Description of a Method for Localizing Swarming Mosquitoes and Other Insects in 3D Space with Visualizations

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Abstract

Male mosquitoes swarm to find mates, but the characteristics of these swarms have not yet been quantitatively analyzed in the field. This paper describes a simple method used recently to localize individual *Anopheles gambiae* in a swarm via stereoscopic image analysis of video footage swarms recorded in Donéguébougou, Mali. The methods described here represent a streamlining of simple triangulation for insect localization in the hope that other researchers will be able to apply the method for studying fundamental questions about flying insects or other taxa.

Key-Words : Stereoscopic image analysis, 3D localization, Insect tracking, Triangulation

1 Methodological overview

Estimating the position of an individual mosquito in video footage involved 1) preparing a stereo image from the movies of two cameras, 2) measuring the location of the individual in the images and 3) using simple geometry to obtain the estimate of position in three dimensions. I describe each of these steps below, as we performed them during a study of mosquito swarms in Mali [Manoukis et al.(2009)]. Figure 1 gives an illustration of the camera orientations and how they are related to world coordinates. I will use that notation throughout the following discussion.

The camera lenses are aligned so as to present a parallel projection. I could identify individual mosquitoes (correspond) using the epipolar constraint method [Hartley and Zisserman(2004)] and by stepping through the images to confirm that both points representing a single individual were moving in similar directions.

2 Creating stereo images

Our Sony HDR-HC7 high definition digital camcorders (Sony Corp., Tokyo Japan) produced HDV compressed video files which could be transferred to the computer. These files are not accessible via most free video processing applications so I demuxed them using ProjectX (`http://project-x.sourceforge.net/`) to extract an MPEG-2 compressed video stream.

The MPEG-2 compressed clips could be used directly with StereoMovieMaker (`http://stereo.jpn.org/eng/stvmkr/`). This application allowed fine adjustments and verification of time synchronization between clips, as well as basic modification of the levels of each image.

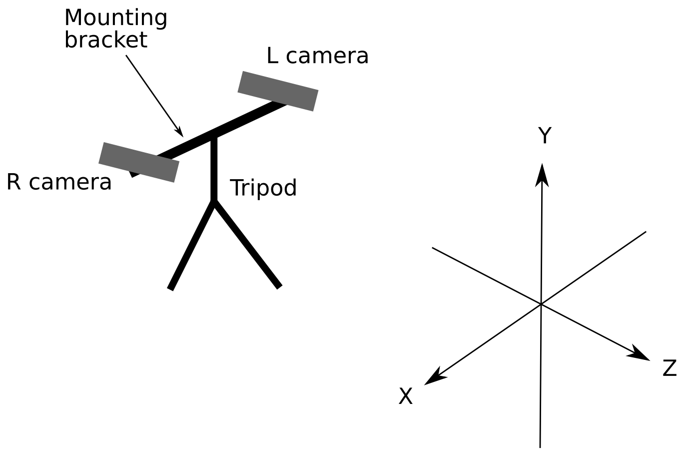

Figure 1: Camera and axis orientation

Once alignment was confirmed to be accurate, greyscale stereo movies were rendered in an intermediate, losslessly compressed format (Huffyuv: `http://neuron2.net/www.math.berkeley.edu/benrg/huffyuv.html`). These stereomovies showed mosquitoes from the right camera's footage in cyan and those from the left in red. I extracted still images from these stereo movies at the native frame rate of 29.97 images per second using VirtualDub (`http://www.virtualdub.org/`) or Cinelerra (`http://cinelerra.org/`); these formed the basis for the analysis described in [Manoukis et al.(2009)] and the visualization presented below.

3 Localizing individuals

Localization of individual mosquitoes in three dimensional space once stereo images were available consisted of two discrete steps. First, I estimated the distance from the cameras of the mosquito using triangulation on measurements taken from the stereoscopic image. Second, I utilized a pin-hole camera model on one of the images from the stereo pair to determine the ray along which the mosquito lay. Using the estimate of distance and knowing the direction, I could obtain an estimate of the position of the individual in three dimensions. I describe each of the steps in detail below, first describing the camera model, as this is fundamental to the discussion below.

3.1 Camera model

The camera model I used is shown graphically in Figure 2. I require f, the focal length of the lens in mm, the size of the sensor (U = horizontal size in mm, V = vertical size in mm), the position of a mosquito in the image ($\{u_p, v_p\}$, in pixels) and the number of pixels in the image horizontally and vertically (h_r and v_h, respectively).

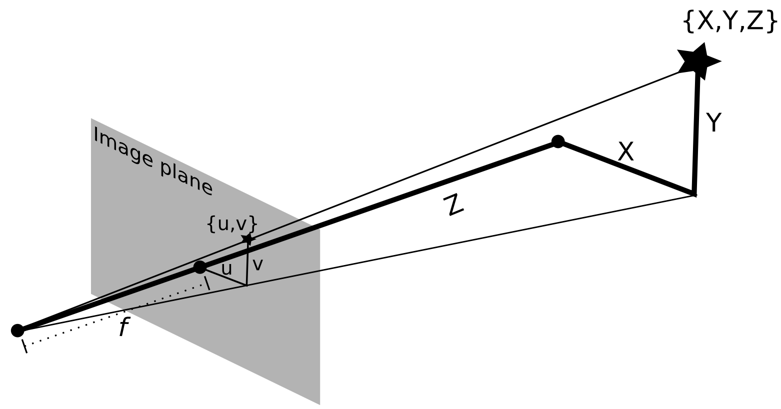

Figure 2: Camera model

I first calculate u, v in mm, as follows; note that u is relative to the image center, which I defined as $\{h_r/2, v_r/2\}$

$$u = u_p \frac{v_h}{U} \quad (1)$$

$$v = v_p \frac{h_h}{V} \quad (2)$$

3.2 Estimating positions

Distance from the camera (Z, Figure 2)was estimated using simple triangulation, as shown below

$$Z = \frac{bf}{u_l - u_r} \quad (3)$$

where b is the baseline (distance between the optic centers of each camera, in m), f is the focal length (in m) and u_l and u_r are the size of u for the left and right cameras, respectively, in m. I note that since the projections are parallel, I expect that $v_l = v_r$ (where v_l, v_r are v for the right and left cameras).

Once Z is known, X and Y could be estimated as follows:

$$X = u_r \frac{Z}{f} \quad (4)$$

$$Y = v_r \frac{Z}{f} \quad (5)$$

I used the right camera for u and v, as shown above, but the left also could have been used.

4 Software availability

An R [R Development Core Team(2008)]function, to calculate positions from stereo measurements, calcxyz.R is available from `http://exon.niaid.nih.gov/3dswarms`. Also available at that site is a convenience plugin for ImageJ which may be used to easily gather these data.

5 Swarm visualizations

I have prepared two complementary types of visualizations of the swarm structure and dynamics based on our first results [Manoukis et al.(2009)]. The first are manipulable virtual reality "worlds" which represent the locations at which individual mosquitoes were seen relative to the swarm centroid at that moment. The mosquitoes are colored to represent their proximity to the nearest neighbor at the moment when they were seen. A sample is given below, in Figure 3.

The second set of visualizations are a pair of animated plots for each swarm depicting the locations at which mosquitoes were seen over time. In the first plot, "Positions per time step", mosquitoes appear in the configurations they were seen for each image analyzed. In the second, "Accumulation of positions over time", mosquitoes appear as they did in each image but are not removed between images. This allows a rough comparison of where individuals were being localized relative to those seen in other images. Playing both files at approximately the same time is helpful to understanding the positions where mosquitoes were observed.

3D visualizations for the remaining swarms and movies are available on line at the following URL: `http://exon.niaid.nih.gov/3dswarms/Vis`

6 Conclusion

I have presented a streamlined method for localizing flying insects in 3D space based on simple principles of triangulation and a basic model of camera optics. In addition, I have provided a sample visualization based on the first analysis using this method [Manoukis et al.(2009)], which has provided some insight into mating aggregations of *Anopheles gambiae*, a vector of medical importance. It is my hope that the approach described here will be useful to other researchers studying flying insects or perhaps other taxa.

7 Acknowledgments

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References

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[R Development Core Team(2008)] R Development Core Team. *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria, 2008. URL `http://www.R-project.org`. ISBN 3-900051-07-0.

Figure 3: Cumulative 3D locations of individuals detected in the swarm of 16 September 2007. All positions are given relative to the swarm centroid at the moment of detection , to control for the effect of camera movement. Colors indicate the natural logarithm of the distance to nearest neighbor (DNN): Red = closer, blue = further. Axis orientation relative to camera position is as follows: Y=vertical axis, X=horizontal, left/right and Z=horizontal, distance from the camera At this time you must use Adobe Reader 8 or later in order to view and manipulate the figure. You can download this software for many platforms free of cost from the following URL: `http://www.adobe.com/products/reader`. A fast computer and accelerated graphics card are helpful to seeing the figure move clearly.