Jaguar Lite Point Tracking

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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

Autonomous localization is a critical step in algorithm development on robotic platforms. Answering the simple question: "Where am I in a known environment?" is a task that can be answered using external sensors. However, before such a question can be addressed, the designers must first understand the limitations of the robot's odometry sensors which form the basis of estimating the robot's pose in a given environment. In the following paper, we the designers carry out a series of experiments necessary to characterize the accuracy of the incremental encoders on the Jaguar Lite platform, and our findings confirm a linear relationship between odometry-based localization and actual robot position for several types of terrain.

We characterize both the robot's linear displacement and angular displacement relative to it's true displacement measured through the use of external measuring equipment.

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.

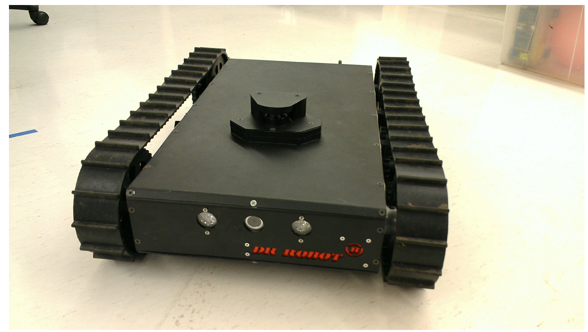

Figure 1.

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.
- **Linear drift** for a given axis is defined to be the difference between the robot's true displacement and the robot's calculated displacement from encoder measurements.
- **Angular drift** is the difference between the robot's true angular offset (relative to a fixed coordinate frame) and its calculated angular offset relative to its starting position.

A measurement is characterized as *true* if it is the measurement calculated in the environment with external measuring tools, such as a meterstick or compass. Another measurement from on-board sensors may be considered true if and only if it corresponds to the localization measurements in the global coordinate frame.

II. Method

A. Motion Model

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

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

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

Assuming the robot is travelling on a circular arc of constant radius, we can apply basic circle geometry to calculate the distance traveled Δs and the change in orientation $\Delta\theta$ of each tread of the Jaguar Lite robot for time step Δt. These changes in displacement are within the local coordinate frame of the robot. To convert the position change of the robot into the global coordinate frame, we assume that the robot's motion is small in a given time step. As a result, the robot's trajectory can be approximated to be a straight path, and using trigonometry we derived the following equations to determine the change in position within a global coordinate frame, where L is the radius of the robot.

B. Experiments Performed

1) Linear Drift: The robot localizes itself from odometry measurements by calculating the linear distance travelled from its last distance. In reality, such a calculation is an approximation, subject to drift. With the given instrumentation, we chose to measure the linear drift along the x-axis, by measuring the robot's true x-displacement and comparing it to the odometry-calculated x-displacement. An illustration of the measurement is shown in figure [xxxxx].

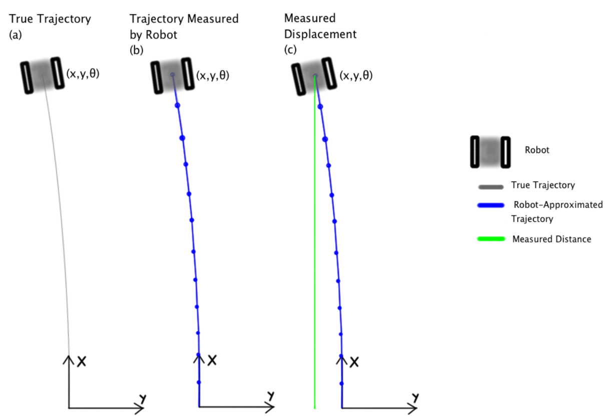

fig 2

To characterize the Jaguar Lite's pose drift, we conducted a series of measurements to compare the robot's odometry-deduced pose with its true pose given by its location in the global coordinate frame. At the high level, the robot, upon reset, places itself in the origin of the map. We define the robot's starting position as the origin of the true map as well, shown in figure [xxxx].

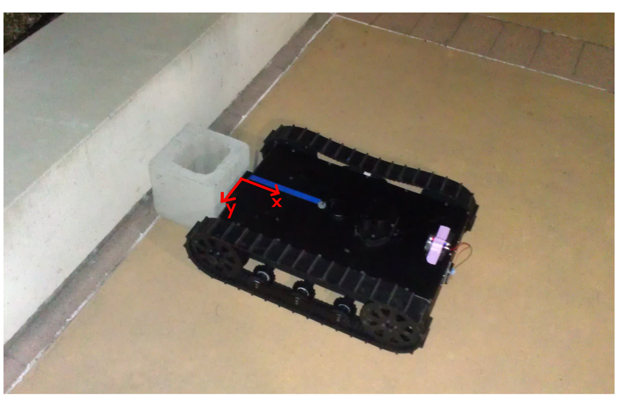

fig 3

2) Angular Drift:

III. Results

A. Linear Drift

From three averaged datasets, we characterized the odometry sensor accuracy on two environments, both grass and concrete. The graphs in figure [xxxx] and [xxxx] display the *True X Displacement* against the *Odometry-Calculated Displacement*. In addition, the ideal Odometry Measurement has also been plotted for reference, where we define ideal measurement to be the case where the true displacement and the perceived displacement match, such that the ideal slope of plotted odometry and external measurements is unity.

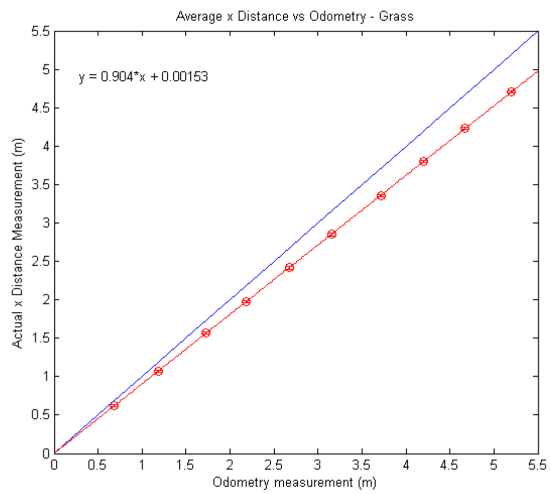

fig 4

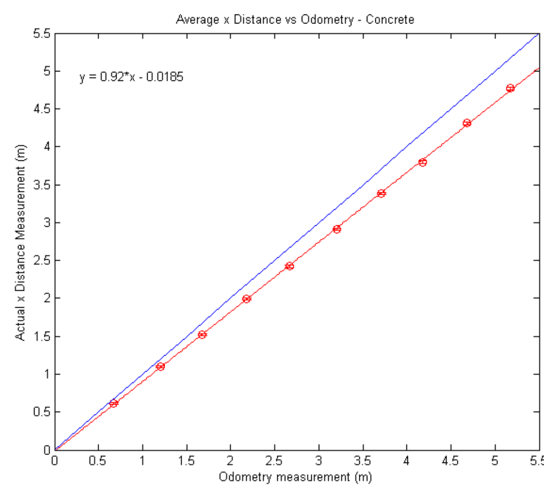

fig 5

The linear fit for the average grass drift was $r^2 = 1.0000$, and the linear fit for the average concrete drift was $r^2 = 0.9998$, indicating that a line is a good fit for both datasets. From both plots on the grass and the concrete forward-driving data, we can see a clear deviation from the ideal odometry value of the encoders. This error is more clearly illustrated in the following graphs, which plot the error as a function of odometry measurement. (Note the units of the y-axis.)

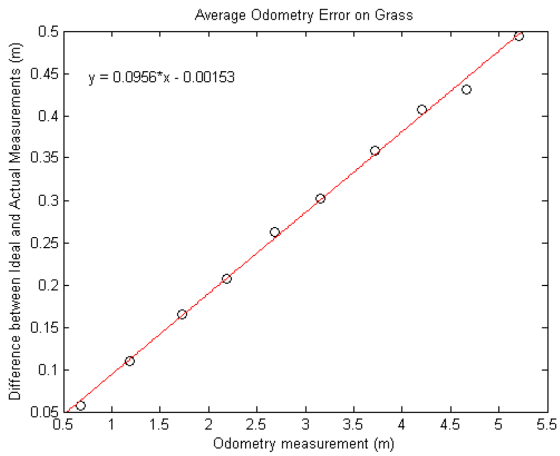

fig 6

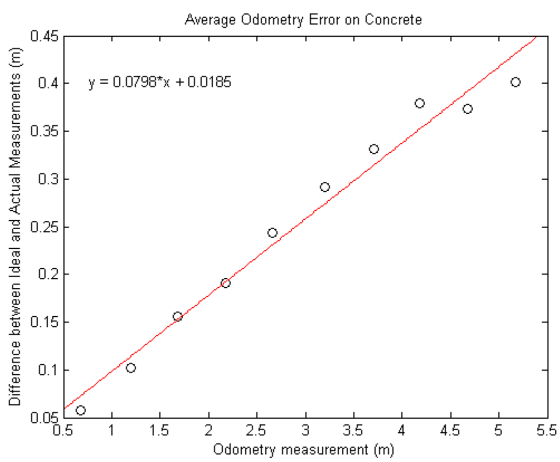

fig 7

Thus, as the overall distance travelled (as recorded by the odometry) increases, the overall error increases in a linear fashion. Furthermore, we can see that slope of the error graph is approximately an order of magnitude smaller than that of the corresponding *Distance vs Odometry* plot.

Additionally, four trials of data were collected on a tile surface wherein the Jaguar Lite travelled either forward or backward along the tile surface. A linear fit of the data produced a fit value of $r^2 = 1.0000$, and the results are depicted in the following graphs.

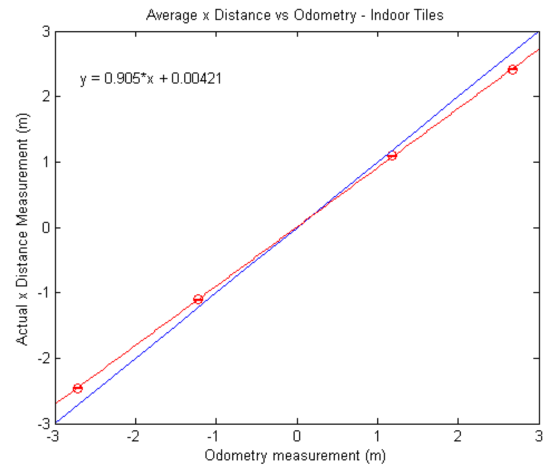

fig 8

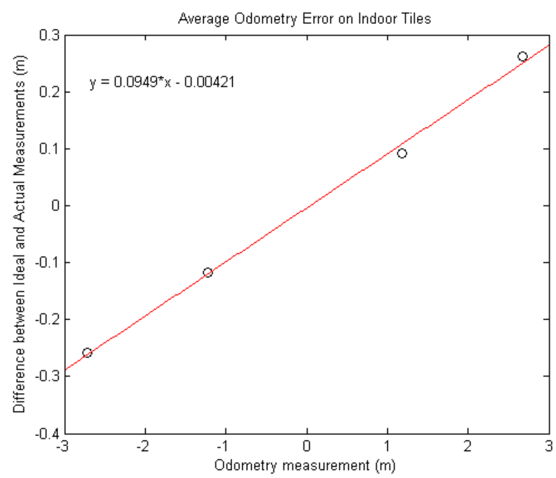

fig 9

Thus, the Jaguar Lite also demonstrates a linear error offset from forward and backward motion on tiled surfaces. An important note about this final dataset, however, is that the Jaguar Lite's forward motion is determined to be characteristically identical to its reverse motion.

B. Angular Drift

To characterize angular drift the robot rotated through several iterations of angles, and both the true angle was recorded (with a compass) as well as the measured angle according to the robot's odometry. The results of the raw data collection are plotted below as true rotations (in radians) versus rotation measurements from the wheel odometry.

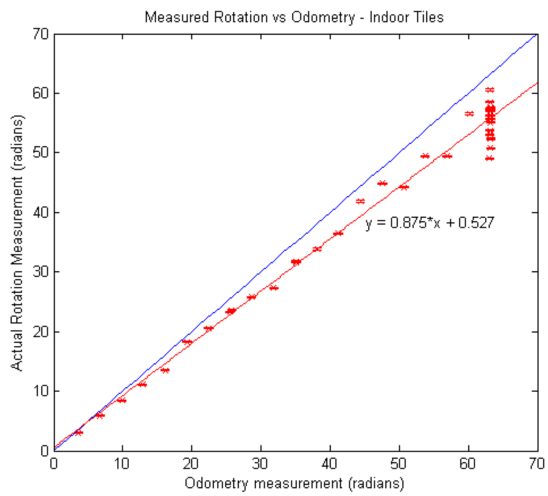

fig 10

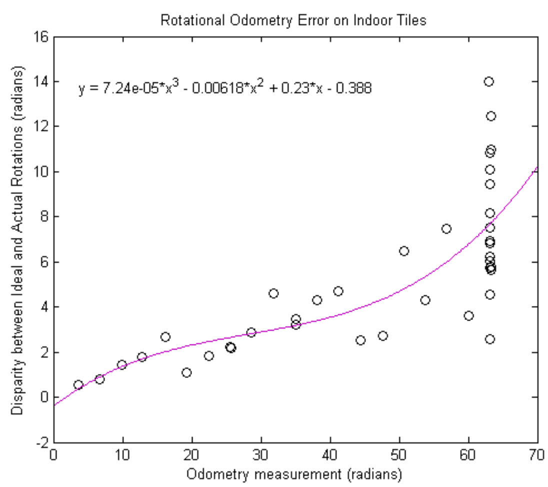

fig 11

IV. Conclusion

The results of this odometry error characterization are promising for future work on the Jaguar Lite robotic platform. With additional analysis (i.e: more data-collection over longer distances), we may be able to throroughly characterize the drift for the robot's pose and calculate an error-correction function which the robot can implement to reduce error from its odometry measurement. From the data collected, we can indeed produce error functions from which the robot can better estimate its true pose; however, more data-collection is necessary to verify the constants associated with the linear fit. Additional testing is necessary, especially for grassy terrain since data-collection was performed on the same patch of grass, potentially changing the characteristics of the grass surface with each measurement.

A. Linear Drift

We successfully characterized the odometry error of the Jaguar Lite for straight trajectors. There is a linear relationship between odometry-based localization and the actual position of the robot in the global coordinate frame. The error in the robot's *[x,y]* pose estimation for three surfaces: tile, grass, and concrete ranges from eight to ten percent.

B. Angular Drift

Overall, we have concluded that for tile surfaces, error does indeed linearly increase as the number of measured rotations increases. We expect that the error can also be fitted with a linear function for other surfaces; however, to generate an actual function, more data collection is necessary.

Furthermore, the order of magnitude over which this linear drift is linear must be explicitly stated to be on the order of rotations. Thus, we cannot generalize that because the error behaves linearly overall for 1,2, or even 10 rotations, so too must the error function be linear on the order of values less than a rotation. While such a conclusion is plausible, more data is needed to verify such a result.

Acknowledgment

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References

[1] `http://newwww.hmc.edu/lair/E190Q/E190Q-Lab01-IntroToTheJaguar.pdf`

[2] `http://jaguar.drrobot.com/specification_lite.asp`

[3] `http://newwww.hmc.edu/lair/E190Q/E190Q-Lecture03-Odometry.pdf`

[4] Thrun, Sebastian, et. all. *Probabilistic Robotics* 2005, The MIT Press.