University of California San Diego

CSE 276A: HW2 (Closed Loop Control using Vision)

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1 Introduction

In this course, we are provided with a metal structured four-omnidirectional-wheeled robot powered by Qualcomm RB5 development kit. Furthermore, we are provided with MegaPi, a programmable micro-controller which is capable of functions such as gesture recognition, line following, and obstacle avoidance with the usage of relevant sensors.

In this particular assignment, we are tasked to use the on-board camera as a feedback mechanism to improve the localization of the robot, and thus drive more efficiently to given waypoints. So, in short we will converting the open loop controller from HW1 to a closed loop controller by incorporating visual feedback. We will be using the AprilTags to retrieve the landmarks positions and thus estimate the pose of the robot. The desired car motion is moving through 4 way points. $(0, 0, 0) \rightarrow (1, 0, 0) \rightarrow (1, 2, \pi) \rightarrow (0, 0, 0)$.

2 Camera Calibration

The camera calibration aims to determine the geometric parameters of the image formation process. This is a crucial step in many computer vision applications especially when metric information about the scene is required. In these applications, the camera is generally modeled with a set of intrinsic parameters (focal length, principal point, skew of axis) and its orientation is expressed by extrinsic parameters (rotation and translation). Thus, the extrinsic parameters consist of a rotation, R, and a translation, t. The origin of the camera's coordinate system is at its optical center and its x- and y-axis define the image plane. The camera intrinsic matrix, K, is defined as:

$$\begin{bmatrix} f_x & s & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{2.1}$$

A pinhole camera is a simple camera without a lens and with a single small aperture. Light rays pass through the aperture and project an inverted image on the opposite side of the camera. We used the Pinhole Camera model to calibrate our cameras. A large checkerboard with know dimensions was stuck on cardboard paper, and using the ROS camera calibration tool, the inner vertices were detected in various different poses to compute the intrinsics, extrinsics and distortion coefficents. The computed camera matrix is as follows:

$$\begin{bmatrix} 711.065 & 0 & 966.422 \\ 0 & 711.738 & 561.473 \\ 0 & 0 & 1 \end{bmatrix} \tag{2.2}$$

The distortion coefficents is as follows:

$$\begin{bmatrix} 0.051606 & -0.031041 & 0.004650 & -0.001969 & 0.000 \end{bmatrix} \tag{2.3}$$

3 Closed Loop Controller

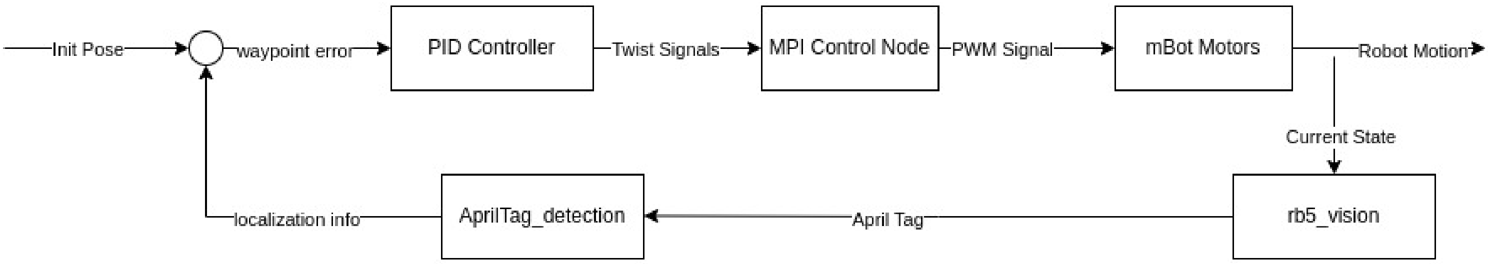

Figure 3.1: Description of Closed Loop Controller

The above diagram explains the architecture utilised for implementing closed loop control to reach the given waypoints. In this particular assignment, we have the complete knowledge about the relative position between the AprilTags and waypoints. Furthermore, we also know the initial robot position at time $t = 0$ and the list of waypoints to be traversed. These poses and position forms the init Pose as shown in the figure. The rb5 vision node is used to launch the main camera of RB5 kit. This node acts a input to the apriltag-detection node.

AprilTag is a visual fiducial system, useful for a wide variety of tasks including augmented reality, robotics, and camera calibration. Targets can be created from an ordinary printer, and the AprilTag detection software computes the precise 3D position, orientation, and identity of the tags relative to the camera. We use the 3D position and orientation obtained from the AprilTag as a feedback to improve the localization of the robot.

Based on the given waypoints, the error in waypoints are calculated, and act as an input to the closed loop PID controller. A PID controller applies a correction based on the proportional, integral and derivative terms. The proportional term produces an output value that is proportional to the current error value, the integral term is proportional to both the magnitude of the error and the duration of the error, derivative of the process error is calculated by determining the rate of change of error wrt time. There are various tuning methods to tune the controller to meet performance requirements such as percentage overshoot, steady state time. Due to time constraints, tuning has not been performed for this particular assignment. The PID controller outputs a twist signal, which consists of the change in x, change in y and change in θ.

The MPI control node (motor driver) converts the twist signal from closed loop PID controller into PWM signals for each of the four motors of the mBOT. This signal results in the motion of the car, which is fed into the localization info to compute the error for the next timestep.

4 Landmarks

Landmarks are the feedback systems which helps in improving the localization of the robot so that it can drive efficiently. The placement of these landmarks is extremely critical so as to ensure constant localization feedback to improve the path planning performance of the robot. The figure below shows the placement of landmarks with respect to the waypoints. The green and grey blocks represent the waypoints and landmarks positions.

These AprilTags were placed in such a way that robot is always able to see the apriltag in its field of view, and thus better performance. Only during few times, the robot is not able to view the apriltags. In such situations, the controller shifts to open loop mode by inputting only rotate signals until it detects a landmarks.

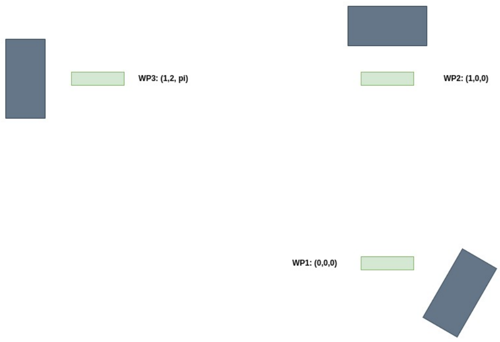

Figure 4.1: Landmarks and Waypoints in World Frame

5 Results

The applied closed loop control performs fairly well in straight line motion. During sliding motion, there is significant vibration due to non-tuned PID parameters. The vibration is also possible due to the type of surface. The hard wooden surface does not provide any cushioning, thus makes it a bumpy ride. Tuning the PID can significantly improve parameters such percent overshoot, steady state error, time required to reach steady state which can significantly improve the overall performance.

Video Link: https://youtu.be/nKT3ybELX-s