Computers and Electronics in Agriculture 135 (2017) 134–142

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

An automatic active contour method for sea cucumber segmentation in natural underwater environments

Xi Qiao [a,d], Jianhua Bao [a,d], Lihua Zeng [a,b], Jian Zou [c], Daoliang Li [a,d,*]

[a] Beijing Engineering and Technology Research Center for Internet of Things in Agriculture, China Agricultural University, Beijing 100083, PR China
[b] College of Mechanical and Electrical Engineering, Agricultural University of Hebei, Baoding 071001, PR China
[c] Chinese Academy of Fishery Sciences, Yellow Sea Fisheries Research Institute, Qingdao 266071, PR China
[d] Key Laboratory of Agricultural Information Acquisition Technology, Ministry of Agriculture, China Agricultural University, Beijing 100083, PR China

ARTICLE INFO

Article history:
Received 10 August 2016
Received in revised form 8 February 2017
Accepted 9 February 2017
Available online 17 February 2017

Keywords:
Underwater image
Adaptive active contour
Color space fusion

ABSTRACT

Sea cucumbers have become an important sector of the marine industry in northern China, with a culture area exceeding one million acres and a production value over one hundred and twenty million dollars. However, sea cucumber culture and fishing are mainly dependent on manual work. To promote the development of sea cucumber culture automation, it is necessary to research sea cucumber automatic segmentation based on machine vision in natural underwater environments. Sea cucumbers usually live in an environment where lighting, visibility and stability are generally not controllable, which cause underwater images of sea cucumbers to be distorted, blurred, and severely attenuated. Moreover, sea cucumbers are flexible and colored much like sandy sediments. Therefore, it is difficult to fully separate a cucumber from the background in an underwater image. For fast and accurate automatic segmenting of sea cucumbers, an improved method based on active contour is presented in this paper. Image fusion based on the RGB color space and the contrast limited adaptive histogram equalization (CLAHE) method are used to increase the contrast of the sea cucumber thorns and body, respectively. Then, an edge detection algorithm is proposed to extract the edge of the sea cucumber thorns as an initial contour for the thorn segmentation, and a rectangular contour based on the edge information is built as the initial contour for the body segmentation. Finally, the results of the thorn and body are fused. All the procedures are automatically completed without human intervention. Qualitative and quantitative analysis indicates that the proposed method outperformed the other two compared methods in sea cucumber segmentation. A test with 120 samples showed that for the proposed method, the mean values of Euclidean distance, sensitivity, specificity, and accuracy were 12.7, 84.51, 96.97, and 96.54, respectively. The average time to run the algorithm for all images is 4.27 s. Thus, the proposed method could work for sea cucumber monitoring and fishing in real time.

1. Introduction

Over recent years, sea cucumbers (*Stichopus japonicus*) have been used for food and folk medicine in the communities of Asia and the Middle East (Bordbar et al., 2011). The aquaculture of the sea cucumber is growing rapidly in China, with more than one million culture acres and over one hundred and twenty million dollars production (Liu et al., 2010). However, sea cucumber culture and fishing are mainly dependent on manual work. Long-term in the underwater working is not only unhealthy, but also potentially life-threatening. With the rapid growth of underwater robot technology (Ferreira et al., 2014; Ozog et al., 2016; Shim et al., 2016; Wang et al., 2016) and its application in aquaculture (Karimanzira et al., 2014), the underwater robot will be used to monitor the growth of sea cucumbers and fish mature sea cucumbers, which can save labor and increase production efficiency.

Automatic segmentation of underwater images is one of the main steps in developing an underwater robot based on computer vision, which enables the robot to perceive sea cucumbers in the real world (Krutz et al., 2000). There are many different methods for separating the region of interest from the background. These include methods based on threshold (Du and Sun, 2007; Duan et al., 2015; Yoon et al., 2015), edges, and region. Methods based on threshold have a good performance in ideal environments or where there is a marked difference in the gray levels of objects and the background, and the Otsu method (Otsu, 1979) is typical.

* Corresponding author at: P.O. Box 121, China Agricultural University, 17 Tsinghua East Road, Beijing 100083, PR China.
E-mail address: dliangl@cau.edu.cn (D. Li).

http://dx.doi.org/10.1016/j.compag.2017.02.008
0168-1699/

Methods based on edges are used for detecting images that have obvious boundary features, and edge detectors that are often used include Sobel, Canny, Laplacian, and Prewitt (Teimouri et al., 2014). Methods based on region are generally used for segmenting images that have complicated backgrounds, in which such features as shape, color, texture, and intensity are considered (Chen et al., 2014; Ravanbakhsh et al., 2015).

In recent years, the image processing of sea cucumbers has been researched (Lee et al., 2014; Liu et al., 2014). The sea cucumber was put in a glass tank with uniform illumination and cameras were installed at the bottom and sides or at the top to capture sea cucumber images. These images have clear objects and monotonous backgrounds. The methods based on threshold accurately segmented the sea cucumber. However, the images of natural underwater environments are not clear, and affected by different factors such as limited visibility range, non-uniform lighting, scattering, bright things, diminished color, and noise (Elibol et al., 2011; Schettini and Corchs, 2010). These factors result in low contrast and blur in captured underwater images. The valuable information from the images is also lost.

To overcome these problems, several authors in recent years have proposed different image segmentation algorithms for separating various types of underwater objects from the background. Chen et al. (2015) used three processing stages to separate a guide rope from the background in a turbid underwater environment. The rope color was chosen as yellow. He used YCbCr color space to convert the images to blue chromaticity for contrast enhancement, then Otsu's two-threshold method and a Canny detector were applied for edge detection, and finally, the Hough transform was used for line detection. The method performs well in line segmentation for rope images, but for other objects with complicated geometry, the segmentation performance needs further verification. Lee et al. (2012) proposed feature-based and template-based approaches for object detection. In the feature-based method, the images of objects were given prior to the test and speeded up robust features key points were extracted and kept in the database to compare with the key points of input images and segment the objects. However, the result was easily affected by background objects. In the template-based method, the prior templates were given to match the objects of input images. The template-based method is more robust and effective than the feature-based method for segmenting two-dimensional objects because the templates contained more information than the key points. However, the method is limited to segmenting objects with simple structures. Chen et al. (2014) developed a knowledge-based information weighting fusion model for underwater object extraction. Color, intensity, and orientation were the three main features for extracting conspicuity maps, then the conspicuity maps were fused by the a priori model. Although the results demonstrate that this method has high precision in underwater object extraction, a calibration procedure was performed before an image capturing session by taking a test picture at known environments. Barat and Phlypo (2010) suggested a fully automated active contours based method to segment objects in underwater environments. Active contours were first proposed by Kass et al. (1987), and a disadvantage is the need to give initial contours manually. In this method, a visual attention scheme was automatically adapted to the region where the object most contrasted the background. The initial contour was based on the visual attention result for object segmentation. This approach not only was applied under different acquisition conditions but also improved the convergence and the processing time. In addition, active contour is especially useful for delineating objects that are difficult to model with rigid geometric primitives (Shortis et al., 2016) and was developed for object segmentation in different fields by many researchers (Mabood et al., 2016; Sun et al., 2014).

The literature review showed that the problems in image processing of underwater natural environments are low contrast, blur, complicated background, and a shortage of prior knowledge. Moreover, sea cucumbers have various shapes and are colored much like sandy sediments. Methods based on threshold and edges are not suitable for fuzzy and uncertain scenes, and flexible objects limit the application of methods based on prior knowledge. Therefore, our goal is to develop an automatic algorithm based on active contour for segmenting sea cucumbers out from underwater images. Color space fusion and edge detection techniques were used to improve the precision and efficiency of the proposed method.

2. Materials and methods

2.1. Image acquisition

The materials used in our experiment are underwater images of sea cucumbers. These images were captured by the C-Watch remotely operated underwater vehicle (ROV) in a sea cucumber fishery at Haiyang Qiandao Lake in Shandong province, China (Fig. 1). The sea cucumber fishery lies in the open air, the water depth is

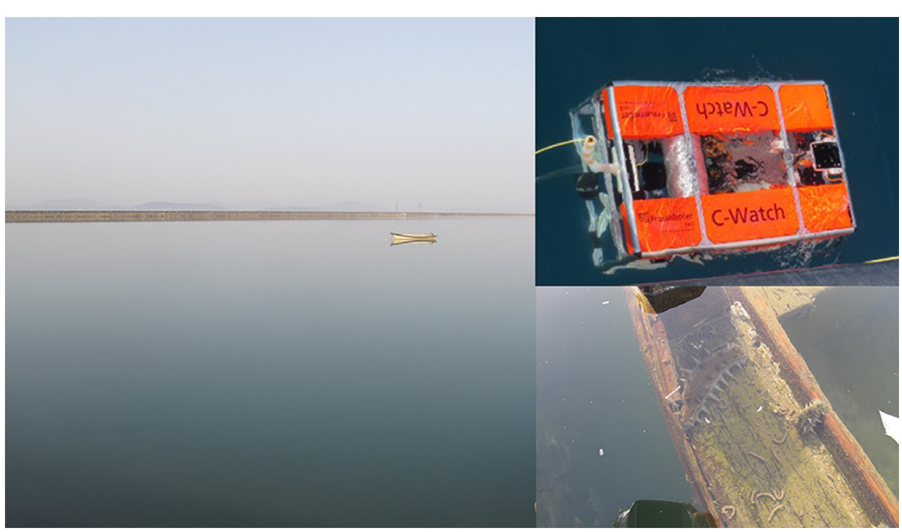

Fig. 1. C-Watch remotely operated underwater vehicle is working in Haiyang Qiandao Lake sea cucumber fishery.