Aalto University
ELEC-E8004 Project work course
Year 2025

Project plan

Project #24
Shoveling earth with the Boston Dynamics Spot robot

Date: 29.01.2025

Principle Investigator
Pajarinen Joni

Team Members:
Saad Iqbal
Akseli Hilander
Miró Michelsson
Dacheng Zhou

Information page

<u>Students</u>
Saad Iqbal
Akseli Hilander
Miró Michelsson
Dacheng Zhou

<u>Project manager</u>
Saad Iqbal

<u>Official Instructor</u>
Joni Pajarinen

<u>Approval</u>
The instructor has accepted the final version of this document

Date: 3.2.2025 Signature
Joni Pajarinen

1) Background

Autonomous excavation is essential for applications in construction, disaster response, and space exploration, where robots must operate in confined or hazardous environments. Traditional excavators are impractical in such scenarios, making agile, small-scale robotic solutions necessary.

This project enables **the Boston Dynamics Spot robot to autonomously dig using a lightweight shovel, addressing challenges like detecting hidden obstacles and selecting optimal digging locations.** These challenges reflect real-world problems in robotic excavation for search and rescue, planetary exploration, and remote construction.

By tackling these issues, the project advances autonomous robotics while providing students with hands-on experience in *robotic perception, manipulation, and decision-making using ROS, Python, and machine learning.*

2) Expected output

This project enables the **Boston Dynamics Spot** robot to autonomously transfer simulated earth between two 1 m^2 containers using a shovel. The robot will detect and avoid immovable obstacles while executing precise excavation and transport. Both **autonomous and manual control** options will be available, with potential integration of **machine learning** for improved efficiency.

The system is developed for **researchers, engineers, and academics** in robotic automation, as well as **industry professionals** in construction, mining, and planetary exploration. It serves as a **proof of concept** for small-scale, adaptable robotic excavation.

For usability, the robot should perform **smooth and efficient excavation** with minimal trial and error. It will provide **clear feedback** through logs, UI, or visual indicators, and the manual control must be **intuitive** for direct intervention. Performance expectations include **successful earth transfer** within a **reasonable timeframe** while maintaining **high accuracy** in obstacle avoidance. If machine learning is used, the system should **adapt to different soil and obstacle conditions** for improved reliability.

The robot should **excavate smoothly and efficiently with minimal trial and error, providing clear feedback via logs, UI, or visual indicators.** It should transfer earth within a reasonable timeframe while accurately avoiding obstacles.

The project will conclude with **a live or recorded** demonstration of the prototype under various scenarios, showcasing its excavation capabilities. The **final report and presentation** will summarize the system design, challenges, and results, contributing to future research in autonomous excavation and robotic manipulation.

3) Phases of project:

To ensure structured progress and timely completion, time constraints have been defined for each phase of the project. **Key milestones (M1, M2, M3, etc.)** have been established as checkpoints to track development and assess achievements against set deadlines. The following table no. 1 outlines the milestones and their corresponding deadlines, ensuring efficient execution and progress monitoring.

Table No. 1 Project milestones and their estimated timeline

Milestone	Phases	Estimated Time
M1	• Project Planning	2weeks
M2	• Tool Familiarization • Knowledge Acquisition	4weeks
M3	• Environment Setup (Digital & Physical) • Prototyping (Digital & Physical)	2weeks
M4	• System Simulation • Testing & Performance Analysis (HIL)	6weeks
M5	• Final Implementation & Delivery • Presentations & Demonstrations • Report Documentation • Documented Source Code	3weeks

4) Work Breakdown Structure (WBS)

The entire product is divided into six distinct packages, as outlined below in figure no.1:

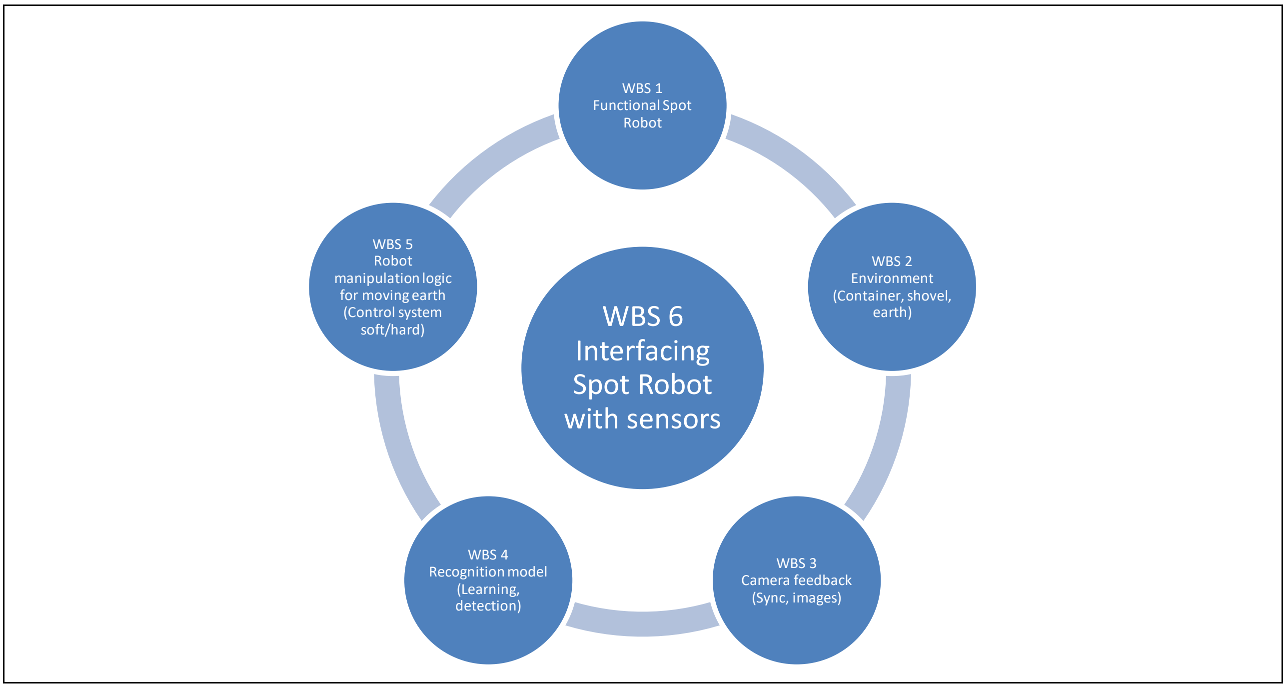


Figure No. 1 Work Breakdown Structure of the project

5) Work packages and Tasks of the project and Schedule

To ensure efficient project execution, work packages have been defined along with their associated tasks and schedules. Each task is systematically planned to align with the overall project timeline. The following table no.2 provides detailed information on **work packages, task distribution, and scheduling**.

Table No. 2 Work Packages and Proposed Schedule

WPs	Detail	Tasks	Duration: Start Date	Duration: Completion Date
WP1	Project Planning	Drafting project plan	15th Jan 2025	31st Jan 2025
		Finalizing the tools & technologies along with WBS	23rd Jan 2025	30th Jan 2025
WP2	Tool Familiarization	Boston Dynamics quadruped Spot robot	3rd Feb 2025	21st Feb 2025
		ROS programming	10th Feb 2025	23rd Feb 2025
		Isaac Sim (Simulator)	4th Feb 2025	28th Feb 2025
WP3	Knowledge Acquisition	Robot manipulation	4th Feb 2025	21st Feb 2025
		Image processing	10th Feb 2025	21st Feb 2025
		Machine learning models	5th Feb 2025	21st Feb 2025
		GPU processing	10th Feb 2025	28th Feb 2025
WP4	Environment Setup (Digital & Physical)	Sourcing materials i.e. robot, shovel, gripper, simulated earth	24th Feb 2025	7th Mar 2025
		Building the “sandbox” & “collection box”	24th Feb 2025	7th Mar 2025
		Tagging environment	3rd Mar 2025	7th Mar 2025
		Creating a digital environment (digital twin)	24th Feb 2025	28th Mar 2025
WP5	Prototyping (Digital & Physical)	Shoveling process	1st Apr 2025	18th Apr 2025
		Robotic movements	1st Apr 2025	18th Apr 2025
		Image processing	24th Mar 2025	18th Apr 2025
WP6	System Simulation	Easy environment (no obstacles)	18th Apr 2025	2nd May 2025
		Medium environment (some obstacles)	28th Apr 2025	9th May 2025
		Hard environment (many obstacles)	28th Apr 2025	9th May 2025
WP7	Testing & Performance Analysis (HIL)	Gathering data	5th May 2025	16th May 2025
		Analyzing data	5th May 2025	16th May 2025
WP8	Final Implementation & Delivery	Business proposal	12th Mar 2025	24th Mar 2025
		Poster	19th May 2025	26th May 2025
		Short video	19th May 2025	26th May 2025
		Physical demo	27th May 2025	27th May 2025
WP9	Presentations & Demonstrations	Preparation & rehearsal	21st May 2025	26th May 2025
WP10	Report Documentation	Drafting final report	28th May 2025	2nd June 2025

The same can be seen from the Gantt chart in **Annex no. 01**.

6) Work resources

The number of hours available for the project (excluding lectures and seminars) per week by everyone in the team is given in Table No. 3.

Table No. 3 Human resource division throughout the project

	Saad Iqbal	Akseli	Miró	Dacheng
Week 1	0	0	0	0
Week 2	0	0	0	0
Week 3	0	0	0	0
Week 4	4	4	4	4
Week 5	10	10	10	10
Week 6	16	16	16	16
Week 7	16	16	16	16
Week 8	18	18	18	18
Week 9	10	16	18	10
Week 10	16	16	16	16
Week 11	16	14	16	16
Week 12	14	10	14	14
Week 13	14	16	10	14
Week 14	12	10	10	12
Week 15	14	14	14	14
Week 16	14	14	14	14
Week 17	14	14	12	14
Week 18	10	10	10	10
Week 19	14	14	14	14
Week 20	14	14	14	14
Week 21	14	14	14	14
Total	**240**	**240**	**240**	**240**

7) Cost plan and materials

The project budget will be supervised by the **instructor**, and procurement will be carried out at only his discretion. The tentative project budget: **500euros** shown in following table no. 04:

Table No. 4 Cost plan and materials of the project

Items	Description	Quantity	Price
Lightweight Shovel	Compact & lightweight shovel	1x	50 Euro
3D-Printed Gripper	For the firm grip on shovel handle	1x	100 Euro
Simulated Earth	Wooden pieces	To fill the container	250 Euro
Containers	Outdoor bathing tub	2x	50 Euro
Simulated obstacle	Heavy rock like material	¼ of the container	50 Euro

8) Other resources

The project workplace is designated in the Aalto Robotics Research Lab, where the team will conduct the majority of their activities. Ensuring access to the necessary resources is crucial for the successful execution of the project. The key requirements include:

- Key & Access Card for research lab entry The Robot Lab
- High-End Computational Resources for simulation software
- Camera for ML data collection
- Storage facility

9) Project Meetings

- **Meeting Schedule:**
  - In-House Team Meetings (Tentative): 1-hour meeting at **5:00 PM each Wednesday**.
  - Official Meetings with Instructor: 1-hour meeting biweekly at **2:15 PM on Friday**.
- **Agenda & Memo Development:**

The team will collaboratively develop the agenda and meeting memo iteratively, ensuring all key discussion points are covered. These documents will be shared via Telegram at least one day prior to each meeting. Moreover, *A structured archive will be maintained to track meeting discussions, decisions, and progress over time.*

10) Project management

Project manager: **Saad Iqbal**

Instructor: **Pajarinen Joni**

Table No. 5 Distribution of Project Responsibilities Among Team Members

Work Packages Number	Description	Responsibility (Tentative)
WP1	Project Planning	Saad Iqbal
WP2	Tools Familiarization	Akseli Hilander
WP3	Knowledge Acquisition	Miró Michelsson
WP4	Environment Setup	Dacheng Zhou
WP5	Prototyping	Saad Iqbal
WP6	System Simulation	Akseli Hilander
WP7	Testing & Analyzing	Miró Michelsson
WP8	Project Demo	Dacheng Zhou
WP9	Presentation	Saad Iqbal
WP10	Final Report	Akseli Hilander

11) Communication plan

A thorough plan for maintaining **consistent and reliable** communication within the team and with the instructor has been proposed and implemented as outlined below:

Within team:

- **Official Email** Communication
- **Telegram Group** for Instant Messaging
- **GitHub** Repository & Issue Tracking
- **OneDrive** for File Sharing & Collaboration
- **Research Lab** (During Contact Hours)

With instructor:

- **Official Email** Communication
- **Instructor's Office** Location in Campus Building (After prior approval)

12) Risk management

Risks in the project are categorized based on their **potential impact and likelihood of occurrence** to ensure effective mitigation. The following table outlines the identified risks associated with the project, along with their corresponding **severity levels** for prioritization and management.

Risks	Description/Stakeholder	Severity
Hardware tool malfunctioning	Boston Dynamics Spot Robot & Accessories	Critical
Unresolved bug in tool's library	SDKs & Required Software Libraries	High
Inefficient Excavation power	Robot Power Constraints & Limitations	Critical
Obstacle Detection Failure	Potential Inaccuracies in the Proposed Model	Moderate
Limited Machine Learning Training Data	Challenges in Model Learning	Moderate
Communication & Coordination Issues	Unforeseen Coordination Issues Among Team & Instructor	Low
Resource Constraints	Delays in Acquiring Necessary Software & Hardware Resources	Moderate
Environmental Factors	Limited Access to Research Lab Facilities for Testbed	Low
Time Management Challenges	Unexpected Setbacks & Time Constraints	Moderate
Final Demonstration Failures	Last-Minute Technical Faults in the Prototype	Low

13) Quality

To ensure project quality, clear roles, structured communication, and proactive issue resolution will be given significance through the following procedure:

Roles of Stakeholders in Quality Management:

- **Team Members:** Maintain quality in assigned tasks, ensuring accuracy and adherence to best practices.
- **Project Manager:** Oversees quality control, monitors progress, and enforces standards.
- **Instructor:** Provides feedback and ensures compliance with academic and professional standards.

Procedure of Handling Quality Issues:

- **Identification:** Issues are detected through testing, peer-reviews, and milestone evaluations.
- **Communication:** Discussed over a telegram app or else in weekly meetings.
- **Decision-Making:** The team collaborates on solutions, prioritizing based on impact, with guidance from the instructor.

14) Changes to the project plan

Any modifications to the project plan will take effect only after receiving **majority approval from the team members and the instructor**. Additionally, all changes must be properly documented, including a detailed root cause analysis of the constraints or challenges that necessitated the change. This ensures transparency, accountability, and informed decision-making throughout the project.

15) Measures for successful project

A successful academic project is defined by both its **technical outcomes and learning objectives**. This includes achieving the *functional goals, maintaining quality and efficiency, and ensuring the team gains valuable knowledge and skills*.

A) Evaluating on Project Outcome:

a. **Functional Performance:**

The robot should autonomously and reliably transfer simulated earth between containers while avoiding obstacles.

b. **Software Testing:**

The system will undergo unit testing, integration testing, and simulation-based validation to ensure correctness and efficiency.

c. **Hardware Testing:**

The robot's physical performance will be evaluated under controlled conditions, assessing excavation efficiency, stability, and obstacle avoidance.

d. **Demonstration & Evaluation:**

The final prototype will be demonstrated in a designated testing environment or research lab, either live or through recorded evidence.

B) Evaluating on Project Process:

a. **Task/Milestone Tracking:**

Progress will be documented through *weekly reports, meeting memos, and checklists* to ensure timely completion of key objectives.

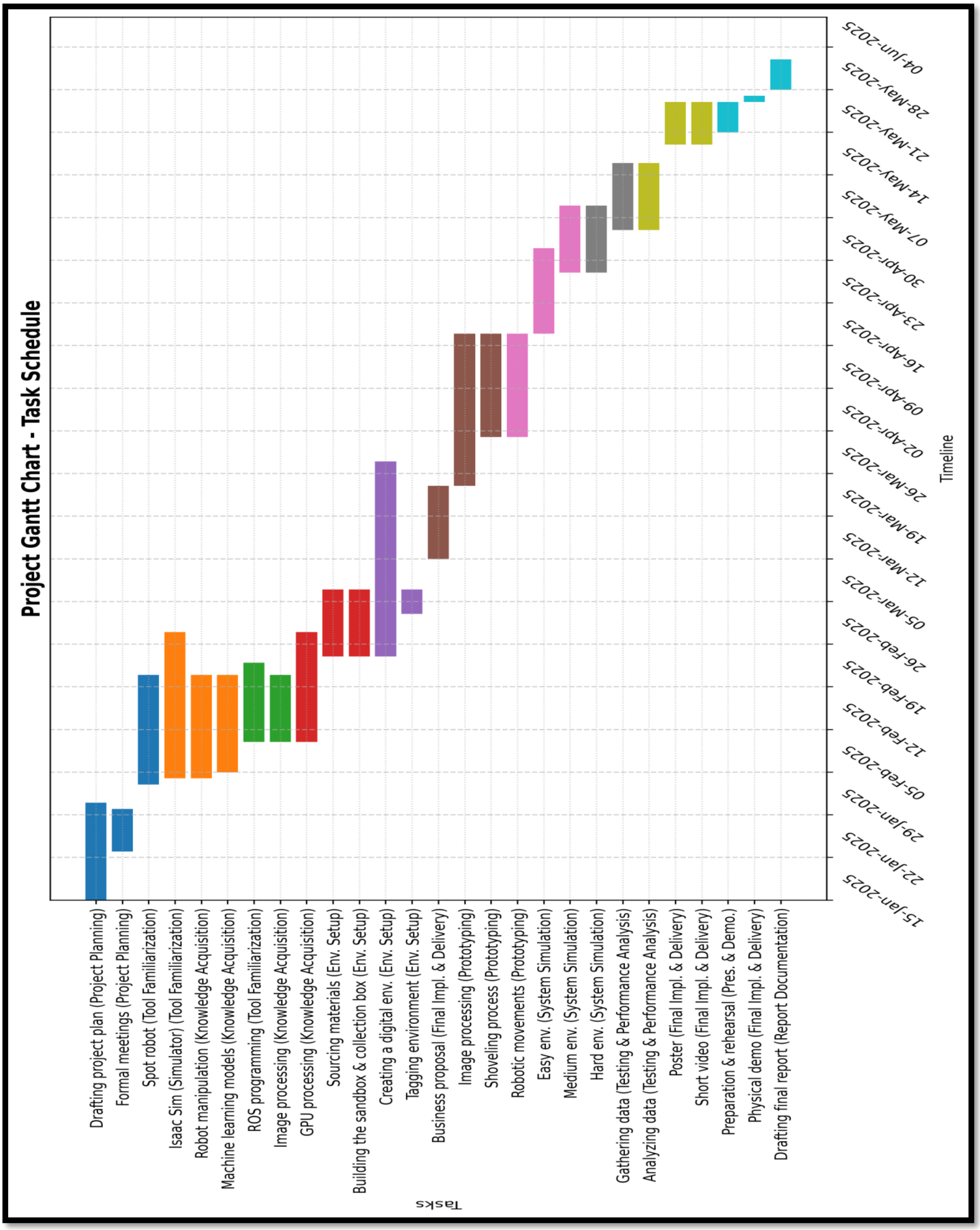
b. **Quality of Deliverables:**

Deliverables will be evaluated based on *code efficiency, hardware integration, documentation clarity, and system performance*.

c. **Learning Goals Measurement:**

Skill development in robotic control/manipulation, machine learning, ROS, and project management will be assessed via *self-evaluations, peer feedback, and instructor reviews.*

16) Annex No. 1



Project Gantt Chart - Task Schedule
Drafting project plan (Project Planning)
Formal meetings (Project Planning)
Spot robot (Tool Familiarization)
Isaac Sim (Simulator) (Tool Familiarization)
Robot manipulation (Knowledge Acquisition)
Machine learning models (Knowledge Acquisition)
ROS programming (Tool Familiarization)
Image processing (Knowledge Acquisition)
GPU processing (Knowledge Acquisition)
Sourcing materials (Env. Setup)
Building the sandbox & collection box (Env. Setup)
Creating a digital env. (Env. Setup)
Tagging environment (Env. Setup)
Business proposal (Final Impl. & Delivery)
Image processing (Prototyping)
Shoveling process (Prototyping)
Robotic movements (Prototyping)
Easy env. (System Simulation)
Medium env. (System Simulation)
Hard env. (System Simulation)
Gathering data (Testing & Performance Analysis)
Analyzing data (Testing & Performance Analysis)
Poster (Final Impl. & Delivery)
Short video (Final Impl. & Delivery)
Preparation & rehearsal (Pres. & Demo.)
Physical demo (Final Impl. & Delivery)
Drafting final report (Report Documentation)
Tasks
15-Jan-2025
22-Jan-2025
29-Jan-2025
05-Feb-2025
12-Feb-2025
19-Feb-2025
26-Feb-2025
05-Mar-2025
12-Mar-2025
19-Mar-2025
26-Mar-2025
02-Apr-2025
09-Apr-2025
16-Apr-2025
23-Apr-2025
30-Apr-2025
07-May-2025
14-May-2025
21-May-2025
28-May-2025
04-Jun-2025
Timeline