Master thesis in Biosystems Engineering

A Low-Cost Eye-Hand Coordination Device for Automated Greenhouse Harvesting and Detection

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MSc Thesis in Biosystems Engineering

A Low-Cost Eye-Hand Coordination Device for Automated Greenhouse Harvesting and Detection

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Abstract

Robotic systems are extensively researched in agriculture. Typically, harvesting in orchards and greenhouses is performed using industrial robotic arms, such as the UR5, equipped with high-accuracy RGB-D cameras. However, these solutions are not cost-effective relative to the tasks they perform. This thesis explores the feasibility of a low-cost alternative utilizing a servo motor arm and an outdated RGB-D camera (Kinect v1). The study demonstrates the potential of achieving the target outcomes with lower accuracy setups by using a learning-based method for object detection and picking. However, in this thesis, a low-cost robotic system is designed using a low-accuracy servo motor robot arm and an RGBD camera (Kinect-V1) for real-time detection and leaf-grasping. The entire setup costs about 300 euros.

Acknowledgements

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Thanks to the developers of the Python libraries used in this project. I am grateful for your open-source libraries, which have significantly accelerated my progress and deepened my understanding of the framework's structure during development.

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Abbreviation

Dof Degrees of Freedom 1

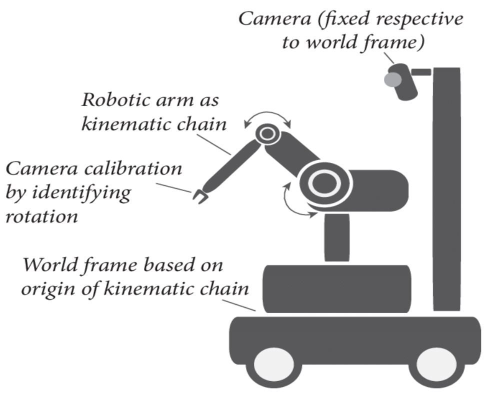
1 Introduction

In Introduction Phase, a brief overview of the current system and its related work is provided. Furthermore, the objectives of this thesis are delineated, and the research problem is explicitly stated.

1.1 Background

In current research, smart greenhouse technology is widely used and extensively studied. Most studies use expensive devices for tasks such as detection, harvesting, and 3D reconstruction. Figure 1.1a shows a mobile picking robot from a Chinese company CloudMinds, which consists of three main parts: a manipulator with a self-designed gripper, a vision system including a depth camera for position detection, and an RGB camera for object detection, and a mobile platform that can provide an additional Degrees of Freedom (Dof), as shown in Figure 1.1b. The camera detects the object and converts the depth image to the target coordinate. After eye-hand calibration, the arm will 'know' the object coordinates in the world frame based on the origin of the kinematics chain. Afterward, the robot arm will navigate to the target point by solving the inverse kinematics problem. The combination of the mobile platform and arm offers the advantage of an additional degree of freedom (Dof), enabling the arm to adjust the base's origin if the current position cannot achieve an optimal solution for the desired position and orientation.

(a) Existing picking robot product



(b) Overview of the eye-hand system

Figure 1.1: Current existing product and its framework

1.2 Objectives

This project aims to design a low-cost picking mobile robot that can detect and pick different kinds of leaves to get information on Chlorophyll. To reach the goal, the following objectives are clarified:

- The robot is affordable enough that we won't need industrial-level cameras and manipulators for this project.
- The robot should be easy to use and implement in a well-defined development environment.
- The robot can detect leaves in real-time and make instance segmentation of the detected leaves.
- The robot's gripper is expected to move to the leaf smoothly.
- There should be an interface for monitoring the area captured by the camera and simplifying communication between the local PC and the robot.

1.3 Challenges

The design and development of low-cost robots pose several potential challenges, particularly concerning the camera and robot arm.

For instance, the robot arm exhibits low rigid stability and vibrates noticeably when touched. It has been tested that the motor gap exists randomly in the range of $-5^\circ \sim 5^\circ$. Another major challenge is that there is no absolute zero position because of the characteristics of the servo motor, making it difficult and even impossible to determine and calibrate the motor's origin accurately.

The camera also has a noise for both RGB camera and depth camera. From the statement of the Kurt Konolige [2012], The formula for calculating depth in the world frame is the authors' best guess at the depth calculation method, based on examining the output of the device and the calibration algorithms they developed. For our project, we are unable to calibrate the depth image because we do not have a high-accuracy calibration tool. Therefore, the distance we obtain from the disparity image is estimated using an experiential formula from individuals who have conducted more accurate calibration.Furthermore, the chosen robot arm for this project lacks one degree of freedom Dof due to its structure, which can sometimes result in an inability to reach the target's orientation.

The second main issue is the alignment between the depth and RGB images. We are using the Kinect v1 camera for this project, an outdated RGBD camera that stopped manufacturing in 2017. Since we are developing the robot using Raspberry Pi, we are unable to use any of the APIs provided by Microsoft. This means that we can only obtain raw data from the current Kinect driver for Linux (libfreenect). Even after camera registration, there will still be a re-projection error.

Due to the challenges mentioned above, two significant issues with noise from the robot arm and camera make conventional calibration methods difficult for camera and eye-hand calibration. Additionally, the distance calculated from depth may not be reliable as it is calculated using estimated parameters rather than calibration.

1.4 Research Problem

The main research problem is addressing the instability and calibration challenges of the robot arm in low-cost robotic systems to enable real-time vision-based leaf picking. This main research question is divided into the following sub-questions.

1. What technology can be implemented for real-time object detection?
2. If conventional eye-hand calibration is ineffective, how can the coordination conversion between the camera and robot arm be resolved?
3. How can the robot arm be made to reach the target as closely as possible if the arm lacks Dof?
4. How can the leaf picking point be mapped from its position in an RGB image to the coordinates of the real-world frame?
5. What motion planning method can be used to make the low-cost robot arm move smoothly along a planned trajectory to pick the leaf?
6. How can the mobile platform, robot arm, and camera communicate in the robot-arm system?

1.5 Scope and Limitations

This thesis does not include research on the mobile platform. Although the communication among the system's parts will be researched, it will be implemented in the future.

2 Theoratical Framework

2.1 Object Detection and Instance Segmentation

2.1.1 YOLO Algorithm

2.1.2 MobileSAM

2.2 Kinematics of Robot Arm

2.3 Motion Planning of Robot Arm

2.4 Camera calibration and Hand-Eye calibration

2.5 IoT Communication

Bibliography

Kurt Konolige, P. M. (2012). Technical description of kinect calibration.