MANCHESTER
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The University of Manchester

Design Requirements Analysis

MSc Robotics AERO62520 Robotic Systems Design Project

Year of submission
2024

Group Number
Group 5

School of Engineering

Contents

1 Stakeholder Engagement

1.1 Introduction

In this project, Group 5 aims to understand and address the customer's requirements effectively. The initial statement provided by the customer is as follows:

> **"Develop a robot which can autonomously retrieve coloured objects from the environment and place them in matching storage bins located at the starting point."**

To further define the project's scope, the team held two engagement sessions with the primary stakeholders, Dr. Simon Watson and Dr. Pawel Ladosz. The following sections summarize their responses to clarify key requirements and expectations for the robotic system design project.

1.2 Engagement Details (Questions and Answers)

1.2.1 Object

1. **What types of objects should the robot retrieve?**
   The objects are colored cubes.
2. **How many different colors of objects will there be?**
   There will be three different colors of objects placed in the environment.
3. **Where should the object be taken?**
   Each object is to be returned to the matching storage bin located at the starting point.
4. **What is the size and location of the storage bins, and will their positions change?**
   The storage bins will be 200 mm cubes with a 150 mm diameter circular hole at the top for placing objects inside. They will be positioned next to the robot at the starting location and will remain stationary throughout the task.
5. **How should the robot identify the objects and storage bins?**
   Objects and storage bins should be identified by color only, with no additional markings, labels, or identifiers on the cubes or bins.
6. **What is the maximum weight of the objects that the robot will need to lift and carry?**
   The robot should be able to carry at least one cube. The maximum weight depends on the robot's design.
7. **How should the robot handle objects that do not have a matching bin?**
   All objects in the environment will have matching bins, so there will be no objects without a matching bin.

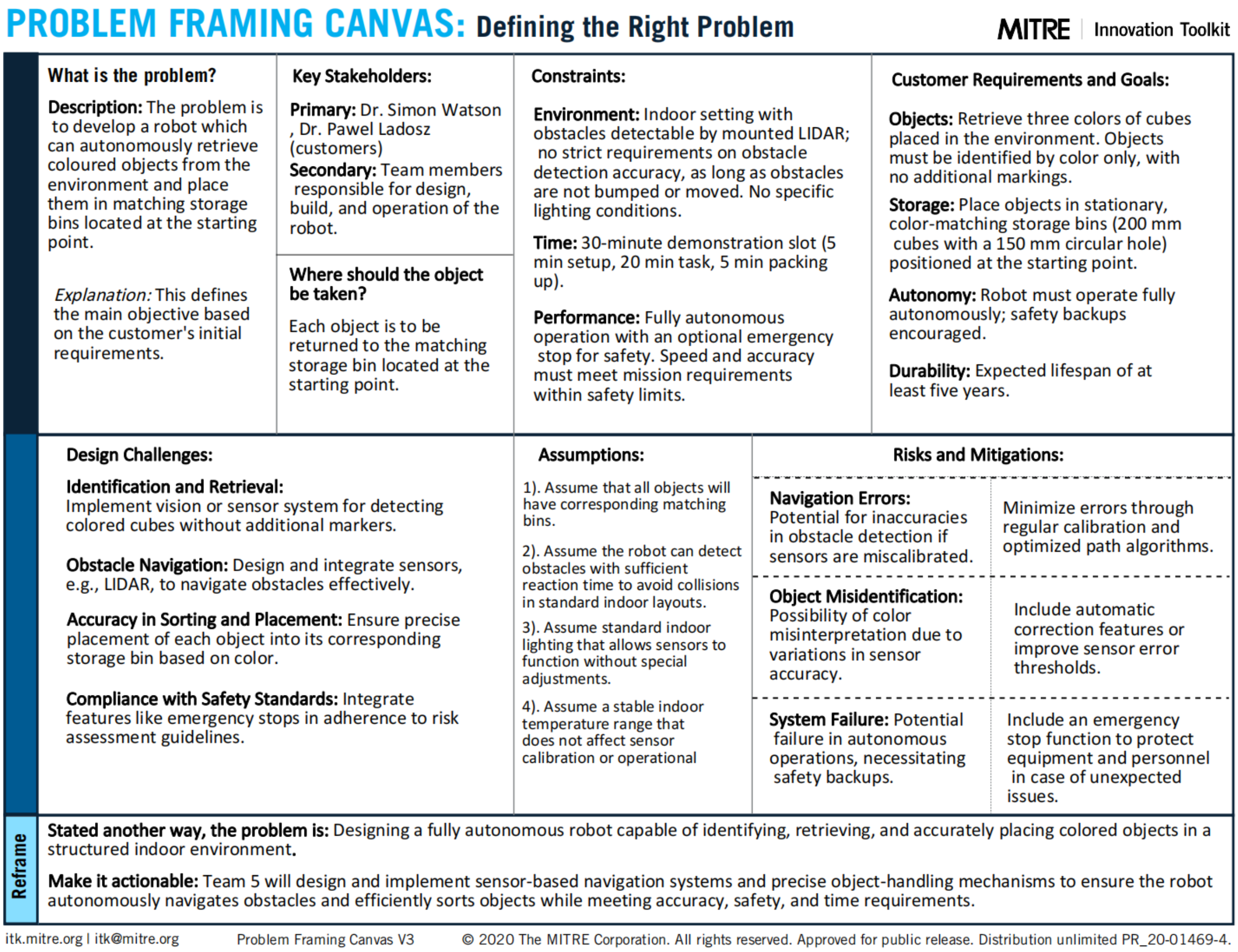
1.2.2 Environment

1. **What kind of environment will the robot operate in?**
   The environment will be indoors with obstacles. These obstacles will be of sufficient height to be detectable by reasonably mounted LIDAR.
2. **Is there any requirement for accuracy of detection of obstacles?**
   No, there is no strict accuracy requirement for detecting obstacles, as long as the mission can be completed without the robot bumping into or moving the obstacles.
3. **Are there any specific lighting conditions in the environment?**
   No specific lighting conditions were outlined, but the environment is standard for indoor settings.

1.2.3 Performance Requirements

1. **What are the time requirements?**
   There is a total of 30 minutes for the demonstration: 5 minutes for setup, 20 minutes for the task execution, and 5 minutes for packing up.
2. **What are the speed and accuracy requirements for the robot?**
   The speed and accuracy should be sufficient to complete the mission, with the maximum speed restricted for safety.
3. **What is the required level of autonomy for the robot?**
   The robot should be fully autonomous, although safety backups (e.g., emergency stop) are allowed and encouraged.
4. **Are there any specific safety or regulatory requirements for the robot?**
   The robot must follow risk assessment guidelines. It is recommended to have an emergency stop feature.
5. **Is there any need for specific integration with a user interface (e.g., mobile app, control panel)?**
   No, there is no specific requirement for user interface integration.
6. **What is the expected lifespan of the robot?**
   The robot should have an expected lifespan of at least five years.
7. **What is the budget or cost range for this robot?**
   The robot itself costs around £4,000. There is an additional manufacturing budget to laser cut or 3D print what is needed.

1.3 Problem Framing Canvas



PROBLEM FRAMING CANVAS: Defining the Right Problem

MITRE | Innovation Toolkit

What is the problem?

Description: The problem is to develop a robot which can autonomously retrieve coloured objects from the environment and place them in matching storage bins located at the starting point.

Explanation: This defines the main objective based on the customer's initial requirements.

Key Stakeholders:

Primary: Dr. Simon Watson , Dr. Pawel Ladosz (customers)

Secondary: Team members responsible for design, build, and operation of the robot.

Where should the object be taken?

Each object is to be returned to the matching storage bin located at the starting point.

Constraints:

Environment: Indoor setting with obstacles detectable by mounted LIDAR; no strict requirements on obstacle detection accuracy, as long as obstacles are not bumped or moved. No specific lighting conditions.

Time: 30-minute demonstration slot (5 min setup, 20 min task, 5 min packing up).

Performance: Fully autonomous operation with an optional emergency stop for safety. Speed and accuracy must meet mission requirements within safety limits.

Customer Requirements and Goals:

Objects: Retrieve three colors of cubes placed in the environment. Objects must be identified by color only, with no additional markings.

Storage: Place objects in stationary, color-matching storage bins (200 mm cubes with a 150 mm circular hole) positioned at the starting point.

Autonomy: Robot must operate fully autonomously; safety backups encouraged.

Durability: Expected lifespan of at least five years.

Design Challenges:

Identification and Retrieval: Implement vision or sensor system for detecting colored cubes without additional markers.

Obstacle Navigation: Design and integrate sensors, e.g., LIDAR, to navigate obstacles effectively.

Accuracy in Sorting and Placement: Ensure precise placement of each object into its corresponding storage bin based on color.

Compliance with Safety Standards: Integrate features like emergency stops in adherence to risk assessment guidelines.

Assumptions:

1). Assume that all objects will have corresponding matching bins.

2). Assume the robot can detect obstacles with sufficient reaction time to avoid collisions in standard indoor layouts.

3). Assume standard indoor lighting that allows sensors to function without special adjustments.

4). Assume a stable indoor temperature range that does not affect sensor calibration or operational

Risks and Mitigations:

Navigation Errors: Potential for inaccuracies in obstacle detection if sensors are miscalibrated.	Minimize errors through regular calibration and optimized path algorithms.
Object Misidentification: Possibility of color misinterpretation due to variations in sensor accuracy.	Include automatic correction features or improve sensor error thresholds.
System Failure: Potential failure in autonomous operations, necessitating safety backups.	Include an emergency stop function to protect equipment and personnel in case of unexpected issues.

Reframe

Stated another way, the problem is: Designing a fully autonomous robot capable of identifying, retrieving, and accurately placing colored objects in a structured indoor environment.

Make it actionable: Team 5 will design and implement sensor-based navigation systems and precise object-handling mechanisms to ensure the robot autonomously navigates obstacles and efficiently sorts objects while meeting accuracy, safety, and time requirements.

itk.mitre.org I itk@mitre.org Problem Framing Canvas V3 © 2020 The MITRE Corporation. All rights reserved. Approved for public release. Distribution unlimited PR_20-01469-4.

Fig. 1. Problem Framing Canvas developed based on customer clarifications

2 Problem Statement

After discussion with the customers, Dr. Simon Watson and Dr. Pawel Ladosz, the requirements for the project were defined. The customer requested a fully autonomous robot equipped with sensors and a manipulator capable of retrieving specific objects from an unmapped environment and placing them into matching storage bins within a limited time. The environment will include several stationary obstacles. This project aims to provide an opportunity to apply our robotics knowledge from lectures into a practical context while fostering teamwork skills, including communication, collaboration, and coordination.

2.1 Objectives

- Ensure the entire operation is safe and fully autonomous.
- Utilize the LeoRover with necessary equipment to complete the project.

- Implement autonomy on the robot to map the environment and navigate automatically.
- Train computer vision systems to identify and grasp objects accurately.
- Prevent the robot from bumping into or moving obstacles within the environment.
- Complete the entire operation within 20 minutes.
- Incorporate safety backups, such as an emergency stop feature, to ensure safety during operation.

3 Functional and Performance Requirements

According to the above customer requirements, the robot to be designed shall be able to achieve autonomous navigation, avoiding obstacles, recognising objects and grasping and placing functions. The following is the detailed function and performance introduction.

3.1 The robot shall have mobility capability

3.1.1 The robot shall be capable of moving on dry, hard surfaces.

3.1.2 The robot shall operate in indoor environments.

3.1.3 The robot shall be able to move forward and backward and to turn.

3.1.4 The robot's movement speed shall comply with safety standards, with a proposed maximum speed of 0.5 meters per second.

3.1.5 The robot shall have an emergency braking function, enabling it to stop within 1 second to comply with safety standards.

3.2 The robot shall be able to autonomously plan its path

3.2.1 The robot shall be capable of generating a map of its surroundings in real-time during operation.

3.2.2 The robot shall be able to autonomously plan navigation paths based on the generated map.

3.3 The robot shall be able to avoid obstacles

3.3.1 The probability of the robot navigating the path without moving obstacles shall be greater than 90%.

3.3.2 The robot shall be capable of detecting obstacles within a one-meter diameter range, including those that may be lower than the robot's frame, with a false detection rate of less than 5%.

3.3.3 The obstacles shall be fixed static objects.

3.4 The robot shall be able to detect objects

3.4.1 In conditions of fixed lighting and color temperature, the robot shall be able to recognize objects based on color, with a success rate exceeding 90%.

3.4.2 The robot shall be able to match recognized objects of the same color, with a matching time of less than 3 seconds.

3.4.3 The robot shall be able to display the quantity and color of recognized objects in real-time.

3.5 The robot shall be capable of grasping and storing objects

3.5.1 The robotic arm shall be able to move to the target position within 5 seconds.

3.5.2 The robotic arm shall be capable of grasping polygonal objects, with the ability to grasp items weighing less than 50 grams at one time, achieving a success rate greater than 95%.

3.5.3 The robot shall be able to place the grasped objects at designated locations, with a drop rate of less than 5% during the process.

3.6 The robot shall have a state tracking capability

3.6.1 During operation, the robot shall be able to continuously monitor the real-time coordinates of its lidar, camera, base, and robotic arm.

3.6.2 The robot shall provide real-time feedback on its operational status: gripping, recognizing, and avoiding obstacles.

3.7 Mechanical design requirements for the robot

3.7.1 The dimensions of the robot shall not exceed 500 mm x 500 mm x 500 mm.

3.7.2 The lifespan of the robot shall be at least 5 years.

3.7.3 The robot shall maintain stable operation in temperatures ranging from 0 to 40 °C and humidity levels between 20% and 80%.

3.7.4 The robot shall be able to operate for at least 2 hours when fully charged.

3.8 The cost of the robot shall be controlled

3.8.1 The cost of the robot itself shall be £4,000.

3.8.2 In subsequent designs, laser cutting and 3D printing shall not exceed the manufacturing budget.

4 Requirements Verification Matrix

After identifying all the specific requirements, it is necessary to identify how to validate that the requirements are realised. The following verification matrix is used to document the validation process. The verification matrix contains test items, test methods and testers. The final test results are recorded in a tabular form. The verification matrix is shown in the table 1 below.

Table 1. Requirements Verification Matrix Table

Requirement No.[A]	**Section**[B]	**Shall Statement**[C]	**Verification Success Criteria**[D]	**Verification Method**[E]	**Responsible Party**[F]	**Results**[G]
P-1	3.1.1, 3.1.2	1) The robot shall be capable of moving on dry, hard surfaces. 2) The robot shall operate in indoor environments	The robot can move normally on a dry, hard indoor surface.	Test the robot's movement performance on dry, hard indoor surfaces.	YunXue	
P-2	3.1.3	The robot shall be able to move forward and backward and to turn.	A. The robot can move forward and backward. B. The robot can rotate.	Test and verify in a laboratory environment, observing and recording the robot's movement performance.	YunXue	
P-3	3.1.4	The robot's movement speed shall comply with safety standards.	The maximum speed does not exceed 0.5 meters	Run the robot continuously for at least half an hour in a laboratory environment, recording the maximum speed during the test.	YunXue	

Requirement No.[A]	Section[B]	Shall Statement[C]	Verification Success Criteria[D]	Verification Method[E]	Responsible Party[F]	Results[G]
P-4	3.1.5	The robot shall have an emergency braking function, enabling it to stop.	Successful stopping.	Simulate emergency scenarios to test if the robot can stop.	YunXue	
P-5	3.1.5	The robot shall can brake successfully in less than 1 second	The time from issuing the stop command to the robot completely stopping does not exceed 1 second.	Simulate emergency scenarios, verify 30 times, and test whether the stop time in all 30 trials does not exceed 1 second.	YunXue	
P-6	3.2.1	The robot shall be capable of generating a map of its surroundings in real-time during operation.	Real-time map navigation updates.	Test, observe, and record whether the map remains active without any crashes or black screens during a 60-minute period.	MingXiang	
P-7	3.2.2	The robot shall be able to autonomously plan navigation paths based on the generated map.	The robot moves according to the planned path.	Test, observe and compare the robot's actual movement path with the planned path.	MingXiang	
P-8	3.3.1	The probability of the robot navigating the path without moving obstacles shall be greater than 90 per cent.	Obstacle avoidance success rate reaches 90 per cent or higher.	Test the robot 30 times in different obstacle scenarios, recording the number of successful and failed obstacle avoidance attempts.	MingXiang	

Requirement No.[A]	Section[B]	Shall Statement[C]	Verification Success Criteria[D]	Verification Method[E]	Responsible Party[F]	Results[G]
P-9	3.3.2	The robot shall be capable of detecting obstacles within a one-meter diameter range, including those that may be lower than the robot's frame, with a false detection rate of less than 5 per cent.	A. The robot can detect all obstacles within a 1-meter diameter range. B. The false detection rate is lower than 5 per cent.	Test the robot 30 times in various one-meter obstacle scenarios, recording the number of false detections and missed obstacles.	MingXiang	
P-10	3.4.1	In conditions of fixed lighting and color temperature, the robot shall be able to recognize objects based on color, with a success rate exceeding 90 per cent.	Target recognition success rate reaches 90 per cent or higher.	Use cubes of different colors in 30 experiments, recording the number of successful color recognitions and calculating the recognition success rate.	MingXiang	
P-11	3.4.2	The robot shall be able to match recognized objects of the same color, with a matching time of less than 3 seconds.	The matching process is completed within 3 seconds.	Conduct 30 matching experiments, recording the time from grabbing the target to receiving the successful match notification.	Zhen Yang	
P-12	3.4.3	The robot shall be able to display the quantity and color of recognized objects in real-time	The color and quantity of recognized objects are continuously printed on the terminal.	During robot testing, record the terminal status information.	Zhen Yang	

Requirement No.[A]	Section[B]	Shall Statement[C]	Verification Success Criteria[D]	Verification Method[E]	Responsible Party[F]	Results[G]
P-13	3.5.1	The robotic arm shall be able to move to the target position within 5 seconds	After recognizing the target, the robotic arm moves to the target coordinates within 5 seconds.	During the robot's target recognition and grabbing tests, record the time it takes for the robotic arm to move and reach the target position, conducting 30 tests.	Zhen Yang	
P-14	3.5.2	The robotic arm shall be capable of grasping polygonal objects, with the ability to grasp items weighing less than 50 grams at one time, achieving a success rate greater than 95 per cent	The success rate of grabbing a multi-sided cube is greater than 95 per cent	Test the robot by grabbing cubes of different shapes, recording the success rate of the grab.	Zhen Yang	
P-15	3.5.3	The robot shall be able to place the grasped objects at designated locations, with a drop rate of less than 5 per cent during the process	The drop rate when the robot places an object is less than 5 per cent	After grabbing cubes of different shapes, place them in the designated position, and record the placement success rate.	Zhen Yang	

Requirement No.[A]	Section[B]	Shall Statement[C]	Verification Success Criteria[D]	Verification Method[E]	Responsible Party[F]	Results[G]
P-16	3.6.1	The robot shall be able to continuously monitor the real-time coordinates of its radar, camera, base, and robotic arm	The robot's base, radar, robotic arm, and camera position coordinates are continuously printed on the terminal.	During robot testing, record the terminal status information.	Yu-Chuan	
P-17	3.6.2	The robot shall provide real-time feedback on its operational status: gripping, recognizing, and avoiding obstacles	The robot's operational status is continuously printed on the terminal.	During robot testing, record the terminal status information.	Yu-Chuan	
P-18	3.7.1	The dimensions of the robot shall not exceed 500 mm x 500 mm x 500 mm	The robot's size is less than 500 mm x 500 mm x 500 mm.	Measure the robot's length, width, and height.	Yu-Chuan	
P-19	3.7.4	The robot shall be able to operate for at least 2 hours when fully charged	The robot can operate for more than two hours on a full charge.	Test whether the robot can continuously run for more than two hours in the laboratory environment with a full charge.	Yu-Chuan	
P-20	3.8.1 3.8.2	1)The cost of the robot itself shall be £4,000 2)In subsequent designs, laser cutting and 3D printing shall not exceed the manufacturing budget.	The cost does not exceed the minimum cost threshold.	Calculate the total cost.	Yu-Chuan	

A. Unique identifier for each Robotic System requirement.

B. Section number each unique Robotic System Requirement is contained within.

C. Text (within reason) of the Robotic System requirement, i.e., the “shall”.

D. Success criteria for the Robotic System requirement.

E. Verification method for the Robotic System requirement (analysis, inspection, demonstration, or test).

F. Responsible person for performing the verification.

G. Indicate documents that contain the objective evidence that the requirement was satisfied.