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Research on Autonomous Picking Algorithm for Table Tennis Balls based on Machine Vision

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Abstract

The identification, positioning and grabbing path planning of table tennis balls are the preconditions for the robot to pick up table tennis balls autonomously. A method of table tennis identification, positioning and grabbing path planning based on monocular vision image processing is proposed. By analyzing the characteristics of table tennis images, a table tennis image segmentation method based on color and contour features is designed. The color and contour features of table tennis images are extracted, and HSV is used for image preprocessing. Image segmentation is processed by binarization, and Hough circle is used to detect contour recognition, and the segmentation image of table tennis balls is obtained by color combination. Convert the camera imaging coordinates to obtain the pixel position of the table tennis ball in the image. A ball picking path planning based on ant colony algorithm is designed. This paper provides a theoretical reference for the identification, positioning and path planning of autonomous ball picking.

Keywords

Target Recognition and Positioning; Image Processing; Image Segmentation; Path Planning.

1. Introduction

Picking up and recycling of table tennis balls is an important part of table tennis training. The table tennis smart pick-up machine requires fast and accurate recovery of table tennis balls. With the rapid development of artificial intelligence, the development of autonomous ball picking robots is an important means to solve the low efficiency of manual picking. The identification and positioning of table tennis and the selection of the shortest picking path are the basis for picking up table tennis.

At present, exploratory research on table tennis identification and positioning has been initially carried out at home and abroad. Ren Qingyun from Nanjing University of Posts and Telecommunications [1]used Kinect v2 and RPLIDAR A1 radar as sensors to scan 360° to obtain the outer contour. Using C++ programming language to complete the realization of automatic ball picking, with certain reliability. Most of the existing researches focus on the identification and positioning of table tennis balls, and have obtained good identification and positioning results. However, most of the methods based on deep learning have complex training processes and high requirements for equipment; most of the current research does not consider the path planning. Li Hongyan[2] from Xi'an University of Posts and Telecommunications, based on OpenCV, collected information through the camera, and then identified the color and position of the table tennis ball through the Raspberry Pi, and finally completed the ball picking work under the control of the STM32 microcontroller. The study did not consider the path planning of the robot. Su Zengdi from Dalian University of Technology[3], based on the color features

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and contour features of tennis balls for identification, picks tennis balls by scraper and belt drive, and completes tennis picking, but lacks the path planning part.

Aiming at the above problems, this paper proposes an image processing-based method for table tennis balll recognition, positioning and path planning. Through the feature analysis and segmentation of the table tennis image, the identification of the table tennis ball is completed; then the positioning of the table tennis ball picking is realized; finally, the simulation experiment of the path planning is designed to verify the selection of the table tennis ball picking sequence path planning.

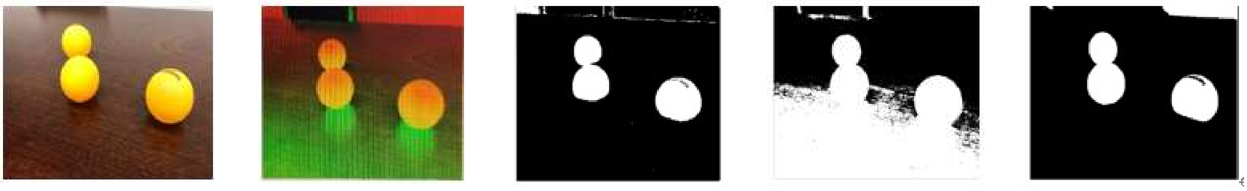
2. The Identification Method of Table Tennis

2.1. Design of Identification System

Table tennis image acquisition is the basis of table tennis recognition and positioning. In this paper, a USB industrial camera is used as the image acquisition device, and the OpenCV computer vision library is used as the image processing platform. The image quality of table tennis is greatly affected by the shooting position of the camera. Because the scattered positions of the table tennis balls are different, when the table tennis ball is located 4cm below the lens, it is in the blind area of the camera's data collection and cannot be displayed in the collected image; when the table tennis ball is located in the lens At 10cm below, the table tennis ball is displayed in the captured image, but it is not detected. After a little adjustment, the table tennis ball can be detected, so the lower limit of the blind area of the camera's field of view is determined to be about 10cm. The table tennis ball is located 35cm below the lens. The table tennis ball can be captured by the camera image but not detected. After a little adjustment, it is detected by the camera, so the upper limit of the blind area of the camera's field of view is determined to be about 35cm. Therefore, in this paper, the table tennis images are collected in the range of 10cm~35cm.

2.2. Analysis of Image Feature

The purpose of table tennis image feature analysis is to process the background where the table tennis ball is located, and then extract the table tennis ball from the background. In this paper, the RGB original image [3] collected as shown in Figure 1(a) is converted into the HSV color space image [4] shown in Figure 1(b), and the color features in the HSV space are used to analyze the table tennis image. Then, Hough circle detection is used to identify the circular contour for the extracted yellow part. The H, S, and V components are extracted from the HSV space for the table tennis image in Figure 1, and the component images shown in Figure 1(c) to Figure 1(e) are obtained.



(a)RGB image (b)HSV image (c)H-component (d)S-component (e)V-component

Figure 1. H, S, V component images of table tennis

It can be seen from Figure 1 that HSV plays a greater role in color segmentation, and through the threshold division, the part of the table tennis ball is prominent, forming a large contrast with the background, obtaining a good segmentation image, and the table tennis ball recognition effect is obvious.

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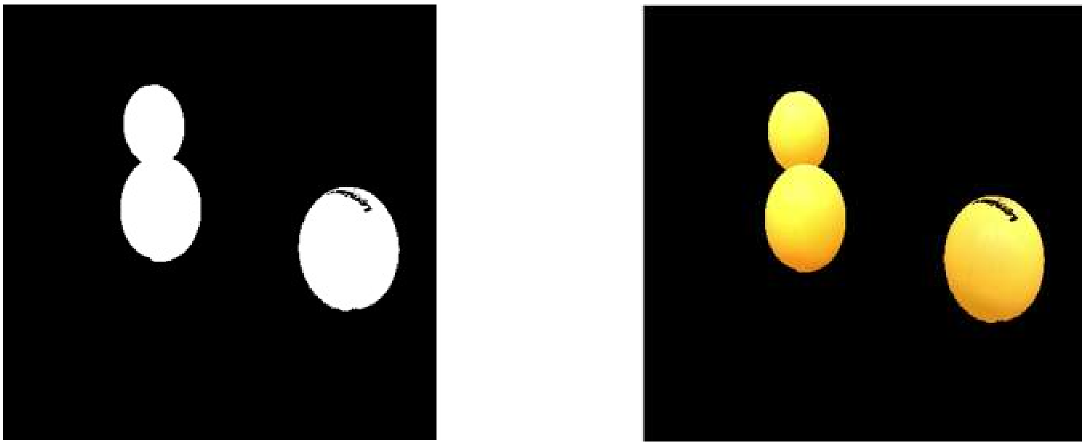
2.3. Image Segmentation

Since the 3 color channels of RGB are closely related, the colors are obtained by mixing different proportions, but the proportion required for mixing and superimposing colors cannot be directly determined in machine vision, so the HSV color space is selected, and the three components of H, S, and V are used. Using the control variable method, confirm that the threshold ranges of the three channels are 20~40, 110~255, and 235~255, respectively. After comparing the test results of several pictures, it is found that the table tennis extraction range of the H channel does not fluctuate much, but the S channel and V channel are significantly affected by the environment. Therefore, in order to ensure the effective extraction of table tennis balls as much as possible, the ranges of S and V should be set larger.

Feature extraction is performed on the table tennis HSV image in Figure 1(b), and binarization is performed, and the segmentation image of the table tennis ball is obtained through color combination, as shown in Figure 2, Figure 2(a) is the segmentation result, Figure 2(b) is the final result image after color merging [5].



(a)Image segmentation result (b)Final result

Figure 2. Image segmentation based on yellow feature

2.4. Hough Circle Detection

In different venues, the images collected by the camera will be affected by the light, and the color features of the table tennis balls alone have certain limitations. In order to improve the recognition rate of table tennis balls, combined with the Hough circle detection, the recognition rate will be greatly improved.This article chooses to use the OpenCV software library for table tennis ball recognition in the Raspberry Pi because the Hough circle change is optimized. Among them, only the Hough gradient method is currently supported in Hough circle detection. The main steps are as follows:

(1) Find the center of the circle by the modulo vector of each point, and convert the three-dimensional accumulation plane into a two-dimensional accumulation plane.

(2) Determine the radius according to the support of all the candidate center edge non-zero pixels. The function to call Hough circles in Python is: cv2.HoughCircles(image, method, dp, minDist, circles, param1, param2, minRadius, maxRadius).

It can be seen from the image shown in Figure 3 that the table tennis ball is identified and the outline of the ball is displayed. Since the captured table tennis ball is close to the camera, the drawn outline cannot completely wrap the table tennis ball.

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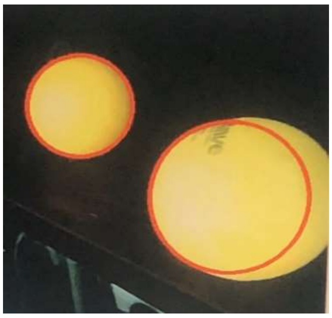

Figure 3. Hough circle detection renderings

3. Table Tennis Positioning

In this paper, the ball picking robot uses a monocular camera to identify and locate the target [3]. Target positioning is the key to the path planning of the ball picking robot. Through the analysis of the camera imaging model, the table tennis positioning is studied.

3.1. Conversion of Camera Coordinate System

The camera calibration under the camera linear model requires the connection between the world coordinate system, the image physical coordinate system, the image pixel coordinate system and the camera coordinate system. The specific process is as follows:

(1) From the world coordinate system to the camera coordinate system

The transformation from the world coordinate system to the camera coordinate system is a rigid body transformation, which only changes the spatial position and orientation of the object, and the shape of the object does not change. This transformation can be represented by a rotation matrix R and a translation vector t.

$$\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = R \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} + t \tag{1}$$

Among them, x_c, y_c, z_c take the optical center O as the origin, and the optical axis is the three axes of the coordinate system established by z_c. Its homogeneous matrix is as follows:

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \tag{2}$$

(2) Camera coordinate system to image coordinate system

This transformation process is the transformation of three-dimensional space into two-dimensional plane. The representation in homogeneous coordinates is:

$$z_c \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} \tag{3}$$

In the above formula, f is the focal length, and x and y are the coordinates of the point on the two-dimensional surface.

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(3) Image coordinate system to pixel coordinate system

Figure 4 shows the pixel coordinate system diagram.

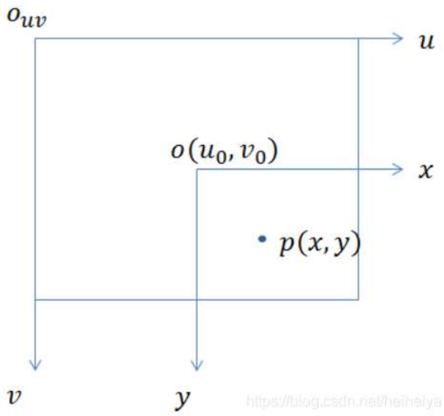

Figure 4. pixel coordinate system

In the conversion of image coordinates to pixel coordinates, only the origin of the coordinates is different and the units are different. Homogeneous coordinates are expressed as:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{4}$$

where u_0, $v0$ is the center of the image plane, and dx, dy represent the actual size of the pixel. Combining the above process, we get:

$$Z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{5}$$

4. Table Tennis Picking Path Planning

In order to improve the efficiency of picking up the ball and find the shortest path in the process of picking up the ball [6], while avoiding obstacles and picking up all the table tennis balls. To sum up, the picking-up path planning problem is analogous to the business travel problem (TSP).

4.1. Principle of Ant Colony Algorithm

When the ant colony begins to search for food, each ant randomly seeks a route based on its own characteristics. They release pheromones along their foraging routes [7]. Therefore, ants with shorter foraging routes have more round trips, and the pheromones released on this route are more and more concentrated. On the contrary, ants with longer foraging routes released pheromones less frequently, and some of the pheromones were volatilized, so the concentration of pheromones was lower [8]. The higher the pheromone concentration, the more ants are selected, that is to say, the higher the probability of selecting the pheromone concentration.

ISSN: 2710-0588

4.2. Simulation Experiment of Ball Picking Path Planning

In order to verify the feasibility of using the TSP problem to solve the path planning problem of picking up a table tennis ball [9], a MATLAB simulation of the TSP problem was carried out. In this experiment, 31 table tennis balls are used instead of cities as the target of the visit, and the coordinates of these cities are randomly determined. The parameters are determined as follows: number of ants m=50; pheromone importance factor α=1; heuristic function importance factor β=5; maximum number of iterations Nmax=200; pheromone constant=1 The simulation results are shown in Figure 5 and Figure 6 :

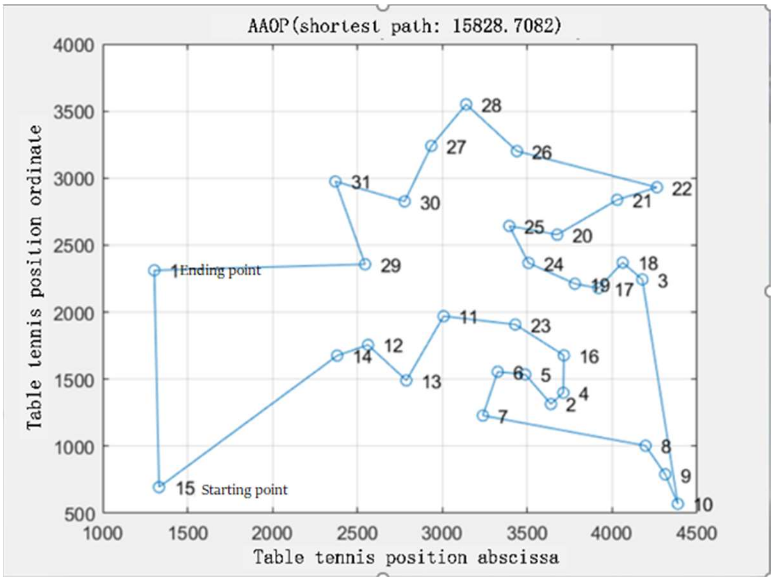

Figure 5. Path Planning Diagram of Ant Colony Algorithm

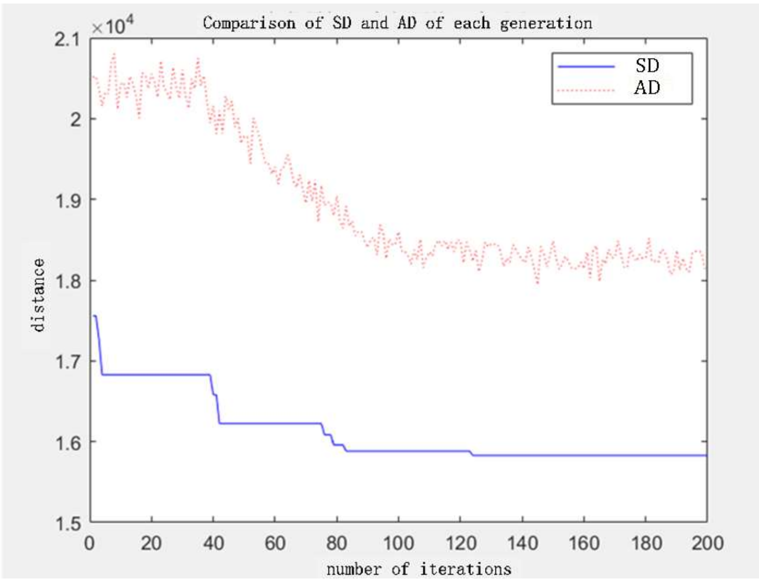

Figure 6. Comparison of the number of iterations and the shortest distance

From the analysis of the experimental results, with the continuous increase of the number of iterations, the AAOP (Ant colony algorithm optimization path, abbreviated AAOP) of the ant colony algorithm is getting smaller and smaller, and finally tends to a stable value. This is the optimal solution in this path planning

ISSN: 2710-0588

5. Conclusion

This paper studies the autonomous picking, identification, positioning and path planning method of yellow table tennis balls during table tennis training. Table tennis images were collected from the range of 10cm~35cm, and the characteristics of table tennis in the HSV color space were studied, and an image segmentation method based on the yellow feature of table tennis was proposed to obtain a good segmentation image of table tennis. On this basis, the Hough circle detection is used to process the contour of the segmented image to obtain a better segmented image, and then the camera imaging model is analyzed to obtain the pixel position of the table tennis ball, thereby realizing the positioning of the table tennis ball. Using the TSP problem, a simulation experiment of the feasibility of solving the path planning problem of picking up table tennis balls based on ant colony algorithm is designed. The experimental results show that the designed method can stably identify the table tennis ball and realize the positioning of the table tennis ball in the image, and has strong robustness. The simulation experiment analysis shows that the path planning of picking up the table tennis ball can be completed stably, and the optimal path is obtained.

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