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굴의 힌지 선 감지를 위한 영상처리 소프트웨어의 개발

Image Processing Software Development for Detection of Oyster Hinge Lines+

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ABSTRACT

굴 까는 작업을 자동화하기 위한 방법으로 굴의 겹질 안쪽에 붙어 있는 근육질을 제거하고 굴 겹질의 힌지(Hinge)를 절단하는 작업을 필요로 한다. 본 논문에서는 굴을 까는 자동화 기계를 개발하기 위한 연구의 일환으로써 컴퓨터 시각 시스템을 이용하여 굴의 힌지 위치를 판단하는 영상처리 알고리즘을 개발하였다. 본 실험에 사용한 굴들은 컴퓨터 비젼 시스템이 굴의 바깥쪽 힌지표면을 감지할 수 있도록 굴을 물로 씻은 후 굴 겹질의 힌지(Hinge)부분을 약간 절단하였다. 칼라 비디오 카메라(color video camera)를 이용하여 굴의 절단된 힌지표면의 영상을 잡은 후 개발한 영상처리 알고리즘을 이용하여 굴의 힌지(hinge) 위치를 감지 하였다. 영상내의 굴의 힌지(Hinge)와 그 밖의 다른 물체를 구별하기 위하여 4개의 변수 {원형도, 사각형도, 장단축비, 유크리드(Euclidian)거리}를 이용하였다. 또한 영상(image)내의 굴의 힌지(Hinge) 위치를 쉽고 효과적으로 파악하기 위하여 몇 가지 영상처리 즉, 수축－확장, 문턱값 처리 등의 방법들을 이용하였다.

Shucking(removing the meat from the shell) an oyster requires that the muscle attachments to the two shell valves and the hinge be severed. Described here is the computer vision software needed to locate the oyster hinge line so it can be automatically severed, one step in development of an automated oyster shucker. Oysters are first prepared by washing and trimming off a small shell piece on the oyster hinge end to provide access to the outer hinge surface. A computer vision system employing a color video comera then grabs an image of the hinge end of the oyster shell. This image is processed by the computer using software. The software is a combination of commercially available and custom written routines that locate the oyster hinge. The software uses four feature variables, circularity, rectangularity, aspect-ration, and Euclidian distance, to distinguish the hinge object from other dark colored objects on the hinge end of the oyster. Several techniques, including shrink-expand, thresholding, and others, were used to secure an image that could be reliably and efficiently processed to locate the oyster hinge line.

주요용어 (Key Words) : 굴(Oysters), 컴퓨터 시각(Computer Vision), 힌지 감지(Hinge detection)

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1. Introduction

Removing the meat from the oyster shell, shucking, requires that the muscle attachment to each shell be severed and the hinge be broken. Severing the oyster hinge involves accurately locationg the hinge end and then applying enough force to sever it. But, accurately locating the hinge is a rather difficult task given the shape variability of wild oysters. In addition to the shape variability, the shell structure is also highly variable, often containing dark lines, dark colored holes and other imperfections. The variability make sautomatically locating oyster hinge very difficult.

Based on the previous studies (Li and Wheaton, 1992; So, 1992; So and Wheaton, 1996), it was found that segmentation of the hinge object from the image background was a major problem in detecting the oyster hinge. Because of the inherent variability of oyster shells and other foreign materials attached onto the oyster shells, there was no clear-cut way of separating objects located within the trimmed-off surface area from objects located outside of the area. This inability to separate the trimmed-off surface area from the rest of the image greatly reduced the computer vision system's ability to distinguish between hinge and non-hinge objects. Another problem was caused by objects that connected to the boundary of the image frame, most were created by shadow under the oyster shell or dark spots on the oyster shell. These objects decreased the discriminatory power of the classification function to detect one and only one hinge object by increasing the number of objects in the image, one of which might take the geometric characteristics of the oyster hinge.

A variety of studies (McDonald and Chen, 1990; Marchant et al, 1990; Ghate et al, 1993) have been done to develop methods capable of segmenting objects and/or separating connected objects in images of biological materials. The general objective of this study is to develop the computer algorithms and methodology used by the computer vision system to locate the oyster hinge in the image of the trimmed-off hinge end of the oyster.

2. Materials and Methods

A. Hardware

Imaging hardware used in this study consisted of a color CCD camera (PULNiX, Model TMC-74 (NTSC)) and associated RGB interconnect (PULNiX, Model CCA-5) and camera shutter controller (PULNiX, Model VP1300-KIT-512-U-AT), color video monitor (SONY, Model PVM-1342Q), and personal computer (DELL, Model OPTIPLEX 466/MX) with an integrated processor. A Commercially available library of subroutines (Imaging Technology Inc., Model VISIONplus-AT CFG) facilitated accessing imaging data. Algorithms were implemented in C (Microsoft Corp., C 5.1).

The optics and front lighting system consisted of two 75W incandescent lamps with individual reflectors, a black scene background, and an 11~110 mm motorized zoom lens (FUJINON, Model CRD-2A). The camera was placed inside the environmental enclosure (PELCO, Model EH-5520) to protect the camera from dust, water and mist. The enclosure was mounted onto an adjustable aluminum platform which was bolted to a vertical aluminum tube. The tube fit over a vertical shaft mounted to an aluminum base. The slide moved up and down on the shaft and was held in place vertically by a horizontal screw threaded through the side of tube. Tightening the screw clamped the tube to the shaft and held it in place vertically. Loosening the screw allowed vertical adjustment of the camera. The camera height was adjusted to align the camera viewing axis in the same horizontal plane as the oyster. A frame to provide mounting for the lighting and to hold the oysters was constructed such that the camera saw exactly what it using the real hinge severing component conveyor (So and Wheaton, 1996). Additional details of the system used are reported in So and Wheaton (1996).

B. Sample Description

A total of 500 oysters were harvested from five different locations in the Chesapeake Bay (i. e., Wild Bar, Eastern Bay, Maryland; Choptank River, Cambridge, Maryland; Sea Side, Virginia; Little Choptank River, Fishing Creek, Eastern Shore, Maryland; and Crisfield, Eastern Shore, Maryland). All samples were washed to eliminate dirt, mud, and foreign materials using the Wheaton Oyster Washer (Wheaton, 1973). Approximately 6 mm was then trimmed from each oyster hinge end to form the flat, white surface using the Oyster Hinge End Trimming System (So and Wheaton, 1996). Each sample was sprayed by water using a hose nozzle before the system grabbed an image. This simulated the "wetted" shell condition typical of oysters after they pass through the Oyster Hinge End Breaker (So and Wheaton, 1996). Spraying also eliminated many foreign materials attached to the cut end of the shell.

3. Software Development

The computer program used in this study consisted of commercially available programs and specially developed programs written with the C languages.

Several assumptions were made for the software development including the following:

1. The object being analyzed are darker in color than the background.
2. Image contrast is sufficient to make object visible.
3. Object connected to the boundary of the image window have an area greater than 1,000 pixels.
4. The hinge object is always found within the trimmed-off surface area on the oyster and is the most distinguishable object.
5. The number of object in an image is neither more than 20 nor less than 1.

The following programs were used to make up the oyster hinge detection software:

1. A Microsoft MS-DOS, version 6.0, disk operating system.
2. A Microsoft C compiler, version 5.1.
3. An ITEX CFG for an Imaging Technology's VISIONplus-AT Color Frame Grabber (CFG) image processor.
4. Custom image processing software for oyster hinge line detection.

A. Overview of Logic

Below is a summary of the image processing software executing procedures. Additional details of each procedure are reported in So (1995) and So and Wheaton (1996).

1. Acquiring an image and windowing the image area to an optimum size needed to cover the trimmed-off oyster hinge end surface (Fig. 1).
2. Transforming the gray-level image to a binary image using an automatic threshold selection method for each image processed (Fig. 2). The threshold value was determined using statistical methods that found the best match of binary image to the gray-level image at each gray level ranging from 0 to 255 (parker, 1995).
3. Smoothing objects and/or eliminating noises (Fig. 3) (Parker, 1995). The objects having nerrow projections (or openings) usually resulted from a thin black streak between the upper and lower beaks of the oyster. Small objects were eliminated and/or narrow projections into objects were closed by first dilating and then eroding three layers of background boundary

pixels. The term "closing" will be used throughout this paper to denote the combination of a dilation followed by an erosion operation. The dilation is the act of adding a layer of pixels around the boundary of a region and erosion is the act of stripping the outer layer of pixels from a region.

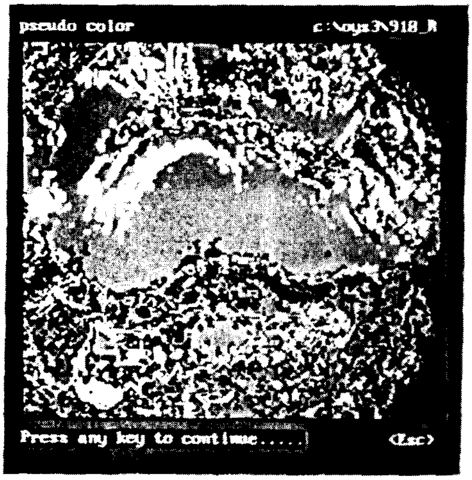

Fig. 1 The oyster hinge end image (red color gray-level) within the image window displayed on the system monitor.

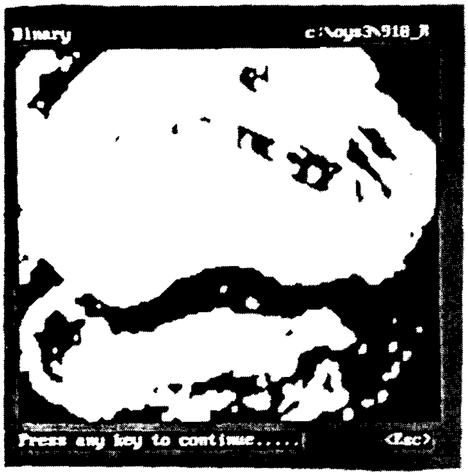

Fig. 2 The thresholded image from the gray-level image in Fig. 1.

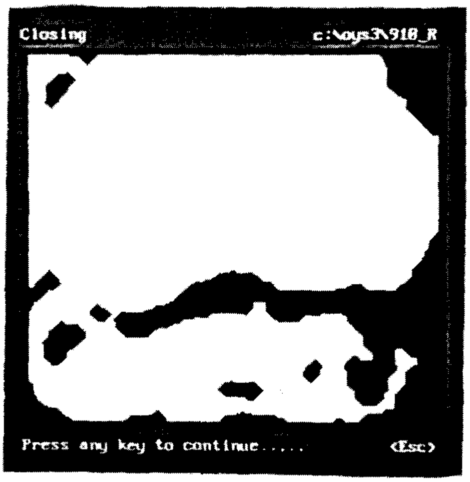

Fig. 3 The image resulting after applying the smoothing and closing process on the thresholded image in Fig. 2.

4. Segmenting a hinge object from the background if the hinge object was connected to the edges of the image window. In this process, the hinge object was segmented from the background by closing a narrow gap or gaps in the background (Fig. 4). However, in some images, hinge objects were still connected to the image window frame after this operation.

Fig. 4 The image resulting after applying the background dilation process on the image in Fig. 3.

5. Removing objects connected to the image window frame edges. By assuming that the hinge object is located at the middle of the image window, other objects connected to the image window frame edges were eliminated to reduce the image processing demand and to reduce the classification confusion. The following discussion explains in detail procedures used to remove objects connected to the image window frame and segment potential hinge objects (Fig. 5).

Fig. 5 The image resulting after applying the object dilation process to the image in Fig. 4.

a. Confining a background region, trimmed-off surface area, that fully surrounds objects. This process extracted a background region containing the hinge object and other objects in the entire image.
b. Locating a minimum enclosing box (MEB) of the extracted background region in step 5 (a). The term "MEBEBR" is used throughout the text to refer to the minimum enclosing box of the extracted background region. The MEBEBR limited further image processing to only area within the MEBEBR.
c. Locating objects connected to an edge or edges of the MEBEBR. The term "edge-bounded object" is used throughout the text to refer to an object connected to an edge or edges of the MEBEBR (Fig. 6).

Fig. 6 The edge-bounded objects.

d. Eliminating edge-bounded objects from the MEBEBR if its area is less than 1,000 pixels. Otherwise, locate a small MEB for each edge-bounded object. Note that the small MEB is located in the MEBEBR determined in step 5 (b). The term "SMEB" is used throughout the text to refer to the small MEB (Fig. 7).
e. Splitting edge-bounded objects by dilating the background within SMEB to isolate potential hinge objects. Splitting only occurred if the object was convex in shape somewhere along its length. The potential hinge objects were shrunk by background dilation (Fig. 7).
f. Expanding isolated potential hinge objects using object dilation to restore the potential hinge objects to their previous shape.

6. Removing unwanted object smaller than 100

pixels in area from within the MEBEBR (e. g., object area thresholding).

7. Determine features of each object.

8. Classify the objects to locate the hinge object (Fig. 8).

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Press any key to continue.....
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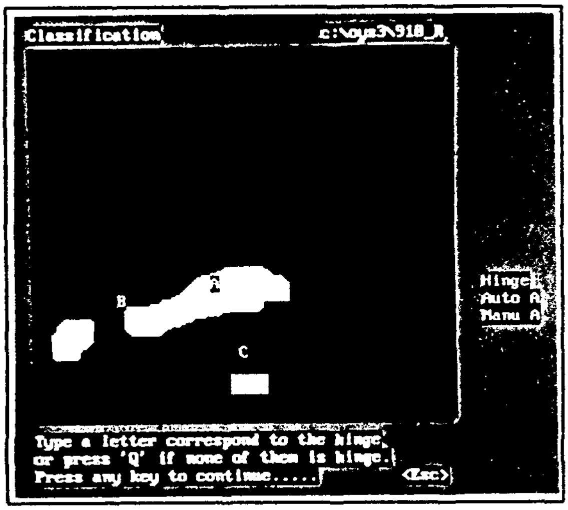
Fig. 7 Objects split form the edge-bounded object.



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Type a letter correspond to the hinge,
or press 'Q' if none of them is hinge.
Press any key to continue.....
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Fig. 8 The result of the oyster hinge line detection.

B. Classification Criterion

Four features of an object, rectangularity, circularity, aspectratio, and Euclidian distance, were used to identify the one and only one hinge object (i. e., only one hinge object was allowed per image) in an image. An object's Euclidian distance was calculated from the center of the MEBEBR to the center-of-mass of each object. The classification function found the hinge object by calculating the squared distances of each object's feature vector to the hinge object's mean vector. The object having the minimum squared distance was assumed to be the hinge object (Johnson and Wichern, 1992; So, 1995).

4. Test Procedure

Four aspects of the algorithms listed above were tested; (1) the effect of field of view size on hinge line detection efficiency, (2) the effect of the closing operation on object segmentation in a binary image and on hinge line detection efficiency, (3) the effect of the background dilation operation within the SMEB on object segmentation in a binary image and on hinge line detection efficiency, and (4) the effect of oyster sample position on oyster hinge line detection efficiency.

Test 1

This test was designed to determine if a field of view of 5.6 by 3.2 cm provided sufficient resolution to produce a high hinge line detection efficiency. The camera lens was adjusted until the 5.6 by 3.2 cm in the real world just filled the 260 by 170 pixel image window. A preliminary test showed that any object less than 36 pixels in size was not the hinge. Thus, objects were thresholded at 36 pixels and smaller objects were discarded.

Two hundred oysters, 100 oysters randomly selected from each of the Choptank River and Wild Bar lots, were used for Test 1. Each 100 oyster sample was divided randomly into two groups; a 50 oyster training sample and a 50 oyster validation sample. A classification crierion was created for each sample set using the training sample and the classification function was evaluated using the validation sample.

Test 2

Based on results of Test 1, the field of view in Test 2 was reduced to real world dimensions of 2.8 by 2.2 cm. The size was selected because it was just large enough to allow the trimmed-off surface area at the hinge end of the oyster to be located within the image window regardless of the oyster size. The camera lens was then adjusted to just fit the image window into a 180 by 170 pixel image in the camera. To locate the trimmed-off surface area within the image window, the camera height was adjusted if necessary for each oyster. The adjustment was occasionally necessary if a large portion of the trimmed-off surface area was found to lie above or below the image window boundary.

The closing process was added to eliminate small objects and/or narrow projections. The smallest area accepted as an object was increased from 36 pixels to 100 pixels based on a preliminary study with the decreased dimensions of the field of view relative to Test 1. A total of 200 oysters, used in Test 1, were selected for use in Test 2. The classification function was trained using 50 oyster samples from each batch of oysters.

Test 3

The object of this test was to determine the effect of the SMEB background dilation on hinge line detection efficiency. The dimensions of the field of view and image window were kept the same as in Test 2. Oysters were used in the test were harvested in four different locations: Wild Bar, Choptank River, Sea Side, and Little Choptank River. Stored image files of oysters from the Choptank River and Wild Bar were used as test samples rather then new samples. New samples were used for the other two locations.

Test 4

Test 4 was designed to determine the hinge line detection efficiency of the classification function with "a controlled best condition." The field of view was reduced to 1.9 x 1.5 (cm) associated with a 180 x 170 (pixel) image window. Oyster samples were placed in front of the camera and positioned the best possible by observing live images displayed on the video monitor. The "controlled best condition" located the trimmed-off surface area as near to the middle of the image window as possible. This was accomplished by adjusting the camera vertical position relative to the oyster. Test 4 was run using 100 oysters harvested from Crisfield, Maryland.

5. Results and Discussion

Test 1

The size of the field of view significantly affected the hinge line detection efficiency. The image processing algorithm also caused hinge detection errors. Overall hinge line detection efficiency for the two sample sets was 61%.

The misclassification rate, 24% and 20% in Wild Bar and Choptank River oysters, respectively, in Test 1 indicated that the object feature characteristics lacked a clear distinction between the hinge and non-hinge groups; the feature characteristics overlapped each other on a sample feature distribution (Johnson and Wichern, 1992). The non-hinge objects appeared in the image due to black dots, black sea weed, mud, and holes on the trimmed-off surface area and oyster shell.

For a binary image modification, the algorithm was designed to segment objects from background and classify only objects fully surrounded by the background. In Test 1, however, this study found that hinge objects intercepted an edge or edges of the MEBEBR in some images. Such edge-bounded objects were not considered to be objects during the object segmentation process. This was due to a thick dark streak extending horizontally from the hinge line and located between the upper and lower oyster beaks. Another cause of hinge detection error was elimination of the hinge object in the binary image during binary image modification. Typically in small oysters, the hinge object appeared as a small and narrow streak in an image. The size of these small hinge object was reduced during a smoothing operation and disappeared at the object thresholding if its area was less than 36 pixels. The hinge detection error due to both the edge-bounded and eliminated hinge objects was 18% and 16% in the sample from the Wild Bar and Choptank River, respectively.

Test 2

In Test 2, the oyster hinge line detection rates were 89% and 83% in Wild Bar and Choptank River oysters, respectively. The reduced field of view size and the image window (higher resolution) decreased the number of objects in the image and increased the discriminatory power of the classification function to separate the hinge and non-hinge group objects. The closing process also decreased the number of objects in the thresholded image. In Test 2, the edge-bounded hinge objects were the major cause of the hinge detection error, which was 7% in 200 oysters.

Test 3

The SMEB background dilation segmented the hinge object by filling a narrow gap or gaps along the streak extending from the oyster hinge object. During the SMEB background dilation and object dilation processes, the segmented objects were distorted to some degree, but the distortion was acceptable for hinge object detection by the computer vision system. The SMEB background dilation process, in most cases, isolated the potential hinge objects from the MEBEBR and allowed the hinge object to be located without losing any object. The SMEB background dilation process also eliminated small hinge objects, as indicated in results of Test 1, from the binary image that were not well defined in the thresholding process. The number of edge-bounded hinge objects caused by the thick dark streak extending from the hinge object were reduced, relative to Test 2, to 3 samples out of 400 oysters (i, e., less than 1%). The overall oyster hinge line detection rate was 91.5% for the 400 oysters from the four different locations.

The causes of misclassification of the hinge objects were the same as the previous test. In some cases, however, the misclassification resulted from some small noises within the hinge object. These noises were usually caused by reflection from water on the trimmed-off surface area and located near to the hinge object's boundary.

During the closing process this small noise caused an erosion of the hinge object and significant deformation of the object's shape. Consequently, the classification function selected a well-shaped non-hinge object as the hinge.

Test 4

In Test 4, the causes of the misclassifications (e. g., hole, black spot, black sea weed, and cutoff hinge line) were corrected by reducing the dimension of the field of view. No edge-bounded hinge objects or eliminated hinge objects were found in Test 4. The hinge line detection rate was 94% in Test 4. Table 1 summarizes the test procedures and results for the four tests described above.

Table 1 Summary of test procedures and results

Test	Oyster sample	Field of view (cm)	Image Window (pixel)	Resolution (mm^2/pixel)	Hinge detection rate (%)	Comment*
1	Choptank River	5.6×3.2	260×170	4.054×10^{-2}	61.0	Closing
2	Choptank River Wild Bar	2.8×2.2	180×170	2.013×10^{-2}	86.0	
3	Choptank River Wild Bar	2.8×2.2	180×170	2.013×10^{-2}	91.5	SMEB dilation and object dilation
4	Little Choptank River Sea side Crisfield	1.9×1.5	180×170	9.314×10^{-3}	94.0	Controlled best condition

* Added binary image modifications and test conditions with respect to previous test.

6. Conclusions

A computer vision system using a front lighting system, a color video camera, and employing an erosion and dilation binary image modification technique was developed to automatically locate oyster hinge lines. From this study the following conclusions were drawn.

1. Selecting the field of view size for the camera was an important factor in segmenting objects from the background and detecting the oyster hinge objects. Increased resolution increases the hinge detection efficiency.

2. The method employing background dilation followed by object dilation on the binary image proved to be the most promising method tested for segmenting the highly diverse hinge objects from other objects that may be overlapped onto or connected to edges of the image frame.

3. The computer vision system described in this study was capable of locating the oyster hinge automatically.

4. the highest success rate on oyster hinge line detection was 94% when using oysters from Crisfield.

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