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A Real-Time Computer Vision System for Tracking of Underwater Benthic Larvas

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Abstract

The paper presents a computer vision system for real-time tracking of underwater benthic larvas. The system is comprised of COTS components and does not require custom hardware for attaining real-time performance.

The system is currently used by marine biologists to study the motion pattern of the larvas in order to better understand their fixation process.

1 Introduction

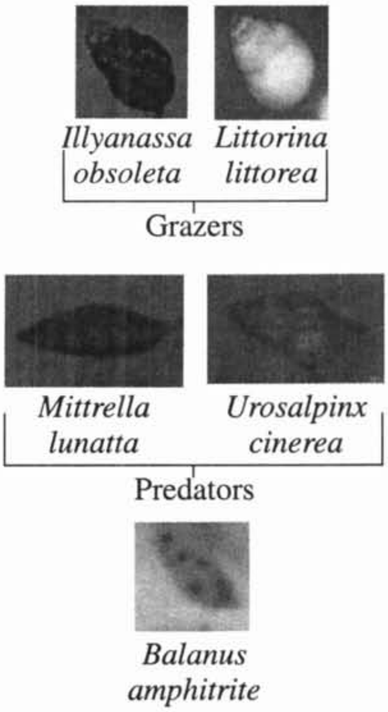
Recent research work in marine biology has shown that there is a link between the heterogeneity of the substrate and the hydrodynamics in the fixation of mollusc larvas. The larvas are suspended in a water flow and are dispersed by advection at several spatial and temporal scales.

Modelling the fixation process with respect to the hydrodynamics of the water flow and other factors such as the presence of predators is an important step in understanding the behavior of the larvas [1]. Such modelling can be achieved by observing their trajectories in the water flow. The observation has been traditionally done by recording videotapes of the trajectories and processing the recorded information manually off-line. Such an approach is slow, inaccurate, and error prone.

This paper describes a computer vision system for accurate real-time *in situ* analysis of the trajectory of larvas in a water flow. In addition to real-time constraints, the vision system must address issues such as *i)* the low contrast between the larva and the background, *ii)* the high speed of the water flow, *iii)* the high turbidity of the water, and *iv)* the narrow field-of-view of the camera.

Figure 1 shows different specimens of larvas.

Figure 1 Predators, grazers, and a balanus specimen.



2 Overview of the Vision System for Tracking Larvas.

The setup for real-time tracking of the larvas is composed of several components.

An endoscope is attached to a camera head that is mounted on a X-Y translation stage (25 cm range for each axis). The endoscope is immersed in the water flow and looks at the ocean bottom (called the substrate).

The images provided by the camera are processed in real-time to first *locate* and then *track* one larva at a time. The X-Y translation stages move the endoscope such that the larva always

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remains on or near the center of the field of view until fixation occurs.

3 Calibration of the system

In order to express the trajectories in real-world coordinates, the system needs to be calibrated.

In the calibration configuration, a target is positioned in front of the endoscope. The target is composed of an array of equally spaced black discs superimposed on a white background. The spacing between discs is known with accuracy. The intrinsic parameters of the camera are estimated with the well-known multi-plane Tsai's algorithm [2]. Once the intrinsic calibration parameters are estimated, the system is configured in operation mode which consists in moving the X and Y translation stages at mid-range and starting a tracking run. The principal point of the camera C_x, C_y is considered as the origin $(0, 0)$ of the world reference frame and all positions on a trajectory are referenced to this origin. It is straightforward to convert image coordinates to world coordinates and to compute the trajectory $(\Delta x(t_i), \Delta y(t_i))$ at each acquisition frame t_i relative to the first frame t_0:

$$\Delta x(t_i) = (x_i - x_0) + T_{xi} \tag{1}$$

$$\Delta y(t_i) = (y_i - y_0) + T_{yi} \tag{2}$$

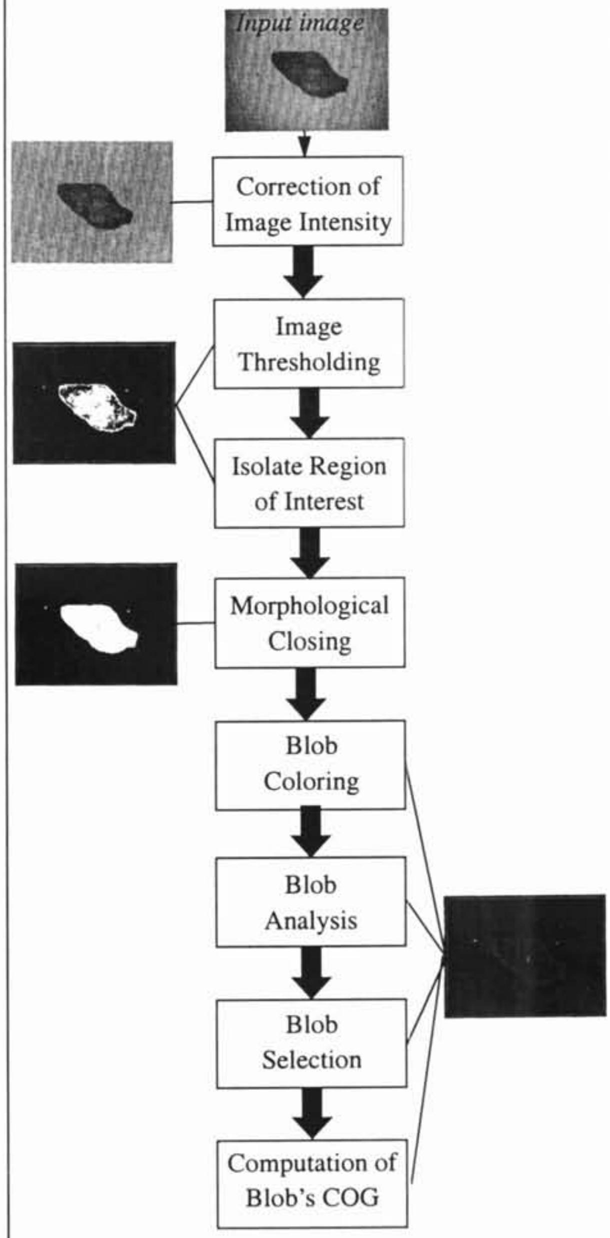
4 Computer vision approach for the detection and tracking of the larvas

The graphics user interface system displays the output of the camera on the computer screen and the user clicks with the mouse on the area near a larva to initiate a tracking run.

Due to the real-time constraints, the image processing algorithms needed to track the larvas must remain simple yet robust and reliable. Figure 2 shows the different steps that were implemented to process each image frame in order to track a larva that has been chosen by the user. Experimental results are presented for most of these steps.

The adopted image processing strategy only performs time-consuming operations on a small subset of candidate blobs (larvas or other objects) and allows to achieve real-time analysis (30 frames/sec acquired by a Matrox Meteor II frame grabber) on a Dual Pentium-3 with a 500 Mhz clock rate with 256 Mbytes of RAM.

Figure 2 Image processing steps for real-time tracking of the larvas and experimental results.



5 Tracking and Control of the X-Y Table

The strategy that has been adopted to track the larva was to move the XY-table so the larva always remains in or near the center of the field of view. This can be achieved by moving both axes at the same speed as the larva. The system thus predicts the speed that the larva should have in the next image frame and imposes this speed on the axes.

The speed prediction is based on the following formula:

$$v_{x,y}(t_{n+1}) = \frac{1}{5}\sum_{i=-5}^{-1} v_{x,y}(t_{n+i}). \qquad (3)$$

6 Experimental Results and Tracking Performance

Since it is difficult to assess the quality of the tracking system for actual trajectories of larvas (since there is now other independent measurement approach to compare with) a lab experiment was designed to estimate the tracking accuracy. A target similar to an actual larva was mounted on a rotating table and the tracking system was set up to track the target moving at different (and known) angular velocities. The results are shown in Figure 3. Figure 3 (a) shows a part of the actual trajectory and the trajectory measured by the system. Figure 3 (b) shows that the error in estimating the position of the larva on its trajectory increases with the speed of the object but that this error remains less than 2% (circular path with 115 mm diameter) at the maximum speed of 50 mm/sec. The main source of error comes from the calibration procedure. However, this error level is acceptable in the context of marine biology and is far more accurate than the results obtained by manual approach. In addition, the tracking is performed automatically in real-time and allows to compile results efficiently on-site. Furthermore, the system is composed of off-the-shelf hardware components and does not require special image processing hardware for achieving real-time performances.

7 References

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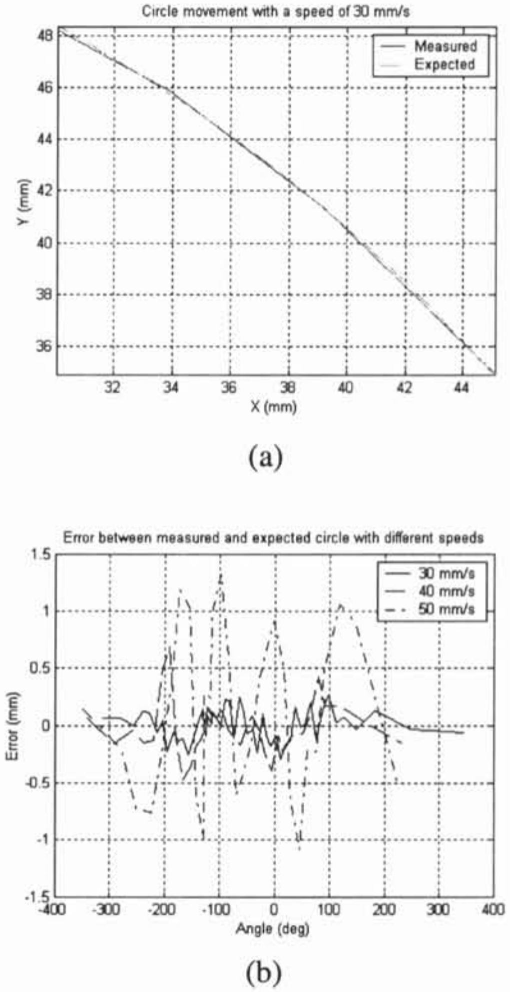
[2] Tsai, Roger Y., "A versatile Camera Calibration Technique for High-Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses," *IEEE Journal of Robotics and Automation*, Vol. RA-3, No. 4, August 1987, pages 323-344

Figure 3 Results of tracking accuracy. Circular path (diameter 115 mm) (a). Position error at different speeds for the circular path.



(a)

(b)