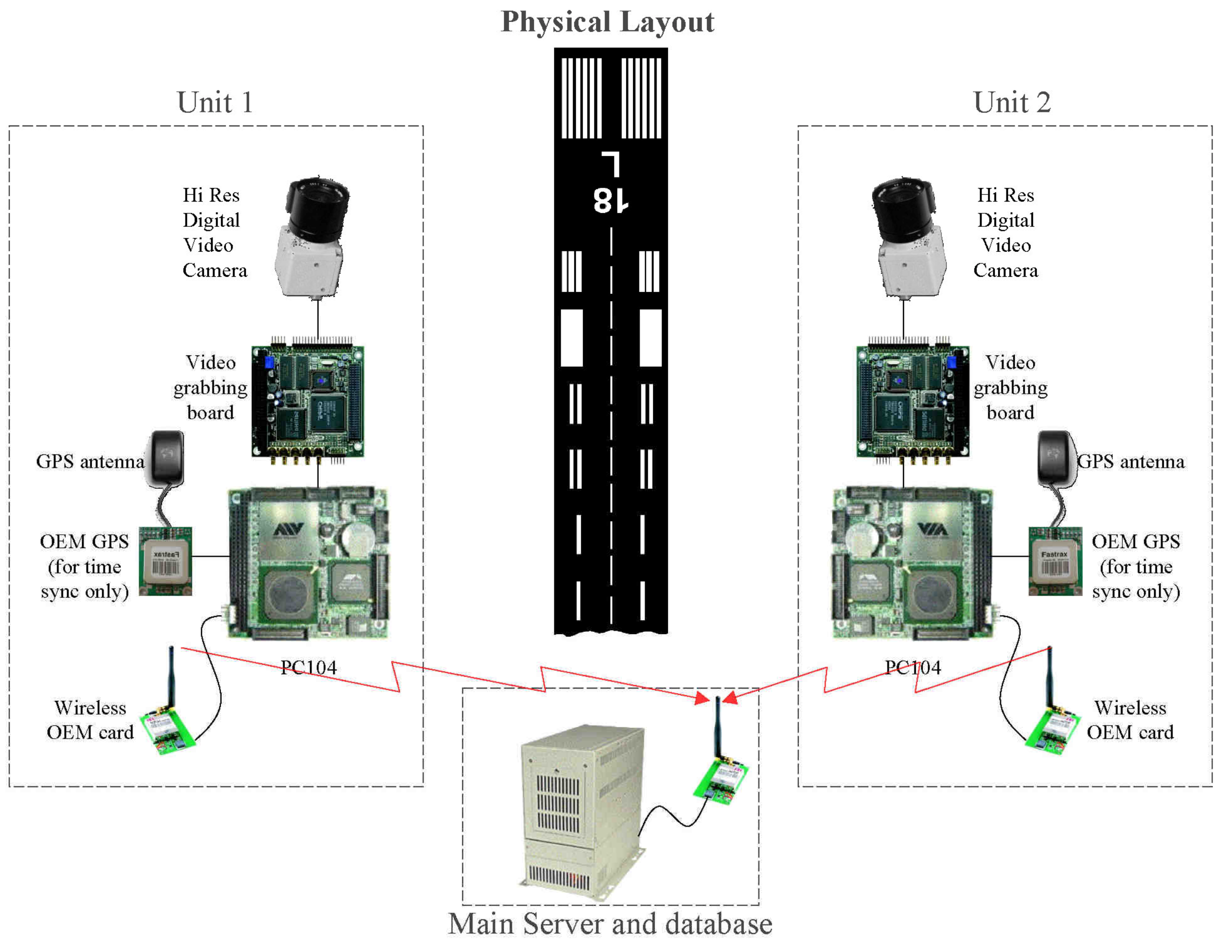


Figure 3. A conceptual layout scheme for the use in airport areas. Acquisition units can be separated from the main server, where the actual calculations take place.

## DETECTION OF FLYING BODIES

For each pair of frames coming from the two videocameras, an automatic recognition procedure must be used to establish which elements appear in both images and which should have their coordinates memorized. For what concerns the detection of birds, the images are processed in such a way as to render birds more easily identifiable. Also, movements detected from one frame to the next are evaluated. Once potential birds have been detected, a cross-check of the data coming from the two images is made in a way that determines which pairs of points (in time) to keep in consideration. In this phase, the calculation algorithm provides for evaluation based on the distance between the two epilines and in this way discards all points that cannot be placed in relation to each other.

For each pair of points for which it is has been possible to establish a plausible relationship, the 3D coordinates are calculated, and these get memorized in a database together with the identification of the object and a time tag.

From one frame to the next, the movement of the single element is followed in order to be able to maintain the identification attributed in the previous step. In cases where it isn't possible to establish a previous identity for a given element (e.g. birds entering the scene) a new ID will be assigned. In a case where a massive presence is detected, with the obvious difficulty of pairing the points, the database will memorize information about the massive presence of birds in the time interval and space subdomain. When a flock of birds is detected, the system will try to distinguish some peripheral points which are more easily identifiable, in order to characterize the whole flock (i.e. it defines the coordinates of the volume in which the flock has been detected).

The greatest difficulty lies in determining the homolgous pairs of points in the two images. This difficulty increases with the number of objects present in the image, and also increases as visibility decreases. On the other hand, the use of complex algorithms to determine homologous points decreases the system's real time performance.

## ANALYSIS OF THE DATA

Once the data have been acquired and memorized in the database, they can be analyzed in order to determine types of bird, high-risk seasons, the presence of flocks, etc. This information becomes a knowledge base to be used in preventing danger to aircraft. For some detections it will be possible to determine flight trajectories and this will help with more precise classification of detected birds.

The average error detected in measuring real points is on the order of 2% and therefore the 3D space that results from the survey is useful for birds detection and their movement-tracking. It also allows to follow objects by giving discrete values to distances and trajectories.

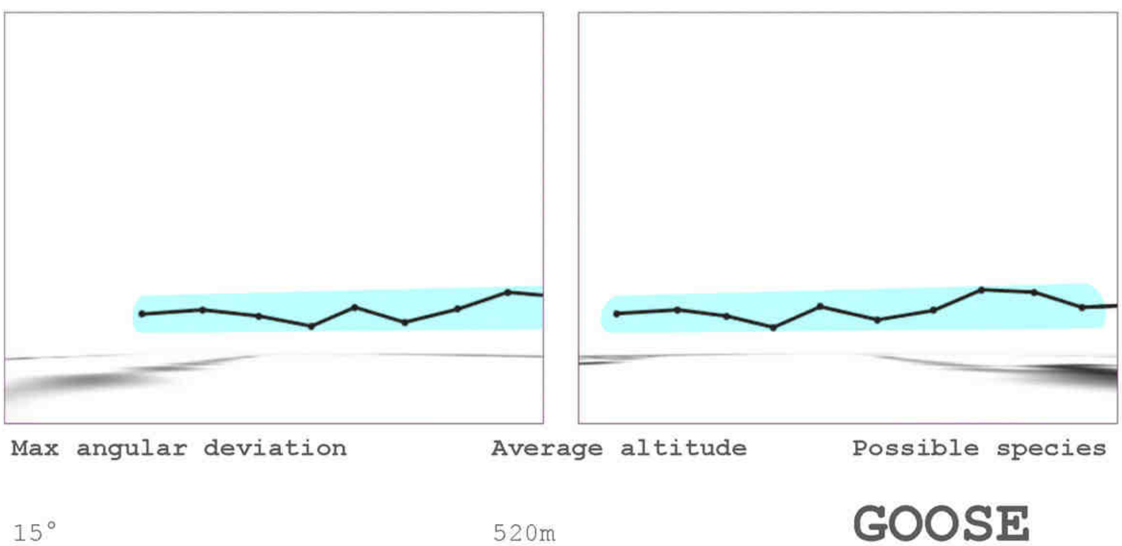


Figure 4. An example displaying the trace of the last detected points and the connecting track. Based on this information (average height, geometrical variation of the track, speed etc.) it is possible to classify the species of bird.

## MODULARITY OF THE SYSTEM

Since the depth of common field of the two cameras is limited, multiple pairs of cameras can be deployed to record data within the same database. This provides a more comprehensive set of data covering a wider spatial area than that covered by a single camera pair. In the same way, using more than one camera pair in a radial arrangement allows to increase the angle of vision in addition to the depth of field.

## FUTURE WORK

Weather conditions, which determine visibility, influence the system's performance. A possible improvement in the detection phase could be obtained by positioning a secondary luminance sensor and feed its readings to an optical filter in order to compensate the variations in lightning.

The two factors contributing to performance are the frequency of acquisition and the processing time for individual data. To acquire images at a high rate and at the same time obtain good detection results, the acquisition phase and the processing phase must be separated. A dedicated post-processing workstation works better than one which processes the images while they are acquired.

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