

Research on Autonomous Spraying Robot Based on Machine Vision

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Abstract. In view of the problems that the current spraying robot needs manual teaching and cannot meet the requirements of flexible processing, this paper carries out the research on the autonomous spraying robot based on machine vision. First, the overall design, structure design and parts selection of the robot system are carried out according to the market functional requirements. Then, the feature extraction algorithm of the workpieces to be sprayed is designed, which mainly uses Opencv to denoise the collected image, remove the background, and extract features. According to the image processing results, the spraying trajectory is determined by trajectory planning. Finally, the autonomous spraying experiment is carried out through the built spraying robot platform, and the functions of spraying process, adaptive workpiece shape, adaptive workpiece pose and other functions are analyzed, and the goal of robot adaptive spraying is realized.

Keywords: spraying robot, machine vision, image processing, trajectory planning.

1. Introduction

Spraying is one of the most important processing steps [1]. With the development of science and technology, spraying robots have gradually replaced people in spraying operations in recent years. However, the existing industrial spraying robots have high requirements on the programming ability of the staff. The robot running trajectory taught each time can only be used for spraying the same kind of workpiece, and the workpiece must be in the same position every time. Different programs or trajectory planning needs to be written for different workpieces, which greatly reduces the working efficiency of the robot. At present, machine vision is increasingly used in industrial robot technology [2,3], combining machine vision with technologies such as robotic arms can create more value [4,5].

Therefore, in order to solve the problems of how to realize the complete automation of the spraying robot, how to improve the spraying quality and the utilization rate of materials, this paper starts from the current situation of the spraying robot, and studies a series of image information processing and feature extraction method, such as image acquisition [6,7], image filtering [8-11], image corrosion, and background removal [12]. A machine vision-based plane spraying trajectory generation algorithm that combines industrial robots and robot vision is designed. This algorithm can not only realize automatic workpiece recognition, but also complete automatic planning of spraying trajectory in real time.

2. Design of Autonomous Spraying Robot System

This paper designs a set of machine vision autonomous spraying robot system based on Opencv and Ros platform, combines traditional spraying robot with machine vision, develops a set of integrated machine vision to recognize workpiece shape, perform workpiece coordinate positioning, trajectory planning, and real-time spraying on All-in-one autonomous spraying robot. Its overall system structure is shown in Fig. 1. The camera is installed at the end of the robot's hand. Control the camera through the Ros system to capture images and return to a format that Opencv can handle. The image is processed through Opencv, and the geometry and relative position of the workpiece to be sprayed are extracted from the image. The relative position of the workpiece and the camera can be obtained from the workpiece image, and the relative position of the spray gun and the workpiece can

be obtained by combining the relative positions of the camera and the spray gun. Then carry out trajectory planning to spray the workpiece. The system mainly includes three modules: image acquisition module, image processing and trajectory generation module, and execution module.

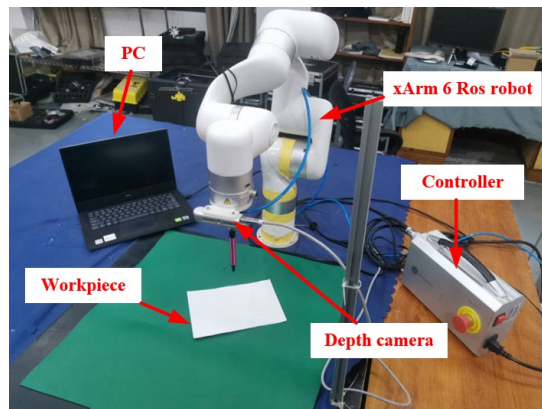


Figure 1. The overall system of autonomous workpiece spraying.

Image acquisition module: The PC controls the depth camera to collect images and return them to the PC. The system uses the Intel RealSense Depth Camera D415 to obtain the workpiece images.

Image processing and trajectory generation module: After the PC receives the image from the depth camera, the PC processes the image to extract the position and geometry of the workpiece. The spraying trajectory is planned in PC according to the position and geometry of the workpiece.

Execution module: The PC sends the spraying trajectory instruction to each joint of the mechanical arm, and each joint driver module works together to control the robot to run according to the predetermined trajectory. The system uses the xArm 6 robot with six degrees of freedom.

3. Design of Spraying Trajectory Planning algorithm based on Machine Vision

3.1 Image Acquisition

ROS system based on Ubuntu system is a modern machine system in the research field of modern robots. This system is very convenient because there are a large number of toolkits, such as the depth camera driver package that can be directly called. After the depth camera successfully collects and converts the image, OpenCV processes and outputs the collected image. The original image output after acquisition is shown in Fig. 2.

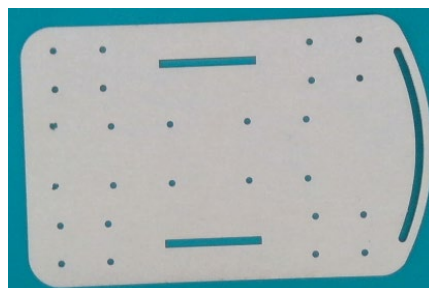


Figure 2. The original image.

3.2 Image Filtering

Image collected by depth cameras has some noise, which will affect the processing results, so it is necessary to remove noise before image processing. In this paper, Gaussian filter is selected for image filtering.

Gaussian filter is a kind of linear smoothing filter which selects weights according to Gaussian function, it is very effective to suppress noise which obeys normal distribution. Gaussian filter is a process of weighted average of the whole image. The calculation process of Gaussian filtering is through convolution calculation for each pixel of the Gaussian template and the input image, and

finally the calculation results are combined to form a new filtered output image. The process can be summarized as follows: Each pixel in the image is scanned by a template, and the weighted average gray value of pixels in the neighborhood replace the value of the center pixel of the template. This method uses a low-pass filter, the whole image becomes low frequency after the low-pass filter, which causes image blurring. The Gaussian filtered image is shown in Fig. 3.

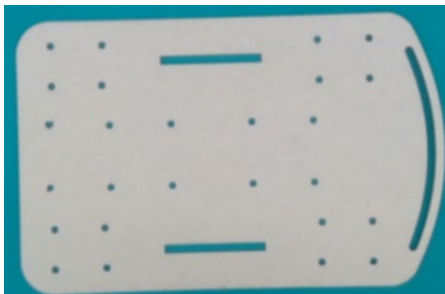


Figure 3. Gaussian filtered image.

4. Image Processing Based on HSV Color Space

4.1 Limitations of RGB color space

RGB color space consists of three components: red, green and blue, which is the hardware-oriented color space in image processing. But for the display system, RGB color space has some disadvantages in image processing as follows: Firstly, when the color change continually, the performance of RGB is not intuitive. The three color components of RGB are highly correlated, they need to be adjusted simultaneously for minor color changes. Secondly, RGB are sensitive to illumination brightness. Once the brightness changes, the three color components will change, and it is difficult to intuitively express this change. Thirdly, The uniformity of RGB color space is poor [13].

Therefore, RGB color space is more used in image display, and it faces many difficult problems in image processing.

4.2 Image processing based on HSV color space

Due to the shortcomings of RGB images, this paper adopts HSV color space for image processing. HSV color space consists of three components: hue, saturation and value. In the HSV color space, it is easier to track objects of a certain color than RGB, and it is often used to segment objects of a specified color [13]. The idea of this paper is to convert RGB images into HSV images for processing, thereby reducing the influence of light, and convert the images in RGB space obtained by Gaussian filtering into images in HSV image space and save them in HSV [14]. The image in HSV image space is shown in Fig. 4.

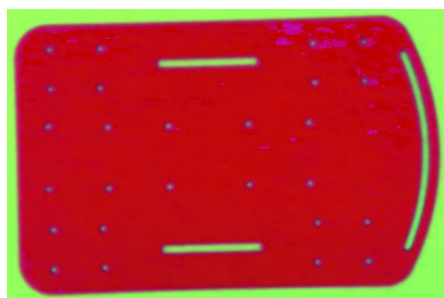


Figure 4. Image in HSV image space.

4.3 Image Corrosion

Since Gaussian filtering is used to remove noise, it is equivalent to expanding the image while removing noise, so that the geometric features of image are blurred. In order to restore the geometric features of the image, it is necessary to corrode the image. Corrosion reduces or refines the bright

area or white part of the image, and the bright area of the resulting image is smaller than the original image. The corrosion operator is '-', defined as follow:

$$A - B = \{ X | B_X \subseteq A \} \quad (1)$$

The formula shows that the minimum pixel value of the cover area of B is obtained by convolution calculation between template B and image A, and this minimum value is used to replace the pixel value of the reference point. This paper adopts default convolution kernel, the number of iterations is 2. The corroded image is shown in Fig. 5.

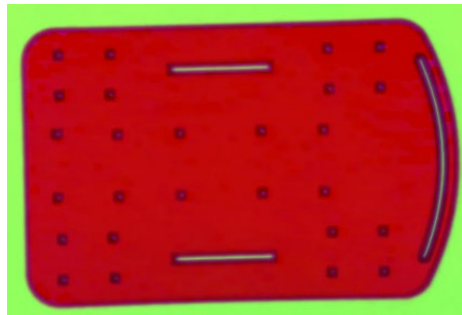


Figure 5. The corroded image.

4.4 Image Background Removal

After a series of processing such as Gaussian filtering, transforming the image into HSV image and image corrosion, the influence of noise has been greatly reduced. The last step of image processing is to remove the background. In this paper, the experiment adopts green background, and set the background pixel value to 255 and the workpiece pixel value to 0 to display the position and geometric features of the workpiece. In the processed image, some pixels within the threshold value are 255, and some pixels outside the threshold value are 0. The image after removing the background is shown in Fig. 6.

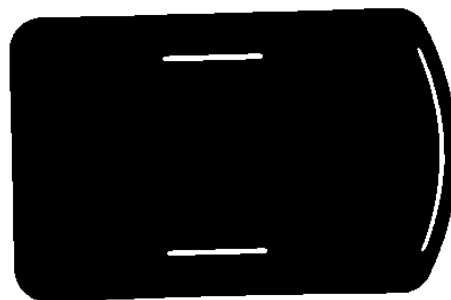


Figure 6. The image after background removal.

4.5 Spray Trajectory Planning

Before trajectory planning, the forward kinematics solution of the robot is calculated according to the DH method of the robot and the transformation matrix of the connecting rod coordinates, and the inverse kinematics solution of the robot is solved by the algebraic solution method. Through image processing, the position and shape of the workpiece are determined. The pixel points of the processed image are scanned line by line, and the pixel points of the image are converted into specific spray point positions. The spraying trajectory is planned to scan the starting point and ending point of each row of pixel points in sequence, and spraying starts from the starting point of each row to the end point. The spraying process is shown in Fig. 7.

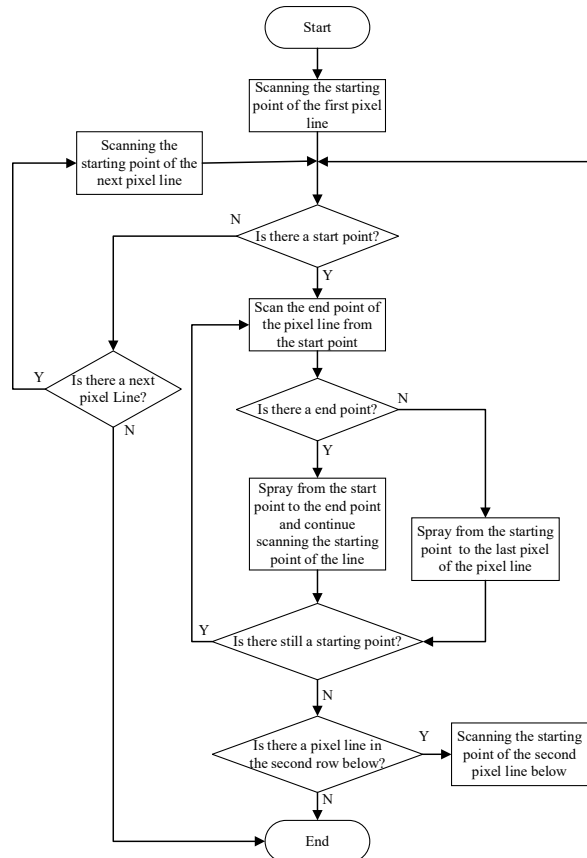
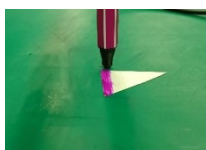


Figure 7. The spraying process.

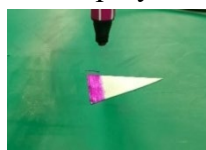
5. Experiments

5.1 Spraying Process

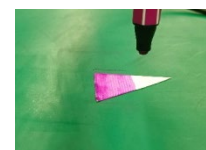
The experiment is carried out on the xArm6 robot platform in the laboratory, and the color pen is used to replace the spray gun during the experiments. Fig. 8 shows the actual spraying process of the robot. The robot sprays the workpiece from top to bottom according to the image pixels. The spraying color is uniform and the speed is stable, which haven't cause the phenomenon of too thick or too thin, and there is no area that cannot be sprayed.



(a) Start spraying



(b) Spray second trajectory



(c) Spraying according to trajectory in turn



(d) Spray last trajectory



(e) Spraying completed

Figure 8. The spraying process.

5.2 Adaptive Workpiece Shape Spraying

Fig. 9 shows the spraying effects for workpieces with different shapes. Different workpieces don't need to be modeled in advance, can plan spraying trajectory adaptively. It greatly saves the time of manual teaching and reduces the error caused by the placement of the workpiece.

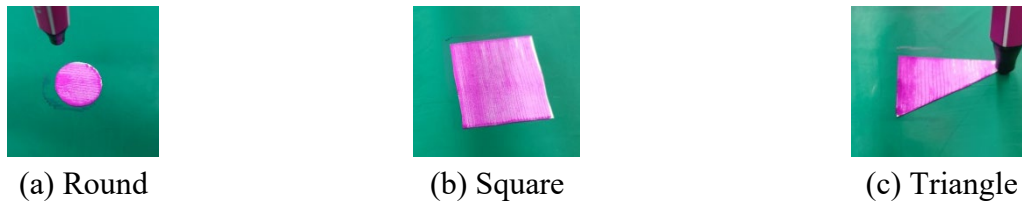


Figure 9. Adaptive workpiece shape spraying.

5.3 Adaptive Workpiece Pose Spraying

Fig. 10 shows the spraying effects for the workpiece with different pose. When the pose of the workpiece is different, the system automatically captures the position and pose of the workpiece. The algorithm will automatically generate spraying trajectories according to the pose, but different spraying trajectories can achieve the predetermined spraying effect, which can achieve the desired spraying effect.



Figure 10. Spraying in different poses.

6. Summary

This paper designs a real-time autonomous spraying robot based on machine vision that combines industrial robots with robot vision. First, image acquisition and format conversion are performed on the workpiece. The second step is to remove noise through Gaussian filtering. The third step is to convert the filtered image in RGB space into an HSV space image. The fourth step is to corrode the HSV space image. Then, the workpiece image information is extracted by removing the background. After the image information is obtained, the pixel points of the image are converted into specific spraying point positions, and the spraying trajectory planning is determined as the starting point and the ending point of scanning each row of pixel points in sequence. Finally, an autonomous spraying experiment was carried out to realize the spraying of workpieces with different shapes and different poses, which verifies the rationality and stability of the proposed algorithm.

Acknowledgments

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