MTE 351 project: food serving differential drive mobile robot

Spring 2025, University of Waterloo

In this project the groups will design and analyze a food serving robot. Only some aspects of the operation of the robot will be considered in this project. The robot will be used in restaurant environments to transport food and drinks from the kitchen to costumer tables. Recently, multiple robots of this kind became commercially available.

Courtesy of www.bearrobotics.ai

Learning objectives

This component of the course is meant to provide you with practical knowledge of system modelling by applying the fundamental materials taught in lectures for the design and analysis of a real-life problem. You will follow the instructions, described in this document, and will perform some investigations. In the design process you will have the freedom of making design choices. This is an easy and fun project but do not expect that everything you need have been given to you in the lectures or the textbook. This project was streamlined to cover graduate attributes Knowledge Base, Problem Analysis, Investigation and Design to name a few.

High-level robot architecture and the expected model

Some background knowledge to start your project:

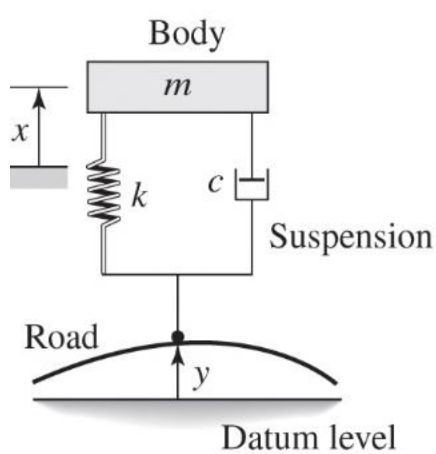
- This is a differential drive mobile robot. The robot will be driven by two independent armature-controlled DC motors. Each motor is connected to one wheel through gears. In addition to the two wheels, the robot can have one or two castors for balance. The casters are not powered.
- You need to consider three subsystems: the robot navigation in the X-Y plane, the DC motors, and the robot suspension system for isolating vibrations induced by moving on a non-uniform floor.
- While the two first subsystems should be modeled coupled together, the suspension system can be modelled coupled or uncoupled with the other two subsystems.

- The project should be done in Simulink and/or Simscape. Simulink and Simscape can be used simultaneously for parts of the projects that are easier or better done in each of these environments. Some parts of the project (e.g., setting parameters, changing parameters in a loop, defining signal functions, etc.) can be programmed in Matlab.
- The robot should be designed in a way that it can transport the food as fast as it can without spilling the food and drinks.
- It should be able to navigate accurately and reach the intended destinated with the correct pose (the direction of the robot when it stops to serve is important as well).

Fundamentals of modelling the differential robot

Navigation and DC motor subsystems: The planar kinematic and kinetic of the coupled robot navigation and DC motor subsystems are well described in [1]. For a more thorough treatment of the kinematics of different types of mobile robots, please see [2]. If you want to consider components and concepts neglected in [1], you can obtain the governing equations as you learned in the course. Alternatively, instead of obtaining and the governing equations in block diagram form in Simulink, you can directly model the subsystems in Simscape by connecting physical elements in your model. Models of DC motors can be started be built from the block diagrams and resources in the textbook, the Simscape training in Learn and Simulink/Simscape models from [3]. For additional reading refer to [4].

Suspension system: Assume suspension subsystems on the wheels only to simplify the model and analysis. There are many sections in the textbook that you can use starting from Section 4.8. Lump the mass of the robot and the food load and consider just one spring and one dashpot on each wheel (below figure). In the simplest form assume the spring and damper are linear. You can ideas from use the related Simscape training that was shared with you in Learn and the Simulink/Simscape models from [3].



Half robot suspension subsystem

Starting assumptions

Start building the model with the following assumptions and refine, improve and make the design more specific by revising these assumptions as you progress:

1. Assume the robot is a cylinder with the height of one meter and diameter of 50 cm.
2. Assume the wheel diameter of 10 cm.
3. Assume the load capacity of 10 kg and the robot weight of 20 kg.
4. Assume uniform mass distribution inside this cylinder.

5. Assume no slippage at the wheel-floor interface.
6. Assume permanent magnet in the DC motor.
7. In your report, list any other initial assumptions that you make to start the simulation/design process.

Final report and deliverables submissions
The final report should not be longer than 10 pages. Extra materials can be put in appendices (no page limit). All graph and table deliverable should be included in the report. The instructor team may not be able to run your submitted programs and models due to path mismatch or other reasons. Include all essential components in your report. Submit all deliverables to the Crowdmark.

Project tasks and deliverables

Task 1- Create the planar kinematic and kinetic model of the navigation and DC motor subsystems as described above. These subsystems should be coupled. Control the input voltage to the DC motor using a signal generator block.

Task 2- Create the suspension subsystem. This subsystem can be uncoupled from the two other subsystems or it can be coupled to them via the planar position variable.

Hint: Instead of using fixed numbers for model parameters, use variables. This will give you the flexibility of easily changing the model parameters in a Matlab script, instead of manually changing every parameter each time.

Deliverables of Tasks 1 and 2: In your report, document your initial assumptions for making the model, include the method with which you created the model (schematic diagrams for Simscape or governing equations and block diagrams for Simulink). Submit the models and their related components.

Task 3- Create the floor signal. The robot will work on a tiled floor. The tiles are 1 ft by 1 ft and there is 1 cm grouting between the tiles that is 0.5 cm deep with a haversine profile. Create a signal representing this vertical input to the wheels. Consider 5 m planar moving in this scenario.

Task 4- Create door threshold signal. The robot should pass a door threshold with the length of 5 cm and height of 3 cm. Assume a haversine cross section (Section 4.8.4) for the door threshold and make one signal corresponding to it. Consider 5 m planar moving in this scenario.

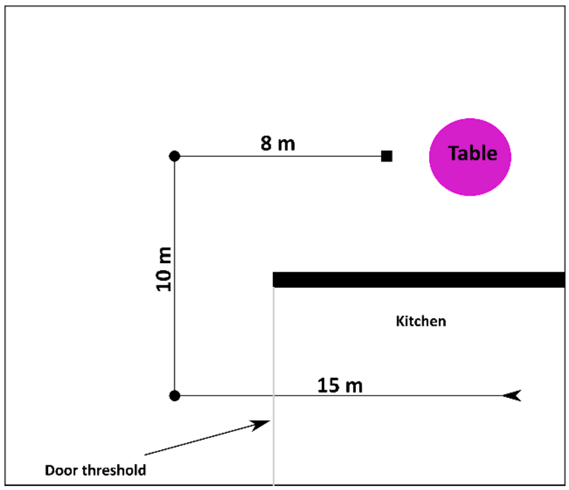
Task 5- Analysis and design of suspension subsystem. Assume motion in the slew phase (steady-state constant planar robot velocity). Iterate on the stiffness and damping parameters of the model and find parameters that isolate wheel motions for an assumed planar velocity (start from the planar velocity of 3 m/s). Fine tune the suspension parameters and planar velocity of the robot to ensure no drink spills (less than 0.5 cm). Consider fully loaded and minimally loaded robot in your analysis. Consider the input signal of the floor. Can the robot handle the floor? Should the specification of the robot include information about the maximum height allowed for door thresholds? Should it specify the required smoothness of the threshold profile.

Task 6- Simulation of vibration isolation of the final suspension design. When the iterations are finalized, run a final simulation and report the vertical force and vertical acceleration versus time for the floor signals.

Deliverables of Tasks 3 to 6: Include at least the following items in your report:

- The floor input signals (Tasks 3 & 4).
- Report of design iteration and parameter selection of Task 5 with related graphs.
- The vertical force and vertical acceleration versus time for the three floor signals (Task 6).

Task 7- Create the planar path. The robot will travel from the kitchen to the costumer table as shown in the below figure. The robot must follow this path. To simplify navigation planning, allow the robot either travel in straight line or spin at any specific time. The spinning should happen at the two points indicated by the two circles in this figure. This figure was not plotted to scale.



Robot intended path food transport path

Task 8- Create input voltage signals. Make the input voltage signals to the two motors to follow planned path. To avoid food spilling, try to follow a trapezoidal velocity profile (acceleration, slew and deceleration phases, see Section 1.5 of the textbook). You may start with trapezoidal segments in the voltage signal.

Task 9- Analysis and design of robot navigating on the planned path. Find the durations of acceleration and deceleration and slew phases of each segment as well as the voltage/velocity of the slew phase to enable the robot to follow the planned path. For the slew velocity, use the velocity you concluded in Task 5 or revise that task to have consistent velocities. Select gear ratio. For motor parameters, select and use a commercial DC motor from [5] or any other sources. Calculate the average rms torque and make sure to select a motor that can provide such duty cycle torque (change motor and/or gear ratio). Alternatively, you can use hypothetical motor parameters.

Task 10- Simulation of the final navigation design. Upon finalizing the model parameters perform a final simulation and plot instantaneous acceleration and jerk of the robot. Plot the actual path that the robot travels with the designed input voltages.

Deliverables of Tasks 7 to 10: Include at least the following items in your report:

- The selected motor and its parameters and datasheet or alternatively selected parameters of the motor.
- The designed geometrical parameters of the robot (e.g., assumed wheel base, distance of the projected centre of mass)
- Gear Ratio
- The input voltage signals and justifications/ design iterations.

- Plots of instantaneous acceleration and jerk of the robot.
- Plot of the actual path that the robot travels.

Include a Conclusion section at the end. In this section, summarize what were done and learned in the project. Also discuss observations about parameters, analyses and components of the models that can be safely ignored or should be added for continuing the design of this robot.

Note: Navigation and suspension systems can be designed and analyzed separate from each other, but they also can be coupled if a tile layout for the floor is assumed. The elegant coupling is not expected.

References

[1] Dhaouadi, R., & Hatab, A. A. (2013). Dynamic modelling of differential-drive mobile robots using lagrange and newton-euler methodologies: A unified framework. *Advances in robotics & automation*, *2*(2), 1-7.

[2] Berry, Carlotta A. *Mobile robotics for multidisciplinary study*. No. 4. Morgan & Claypool Publishers, 2012.

[3] " Control Tutorials for Matlab and Simulink", https://ctms.engin.umich.edu/CTMS/index.php?aux=Home

[4] R. Siegwart, I. R. Nourbakhsh, and D. Scaramuzza, *Introduction to autonomous mobile robots*. MIT press, 2011.

[5] Moog, "Permanent Magnet DC Motors" [Online]. Available: https://www.moog.com/content/dam/moog/literature/MCG/moc23series.pdf