Jaguar Lite Point Tracking

Lauren Lieu
Department of Engineering
Harvey Mudd College
Email: llieu@g.hmc.edu

Joshua Vasquez
Department of Engineering
Harvey Mudd College
Email: jvasquez@g.hmc.edu

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***Abstract*—This paper describes the implementation of point tracking for the *Jaguar Lite Mobile Robot Platform*. Motion control of the autonomous vehicle is achieved using a Proportional-Integral-Derivative controller. In both simulation and hardware mode, the control law parameters and control gains have been tuned to demonstrate stable, precise motion towards desired goal states.**

I. Introduction

Point Tracking refers to a robot's ability to transition from one pose to another on a known map of its environment. By modeling the robot's drive train with a motion model and by incorporating odometric sensor reading into this motion model, the robot can develop a trajectory between points. In the following paper, we incorporate both a differential drive-train motion model with a PID-controlled differential drive train to designate the Jaguar Lite robotic platform to track points on a two-dimensional environment.

A. Hardware Platform

The hardware platform of choice is a Jaguar Lite autonomous vehicle, sourced by Dr. Robot. This differential-drive platform is fairly rugged, and features a suite of sensory inputs: a 9 DOF Inertial measurement unit (IMU), two rotary encoders, a 240° field-of-view laser range finder, and an on-board webcam [2]. With a wireless wifi interface, the designer can implement navigation algorithms in *C#* within Microsoft Visual Studio to communicate with the Jaguar platform. Most importantly, the platform can be driven both indoors and outdoors.

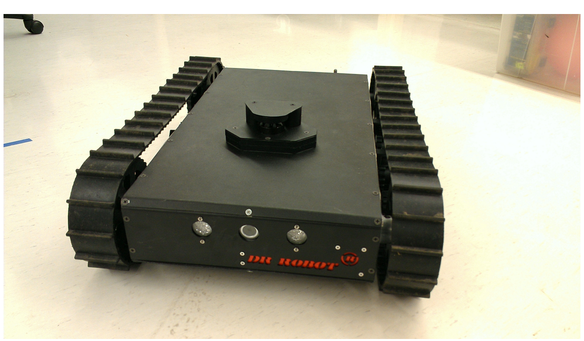

Figure 1. The Jaguar Lite Platform

B. Terminology

This paper refers to specific definitions and usage of the following terms:

- **Pose** represents the robot's position: $[x, y, \theta]$ relative to a coordinate frame fixed to the environment that the robot navigates.
- **Nonholonomic Constraints** refers to a restricted motion path constrained by the physcial construction of the robot. On a two-dimensional coordinate frame, a robot that can freely rotate and translate is considered a holonomic robot.
- **Point Tracking** refers to the Jaguar Lite's ability to drive from one pose to another on a navigable coordinate frame.

II. Method

A. Motion Model

Developing a method of navigating from one waypoint to another ultimately simplifies to determining the appropriate motor speeds of the Jaguar Lite at any given point as the robot pursues a goal pose. To determine the robot's motor outputs, an effective motion model which reflects the robot's holonomic constraints must first be developed. The Jaguar Lite moves with a differential drive train. For this reason, the motion model cannot incorporate direct translation of the robot in a direction normal to the sides of the robot. Figure XXXX illustrates possible trajectories, each of which is governed by the speed of the right wheel, ω_1 and the left wheel, ω_2.

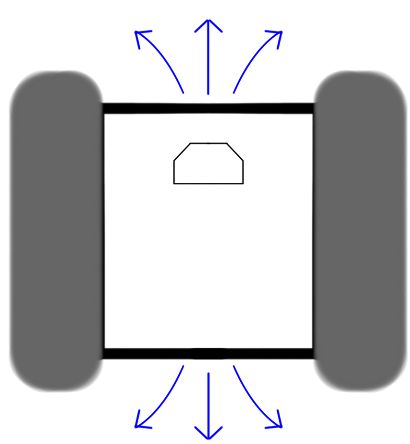

Figure 2. Realizable Trajectories

Given a differential drive train, we can have chosen the following motion model [4]:

$$\rho = \sqrt{\Delta x^2 + \Delta y^2} \tag{1}$$

$$\alpha = -\theta + atan2(\Delta y, \Delta x) \tag{2}$$

$$\beta = -\theta - \alpha \tag{3}$$

In the equations above, x and y define the horizontal and vertical displacements respectively, relative to a fixed initial coordinate frame. θ defines the angular displacement of of the robot normal vector relative to the x axis. ρ defines the magnitude of the displacement from the robot pose to the desired pose. α defines the error of the robot normal vector relative to the desired angle relative to the goal. β defines the angle of the goal vector relative to the horizontal. These angles are depicted in the illustration below:

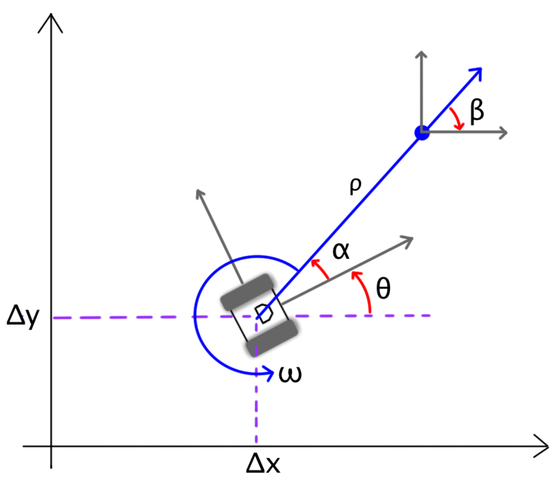

Figure 3. Linear and Angular Errors

The above equations are sufficient to determine the error in the robot's pose from the desired pose, as well as the linear and angular corrections that must be made. Next, by weighing the errors, two more equations can be produced, which define the Jaguar Lite's *linear*, v, and *angular*, ω, velocities as a function of the error values: ρ, α, and β.

$$v = k_\rho \rho \tag{4}$$

$$\omega = k_\alpha \alpha + k_\beta \beta \tag{5}$$

where k_ρ, k_α, and k_β are constants.

Therefore, given that equations [4] and [5] model the Jaguar Lite's desired change in displacement over time, the equations below must ultimately be solely determined from the rotations of the left and right wheels. Equations [6] and [7] fulfill this requirement.

$$\omega(t) = \omega_1 + \omega_2 \tag{6}$$

$$v(t) = L\,(\omega_1 - \omega_2) \tag{7}$$

where L is the radius of the robot. Thus, the overall left and right angular velocities, ω_1 and ω_2, may be determined by combining the previous equations to produce:

$$\omega_1 = \frac{v}{2L} + \frac{\omega}{2} \tag{8}$$

$$\omega_2 = -\frac{v}{2L} + \frac{\omega}{2} \tag{9}$$

B. PID Motor Control

The above equations rely on accurate determination and control of the left and right wheel speeds. To determine the actual wheel speeds the Jaguar Lite receives sensory input from quadrature encoders. Overall, the point tracking trajectory becomes far more accurate in implementation if the left and right motor speeds are controlled with a tight control loop. Thus, the desired left and right motor speeds (derived from ω_1 and ω_2) can be far more closely approximated by the actual Jaguar Hardware. To achieve wheel-speed control, a PID controller was implemented. to stabilize the individual wheel speeds of both motors.

At the low, level the Jaguar Lite's left and right wheel motors can change speed through *pulse-width modulation*, and a specified duty cycle. By tuning P, I, and D values, The PID controller changes the duty cycle, effectively maintaining the wheel speeds at speeds far closer to the desired wheel speeds.

III. Results

Overall, after tuning the three constants K_ρ K_α, and K_β that govern the error influence on the desired correction speed and after tuning the three (P, I, D) constants of the motor velocity controller, the robot does indeed traverse successfully from an initial point to an end point visually within range of the actual desired final point.

The presented model above, however, does not encompass all cases of possible robot locomotion. In particular, the motion model does not account for spinning the robot about its center of mass. This occurence arises when the robot begins at the [x,y] location of its goal pose, but is oriented in a different angle than the desired angle. Given the Jaguar Lite's ability to spin in place, this possibile method of movement is not encompassed by equations [1], [2], and [3]. However, by removing the α term in equation [2], corrected desired velocities can be written as follows:

$$v = 0 \tag{10}$$

$$\omega = K_\beta \beta \tag{11}$$

Thus, redefining v and ω when ρ is sufficiently small, allows the Jaguar Lite to rotate in place.

IV. Conclusion

By combining a motion model with odometric sensor readings, the Jaguar Lite can effectively transition from one pose to another. Furthermore, by simplifing trajectories into a series of desired poses, Point Tracking presents a powerful solution to generating trajectories for the robot to follow. Thus, the initial development of a motion model can effectively lead to the implementation of obstacle avoidance and tracking of waypoints on a known map.

Acknowledgment

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