EEET2610 – Engineering Design 3

Design of a Mecanum Robot with Autonomous Behavior

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Abstract

This document presents the description of the course EEET2610: Engineering design 3. The course is project-based: the students are invited to form a group of 5-6 members from different programs and to complete a design project. At the end of the semester, they should successfully build and control a Mecanum wheel robot with four motors and encoders, with autonomous behavior. This project will greatly contribute to your engineering portfolio, as it combines elements of mechanical design, electrical design, app design, and project management.

The project is divided into smaller projects called work packages (WP). Work packages are further divided into milestones and deliverables. Deliverables are tangible achievements that complete a work package and that are presented to stakeholders. Milestones are more conceptual and correspond to smaller and achievable tasks to complete a deliverable. This document presents the work packages and the minimum deliverables to be achieved. The intermediate tasks, milestones, and project planning must be performed by the student group.

Please read this document carefully for the following points:

- *Most of the information to finish the project successfully is in this document.*
- *Report submission should follow this template report. If your document does not look like this project description document, please use the correct provided template.*
- *If the information diverges between this project presentation document and Canvas, then the information on Canvas has higher priority.*

Introduction

A Mecanum wheel robot, as shown in Figure 1, is a type of mobile robot consisting of four special wheels based on rollers. It is designed for maneuverability, making it ideal for tasks like packaging in warehouses. A Mecanum wheel robot, also named Swedish wheel, is gaining popularity for omnidirectional wheelchair, truck lift, and Automated Guided Vehicles (AGVs) [1].

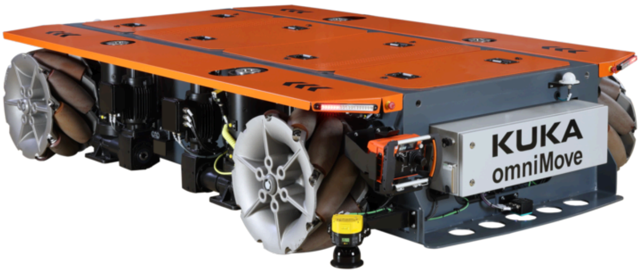

Figure 1: OmniMove from Kuka: https://www.kuka.com/

Please note the following point:

- Figures are centered, high quality, readable, with a precise description. All figures must be referenced in the text.
- References are from journal articles. Web articles should not be more than 20% of your literature review.

The aim of ED3 is to design and control an autonomous Mecanum wheel robot. Since the semester consists of twelve weeks only, the course is guided, so that the students can achieve the project in the allocated time.

The project is based on the following work packages:

- *WP1: Simulation with MATLAB*
- *WP2: Physical prototyping: CAD and PCB design*
- *WP3: Embedded system testing: ESP32 and DC motors*
- *WP4: Autonomous implementation with ROS2*
- *WP5: Integration and pitch presentation*

Project Proposal

The project proposal corresponds to the prior literature required to understand the context and the background of the mechanism. The project proposal consists in the following sections:

- Abstract
- Introduction
- Tasks description
- Time management with a Gantt chart
- Resources management with a bill of material (BOM)
- Presentation of potential stakeholders
- Risk analysis with a table of risk and probability
- Team introduction and team contract
- Conclusion
- References
- Appendix (if any)

Please refer to Canvas for more details about this assignment.

The main deliverable is:

- *Project proposal document, in pdf format, including the aforementioned sections.*
  Suggested time: 4 weeks

Suggested milestones are introduction, literature review, contract redaction, etc.

1. WP1: Simulation with MATLAB

This work package focuses on the use of MATLAB to simulate the motion of the Mecanum robot and implement its autonomous behavior. The deliverables for this work package are:

- *D2.1: Kinematics of the robot. Suggested time: 1 week.*
- *D2.2: Trajectory visualization. Suggested time: 3 weeks.*

1.1. D1.1 Kinematics of the Mecanum robot

The Mecanum robot is based on a DC motor with encoder: the main positioning system is called odometry. The size of the wheel and the footprint of the robot influence the movement speed of the robot: this problem is known as kinematics and should be solved for this project.

The aim is to derive the kinematics of the Mecanum robot. This information can be found online, but the student must make sure that linear algebra and its implementation in MATLAB is well-understood.

1.2. D1.2 Trajectory planning

The aim of this deliverable is to simulate the movement of the Mecanum robot with different parameters (wheel size, frame size) for different trajectories, for example:

- A square of 1mx1m with constant orientation
- A circle of 1m diameter with constant orientation
- A circle of 1m diameter with orientation pointing toward the centre of the circle.

More trajectories should be proposed by the students to showcase their skills and achieve better course performance.

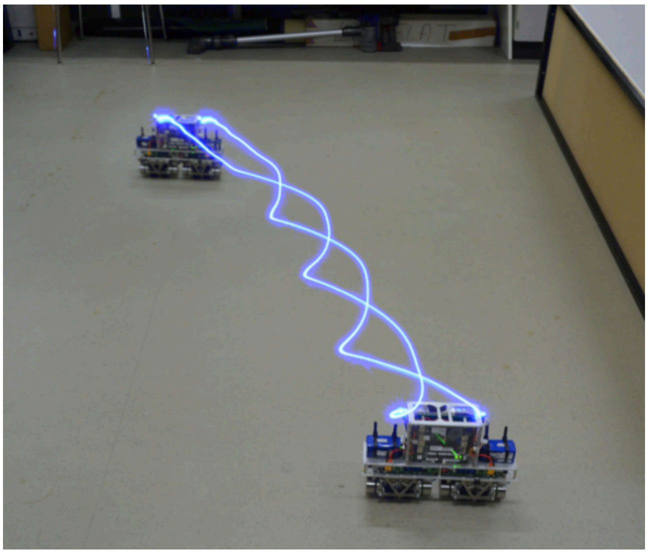

Figure 2: Example of trajectory with a colinear Mecanum wheel [2]

2. WP2: Prototyping of the Mecanum Robot

This work package focuses on the design and control of the mechanism. The deliverables are

- *D3.1: CAD modeling of the system. Suggested time: 4 weeks*
- *D3.2: PCB design and electrical wiring. Suggested time: 4 weeks*

2.1. D2.1 CAD Design

Software such as Fusion 360 or SolidWorks can be used to model the system. The aim is to understand the size of the system, its assembly, and the bill of material including all the fasteners required to build the system. This deliverable should include:

- The CAD model of the system (cf. Figure 3)
- A bill of material
- Technical drawing is not required, but highly appreciated. The key dimension of the system is mandatory.

3D printers can be used to build the prototype of the system. However, since the access to the printer is limited, each group can print their model a limited number of times (max twice). It is thus advised to learn from the mistakes of each other and to attend the online class to understand the concept of mechanical assembly.

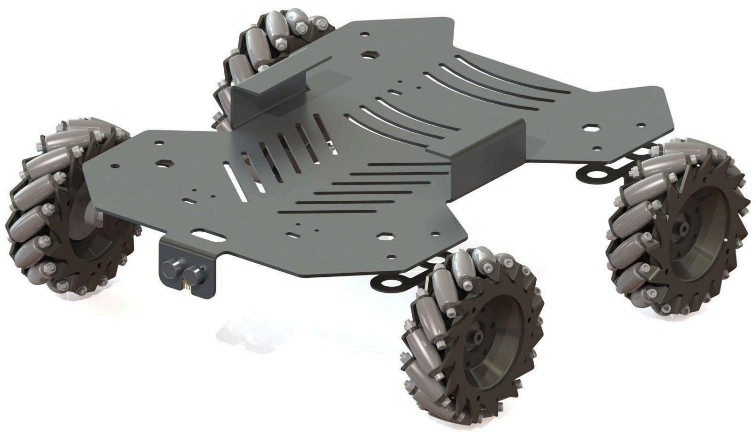

Figure 3: Example of a CAD modeling of the system, from www.cgtrader.com

2.2. D2.2 PCB design

There are several electronics components to connect: motors, motor driver, microcontroller. A clear wiring diagram must be provided, so that another person can replicate the results. Two programs can be used for the wiring diagram, one is EasyEDA, the other one is Cadence. With EasyEDA, it is possible to wire the different components of the system, configure the routing for a potential PCB, and have a 3D rendering of the final product.

Note: a physical PCB design is not required but having a board to connect all the components without the risk of short-circuit is highly advised.

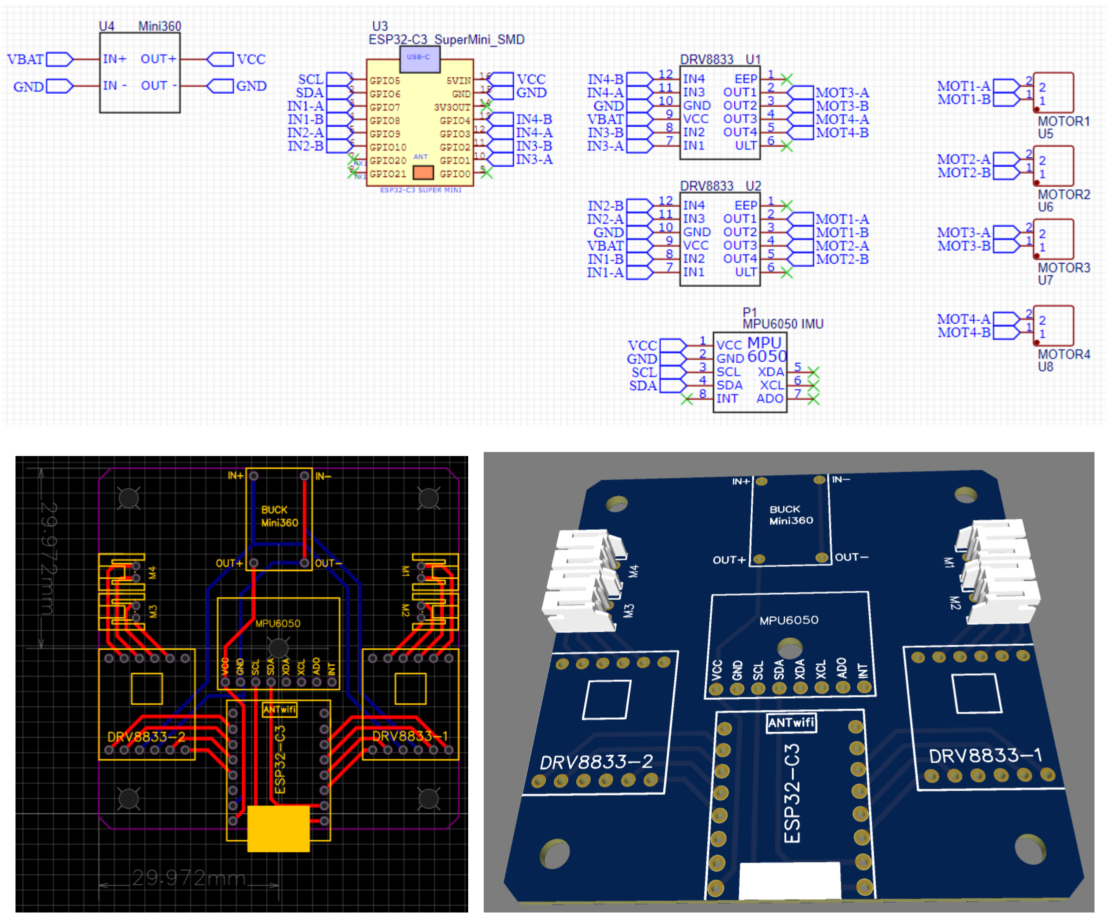

Figure 4: Examples of PCB design

3. WP3: Embedded and control system

The use of a microcontroller is mandatory to drive the DC motors. The deliverables are as follows:

- D3.1: Control of DC motor with PID controller
- D3.2: Integration of an IMU

3.1. D3.1 *DC motor control*

The robot includes the following components:

- The microcontroller: ESP32
- The motor and sensor: DC motors with encoders
- The power driving unit: DC motor driver

The components must be tested individually before integrating them together. In particular, the following aspect of the project must be tested:

- Reading the encoder value
- Implementing a PID controller to control the position of the motor
- Implementing serial communication between the microcontroller ESP32 and the computer

It is up to the students' group to design and verify the functioning of their hardware.

Figure 5: Microcontroller (ESP32), DC motor, and DC motor driver (IBT-2): main hardware component for the robot

RobotDog-v1 > src > main.cpp > ...

```
#include <Arduino.h>
#include "MyMotor.h"
#include "MyEncoder.h"
#include "MyPID.h"
#include "MySerial.h"

void setup()
{
  Init_Motor();
  Init_Encoder();
  Init_PID();
  Init_Serial();
}

void loop()
{
  Get_Angle();
  Compute_PID();
  Run_Motor();
  SerialDataPrint();
  SerialDataWrite();
}
```

Figure 6: Example of code architecture. Unit testing verifies that each piece of code can work individually.

3.2. D3.2: Integration of an IMU ICM_20948

The IMU is an essential component regarding the robot, as the Mecanum wheels tend to slip a lot.

Figure 7: ESP32-CAM Camera Module

Figure 7 shows the module for the project. More information should be found online, and it is expected for the student to explain it in the project proposal. The code is provided on Github, but the student must verify its accuracy and functioning.

4. WP4: Autonomous implementation with ROS2

This work package focuses on the autonomous behavior of the robot. This part is heavy and it is recommended that at least two students focus on this part. The deliverables for this WP are:

- *D4.1: Lidar implementation. Suggested time: 4 weeks*
- *D4.2: Camera implementation. Suggested time: 4 weeks*
- *D4.3: Navigation and Mapping. Suggested time: 4 weeks*

4.1. D4.1 Lidar implementation

A LiDAR (Light Detection and Ranging) is a remote sensing technology that uses laser light to measure distances to objects. Its implementation with ROS2 is performed with the package *rplidar_ros*. It can be used to map the area around the robot.

Figure 8: Lidar A1M8 is a common lidar used for simple autonomous system.

4.2. D4.2 Camera implementation

The Raspberry Pi Camera Module can be used for AI applications such as: Object Detection, face recognition, QR code, surveillance and security. The ROS2 package to implement this camera is *camera_ros*. Note that if the RPI camera module is used, then the ESP32 camera module does not need to be implemented.

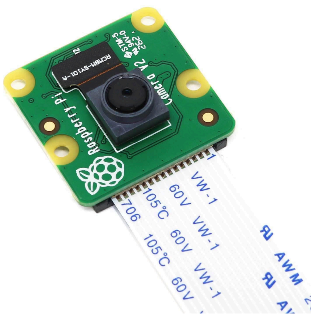

Figure 9: RPI Module V3.

4.3. D4.3 Navigation and Mapping

Mapping is the process of creating a map of the environment using the robot's sensors. Sensors used are LiDAR, wheel odometry, and AprilTags detected by the camera module. ROS2 packages for this task are *robot_localization* and *nav2*.

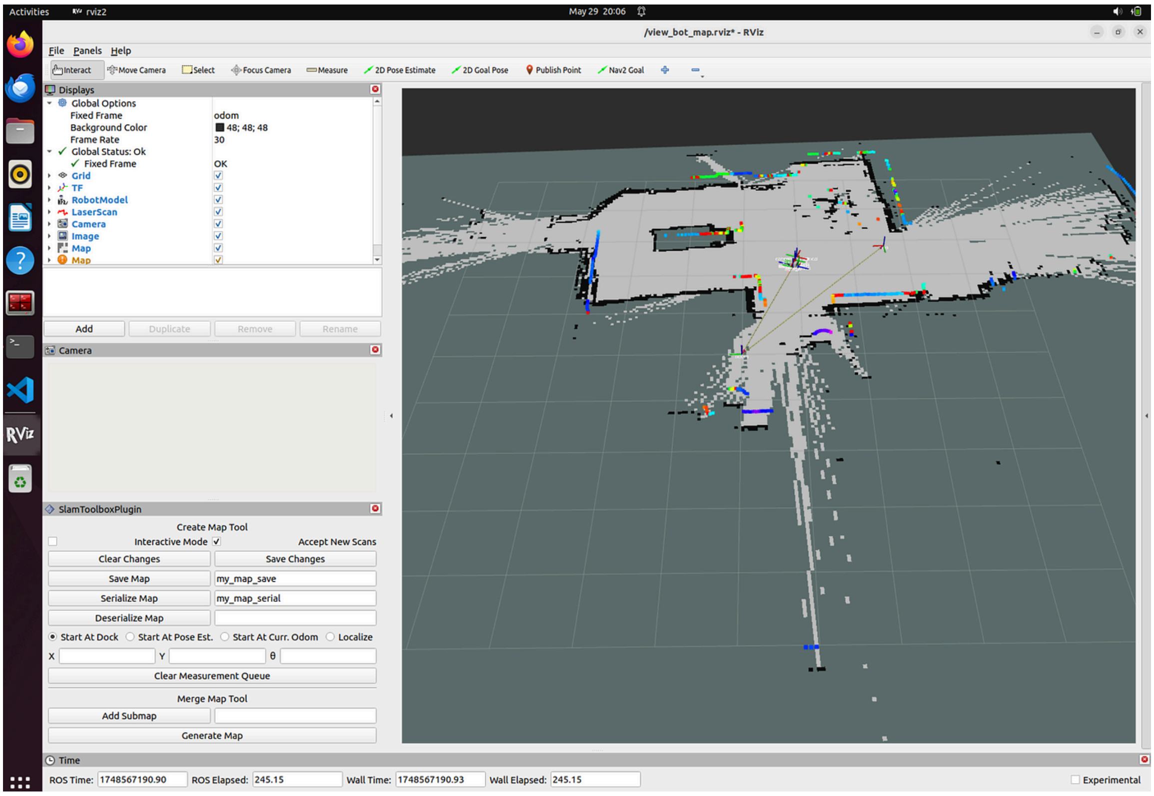

Figure 10: SLAM toolbox used lidar information to map the robot surrounding.

5. WP5: Integration and pitch presentation

This work package corresponds to the final presentation of the system. Stakeholders will be present during the final presentation to give you feedback and to see potential applications of your system. Some lecturers are looking for students to collaborate with, so consider this presentation as a way to obtain additional opportunities.

The deliverables are given as follows:

- *D5.1: Full integration of the mechatronics system following SDG guidelines. Suggested time: 2 weeks*
- *D5.2: A PowerPoint presentation summarizing the work done during the semester, to be presented during the demonstration day. Suggested time: 1 week*

5.1. D5.1 Full integration of the robotics system

The developed autonomous system should be functioning during the demonstration day. The system should solve one of the problems related to Sustainable Development Goals (SDGs). On the demonstration day, the examples of tasks are given as:

- The robot moves in the Cartesian direction, with the keyboard, joystick, or WebApps.
- The MATLAB simulation shows potential movement of the robot.
- Mapping of the room with the Lidar is encouraged.
- Navigation inside the room with nav2 should be showcased.
- A scenario solving one of the SDGs should be described, e.g., navigating from table to table for distributing medicine.
- More tasks are encouraged by the students, in particular:
    - The group has underperformed, the prototype is not ready and should at least display their work-in-progress.
    - The group is over performing and wants to display additional tasks, just like high speed/acceleration movement, getting along with other groups to make collaborative tasks.
    - The robot has camera vision capabilities.

Figure 11: SDGs goals are available at: https://sdgs.un.org/goals

5.2. D5.2 PowerPoint presentation

The presentation of the work during the semester is expected. However, during the demonstration day, the time is limited to 10 – 15 min per group, which is not enough to explain the details of the project. The PowerPoint presentation should be presented in a video where each student presents a section of the project. One video per group is expected, but the video will be graded individually, thus it is important that each student is prepared to talk about a technical aspect of the project. The guidelines of the video can be found on Canvas.

Figure 12: Video presentation example: the video is available at https://youtu.be/7x5sNOiZqrI?si=KrBkgil8u84rI1BL

The video should be clear and professional, as a way to demonstrate your professionalism and your communication skills.

6. Group work and team management

During extended group work with people from different backgrounds, tension may arise between individuals, which is totally normal and will occur in the professional and personal life. Problems that are quite common are:

- You have an idea, but the other group members do not agree or do not listen.
- You have an idea, but you feel like the discussion has already moved on.
- You feel like you are participating, but the other group members do not agree and blame your lack of proactiveness.
- You feel like your teammates are not participating enough or are missing meetings.

Other cases can arise. You may refer to the following options to alleviate potential group problems:

- Tutorial sessions are used for technical questions and potential moderation between the group members. The lecturer and the other groups present at the tutorial sessions will be happy to give their opinion and objective observation.
- You can address your problem during the office hours session. They will be reported in the minutes of meetings.
- The group contract is essential to set ground rules between all members. An example of basic rules is given thereafter. If one student fails to follow them, then its behavior may collectively be reported to the lecturer and the grade of the concerned student may be altered. An alternative punishment, without going through the lecturer, could just be a cup of coffee to be offered to the other team members as an act of forgiveness.
    - Set a (rigid) weekly group meeting: e.g., Friday 13:30pm for at least 30 min. There is always something to observe, to note, or to discuss about.
    - Each member should verbally contribute at least for 5 minutes during the meeting: to present the current work, challenges, or the on-coming tasks.
    - Split the tasks: this project must be divided into smaller deliverables, and each individual can work independently on them. Power point presentation, report writing, components purchasing, prototype assembly, and coding are tasks that can be performed in parallel.
    - Only five minutes of meeting are graded in this course. However, after every group meeting, each student should have a clear understanding of their personal tasks, which should be written in a shared file.

7. Conclusion

Some recommendations are given as follows:

- Ordering items takes time. Try to order in advance and prepare preliminary works before the arrival of the components (this should be considered in your project proposal).
- During experimentation, mechanical or electrical components may get damaged. Be sure to order spare parts and to keep yourself safe: a motor even rotating at low speed can easily overheat.
- This is a guided project. You are more than welcome to introduce your own creativity in your work.

References

[1] K. Kanjanawanishkul, “Omnidirectional wheeled mobile robots: Wheel types and practical applications,” *International Journal of Advanced Mechatronic Systems*, vol. 6, no. 6, pp. 289–302, Feb. 2015, doi: 10.1504/IJAMECHS.2015.074788.

[2] M. T. Watson, D. T. Gladwin, and T. J. Prescott, “Collinear Mecanum Drive: Modeling, Analysis, Partial Feedback Linearization, and Nonlinear Control,” *IEEE Transactions on Robotics*, vol. 37, no. 2, pp. 642–658, Apr. 2021, doi: 10.1109/TRO.2020.2977878.