(ECE183DA/MAE162D)

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Joint Lab Assignment 1
Due 3pm Saturday, Jan. 16, 2021
3pm Friday, Jan. 22, 2021

1 Lab Overview

1.1 Objectives and Goals

In this lab, you will characterize and simulate a simple instrumented 2 wheeled robot.

Both ME and ECE students will generate a mathematical input-output model of its system dynamics. In addition, ECE students will create an interface to a coded simulator, and in following labs compare to a simulator based on CAD, whereas ME students will assemble CAD models.

You will be working in your project teams, and will be responsible as a team for dividing the various tasks of this project between all members. Your grade will be based both on team and individual performance. *Be sure that all team members, both ME and ECE, work on the mathematical formulation as it is an essential skill*

1.2 General Aims

Perhaps similar to your final projects, the focus of the design will be a larger production-grade system (in this case a Segway-like personal scooter), that would be beyond the scope of this class to manufacture. Thus we will develop a parameterized framework to use the exact same engineering process to similarly design a prototype system (the LEMUR paperbot); validating the prototype would provide support for the correctness of the production design.

1.3 Specific Aims

Through this lab,

- Both ME and ECE students are to demonstrate understanding of the mathematical formulation of the system dynamics of a 2 wheeled robot with system noise.
- Both ME and ECE students are to demonstrate understanding of the mathematical formulation of the sensor dynamics of the system with sensor noise.
- ECE students are to understand actuation and sensor noises that are expected in hardware.
- ME students are to review and demonstrate proficiency with the use of modifying and creating assemblies in the CAD software SolidWorks.

1.4 Deliverables/Method of Reporting

For this joint lab, your team is required to submit 2 documents:

- The symbolic mathematical formulation of the given robot by 3pm Saturday, Jan. 16, 2021.
- A write-up describing your mathematical formulation and computational implementation, and simulation results and data by 3pm Friday, Jan. 22, 2021.

ECE students will also create a well documented git repository for your simulator containing all your code and data. Include in your write-up links to your code repository / documentation, as well as a complete list of references you've used and in what manner.

ME students will individually submit PDFs showing completion of their CAD assemblies as detailed in "Lab Assignment 1". This pdf will be due 3pm Friday, Jan. 22, 2021.

For all deliverables, you will be assessed on both the clarity and completeness of your content. Submit pdfs on CCLE.

Submissions that are late will be accepted with a 50% grade penalty.

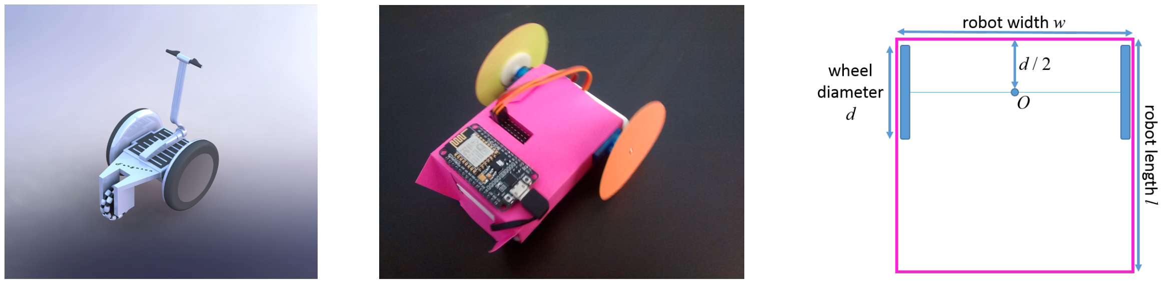

Figure 1: Two wheeled tank-drive robots with symbolic dimensions.

2 Joint Assignment Descriptions

2.1 System overview

Both ME and ECE students will model two-wheeled robots similar to the Segway and Paperbot shown in Fig. 1. These robots have two wheels of diameter $d \approx 502mm/50mm$ (Segway/Paperbot), separated by a distance $w \approx 530mm/90mm$. Each wheel is direct driven from a continuous rotation servo. They drag a tail (or castor wheel in the case of the Segway) for stability, that contact the ground at a distance $l \approx 682mm/75mm$ behind their front edge. The position of each of these robots in the environment is defined relative to their centerpoints O. Keep all dimensions symbolic as defined here for the following sections.

We consider two laser range sensors and an IMU for extrinsic position sensing. The output of these sensors will be a function of the positional state of the robot relative to its environment. More details about Paperbot is available at the git repository: `https://git.uclalemur.com/mehtank/paperbot`

2.2 Actuation model

Each wheel is powered independently by a continuous rotation servo —part number FS90R for the Paperbot, an unspecified industrial continuous rotation servo for the Segway— with the angular velocity of the wheel controlled by a PWM signal from the microcontroller. The control input to the robot hardware will be the PWM values you send to each wheel, for a total of 2 input variables. This allows the robot to drive forwards or backwards at variable speed, or turn with any turning radius.

Do we have any other noises in the robot dynamic system? Explain what they are and how you can add them into the dynamics equations.

2.3 Sensing model

Consider adding two laser range sensors —Lidar lite v3 (Segway) and part number GYVL53L0X (Paperbot)— and an inertial measurement unit (IMU) —part 3DM-GX5-10, LORD MicroStrain (Segway) or part MPU9250 IMU (Paperbot) onto your robot. The output of these sensors will be a function of the state of the robot within its environment.

The laser range sensors are mounted on the robot such that they measure 1) the distance to a wall in a straight line in front of the robot, and 2) the distance to a wall in a straight line to the right of the robot. The IMU will return 1) a measurement of the in-plane rotational speed from a angular rate (gyro) sensor, and 2) the components of the measured magnetic field along each of the 2 in-plane coordinate axes, which can be used as a compass for absolute orientation relative to Earth's magnetic field. We will ignore the out-of-plane gyro and magnetometer axes, as well as the accelerometer on the IMU. Thus this robot will produce 5 output values.

2.4 Mathematical formulation

The state of your robot will satisfy the Markov property, capturing the complete history of actuator inputs (and noise!) to the robot hardware, allowing for computation of the dynamics update as well as all of the sensor measurements. Define this state, and then write out the analytic mathematical models for the system dynamics and measurement processes, starting with an ideal theoretical model based on fundamental principles then including terms for noise where appropriate.

Be sure to clearly define and describe all variables and equations, and produce illustrative diagrams as necessary.

3 Section Specific Tasks

3.1 ECE Students Only

3.1.1 Actuation Non-linearity:

In real hardware, mapping from PWM to rotational speed is not linear. What effects (nonlinearities) could we expect if we were to experiment with actual servo motors? Graph an expected relationship between PWM duty cycle [-1, 1] and rotational speed [-100RPM, 100RPM], then mark and explain effects.

3.1.2 Sensor Noises:

What are the expected sensor noises for the laser range sensors and IMU? Are they additive noises? Is there any bias? Use the data sheets for these specific sensors of *either Segway or Paperbot* to support your answers.

3.1.3 Simulation:

Implement this mathematical model as a computational simulation. The robot will be driving within a rectangular environment consisting of 4 walls bounding an open space. Create appropriate functions or classes for your robot and environment with variables. Your simulation should be capable of individually simulating both the Segway and the Paperbot depending on input. Your simulation should allow for further computational systems to be connected to the input later on, including e.g. open loop programmed inputs from a text file, human driven inputs from a controller, closed-loop feedback inputs from a planner, etc. Be sure to have options to add noises based on your answers above.

We will extend your simulator in the next lab. In the following labs we will compare the results to physical simulation using the CAD design that the ME students will build.

3.2 MAE Students Only

3.2.1 CAD:

ME students will individually be creating a CAD assembly of an equivalent robot based off a Segway with an omni wheel castor. Details are provided in the “Lab Assignment 1” for the MAE Lab.