ECE 486 / 687 Robot Dynamics & Control

Gennaro Notomista

PROJECT DESCRIPTION

Due date: Aug 6, 2026
Proposal due date: June 7, 2026 (extended)

Contents

1 ECE 486 **2**
1.1 Approximate linearization control design . . . 2
1.2 Performance evaluation . . . 3

2 ECE 687 **5**
2.1 Approximate linearization control design . . . 5
2.2 Performance evaluation . . . 6
2.3 Alternative for MASc and PhD students . . . 6

3 Code **8**
3.1 ROS2 packages . . . 8
3.2 Simulator . . . 8

4 Robohub schedule **9**

1 ECE 486

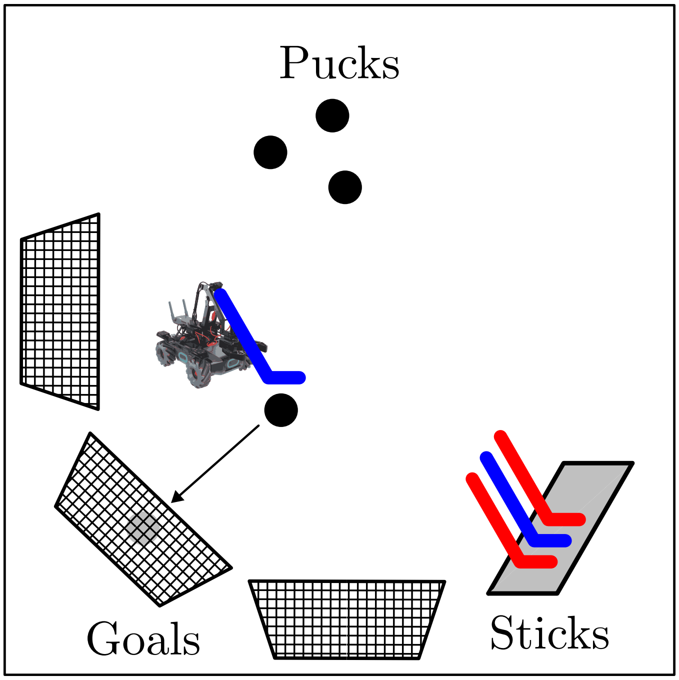


Figure 1: A RoboMaster EP mobile manipulator with the basic elements of a hockey game: the robot has to pick up a stick and use it to shoot a puck into a goal.

Objective

The objective of this project is to control a mobile manipulator to pick up a hockey stick and use it to shoot a puck into a goal. The robot, modeled as a unicycle, has to be controlled using the approximate linearization method learned in class.

The approach will consist of the following tasks (see Fig. 1):
(T1) Navigating to a known stick pick-up location
(T2) Picking up a stick
(T3) Navigating to a known puck location
(T4) Shooting a puck into a goal at a known location

1.1 Approximate linearization control design

The robot is modeled as a unicycle, i.e. its kinematic model is

$$\begin{cases} \dot{x} = v\cos\theta \\ \dot{y} = v\sin\theta \\ \dot{\theta} = \omega, \end{cases} \tag{1}$$

where x and y are the components of the position of the robot in the plane, θ is its heading, and v and ω are the longitudinal and angular velocity inputs, respectively. See also reference frames in Fig. 4b.

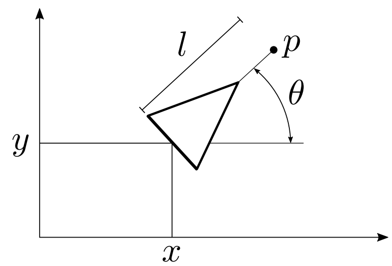


Figure 2: Geometric quantities of the unicycle robot required to derive the approximate linearization method.

Recall that the motion of the point p in Fig. 2 is described by the following differential equations:

$$\dot{p} = \underbrace{\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}}_{R(\theta)} \underbrace{\begin{bmatrix} 1 & 0 \\ 0 & l \end{bmatrix}}_{L(l)} \begin{bmatrix} v \\ \omega \end{bmatrix}, \tag{2}$$

so that, once a controller for $\dot{p}$ is designed, the inputs v and ω to the unicycle can be easily computed as follows:

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = L^{-1}(l) R^T(\theta) \dot{p}. \tag{3}$$

It is convenient to define the point p in front of the unicycle to coincide with the tip of the stick.

1.2 Performance evaluation

A successful implementation of the tasks described in the previous section consists in the robot being able to:

- Navigate to known locations with desired orientations
- Pick up a stick
- Hit a puck with the grasped stick
- Shoot a puck into a goal

The tasks defined above have to be described and demonstrated via:

- A report containing
  - The detailed description of the approach adopted to solve the project tasks
  - Any plots required to back up your claims
  - Explanation and reference to the parts of the code that solve each part of the tasks
- The code written to solve the project tasks

Recall that the deliverables related to the project are as follows (including percentage of the overall course grade):

- Final project report: 20%
- Project code: 5%

The format and the structure of the report must be as follows:

- Maximum length: 4 pages

- Format: PDF
- Template: IEEE conference template (`https://www.ieee.org/conferences/publishing/templates.html`)
- Structure
  - Section I: Proposed approach
  - Section II: Results
  - Section III: Discussion

The reports must include also the detailed description of the work carried out by each member of the group, including what sections of the report were written by whom.
A short video (maximum 1 minute) to supplement the results may also be attached.

2 ECE 687

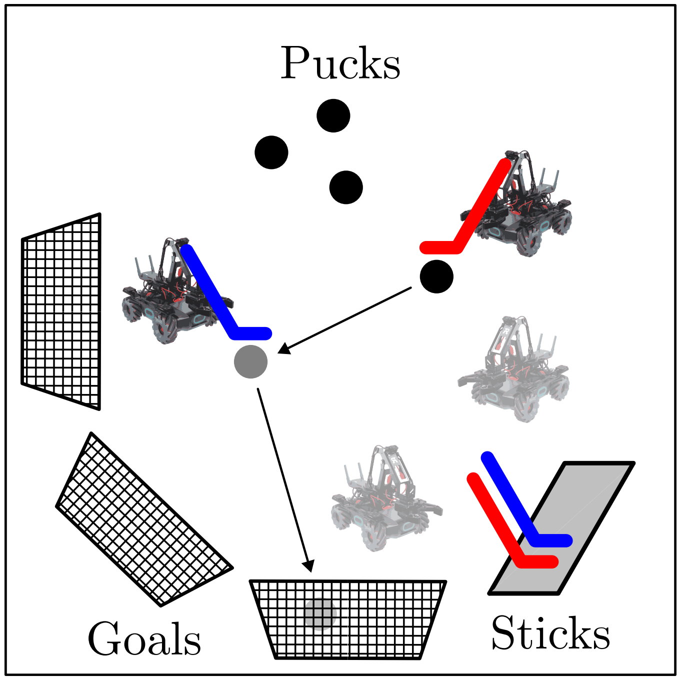


Figure 3: Two RoboMaster EP mobile manipulators with the basic elements of a hockey game: each robot has to pick up a stick, after which one robot has to pass the puck to the other robot, which in turn has to shoot the puck into the goal; all this while avoiding other robots on the field (shaded robots in the figure).

Objective

The objective of this project is to control two mobile manipulators, in cooperation with another group, to pass and shoot a puck into a goal. The robots, modeled as unicycles, have to be controlled using the approximate linearization method learned in class, while safe navigation has to be achieved using CLF-CBF-QP-based controllers.

The approach will consist of the following tasks (see Fig. 3):

(T1) Navigating to a known stick pick-up location
(T2) Picking up a stick
(T3) Navigating to a known puck location
(T4) Passing a puck to another robot at a known location / Shooting a puck into a goal at a known location
(T5) Avoiding obstacles placed in the environment at known locations

2.1 Approximate linearization control design

See Sec. 1.1 for robot modeling and notes available online here `https://www.gnotomista.com/files/teaching/optimization_based_robot_control_course_notes.pdf` for optimization-based control design.

2.2 Performance evaluation

The tasks defined above have to be described and demonstrated via:

- A report containing
  - The detailed description of the approach adopted to solve the project tasks
  - Any plots required to back up your claims
  - Explanation and reference to the parts of the code that solve each part of the tasks
- The code written to solve the project tasks

Recall that the deliverables related to the project are as follows (including percentage of the overall course grade):

- Final project report: 40%
- Project code: 10%

The format and the structure of the report must be as follows:

- Maximum length: 4 pages
- Format: PDF
- Template: IEEE conference template (`https://www.ieee.org/conferences/publishing/templates.html`)
- Structure
  - Section I: Proposed approach
  - Section II: Results
  - Section III: Discussion

The reports must include also the detailed description of the work carried out by each member of the group, including what sections of the report were written by whom.
A short video (maximum 1 minute) to supplement the results may also be attached.

2.3 Alternative for MASc and PhD students

The project will consist of the solution to a problem in the student's research area using the techniques covered during the course.
In addition to the final deliverables, a proposal should be submitted following the instructions below:

- Maximum length: 1 page
- Format: PDF
- Template: IEEE conference template (`https://www.ieee.org/conferences/publishing/templates.html`)
- Structure
  - Section I: Problem description
  - Section II: Novelty and/or impact
  - Section III: How robot dynamics and control techniques play a key role
  - Section IV: Technical challenges
  - Section V: Metric for success
  - Section VI: Timeline
- Deadline: **June 7 (extended)**

The format and the structure of the final report must be as follows:

- Maximum length: 4 pages
- Format: PDF
- Template: IEEE conference template (`https://www.ieee.org/conferences/publishing/templates.html`)
- Structure
  - Section I: Introduction
  - Section II: Literature review
  - Section III: Materials and methods
  - Section IV: Results
  - Section V: Discussion

A short video (maximum 1 minute) to supplement the results may also be attached.

3 Code

The controller for the RoboMaster EP robots must be developed on your PC using Python and ROS2. Instructions to build a development environment are provided on LEARN, under Content/Project, for Linux, Windows, and Mac operating systems.

3.1 ROS2 packages

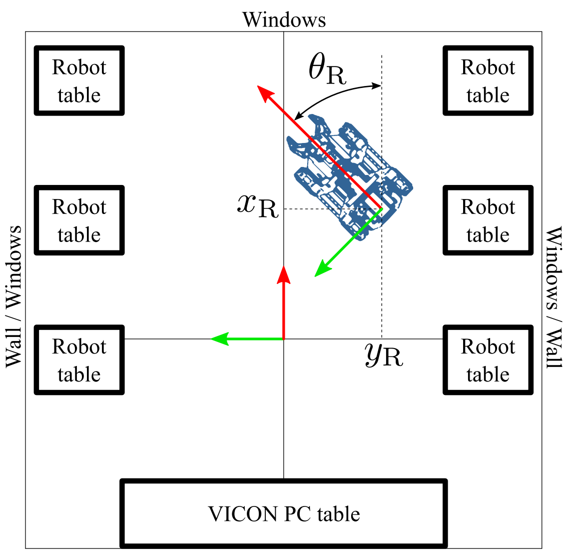
The robots are controlled using this ROS2 package: `https://github.com/erablab/robomaster_ros`. A detailed description of the ROS2 package used to control the robots is available here: `https://jeguzzi.github.io/robomaster_ros/introduction.html`. Poses of all objects (robots, sticks, pucks, goals) will be published on ROS2 topics using this package: `https://index.ros.org/p/vrpn_mocap/`.

3.2 Simulator

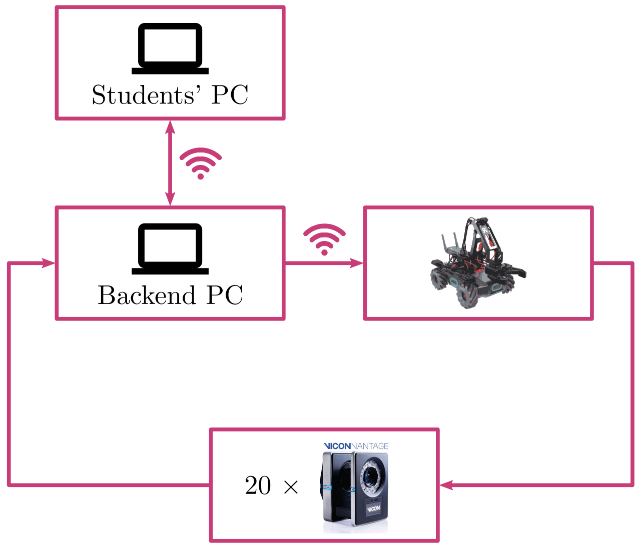
You are encouraged to develop and develop your motion control strategy in simulation. A ROS2 package that simulates the motion of multiple robots is available here: `https://github.com/erablab/multi_robomaster_ros_sim`.

4 Robohub schedule

(a) A humanoid, a mobile manipulator, and the ceiling camera system in the Robohub.



(b) Global reference frame in the Robohub (red and green arrows are x and y directions) and local reference frame of the robot (red and green arrows centered at the robot).



(c) Block diagram of the closed-loop control of the mobile manipulators in the Robohub.

Figure 4: The Robohub at University of Waterloo.

The Waterloo Robohub (Fig. 4a) is a collaborative robotics research facility located on the ground floor of PSE. It hosts a diverse fleet of robots (humanoids, quadrupeds, manipulators, ground, and aerial mobile platforms) and it is equipped with an indoor positioning system comprised of a set of 20 Vicon Vantage V5 cameras. The RoboMaster EP robots are controlled according to the feedback control loop shown in Fig. 4c.

The schedule to perform project-related activities in the Robohub is reported in the table below (as well as in the course syllabus). You may come in at any time during the time slots listed in the second column. Activities in the last column are just a suggestion, you are completely free to complete the project tasks in any order you would like.

Date	Time	Suggested activity
Jun 15	10–12, 13–15	Getting started with controlling the RoboMaster EP
Jun 22	10–12, 13–15	Getting started with controlling the RoboMaster EP
Jun 29	10–12, 13–15	Picking up a stick and hitting a puck
Jul 6	10–12, 13–15	Picking up a stick and hitting a puck
Jul 13	10–12, 13–15	(Safe) Navigation to desired poses
Jul 20	10–12, 13–15	(Safe) Navigation to desired poses
Jul 27	10–12, 13–15	Putting it all together
Aug 5	10:30–16:30	Putting it all together