

Automated Image Processing of X-Radiographics of Digestion in Stingrays

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Abstract – This paper presents the development of an application for digital image processing of x-rays of stingrays. In order to measure the rate of absorption at varying temperatures, stingrays were fed detectable ball bearings. Using image processing techniques similar to digital mammography before the development of PACS, ball bearings and anchor points are detected in 111 scanned x-ray images of stingrays. Automatic measurements of distance between the ileum and the ball bearings are taken. The application incorporates image processing techniques and a graphical user interface. The development of the application to automate the measurement process is discussed, as well as its potential use, and its modification for use for different species of aquatic life.

Keywords: Digital image processing, edge detection, marine bioinformatics, stingrays, X-radiographics, C and Java programming.

1 Introduction

Research studies have shown that water temperature plays an important role among aquatic life [1]. Temperature has been shown to affect behavior, gestation, and digestion [2] [3]. In digestion, it has been suggested that many predatory fishes prefer to hunt in warm water and then move to cooler temperatures once they have fed. Some researchers suggest that metabolic processes are affected by water temperature. Metabolic processes increase in warm water and decrease in cool water; hence, temperature provides higher metabolism for hunting and slower metabolism for absorption of nutrients. Research has shown that fishes have varying temperature preferences for hunting and resting, but the results of this gradient in temperature are still being researched [1].

In order to increase our understanding of this environmental factor, the researchers along with students from the Department of Biology at the University of West Florida have observed the effects temperature plays on stingrays. Stingrays consumed detectable ball bearings in their feedings. Using x-

rays, the effects of temperature can be seen by observing the time of passage of these ball bearings at varying temperatures. For each x-ray, the distance between a ball bearing and the ileum is manually measured.

Due to the variability in manual measuring, a need exists to automate the measuring process. A software system would produce results that are precise and accurate more quickly than human measurements. In this paper, we describe the development of an application to automate the measurement process. This application integrates image processing algorithms implemented in the C programming language and a simple graphical user interface implemented in the Java programming language. Although this application was developed for this specific domain problem, it is designed to allow ease of modification for other species of aquatic life. Using the automated measurements of each image from this application, measurements taken in sequence will assist in the understanding of temperature's effect on the metabolic processes of stingrays.

The following section presents related work, including similar studies on metabolic processes and a survey of image processing and edge detection techniques for comparable applications. Section 3 describes the data that was used for the research study, as well as the constraints on the development of the application. Section 4 presents the image processing and graphical user interface methods that were used in developing the application. The paper concludes with a discussion of the uses and benefits of the application, including its potential use for other marine bioinformatics problems, as well as opportunities for future work.

2 Related work

Similar research in temperature influences on metabolic processes was previously conducted on lemon sharks at the University of Miami [4]. This study used x-rays to observe the absorption of food through the digestive system. This research also used manual measurements without the aid of image processing techniques.

Image processing algorithms have had great success in other domains. For example, digital mammography uses techniques such as manual intensity windowing, histogram-based intensity windowing, mixture-model intensity windowing, contrast-limited adaptive histogram equalization, unsharp masking, peripheral equalization, and trex processing in the detection of cysts in breast tissue [5]. Given the success of image processing algorithms in other domains, a software application could be developed to automate the process of detecting ball bearings and the ileum using appropriate image processing algorithms; and furthermore, automate the process of measuring distances of food passages through stingrays.

Edge detection theory and algorithms have been used throughout the biomedical sciences. Computational theory of edge detection and its application to the biological sciences have been discussed at length. In an article by Marr and Hildreth, edge detection theory is discussed in terms of intensity changes occurring naturally in an image and intensity changes occurring from surface discontinuities, reflectance, or illumination boundaries [6]. Issues regarding distortion in x-ray images have been discussed and methods for dealing with these inconsistencies in edge detection have been developed. In an article by Lashkia that described the application of fuzzy reasoning to image processing, several issues and challenges in applying image processing algorithms are discussed [7].

3 Data and constraints

Fifteen stingrays were collected from off the coast of Florida and kept in temperature-conditioned environments. After being fed the detectable ball bearings, x-rays were taken at varying temperatures. These x-rays were then scanned in JPEG format resulting in 111 JPEG images of four stingrays. The source x-rays consistently have dimensions of 20.1 centimeters by 25.2 centimeters, the preferred unit of measurement. Unfortunately, not all of the images are good quality, with some underexposed or overexposed during acquisition. Additionally, some of the images appear to have been dusty when scanned, while others are blurry and distorted. These issues cause no problem when manual measurements are taken but present challenges for automated image processing.

In determining the development platform for this project, two constraints were considered: (1) the computers used by the University of West Florida Department of Biology all run the Microsoft Windows XP operating system, so any application developed would have to be compiled for the Windows environment, and (2) most or all of these computers also already have Java Runtime Environment 1.5 or higher installed. Given these constraints, it was determined that any application developed should avoid requiring the installation of any additional software packages.

4 Methods

To measure the distance between the ball bearing and the ileum, image processing algorithms must suggest locations for these areas. However, the ileum is not visible in the x-ray image. Fortunately, a simple function exists that returns the approximate location of the ileum, given the location of the pectoral girdle and the length of the stingray. The pectoral girdle appears as an arch below the ribs and above the pelvic girdle, which appears as a half circle. The intestines of the stingray sit between the pectoral and pelvic girdle.

Although it was originally planned to develop the entire application in C using the GTK+ graphical user interface toolkit, the decision to use Java for the user interface was guided by the constraints described in the previous section. The developed application has two components: the image processing module and the graphical user interface.

4.1 Image processing

The image processing application was developed in the C programming language using the MinGW application. A combination of Cygwin and MinGW allows executable applications compiled with the GNU Compiler for C (GCC) to run on any 32-bit Windows computer without the requirement of the Cygwin runtimes [8] [9] [10]. The arguments for the image processing module are simply the paths and filenames for an input and output Joint Picture Experts Group images (JPEG). From there, system calls are made to the bundled djepg and cjpeg applications provided by the Independent JPEG Group. These tools allow conversions between JPEG and other popular image formats, including portable gray map (PGM) [11]. This image format was selected because it is a simple plain text file that can easily be parsed and converted to other formats. The PGM file is simply defined as a white-space delimited text file of P5, the integer width of the image, the integer height of the image, the integer grey-level scale (255), and an array of unsigned characters representing the grey-level of each pixel. A problem was discovered when reading PGM files in Windows. There is an unsigned character that represents EOF in Windows that does not exist in other operating systems. This character resulted in output of pure black images. Opening the files in binary served as an adequate workaround.

Of the 111 JPEG images supplied, 21 of these images were too poor in quality for image processing. For the purposes of automated detection of the pelvic girdle and the ball bearings, a pre-processed image is desired. Given an image, the result of this pre-processing phase would be a binary image containing edges around the brightest areas of the image, which are the pelvic girdle and ball bearings. In the 21 suboptimal images, the edges of the image are not well defined. Although the shape of the stingray may be seen, the

stingray's skeletal system is not visible, and the ball bearings are lost in the cloudiness of the images. A sample low quality image is shown in figure 1.

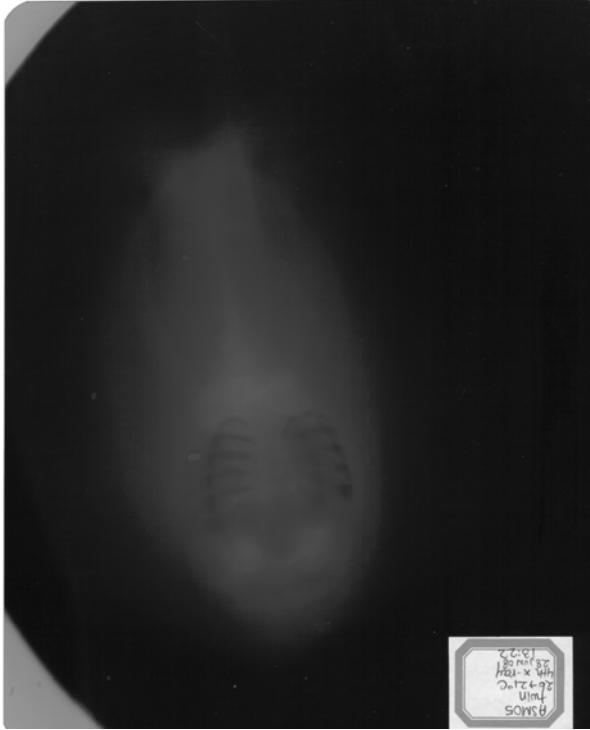


Figure 1—Sample low quality image

The image processing application begins by running a Histogram Equalization operation on the image. A sample image that is usable for pre-processing as shown in figure 2. This operation takes the gray levels of each pixel and distributes them uniformly and roughly sets all the images to be the required brightness. Next, an Alpha-Trimmed Mean Filter operation is performed on the image in order to remove both Gaussian and salt-and-pepper noise. Next, a simple filter is run to blacken any pixels that are not at least a specific brightness. Last, a Sobel Filter is run on the image as an edge detector. The resulting pre-processed image consists of a clear, binary image with the pelvic girdle, ball bearings, as well as some ribs of the skeletal system [12]. A sample image after pre-processing is shown in figure 3.

During the process of selecting algorithms for image pre-processing, a number of other techniques were analyzed. An attempt was made to use a harmonic mean filter and brightness/contrast changes instead of using the histogram equalization filter. The results of using this sequence of algorithms were inconsistent results from image to image, due to varying exposure levels in the images. Some images appeared solid black after these pre-processing techniques were applied. Alternatively, using the histogram equalization filter rather than changing brightness and contrast by hand yielded consistent results across most images.



Figure 2—Sample image before pre-processing

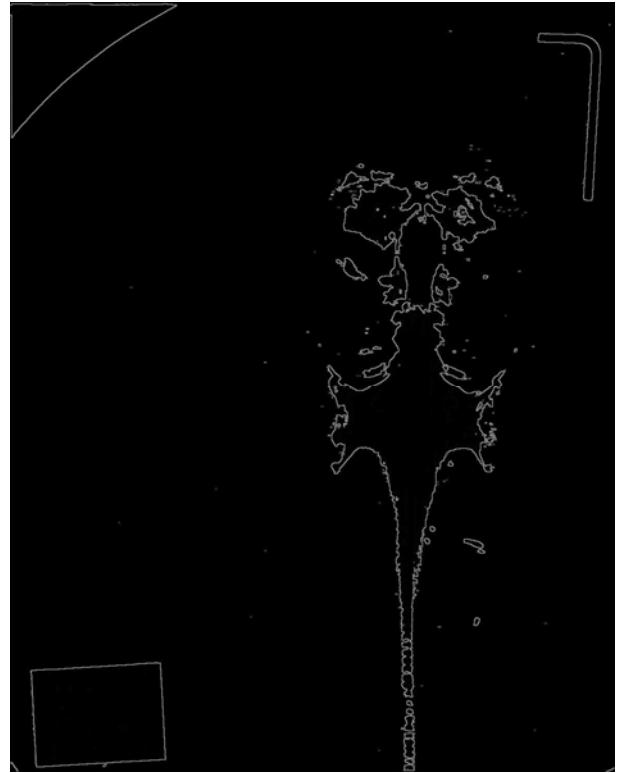


Figure 3—Sample image after pre-processing

4.2 Graphical user interface

The graphical user interface component was developed in the Java programming language version 1.5. The application begins by launching an executable program (StingRay.exe), which is implemented in C and is used for executing a system call to the Java runtime environment. A program icon was created from one of the x-ray images and modified using the GNU Image Manipulation Program (GIMP), a raster graphics editor [13]. The icon was then compiled into the application using the windres tool provided by MinGW. MinGW (Minimalist GNU for Windows) is a Windows port of GCC and Windows API headers [9]. This approach to starting the Java application was used to keep the application intuitive to program users. The user interface is a Java Swing application that is ready to open a JPEG image. When the user clicks the Open File button, a JPEG can be selected to open.

The graphical user interface will allow the user to click the image and select the nearest point of interest. The location of the ileum is calculated based on the location of the pectoral girdle. Once the user clicks the second point of interest, the distance calculated is based on the dimensions of the image in centimeters. The length of the stingray is required for calculating the location of the ileum. The user is asked to provide a length in centimeters upon loading the image before the distance can be calculated. A sample screenshot of the user interface is shown in figure 4.

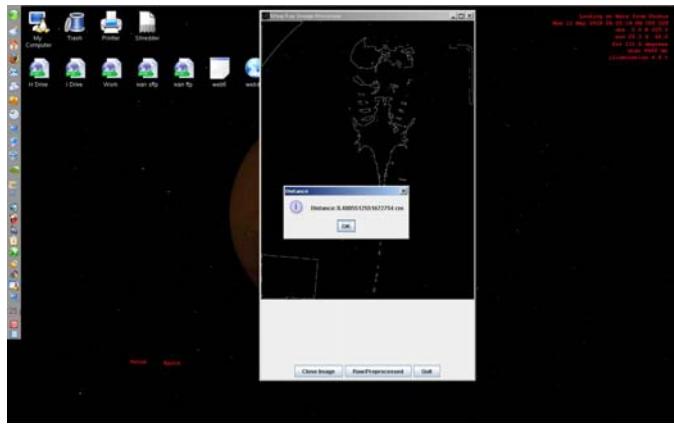


Figure 4—Sample screenshot of the user interface

5 Conclusions and discussion

This paper describes the development of an application to automate the measurement of food passage through the digestive tract of stingrays at varying temperatures. In order to measure food passage, stingrays are fed ball bearings and x-ray pictures are taken at varying temperatures. Research in temperature influences on metabolic processes is important

for understanding environmental factors on stingrays and other aquatic species. Automating the measuring process using a software system can produce results that are more accurate and efficient than human measurements.

The application integrates an image processing component developed in the C programming language and a graphical user interface developed in the Java programming language. The application processes scanned x-rays images and uses image processing algorithms, including Histogram Equalization, Alpha-Trimmed Mean Filter, and the Sobel edge detector to accurately detect the pectoral girdle and ball bearings inside a stingray. Given the location of the pectoral girdle, dimensions of the image, and length of the stingray, the system then calculates the location of the ileum, and the distance between the ileum and the ball bearings can be measured.

After pre-processing of the image, the next phase is to suggest points of interest to the graphical user environment. This phase can be accomplished through the use of algorithms such as the Hough transform on the pre-processed image to find the pectoral girdle. Once the points of interest are provided to the graphical user interface, it should identify the ileum based on the location of the pectoral girdle and the provided length of the stingray. The user can then click on the image and the closest point of interest will be selected. The distance between the two points of interest will be calculated based on the pixel locations and the dimensions of the x-ray in centimeters. Additionally, even if the image processing fails to detect the points of interest, the application can still allow the user to click on any two points in the image to calculate the distance in centimeters. The final application will be released to the general public under the current version of the GNU General Public License for any interested party.

The application was developed to be flexible and easily adaptable for use for different aquatic species, and accordingly, can be used for other marine bioinformatics problems. The Hough transform algorithm may need to be adapted to find a different point of interest for calculating the ileum, or similar anatomical structure, but the basic structure and interface of the system will remain the same. Furthermore, the formula for finding the ileum given the pectoral girdle may also need to be adapted based on anatomy. All other features of the application will likely not need to be changed in any way.

Future work opportunities include comparing the automated measurements of the distance between the ileum and ball bearings to manual measurements. Not only are the results of the automated measurements faster to obtain than the manual measurements, they are also expected to be more accurate. However, because some of the data images are poor quality for image processing, some images will still need to be manually measured. For future applications, quality checks

should be made on the images prior to the scanning process in order to prevent dust, distortions, and over/underexposure issues.

The results from the application can be used to compare each image's automated measurement with the manual result. The automated measurements will assist in identifying the effect of temperature on the metabolic processes of stingrays, and further understanding the impact of environmental factors on stingrays and other aquatic species. In addition, such an application can be potentially useful in other marine bioinformatics research studies.

6 References

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