International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-4 Issue-2, July 2014

Linear-Quadratic Regulator Control for Human Following Robot in Straight Path

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Abstract—the paper presents the design of controller for wheeled mobile robots (WMRs) which continuously follows humans indoors in straight path only. This task uses computer vision in the controller feedback loop and is referred to as vision-based control or visual servo control. Typically, visual servo techniques can be categorised into image based visual servoing (IBVS) and position-based visual servoing (PBVS). The paper discusses Image based visual servoing approaches for following human in an indoor environment.The Robotics system used here consists of camera for extracting the image features. A suitable control law is developed which can learn the robot behaviour policy and autonomously improve its performance to achieve the smooth and efficient travel path towards the object of interest.

Index Terms— Embedded Computer Vision, Target Tracking, Correlation based Template Matching, Particle filters, Distance Measures, Re-Sampling, ARM, Beagleboard-xM, Linux.

I. Introduction

Visual servoing concerns several field of research including vision systems, robotics and automatic control. Visual servoing can be useful for a wide range of applications and it can be used to control many different dynamic systems (mobile robots, aircraft, etc.). Visual servoing systems are generally classified depending on the number of cameras, position of the camera with respect to the robot, design of the error function to minimize in order to reposition the robot. Vision feedback control loops have been introduced in order to increase the flexibility and the accuracy of robotic systems. The aim of the visual servoing approach is to control a robot using the information provided by a vision system. Control Strategy. The main difference between PID controllers to the full state feedback control is as explained below. PID or Proportional-Integration-Derivative controllers take into account three separate parameters: a proportional, an integral and a derivative values. These values are used to try and eliminate errors in a feedback loop and adjust the process accordingly. Fig 1 shows a generic PID block diagram control loop. A full state feedback control is a control method used to place the closed-loop poles of a plant in user specified locations in the complex s-plane. This is desirable because the stability and characteristics of the system are directly related to the placement of a system's poles in the s-domain.

Manuscript published on 30 July 2014.
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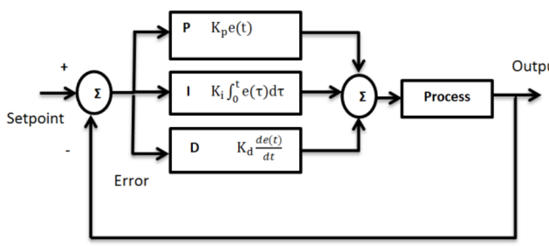

Figure 1. A generic PID controller block diagram

Fig 2 shows a generic full state feedback controller block diagram control loop. The physical model will utilize the camera located on the top of the robot base to continuously capture and process live images of the target object. The current captured images are then compared to pre-recorded images of where the object should be located when the robot is within grasping distance. Using visual error between the current image position and the desired, the Image Based Visual Servoing (IBVS) controller will compute angular wheel velocities. These angular wheel velocities are what are sent down to the PID controller utilized by classical models and the full state feedback controller that was developed for this project. In both cases, the robot will translate and rotate continually till it reaches the desired position and ordination. [6]

II. Controller Design

A. Full State Feedback Control

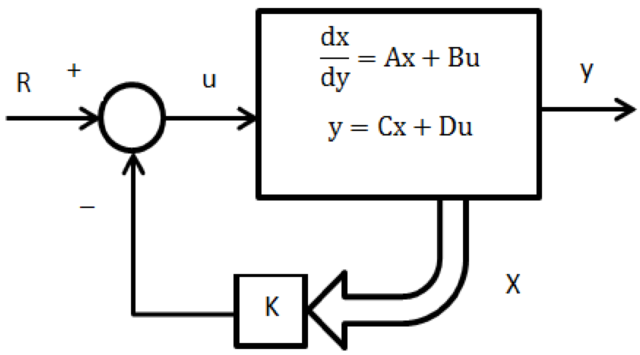

Figure 2. Full State Feedback Control

The Full state Feedback control is shown in Fig 2. Full state feedback is a control method used to place the closed-loop poles of a plant in user specified locations in the complex s-plane. The idea behind this method is that the state variables, which are the major representations of a system, can be manipulated to push the poles of the characteristic equations of the system to specific user defined poles.

The first step developing a full state feedback controller is to set the input vector as

$$\underline{u} = -K\underline{x} \quad (1)$$

Where x is the current state variable and K is a scalar gain constant.

$$\underline{\dot{x}} = (A - BK)\underline{x} \quad (2)$$

A typical method to solve for a K value involves using the characteristic equation for the state space equation, choose pole locations, and solve a polynomial equation with K values based on predetermined pole locations.

$$\det(sI - A) \rightarrow \det[sI - (A - BK)] = \det(sI - A + BK) = 0$$

The issue with the approach mentioned is that it only works for SISO (Single Input Single Output) systems. In the MIMO (Multiple Input Multiple Output) case, the K value becomes non-unique and it is not trivial to calculate since there are more K values then equations. Another method must be used in order to calculate the gain value. The use of a Linear-Quadratic Regulator function is to determine a gain constant for a system. A LQR (Linear-Quadratic Regulator) function uses a mathematical algorithm that calculates a K which minimizes the cost based on the given cost factor and weighting factor. The base formula used is

$$J = \frac{1}{2}x^T(t_1)F(t_1)x(t_1) + \int_{t_0}^{t_1}(x^TQx + u^TRu)dt \quad (3)$$

For this project, the system is a MIMO. Therefore, a LQR calculation was required to compute the value of K. The LQR calculations were computed in MATLAB using the Control Systems Toolbox. [6]

III. MODULES

The following modules were combined together to follow a human being in a straight line.

Camera: Camera to get real time image frames and to keep track of the desired object in the region of interest.

PC: A laptop running Ubuntu Operating System is used as a processing device to integrate both image and range data and to obtain the desired 3D coordinates of the Human with respect to Robot Coordinate frame. The obtained coordinates are further passed on to a lower level PID controller which takes care of robot motion.

ROBOT: A non-holonomic mobile robot frames with two DC motors is used as a Robotic platform.

IV. RESULTS AND ANALYSIS

The system has two inputs i.e the desired feature point location in r and c. Also, the system has two outputs i.e location of actual feature point. The simulation results show the system is stable and converging. An input value of one was utilized though out the simulation. The initial step was to input the state matrices into MATLAB as a state-space model and simulate the uncontrolled response. In Fig 3-4 error pixel and robot velocities are shown for straight path followed by robot. In Fig 5, the robot following human in straight path is shown in frames.

Specifications:

Focal F = $1.8e^{-3}$ m Focal X F_x = 412.688 mm

O_r = 355.329 Focal Y F_y = 466.778 mm

O_c = 466.7853 Wheel radius = 9.75 e^{-2} m

r = 720 Wheel distance = 49 e^{-2} m

c = 576

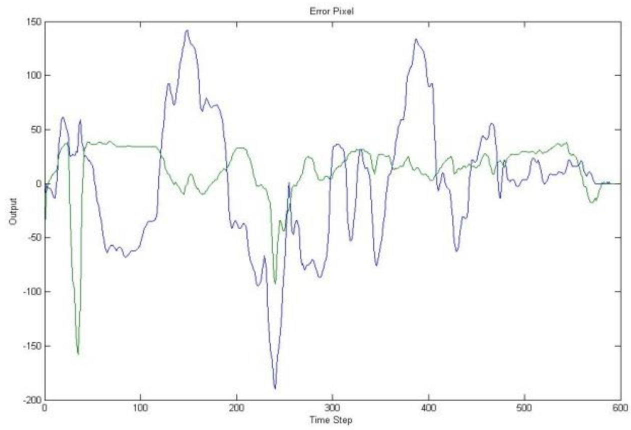

Fig. 3 Error pixel for Straight path

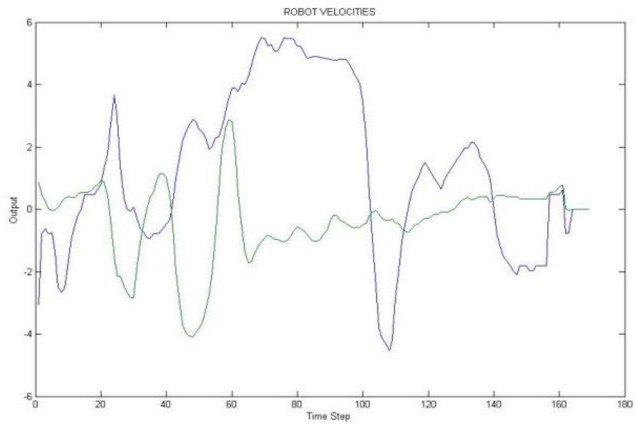

Fig. 4 Robot Velocities for Straight path

V. CONCLUSION

The main focus of this paper was to develop a full state feedback controller for a system. I believe I have achieved creating a full state feedback controller which will stabilize and control the mobile robot system. Throughout the entire process of developing the full state feedback controller, I learned robotic systems, kinematics, Linear Algebra, space transformations, basics of computer vision, some advanced subjects in State Space Modeling, and a brief glimpse of what modern control theory can offer. The information that I obtained from the process of this paper will help strengthen my ability to work on larger projects in the future.

ACKNOWLEDGMENT

The authors express their sincere gratitude to Prof N R Shetty, Director, Nitte Meenakshi Institute of Technology and Dr H C Nagaraj, Principal, Nitte Meenakshi Institute of Technology for providing encouragement, support and the infrastructure to carry out the research.

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Fig. 5 Human following robot in straight path

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