A Tableware Recycling Device Based On RGB-D SLAM Technology

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Abstract. This project involves a robot that can autonomously recycle desktop tableware, especially a robot that uses RGB-D cameras and uses simultaneous positioning and mapping technology (SLAM).

1. Introduction
The catering industry, as one of the four basic living needs of residents "food, clothing, housing, and transportation", has a huge scale. In 2019, China’s catering industry revenue reached 4672.1 billion yuan, accounting for 11.3% of the total retail sales of consumer goods, and it is a veritable national pillar industry.

However, it is increasingly difficult for catering companies to operate. The monthly closure rate of catering outlets in the four major cities of Beijing, Shanghai, Guangzhou and Shenzhen is as high as 10%, and the high elimination rate has become the norm in the catering industry. According to data from the China Culinary Association, in 2016, the profit margin of the top 100 catering companies in the country was only 4.70%. Many catering businesses are facing the dilemma of “three highs and one low” of high rents, high labor costs, high cost of ingredients, and low gross profit. The space is constantly compressed, and the majority of diners are also disturbed by high catering expenses.

In order to alleviate the problem of high labor costs in the catering industry, the concept of "robot restaurant" has begun to be put into practice. Bi Guiyuan has developed and launched a robot restaurant. The restaurant is equipped with 46 robot equipments. The side dishes, cooking and delivery are all done by robots. The robot restaurant saves a lot of manpower and significantly reduces manpower costs. With the continuous improvement of restaurant robot performance and reliability, robots are expected to be widely used in the catering industry.

Now a tableware recycling robot based on RGB-D SLAM (Simultaneous Localization and Mapping, SLAM simultaneous positioning and map construction technology) technology is proposed to complete tableware recycling. RGB-D SLAM refers to a technology that uses an RGB-D camera as a visual sensor for simultaneous positioning and map construction. In the cutlery recycling link, the device should first reach the tray recycling location, and then use the RGB-D camera to obtain the RGB visual information and depth information on the dining table, detect the feature points of the customized tableware through algorithms, and construct a virtual map by the computer. Then, the onboard position sensor and the loop detection algorithm cooperate to obtain the real-time position of the device on the virtual map, and finally the tableware is picked up by the robot for recycling.
2. Research Content and Research Objectives of the Project

2.1. Research Objectives
1) Research and design special tableware, without basically changing the shape and structure of the tableware, so that it has clearer visual characteristics and is easy to be recognized by machine vision.
2) Study how to use the RGB-D SLAM method to obtain the visual information of the special tableware on the dining table through the RGB-D camera, and perform analysis operations to analyze the visual characteristics and location information of the tableware to construct a virtual map.
3) Design a manipulator with a certain degree of adaptability

2.2. Research Content
Need to study the use of RGB-D vision sensor. As an emerging sensor, RGB-D camera can simultaneously obtain the RGB image of the surrounding environment and the depth information of each pixel, and can obtain 3D information of spatial points more directly and conveniently, which is conducive to constructing virtual maps containing three-dimensional spatial information. The application of RGB-D cameras on the dining table should be studied. The appropriate camera should be selected and the installation location should be considered to obtain better visual information of the tableware on the dining table.

Need to study the operation process and transplantation of SLAM method. At present, the feature-based SLAM method is often used, and the feature point method is considered to be the mainstream method of SLAM. The key point refers to the position of the feature point in the image. The descriptor is usually a vector, which describes the information of the pixels around the key point according to people’s needs. Commonly used feature extraction algorithms include SIFTI, SURF and ORB. According to experiments, the most efficient one is the ORB algorithm. If a more efficient solution is adopted, it is necessary to study the principles and usage methods of the ORB algorithm, explore how to use the ORB algorithm to extract the feature points of the tableware under the conditions of the table, and then build a virtual map.

Need to study the characteristic point setting method of typical tableware. After studying the feature-based SLAM method, we can understand how to set feature points to make it easier for the RGB-D camera to recognize and improve the accuracy of recognition. Based on this, a more reasonable feature point design scheme is designed for typical tableware.

It is necessary to study the structure of the gripping manipulator, and design a special manipulator with lower cost and simpler structure, which is specially designed for gripping a limited number of typical tableware. Under the consideration of low cost, the manipulator cannot be designed with precision and complexity, so it is necessary to reduce unnecessary structures as much as possible while
meeting the task requirements. Now set two clamping targets for the robot, one is a round or oval bowl, and the other is a plate-shaped tableware with clamping edges.

It is necessary to study how to combine the manipulator and the RGB-D SLAM method, so that the latter provides the required information for the former and solves the problem of "where am I" and "where am I going". After reaching the predetermined position, the manipulator implements the tableware recycling work.

![An example of RGB-D camera obtaining spatial information.](image)

**Figure 2.** An example of RGB-D camera obtaining spatial information.

### 3. Implementation Plan of Project Research

This project mainly conducts research through theoretical research and experimental simulation.

In the theoretical research stage, the use of RGB-D vision sensors should be studied successively; the operation process and transplantation of the SLAM method; the feature point setting method of typical tableware; the structural design of the clamping manipulator; the manipulator and the RGB-D SLAM method Combined method.

After the theoretical research, it is necessary to make the physical manipulator and purchase the necessary equipment, and then perform simulation verification. The ideal experimental plan is to randomly place two set tableware on the table, and then verify whether it can be recovered by the robot.

#### 3.1. Tableware Design

The RGB-D vision sensor needs to obtain specific point information of the tableware from the table, and then the robot will grip and recycle the tableware. These two processes put forward requirements on the tableware: the tableware should have easy-to-extract feature point information, which can improve the accuracy and efficiency of recognition; the tableware should be more classic and practical, and avoid too many shapes to make the structure of the gripping manipulator complicated.

Under the above requirements, two types of tableware are now designed, which can not only meet the use requirements but also reduce the design difficulty of the manipulator. The first is a round or oval bowl with a round or oval cross section. The design can directly refer to the round bowls used in home-style rice bowls or restaurants. The top of the bowl is circular, with clamping edges and feature point recognition positions designed on both sides. The existence of the clamping edge is used to reduce the difficulty of clamping round tableware. The manipulator only needs to clamp the clamping edge, and then the bowl can be adaptively contacted and fixed through the variable structure of the manipulator to realize stable and safe clamping and recycling.

The second tableware is a plate-shaped dinner plate with clamping edges. The plate is used to hold various tableware, which can not only meet the restaurant’s requirements for diversified tableware, but also significantly reduce the difficulty of project realization, avoiding the high requirements for the functions of the robot due to the variety of tableware. After the meal, all kinds of tableware are placed on the plate, and finally recycled. There are clamping edges on both sides of the dinner plate, and feature point recognition positions are designed on the clamping edges. The manipulator can clamp the clamping edge stably to realize the recovery function.
Figure 3. The designed clampable tableware.

3.2. Clamping Mechanism Design
After using the RGB-D SLAM method to solve the "where am I" and "where am I going" problems of the tableware recycling device, the clamping mechanism needs to perform the tableware recycling work. The gripper requires two types of tableware to be recycled: round or oval bowls, and plate-shaped dinner plates with gripping edges. In order to implement the recycling function for these two tableware, a preliminary design has been made. The gripping hand mainly uses the gripping edge of the gripping palm to grip the tableware to realize the gripping and recovery of the tableware. In order to enhance the adaptability of the manipulator to the round or elliptical bowl, the inner end of the lower gripping palm is designed with a stretchable and deformable elastic clamping strip. When the device is to recycle round tableware, the elastic clamping strip will be deformed into a ring under the action of the thrust rod, and will continue to deform until it is firmly attached to the tableware to play a fixed role.

The gripping hand moves to the designated recovery position before gripping, and then returns according to the path after gripping, and the tableware is sorted and stored in the storage place. The movement path is limited to the track.

Figure 4. Working demonstration of the clamping mechanism.

4. Research Basis and Feasibility Analysis of the Project

4.1. The Innovation of the Project
1) Combine the simultaneous positioning of RGB-D SLAM with map construction technology and the grasping ability of the robot, use the RGB-D camera to obtain the location and morphological
characteristics of the items to be picked up, construct a virtual map, and then use the robot to realize the function of physical recycling.

2) The design of an adaptable manipulator can realize the clamping of typical tableware in various shapes.

3) Simultaneous positioning is combined with map construction technology and location sensors, and at the same time solves the problem of "where am I" and "where am I going".

4.2. Research Foundation

The research foundation of this project lies in the practical application of RGB-D SLAM method. At the same time, the problem of positioning and map construction is described as: a robot moves in an unfamiliar environment, perceives the surrounding environment through its own sensors, and then draws a map of the unfamiliar environment, and at the same time locates its position on the map. The SLAM method can solve the positioning and mapping problems of autonomous mobile robots. The SLAM method that uses a camera as a sensor is called visual SLAM (VSIAM). Compared with traditional Inertial Measurement Unit (IMU) and Laser Scanner (Laser Scanner) sensors, cameras have outstanding advantages such as small size, low quality, and low price. Therefore, VSLAM has become a hot spot for SLAM algorithm research in recent years. Among various cameras, the RGB-D camera is a new visual sensor, which can simultaneously obtain the RGB image of the surrounding environment and the depth information of each pixel. Compared with monocular cameras and binocular stereo cameras that use algorithms to calculate the three-dimensional coordinates of spatial points, RGB-D cameras are more direct and convenient to obtain the 3D information of spatial points. Off-light (TOF) principle is measured, which is somewhat similar to lidar. Therefore, RGB-D cameras are sometimes called Fake Laser. Because the RGB-D camera can obtain the depth data of each pixel on the RGB image relatively easily, and the price of the RGB-D camera is relatively cheap, the RGB-D SLAM technology has developed rapidly in recent years.

4.3. Feasibility Analysis

The project uses robots instead of labor to realize tableware recycling, reduces labor costs, and generates economic benefits for restaurant operators and consumers. The operating cost advantage of robotic restaurants is obvious. It is understood that an average food delivery robot can deliver more than 300 dishes per day, and it can deliver more than 400 dishes during peak passenger flow. The average food delivery robot can replace the work of 1.5-2 full-time food delivery staff with 200 dishes per day. The monthly cost is between 2000 and 3000 yuan. In the future, robot restaurants can manage catering robots in one area by 1-2 staff members through data management, and realize intelligent management and control, which can greatly improve efficiency and further reduce operating costs. The economic benefits are significant, and the project has a good market prospect.

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