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An Automated Approach to the Initialization of the Snakes Algorithm for the Detection of Swimbladder Regions in X-ray Image Data

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Abstract

Snakes have been widely used for object tracking, shape detection, and segmentation of an area of interest within image data. A snakes algorithm uses an energy minimization approach to deform an initial boundary or curve so that it traces along the contour of a shape in an image. However, a major disadvantage of the algorithm is that it requires users to draw the initial boundary in the image of an object, which is not feasible when large number of images need to be processed or when user-introduced bias in the selection of the initial boundary may influence the accurate detection of objects. This paper reports on an algorithm for the automatic detection of a region of interest that utilizes a snakes algorithm for image segmentation. It specifically combines multiple image processing and screening techniques to build a pipeline of processing steps that produces the initial boundary of a region in an image for the initialization of a snakes algorithm. The approach has been evaluated on X-ray images of the striped burrfish to detect the swimbladder as a region of interest. Results from the fully automated algorithm are compared against ground truth values and semi-automated algorithm results.

Introduction

The Biology Department at the University of West Florida has conducted several studies on the impacts of pressure changes on a fish's swimbladder (Rummer and Bennett, 2005). In the current study, X-ray images of swimbladders of the striped burrfish, *Chilomycterus schoepfii,* were taken with the goal of measuring swimbladder areas to determine if the unique design of the swimbladder of this species offers the option of moving between naturally encountered depths/pressures with impunity.

The original X-ray films in this project were initially manually analyzed, with a human scientist visually identifying the swimbladder in each film and drawing a boundary around that region by hand for subsequent measurements. This process was subject to measurement bias and noticeably time consuming and unreliable with films that showed underexposure, overexposure, poor contrast, or were damaged due to the chemical development process or aging. Even with digitization, thresholding operations and other histogram-based preprocessing techniques could not be applied to the complete data set without user-guided customizations on each image. Since reacquiring the images for this research was not possible and given the additional variability in fish orientation and position, as well as camera positioning within the data set, an automated and unbiased algorithm to segment and measure swimbladder regions was needed.

Snakes (Kass, 1988) have been successfully used to solve a wide range of research problems due to a snakes algorithm's capability to accurately and rapidly segment regions of interest. However, a major disadvantage of a snakes algorithm is the need for manual initialization by choosing points to define a region of interest for the algorithm to run its course. While the application of the algorithm has helped in greatly reducing the workload of users processing and evaluating image data, the requirement for point selection during initialization can be a time-consuming task on some image sets and can additionally introduce error or bias from the direct human involvement.

This paper presents and evaluates a new algorithm that automates the initialization stage of a snakes algorithm for segmenting regions of interest. The new algorithm is based on a pipeline of well-known, automated image processing methods that have been combined to compute a set of boundary points as input for a snakes algorithm. The methods are configured using a set of constraints derived from expert analysis of the data as well as the anatomy of objects under investigation to choose boundary points for a snakes algorithm to execute. The image processing pipeline can be easily adapted to other image data that require segmentation of a region of interest by reconfiguring the individual stages using a different training data set.

The remainder of the paper describes work related to the research, the data set used for training and testing, the different processing steps of the pipeline, and an evaluation of the algorithm. The paper concludes with a discussion of results and future directions for the research.

Related Work

Snakes have been widely used to solve segmentation problems in image data. Successful applications of a snakes algorithm on marine biology data have aided researchers by automating parts of the evaluation of research results (Blaschko et al., 2005; Kreho et al., 1999), thereby reducing the time to complete experimentation and the possible introduction of errors due to factors such as bias and fatigue compared to manual evaluation only. Use of a snakes algorithm in conjunction with automated enhancements has also made its presence felt in other imaging domains, such as aerial image analysis applications for automated contour correction of roadways (Klinger, 2010). Work closely related to ours includes a sample application of automatically assisted snakes segmentation in medical image data (Zhang, 2007). The application computes the initial starting points for a snakes algorithm for polar edge detection on images of human tongues. However, the presented methods in this paper differ from the tongue approach in that the burrfish pipeline uses fewer preprocessing stages, and the constraints for each stage are easily modifiable for use in other types of image data.

X-ray Image Data of the Striped Burrfish for Building a Swimbladder Detection Algorithm

The complete data set used for developing and evaluating the swimbladder detection algorithm includes 65 X-ray images taken from the dorsal and lateral views of the striped burrfish as each one is exposed to variations in pressure conditions simulating different depths of water. Figures 1 and 2 illustrate sample data of the striped burrfish from both the lateral and dorsal view with different image contrasts. As the figures illustrate, the swimbladder (darker shaded regions within the fish) is in some cases extremely difficult to detect and requires significant domain knowledge of the approximate size and location of the swimmbladder region to be able to detect and mark it in the images with high accuracy for subsequent measurements of its size.

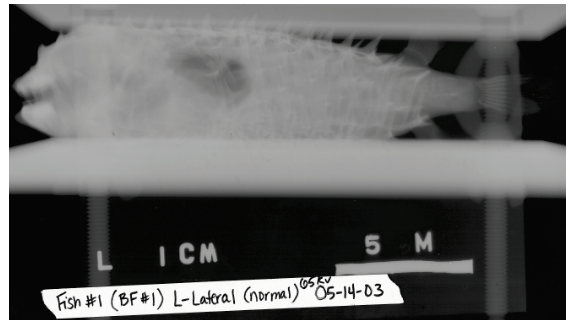

Figure 1: Lateral X-ray of non-inflated burrfish.

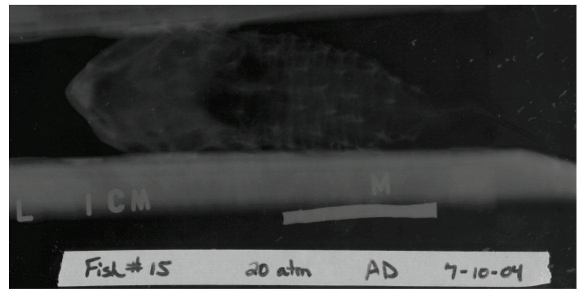

Figure 2: Dorsal X-ray featuring low image contrast.

For the development of the automated algorithm, the data was split into a training and a testing set. The training set was used to configure the different stages of the image processing methods in the pipeline; the testing set was used to compare the results of the algorithm against a domain expert's results of detected swimbladders. Images used for the training set consisted of 3 images taken from the lateral view which depicted one visible swimbladder in each image and 2 images taken from the dorsal view which each depicted two visible swimbladder regions. This overall training set thus consisted of 5 images covering 7 swimbladder regions to be detected. The remaining 60 images were utilized for testing of the developed algorithm.

From the training set, allowable dimensions for swimbladder size and placement within the fish were derived for use across the full data set during testing. Measurements based on expected burrfish anatomy yielded allowable swimbladder major axis dimensions to be within 1/5 – 1/2 of total fish body length.

An Architecture for Automated Snake Initialization

The automated initialization pipeline consists of three preprocessing stages as well as a preliminary stage (0) that is specifically designed for detecting swimbladders in fish. The constraints applied to each stage are customized for use in swimbladder detection. However, these constraints are easily exchangeable for other constraints to perform different segmentation tasks in other data sets. The complete algorithm of the pipeline was developed in C++ with the help of the Open source Computer Vision (OpenCV) programming library version 2.4.6.

Stage 0: Narrowing of search window

The preliminary stage of the snake initialization process is used to identify a search window within the striped burrfish X-ray where a swimbladder is to be expected. This stage may therefore not be required in data sets that exhibit better image positioning consistency. For this data set, a simple feature detection algorithm is used to identify the fish's body cavity through detection of mouth and tail regions and thus limit the search window to only search for regions of interest that are bounded by the fish's body cavity.

Stage 1: Thresholding and Blob Detection

As the first stage of the automated pipeline, binary thresholding is performed at several threshold values, with blob detection performed at each iteration. Thresholding across several values is used to highlight distinct features (blobs) that are present across multiple threshold values and distinguish these features from artifacts that may appear in the image. Figures 3 and 4 illustrate the appearance of true swimbladder regions as elliptical-shaped blobs for two arbitrary selected threshold values.

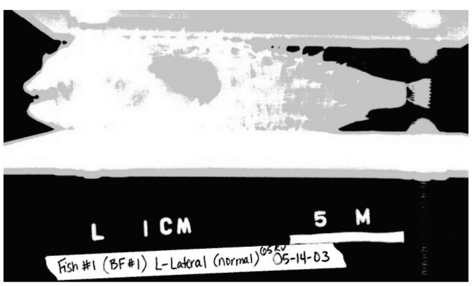

Figure 3: Thresholding X-ray image with a value of 92.

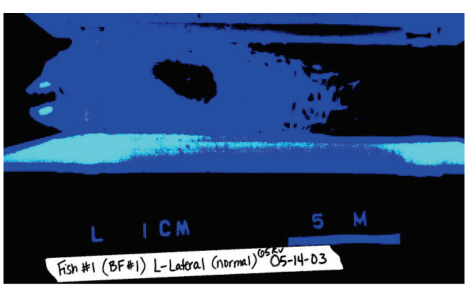

Figure 4: Thresholding X-ray image with a value of 180.

Stage 2: Blob Identification

At stage 2, candidate blobs attained from stage 1 are evaluated based on their dimensions and location within the image. A voting algorithm is employed to sort through all candidate blobs and determine the most likely position and dimensions of the region representing the swimbladder area. Voting is accomplished through use of a binning technique that rounds x and y coordinates to units of 10 pixels and angle measurements to units of 10 degrees. Counting of blobs in each bin is subsequently used to implement the voting scheme.

Blob size, location, orientation, and relationship to other blobs (dorsal images only) are used as comparisons among candidate blobs. Previously binned and counted blobs are evaluated by these measures, and outliers are eliminated using expected (a) blob position and (b) blob major axis orientation for the object of interest. False candidate blobs are eliminated based on allowable blob sizes, as determined by fish body size constraints learned from stage 0 of the algorithm.

Stage 3: Initial Snake Placement

At the conclusion of stage 2 a single region that defines the most likely swimbladder region and its dimensions are determined and ready to be segmented by a snakes algorithm. The initial snake placement stage chooses coordinates immediately "next" to the identified region of interest to run a traditional contour algorithm. Initial snake points are assigned as a rectangular (rotated, where necessary) boundary that is slightly larger than the size of the region of interest in order to enclose all of the desired area. At the completion of the initial coordinate assignment, the traditional form of a snakes algorithm is executed on the thresholded image.

Experiments and Results

Results generated by the swimbladder detection algorithm on training images were compared to human-generated ground truth images. Ground truth images were produced collaboratively by two domain experts and were created by various manual pre-processing methods to enhance swimbladder appearance, followed by hand labeling of the actual swimbladder boundary.

Accurate region of interest identification occurred for 5 of the 7 cases with a success rate of 71.4% for the training set. Cases of failure always occurred at stage 1 of the automated pipeline where candidate regions are identified based on elliptical fitting and blob dimension constraints. All cases of failure resulted in the identification of zero candidate regions at stage 1, thus no false positive results were generated from trials of the training set. Cases of success (5 of the 7) indicate 100% success for each stage in the automated pipeline, and cases of failure (2 of the 7) indicate stage 1 of the pipeline as the most sensitive stage, with the assumption that this was due to the large variations in image quality.

Figures 8 and 9 below illustrate an example comparison of the human ground truth identification and the fully automated algorithm result on a selected training image.

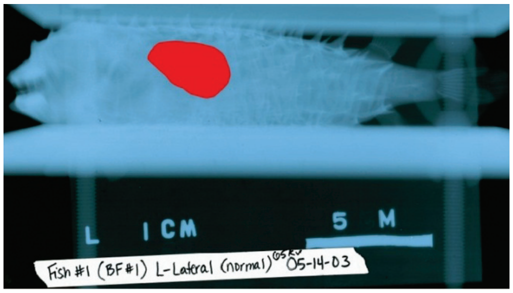

Figure 8: Human-generated ground truth segmentation of swimbladder in lateral view.

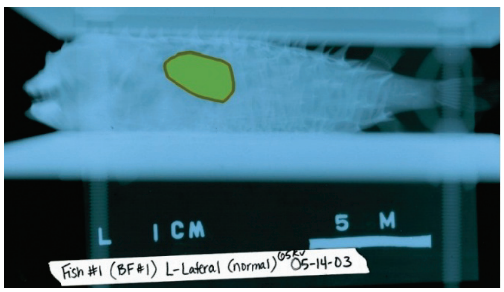

Figure 9: Fully automated identification and segmentation result.

The criteria for measuring success for the fully automated algorithm are shown in Figure 12 where measurements of detected swimbladder regions from the 60-image testing set are compared between the fully-automated and manually initialized algorithm.

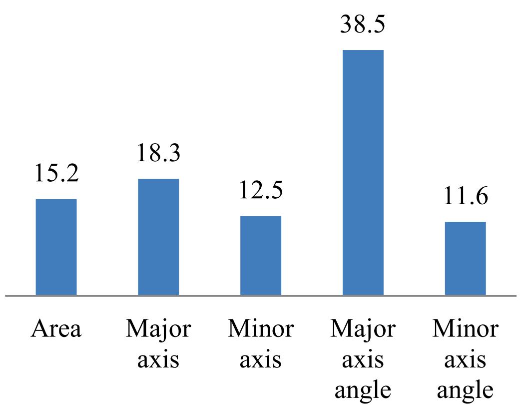

Figure 12: Average % difference measurements between manually initialized snake and fully-automated snake on testing data set.

Conclusions and Future Work

This paper proposes and evaluates an initialization method for use in conjunction with the traditional implementation of the snakes algorithm to identify and segment swimbladder regions from X-ray images of the striped burrfish. The approach is unbiased and fully-automated, and its evaluation shows promising results demonstrated by average measurement differences ranging from approximately 13-39%.

Total run time for the fully automated method (approximately 6 seconds on large 1000 x 2000 pixel images) presented a significant improvement in swimbladder identification and segmentation time compared to the manual method (approximately 1 hour) involving two domain experts. Use of the automated algorithm also eliminates detection and measurement bias that may be introduced by human researchers. This research may therefore also be useful to other marine biologists with similarly challenging image sets where a traditional application of a contour algorithm failed (Cocito et al., 2003).

Future work includes further analysis of the robustness of the automated pipeline and application of additional preprocessing steps to help the method accurately analyze a broader range of input image quality.

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