STUDY ON THE SHAPE DETECTION METHOD FOR THE PRECIOUS SEAFOODS BASED ON COMPUTER VISION

/

基于计算机视觉的海珍品体形检测方法研究

Assoc. Prof. Huihui Wang[1,2], Master.stud. Shiyuan Xing[1,2], Master.stud. YuansongZheng[1,2], Master.stud. Weiwei Gu[1,2], Lect. Master. Yan Lv[1,2], Prof. Ph.D. Jixin Yang[1,2]
[1]School of Mechanical Engineering and Automation, Dalian Polytechnic University, Dalian Liaoning 116034;
[2]National Engineering Research Center of Seafood, Dalian Liaoning 116034
Phone:(+86)0411-86323682；E-mail:15040537906@126.com

***Abstract**: The precious sea foods are rich in nutrients and have fairly high commercial values. The appearance quality is an important criterion for assessing their commercial values. Currently, the assessment of the precious sea food appearance quality mainly depends on manual detections on its body size and colour, with great labour intensity and strong subjectivity. In this article, using the sea cucumber and abalone, two typical precious sea foods, as the research objects, a vision detection system was established. Because of the big differences between sea cucumber and abalone, according to typical body size characteristics, the targeted non-destructive testing methods based on computer vision technology were proposed. In the previous studies, the detection accuracy using the enclosing rectangle method was not high and the thorns on sea cucumbers imposed severe effects on the detection results. To solve these problems, the neighbourhood comparison method was proposed, so that an accurate and non-contact measurement of the long-axis and short-axis sizes of the sea cucumber body except thorns can be achieved. With the actually measured values as the standards, the average detection errors of long-axis and short-axis sizes are +2.10 and +1.61mm, respectively. According to the habits in manual detection for abalones, the area and perimeter of the Region of Interest (ROI) in the abalone image were adopted as the detection characteristics, and thus the rapid abalone shape detection can be realized. By contrast with the clustering results using the estimated values, it can be concluded that the proposed detection method can be applicable to the practical production, detection and grading of abalone, algorithm detection rate can be up to 14 abalones per second.*

***Keywords:** computer vision; sea cucumber; abalone; shape detection*

***摘要：**海珍品营养丰富、商业价值高，外观品质的好坏是决定其商业价值高低的重要标准。目前海珍品外观品质主要依靠人工进行体形、体色等特征的检测，劳动强度大、主观性强。本文以海参、鲍鱼为研究对象，建立视觉检测系统，进行了基于计算机视觉技术的海珍品体形检测方法研究。针对海参前期研究使用的外接矩形法检测精度不高、肉刺影响严重的问题，提出邻域比较法，实现了无肉刺参体长轴和短轴尺寸精确、无接触检测，以实际测量值为标准，长轴平均误差为+2.10mm，短轴为+1.61mm。依照人工检测习惯，选择鲍鱼图像感兴趣区域面积和周长作为检测特征，实现了鲍鱼体形的快速检测，与实际测量值的聚类分析比较结果表明，该方法可以用于鲍鱼实际生产检测分级，算法检测速率可达14个/s。*

***关键词：**计算机视觉；海参；鲍鱼；体形检测*

INTRODUCTION

China has a vast maritime territory and boasts a coastline of 18 thousand kilometres. The sea areas along the continental margins are rich in nutrients and therefore favourable for the reproduction and growth of marine organisms. As the sea foods occupy a significantly increasing ratio in human diets, the consumers set increasingly high demands for their appearance quality. In particular, for some precious sea foods with relatively high prices such as sea cucumber and abalone, their commercial values largely depend on their appearance quality grades mainly including body size and colour. With the advancement of the deep processing industrialization, manual detection has become a major factor hampering its development. Using the computer vision technique, the sample shape can be described in a non-destructive, non-contact and visual way. Owing to these strengths, the shape tracking of crops and foods based on computer vision and image processing technology now has become a subject of intense interest, and a lot of favourable detection results were achieved [1],[2],[5-8]. Yang *et al.*

引言

中国海域辽阔，海岸线长约1.8万千米，大陆边缘内海域，营养丰富，有利于各种海洋生物的繁殖和生长。随着海产品在居民膳食结构中的比重显著增加，消费者对于海产品的外观品质要求越来越高。特别是价格相对较高的海珍品，如海参、鲍鱼，体形、体色等外观品质的等级在很大程度上决定了其商业价值。随着海珍品深度产业化加工的进程，人工检测成为了制约其发展的重要因素之一。计算机视觉技术可以无损、非接触、直观的表达被测物形态，因此利用计算机视觉和图像处理技术跟踪农作物、食品等形态的研究已成为热点，同时取得了较好的检测效果

extracted the morphological characteristics from the crop pest images and constructed the score function for effectively distinguishing the pests [15]. By extracting some image characteristics such as the morphological structural parameters, Yang *et al*. proposed an effective identification scheme for the rice types based on sparse presentation [11].In view of the diversity and complexity of the precious sea foods, there are few reports on the automatic shape detection by means of computer vision technique. In this article, the sea cucumber and abalone from the Bohai Gulf were adopted as the detection objects. In consideration of the thorns on the sea cucumber, the long-axis and short-axis sizes can be detected using the proposed neighbourhood comparison method. According to the habits in manual detection for abalones, the area and perimeter of Region of Interest (ROI) were adopted as the characteristic parameters for rapid abalone shape detections.

[1][2][5-8]。杨炎等提取作物害虫图像形态特征，建立判别评分函数，从而有效区分害虫[15]；杨蜀秦等通过提取图像的形态结构参数等特征，利用稀疏表示法提出了大米品种识别的有效方案[11]。由于海珍品的多样性和复杂性状，利用计算机视觉技术进行其体形自动检测的相关报道较少。本文以渤海湾刺参和鲍鱼为检测对象，针对刺参存在肉刺的特殊性状实现无肉刺影响的体壁长轴、短轴检测；根据人工检测习惯，提取鲍鱼图像感兴趣区域（ROI）面积和周长作为检测特征，实现了鲍鱼体形的快速检测。

MATERIALS AND METHODS

Materials

The ready-to-eat sea cucumbers and the fresh and alive abalones purchased from Changxing seafood market, Dalian, were adopted as the experimental materials, which were then placed in the preservation boxes and transported to the laboratory for image acquisition.

试验材料与方法

试验材料

试验材料选用购置于大连长兴海产市场的即时海参和鲜活鲍鱼，由保鲜盒快速运送至实验室进行图像采集。

Visual Detection System

The detection system mainly consists of a computer, a dome diffuse-reflection light source and an industrial camera (MV-1300C, Microvision, China). As shown in Fig. 1, the white light was produced and the samples were placed in the dome diffuse-reflection light source so that the stability of collecting environment could be guaranteed. The control system based on Windows operation system was programmed with Visual C++, in which the images were collected by the industrial camera via software triggering. Moreover, using the control system, the collected images could be automatically displayed, processed and stored. All the collected images were the 24-bit colour images in the format of BMP, with image resolution of 640*512.

视觉检测系统

检测系统主要由计算机、漫反射圆顶光源、MV-1300UC 工业相机（维视，中国）组成。如图 1 所示，光源为白光，检测样本置于漫反射圆顶光源内，可保证采集环境的稳定性。使用 Visual C++开发工具，设计开发基于 windows 平台的控制系统，可通过软触发控制工业相机采集图像，并自动实施显示、处理、存储动作。所采集图像为 24 位 BMP 彩色图像，图像分辨率为 640×512。

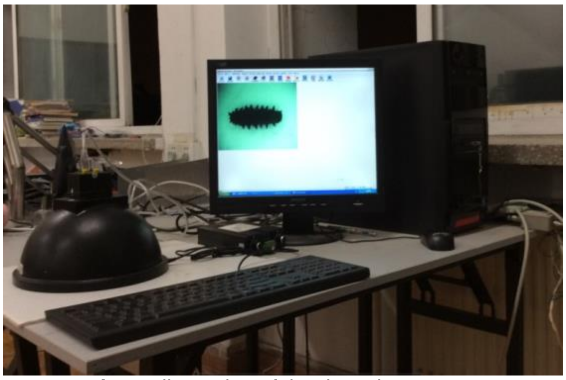


Fig. 1- Illustration of the detecting system

Precious Seafood Shape Detection Method Based on Computer Vision

Data Pre-processing

As described above, the sample images were collected and displayed via the control system. In order to improve the shape information precision in the images, the image backgrounds were removed using the maximum class square error method [12], [14] and then ROI was extracted. A denotes the ratio of the ROI pixel numbers to the pixel numbers of the whole image, with the average grey degree of G_1, and B denotes the ratio of the pixel numbers of image backgrounds to the pixel numbers of

海珍品体形计算机视觉检测方法

预处理

利用控制系统采集并显示样本图像，为提高体形的图像信息精度，首先使用最大类间方差法将图像背景去除[12][14]，提取 ROI， ROI 像素数占整副图像的比例为 A，平均灰度为 G_1；图像背景像素数占整副图像的比例为 B， the whole image, with the average grey degree of G_2, the overall average grey value of the sample image can be calculated by:

平均灰度为 G_2，计算得样本图像的总平均灰度值，如式 1 所示，

$$G_{SUM} = A \times G_1 + B \times G_2 \quad (1)$$

in which G_{SUM} denotes the overall average grey value of the sample image.

The variance (VAR) of the ROI and the image backgrounds can then be calculated by:

式中，G_{SUM} 为样本图像的总平均灰度值。

根据式 1，计算 ROI 与图像背景的方差 VAR，结果如式 2 所示，

$$VAR = A(G_1 - G_{SUM})^2 + B(G_2 - G_{SUM})^2 \quad (2)$$

Bring Equation (1) into Equation (2), VAR:

把 1 式带入 2 式，VAR 得：

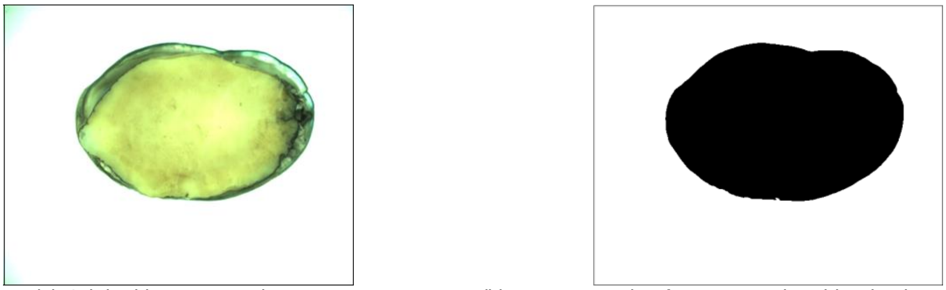
$$VAR = A \times B \times (G_1 - G_2) \quad (3)$$

The calculation was conducted by traversing the image. When VAR is maximal, it is supposed that the great difference exists between ROI and image backgrounds, i.e., VAR can be regarded as the segmentation threshold between ROI and backgrounds. Considering that only the shape information was extracted in the present study, we then performed binary conversion and filtering processing on the images after segmentation for improving the detection speed. Fig. 2(a) and Fig. 3(a) display the original images of samples, while Fig. 2(b) and Fig. 3(b) display the images after segmentation, binary conversion and filtering.

遍历图像并进行计算，当 VAR 最大时，可认为 ROI 与样本图像背景间存在最大差异，即为 ROI 与背景的分割阈值。由于只进行体形信息的提取，为提高检测速度，将分割后图像进行二值及滤波处理，样本图像原图如图 2(a)、3(a)所示，分割后二值滤波图像如图 2(b)、3(b)所示。

(a)Original image sample (b) Image sample after segmentation, binarization and filtering

Fig. 2 - Image of sea cucumber



(a) Original image sample (b) Image sample after segmenting ,binarization and filtering

Fig.3 - Image of abalone

Shape Detection of Sea Cucumber

According to the manual detection habits, the body core size not including the thorns was adopted as the primary index for the appearance quality detection of the sea cucumber. In the previous studies, the minimum enclosing rectangle (MER) was determined using the rotation comparison method [4],[10]. Then the long-axis and short-axis sizes of the sea cucumber were acquired by calculating the length and width of the enclosing rectangle. Fig.4 displays the minimum enclosing rectangle of the sea cucumber, from which we can observe that the acquired long-axis and short-axis sizes are only the estimated values due to the existence of thorns. The researches have conducted the detection on 30 sea

海参体形检测

依据人工检测习惯进行海参外观品质检测，主要指标为不包含肉刺的参体尺寸。在前期研究中通过旋转比较法[4][10]确定了海参图像的最小外接矩形，如图 4 所示。通过计算外接矩形的长、宽，获得海参长轴、短轴尺寸。由于肉刺的影响，所得长轴、短轴尺寸仅为估算

cucumber samples, and the results indicate that the average detection errors of the long-axis and short-axis sizes were +2.15 and +8.97mm, respectively. The primary reason of the great errors is that the effect induced by the thorns was not eliminated in calculating the body core size.

值，对 30 份海参样本进行检测，长轴平均检测误差可达+2.15mm，短轴为+8.97mm。未消除肉刺的影响是造成上述误差的最主要原因。

Fig.4- Minimum enclosing rectangle of the sea cucumber

Based on the above-described studies, by taking the special structures of the sea cucumber (including thorns and body) into account, the marking of the body core and the fitting of the body core outer contour were implemented with the use of neighbourhood comparison, i.e., the auto-detection of the sea cucumber body core size can be achieved. The proposed algorithm consists of two steps, firstly, the overall contour tracing and then the body contour identification. In this article, the eight neighbourhood boundary tracking method was adopted for contour tracing. On the basis of the contour tracing results, the coordinate sequences of the sea cucumber boundary were denoted as $P(x_k, y_k), k = 1, 2, \ldots, N$, in which N denotes the number of the boundary coordinate points. In other words, x_k and y_k denote the coordinates of the sea cucumber boundary points in the image.

Then the centre coordinate of the sea cucumber image was determined using the minimum enclosing rectangle, denoted as $O(x_0, y_0)$ .Generally, a sea cucumber except the thorns is elliptical. Assuming that Ny_0 denotes the centre line of the horizontal axis, the distance between the boundary point and the centre line of the horizontal axis, denoted as r_k, can be calculated by:

基于上述研究和海参肉刺、体壁的特殊结构，本文通过邻域比较法完成了无肉刺体壁的标记和体壁外部轮廓拟合，实现了海参体壁尺寸的自动检测。算法需首先进行整体轮廓的跟踪，再实现体壁轮廓的识别。本文采用八邻域边界跟踪法进行轮廓跟踪，基于轮廓跟踪结果，记海参边界坐标点序列为 $P(x_k, y_k)$，其中 $k = 1, 2, \ldots, N$，N 为边界坐标点个数，x_k 和 y_k 即为海参边界点在图像中的坐标值。

通过最小外接矩形确定海参图像中心坐标，记为 $O(x_0, y_0)$，设横轴中心线为 Ny_0，由于除肉刺外参体呈椭圆状，利用 4 式求出海参边界点坐标到横轴中心线 Ny_0 的距离，记为 r_k，

$$r_k = |y_k - y_0| \tag{4}$$

The distance between each pixel point and the centre line of the horizontal axis Ny_0, was calculated by traversing the contour tracing image, and then compared with the neighbouring points according to the comparison flow as shown in Fig. 5.

遍历轮廓跟踪图像，计算每个像素点到横轴中心线 Ny_0 的距离 r_k，并对相邻若干点进行比较，比较流程如图 5 所示。

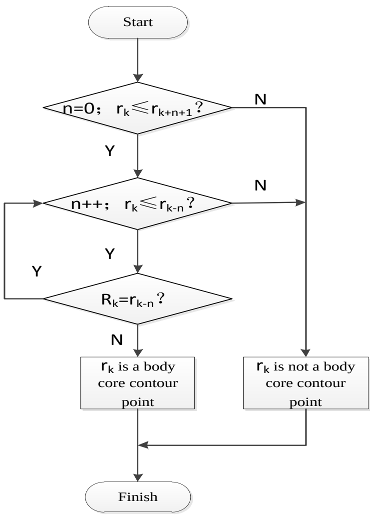
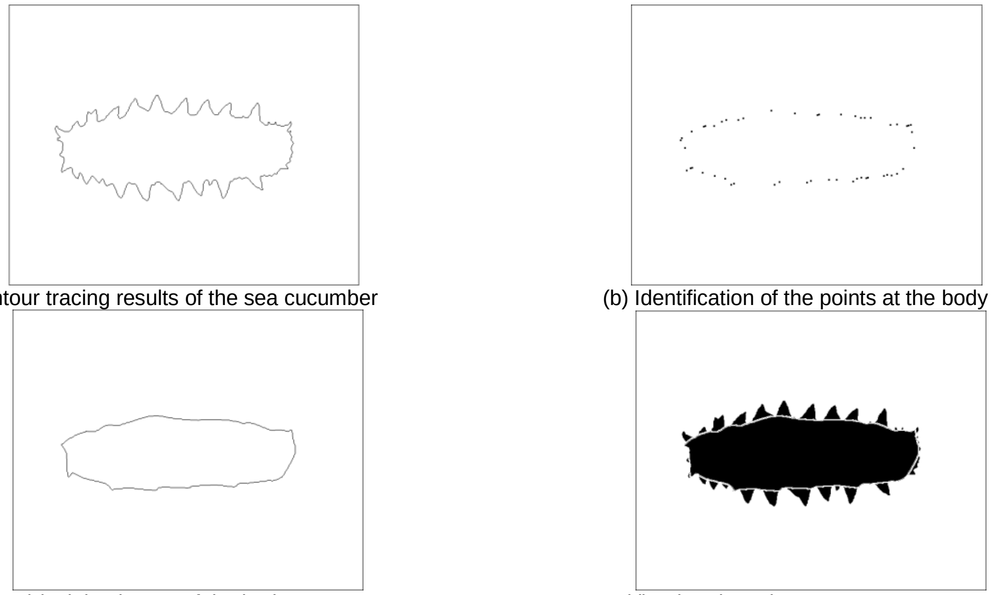


Fig. 5 - Flow chart of the comparison

Then an array R was constructed. The point whose coordinate can meet the body core contour requirements was added into R, and the body core coordinate sequence was acquired, as shown in Fig. 6(b). According to the parabolic spline principle [3],[13], using the interpolations of coordinate sequence to obtain the closed curve, the outer contour of the body core was fit, as shown in Fig. 6(c). Therefore, the body size of the sea cucumber, i.e., the body size not including the thorns, can be calculated.

建立数组 R，当满足体壁轮廓要求时，将该点坐标赋于 R，获得体壁坐标序列，如图 6(b)所示。根据抛物线样条原理[3][13]，利用上述坐标序列插值，使其呈闭合曲线，实现海参体壁外部轮廓拟合，结果如图 6(c)所示。由此可计算体壁尺寸，即得去除肉刺后参体大小。



(a)Contour tracing results of the sea cucumber (b) Identification of the points at the body core

(c) Fitting image of the body core (d) Edge detection

Fig.6-The image processing and feature extraction

Shape Detection of Abalone

The abalones have much simpler shapes and contours than the sea cucumbers. It's no need to deal with abalone images in accordance with aforesaid methods. The size of the abalone is generally adopted as the index for manually detecting its appearance quality. According to the habits in manual detection, the area and perimeter of the ROI in an abalone image were used as the shape characteristics for detecting the appearance quality.

The abalone contour was traced using the method proposed in aforementioned content, with the tracing results presented in Fig. 7. The calculations of area and perimeter were conducted by traversing the binary contour tracing image. Assuming that the pixel point in the image is denoted as $f(x,y)$, the perimeter can be calculated by the following Eq.(5) and Eq.(6). Using the extracted binary ROI after filtering, the area was calculated by the following Eq.(5) and Eq.(7). The algorithm detection rate can be up to 14 abalones per second.

鲍鱼体形检测

与海参的体形轮廓比较，鲍鱼体形简单，无需完全按照前述方法进行处理。人类鉴评鲍鱼外观品质指标主要为获取其尺寸信息，根据人类的检测习惯，应提取鲍鱼图像 ROI 面积、周长作为鉴评鲍鱼体形特征，进行外观品质鉴评。

通过前述方法跟踪鲍鱼轮廓，跟踪结果如图 7 所示，遍历二值化轮廓跟踪图像，设图像像素点 $f(x,y)$ ，根据式 5、6 计算周长 C。按式 5、7 方法，利用 ROI 提取后的二值滤波图进行面积 S 的计算。鲍鱼体形算法检测速率可达 14 个/s。

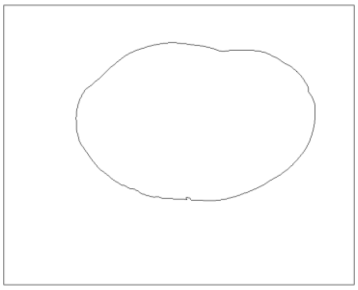


Fig. 7 - Contour tracing results of the abalone

$$Q(x,y)=\begin{cases}1, f(x,y)=0\\ 0, f(x,y)=255\end{cases} \tag{5}$$

$$C=\sum Q(x,y) \tag{6}$$

$$S=\sum Q(x,y) \tag{7}$$

RESULTS

Detection Results of Sea Cucumber

Using the aforesaid method, the body cores of the sea cucumbers were identified. By effectively eliminating the effects of the thorns on the detected sizes, this method can significantly enhance the detection precision. With the adoption of the actual body core sizes as the standard, using neighbourhood comparison method, 30 sea cucumbers were used to verify the detection performances. The results demonstrate that the average detection errors of long-axis and short-axis sizes are +2.10 and +1.61mm, respectively.

Detection Results of Abalone

According to the habits in manual detection, the area and perimeter of abalone were used as detection indexes. Quick and non-destructive detection for abalone was realized utilizing computer vision technology. Since the abalones are generally irregular ellipses, the actually measured long-axis and short-axis lengths were used to estimate the areas and perimeters according to calculation formula for ellipse. Then, using the ROI and estimated areas and perimeters as the samples values, the cluster analysis was conducted by within-group linkage method in hierarchical clustering. Fig. 8 displays when the number of clusters is less than 6, grading results based on the vision characteristic parameters and the estimated values are consistent. The results indicate that the proposed method can be applicable to the quality assessment of abalones.

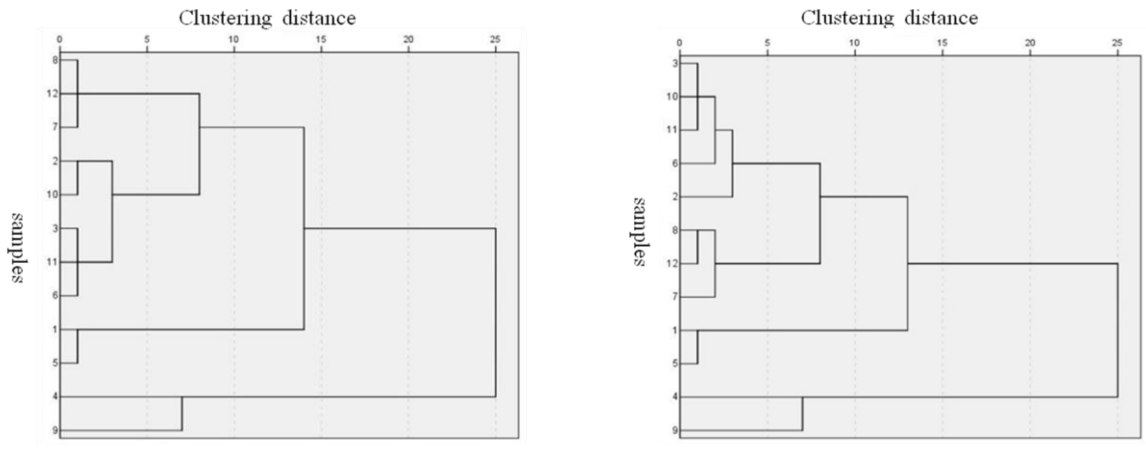
检测结果分析

海参检测结果

使用前述方法进行海参体壁的识别，能够有效规避肉刺在图像上对于测量尺寸的影响，与通过外接矩形获得的海参尺寸相比，该方法大幅提高了检测精度，以实际体壁尺寸为标准，进行邻域比较法验证，通过 30 个海参样本计算得，长轴平均误差为+2.10mm，短轴为+1.61mm。

鲍鱼检测结果

根据人工检测习惯，将面积和周长作为鲍鱼主要检测指标，利用计算机视觉技术实现鲍鱼体形快速无损检测。由于鲍鱼为不规则椭圆状，因此通过实际测量的长轴、短轴长度，按椭圆面积、周长计算公式进行估算。选择系统聚类的组内联结法，对 ROI 和估算所得面积 S 和周长 C 分别进行聚类分析，聚类图谱如图 8 所示，当聚类数小于 6 时，基于计算机视觉检测的样品分类与基于估算值的分类一致，因此该方法可用于鲍鱼的快速分级。



(a) Clustering chart based on the visual sample values (b) Clustering chart based on estimated sample values

Fig. 8 - Clustering charts

CONCLUSIONS

(1) Using the neighbourhood comparison method, the identification of the body core coordinates of the sea cucumbers and the fitting of body core can be achieved in this article. By effectively avoiding the effects of thorns on the detection results, the non-contact detection of the long-axis and short-axis sizes of the sea cucumbers can be realized. The results demonstrate that, using the proposed method, the errors of the long-axis and short-axis errors are + 2.10 and +1.61 mm, respectively.

结论

(1)利用邻域比较法实现了去除肉刺后海参体壁坐标的识别和体壁的拟合，从而有效规避了海参肉刺影响，实现去除肉刺参体长轴、短轴尺寸的无接触检测，长轴平均误差为+2.10mm，短轴为+1.61mm。

(2) According to the habits in abalone manual detection, the area and perimeter of the ROI in the image were adopted as the characteristic parameters for rapid detection. By comparing with the clustering results using the estimated values, the effectiveness and accuracy of the proposed method were proved, i.e., the proposed method can be applied to abalone detection, the algorithm detection rate can be up to 14 abalones per second.

ACKNOWLEDGEMENT

This study is funded Public Science and Technology Research Funds Projects of Ocean (201505029) and National Engineering Research Centre of Seafood (2012FU125X03).

REFERENCES

[1]. Baohua Zhang, Wenqian Huang, Liang Gong, Jiangbo Li, Chunjiang Zhao, Chengliang Liu, Danfeng Huang, (2015) - *Computer vision detection of defective apples using automatic lightness correction and weighted RVM classifier*, Journal of Food Engineering, Volume 146, pp.143–151;

[2]. Chandraratnea M.R., Kulasirib D., Samarasingheb S., (2007) - *Classification of lamb carcass using machine vision: Comparison of statistical and neural network analyses*, Journal of Food Engineering, Volume 82, Issue 1, pp. 26–34;

[3]. Chenglong Wang, Xiaoyu Li, Wei Wang, Yaoze Feng, Zhu Zhou, Hui Zhan, (2011) - *Recognition of worm-eaten chestnuts based on machine vision*, Mathematical and Computer Modelling, Volume 54, Issues 3–4, pp. 888–894;

[4]. Chi-Chang Wang, (2010) - *Applying the differential equation maximum principle with cubic spline method to determine the error bounds of forced convection problems*, International Communications in Heat and Mass Transfer, Volume 37, Issue 2, pp. 147–155;

[5]. Eunju Kwak, Ayman Habib (2014) - Automatic representation and reconstruction of DBM from LiDAR data using Recursive Minimum Bounding Rectangle, ISPRS Journal of Photo grammetry and Remote Sensing,Volume 93, pp. 171–191;

[6]. Hanmei Hong, Xiaoling Yang, Zhaohong You, Fang Cheng.(2014) - *Visual quality detection of aquatic products using machine vision*, Aquacultural Engineering, Volume 63, pp. 62–71;

[7]. Kurtulmuşa F., Kavdir İ., (2014) - *Detecting corn tassels using computer vision and support vector machines*, Expert Systems with Applications, Volume 41, Issue 16, pp. 7390–7397;

[8]. Kurtulmuş F., Ünal H., (2015) - Discriminating rapeseed varieties using computer vision and machine learning, Expert Systems with Applications, Volume 42, Issue 4, pp. 1880–1891;

[9]. Muhammad Makky, Peeyush Soni., (2013) - *Development of an automatic grading machine for oil palm fresh fruits bunches (FFBs) based on machine vision*, Computers and Electronics in Agriculture, Volume 93, pp. 129–139;

[10]. Ni Jiang, Wanneng Yang, Lingfeng Duan, Xiaochun Xu, Chenglong Huang, Qian Liu, (2012) – *Acceleration of CT reconstruction for wheat tiller inspection based on adaptive minimum enclosing rectangle*, Computers and Electronics in Agriculture Volume 85, pp. 123–133;

[11]. Shuqin Yang, Jifeng Ning, Dongjian He, (2011) - *Identification of varieties of rice based on sparse representation*, Transactions of the CSAE, Volume 27, pp. 191－195;

[12]. Weiya Guo, Xiaofei Wang, Xuezhi Xia. (2014) -

(2)依据人工检测鲍鱼的习惯，选择鲍鱼图像 ROI 面积和周长作为特征实现了快速检测，与估算值聚类分析结果比较，说明根据此方法可对鲍鱼体形大小进行有效、准确分级，算法分级速率可达 14 个/s。

基金支持：

海洋公益性行业科研专项经费资助（201505029），国家海洋食品工程技术中心资助（2012FU125X03）。

参考文献

[1]. Baohua Zhang , Wenqian Huang , Liang Gong , Jiangbo Li , Chunjiang Zhao , Chengliang Liu, Danfeng Huang.计算机视觉检测有缺陷的苹果使用自动亮度校正和加权 RVM 分类器[J].食品工程学报,2015(146):143-151;

[2]. Chandraratnea M.R., Kulasirib D., Samarasingheb S. 基于机器视觉的羔羊胴体分类：统计与神经网络分析比较[J].食品工程学报, 2007,82(1): 26–34;

[3]. Chenglong Wang , Xiaoyu Li, Wei Wang, Yaoze Feng, Zhu Zhou, Hui Zhan.基于机器视觉的虫蛀栗子的识别[J].数学和计算机建模, 2011,54(3-4):888-894;

[4]. Chi-Chang Wang.运用微分方程最大值原理与三次样条方法来确定强制对流的问题误差范围[J]. 热与传质的国际交流, 2010,37(2):147-155;

[5].Eunju Kwak, Ayman Habib.自动代表性和使用递归最小边界矩形 LiDAR 数据重建的 DBM[J]. 摄影测量学与遥感学报, 2014(93):171-191;

[6].Hanmei Hong, Xiaoling Yang, Zhaohong You, Fang Cheng.利用机器视觉检测水产品的视觉质量[J]. 水产养殖工程, 2014(63): 62–71;

[7]. Kurtulmuşa F., Kavdir i.检测基于计算机视觉的玉米穗和支持向量机[J]. 应用专家系统, 2014,41(16): 7390–7397;

[8].Kurtulmuş F.,Ünal H.利用计算机视觉和机器学习鉴别油菜品种[J]. 应用专家系统,2015,42(4): .1880–1891;

[9].Muhammad Makky, PeeyushSoni.基于机器视觉的油棕鲜果的自动分选机的开发[J].农业电子计算机, 2013(93:) 129–139;

[10]. Ni Jiang, Wanneng Yang, Lingfeng Duan, Xiaochun Xu, Chenglong Huang, Qian Liu.基于自适应最小外接矩形的小麦分蘖 CT 重建[J]. 农业电子计算机,2012(85): 123–133;

[11].杨蜀秦，宁纪锋，何东健. 基于稀疏表示的大米品种识别[J]. 农业工程学报,2011(27): 191－195;

[12].Weiya Guo , Xiaofei Wang , Xuezhi Xia.基于网格框

Two-dimensional Otsu's threshold segmentation method based on grid box filter, Optik - International Journal for Light and Electron Optics, Volume 125, Issue 18, pp. 5234–5240;
[13]. Xiaofeng Xue, Xingwu Zhang, Bing Li, Baijie Qiao, Xuefeng Chen (2014) - *Modified Hermitian cubic spline wavelet on interval finite element for wave propagation and load identification*, Finite Elements in Analysis and Design, Volume 91, pp. 48–58;
[14]. Xiaolu Yang, Xuanjing Shen, Jianwu Long, Haipeng Chen (2012) - *An Improved Median-based Otsu Image Threshold Algorithm*, AASRI Procedia, Volume 3, pp. 468–473;
[15]. Yan Yang, Sa Liu, Shibin Lian, Xiaodong Zhu. (2013) - *Analysis of fruit tree pests morphological characteristics based on computer vision*, Journal of Jilin University (Engineering and Technology Edition), Volume 43,Sup, pp. 235-236.

过滤器的维大津的阈值分割方法[J].光学和电子光学国际学报，2014，125(18): 5234–5240;
[13].Xiaofeng Xue, Xingwu Zhang, Bing Li, Baijie Qiao, Xuefeng Chen.改进的 Hermite 三次样条小波区间有限元波动和负载识别[J].有限元分析与设计，2014(91): 48–58;
[14].Xiaolu Yang, Xuanjing Shen, Jianwu Long, Haipeng Chen.一种改进的基于中值的 Otsu 图像阈值分割算法[J].AASRIProcedia, 2012(3): 468–473;
[15]. 杨 焱,刘 飒,廉世彬,朱晓冬.基于计算机视觉的果树害虫的形态特征分析[J].吉林大学学报(工学版), 2013,43(Suppl): 235-236.