For use by the Project lecturer	Approved		Revision required	

Feedback

To be completed by the student						
PROJECT PROPOSAL 2021				Project no	HG2	Revision no 0
Title	Surname	Initials	Student no	Study leader (title, initials, surname)		
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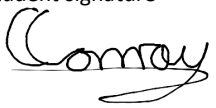
Project title						
3D cube-world construction robot						

Language editor name	Language editor signature
Mr CH Conroy	
Student declaration I understand what plagiarism is and that I have to complete my project on my own.	**Study leader declaration** This is a clear and unambiguous description of what is required in this project
Student signature 	Study leader signature and date

1. Project description

What is your project about? What does your system have to do? What is the problem to be solved?

There are a wide range of tasks that humans find trivial to complete but prove challenging for an artificial system to perform. Solving 2D puzzles is an example of such a task which has been successfully emulated by robotic systems to a limited degree. This project aims to expand on this by exploring the task of building 3D puzzles using a robot. The 3D puzzles to be investigated in this project entail both novel and moderately complex 3D shapes consisting of small cubes. The shapes will be defined by an operator through a graphical user interface (GUI) and the robot will be required to manipulate the cubes, which will initially be scattered randomly across a flat surface, to construct the specified shape.

In order to realise this functionality, a robot capable of manipulating small cubes will be developed along with an embedded platform to perform the processing required to control the robot and cube manipulation mechanism. A PC-based computer vision system will be implemented to allow the localisation of the robot and the detection of the construction pieces (cubes). Lastly, a PC-based GUI that facilitates the definition of the 3D shapes to be constructed will be designed and implemented along with the software necessary to plan and control the robotic actions required to build the shape.

2. Technical challenges in this project

Describe the technical challenges that are *beyond* those encountered up to the end of third year and in other final year modules.

2.1 Primary *design* challenges

A computer vision algorithm and model needs to be designed to detect the presence, location and pose of multiple small cubes with a high-degree of precision using input from a camera feed of the robotic manipulator's workspace. A mechanism also needs to be developed to allow the accurate localization of the robotic manipulator with respect to its environment and the cubes. The mechanical design component of the robotic manipulator and end-effector needs to facilitate stable movement in 3D space. The end-effector needs to be designed to reliably manipulate the small cubes and integrate with the robotic manipulator such that rotation about the z-axis is supported. Lastly, the design of the 3D shape renderer in the GUI will require a mathematical understanding of computer graphic principles.

2.2 Primary *implementation* challenges

The high accuracy of the control required for the system as a whole to accurately position the end-effector and the cubes it manipulates in 3D space is the primary implementation challenge of this project. The construction of the mechanical components of the robotic system needs to be of a high standard to ensure precision of the robotic manipulator which needs to be implemented in a manner that minimizes oscillations and vibrations generated by the mechanical drivers. The precision implementation and calibration of the cube detection and robotic localisation mechanisms using real-world data will also be challenging. Lastly, the integration of all the software and hardware components within the system is anticipated to be a challenge due to the number of subsystems on the I/O path.

3. Functional analysis

3.1 Functional description

Describe the design in terms of system functions as shown on the functional block diagram in section 3.2. This description should be in narrative format.

The system in Figure 1 below has two interfaces through which it receives data input from the external environment. The first interface exists at the image acquisition unit (FU1) which captures the light reflected off the workspace containing the cubes and robot and converts it to a digital image. The digital image is transmitted to the cube detection and localisation unit (FU2.2) which uses localisation techniques to align the image with the coordinate system of the robotic manipulator (FU3.4). Following this, FU2.1 detects all the cubes within the workspace image and passes this information to the system controller (FU2.3). The second interface exists at the shape definition unit (FU2.1) which is a GUI that facilitates the capture of the user's desired 3D shape input. The shape is defined through the specification of the relative positions of each individual cube in 3D space and this information is passed to FU2.3.

FU2.3 is the central system control point which coordinates all major system activities and integrates the computer vision, shape definition and robotic subsystems. FU2.3 forwards the shape definition and cube position information to the construction planner (FU2.4) which computes the translational and rotational transformations as well as the sequence of transformations that need to be applied to the cubes in order to realise the desired 3D shape in the coordinate system of FU3.4. The robotic motion planner uses these transformation sequences to compute the robotic actions required to replicate these transformations with the physical cubes.

The communication unit (FU3.1) facilitates data exchange between the PC-based software (FU2) and the embedded robotic controller (FU3.2) which converts the received robotic action sequence to digital signals for the drive systems of FU3.4 and the robotic end-effector (FU3.5). These signals first pass through the driver unit which increases the signal power to a level sufficient to power the drive systems. FU3.4 manipulates the position of FU3.5 in 3D space according to the signal it receives from FU3.3 and the actuation state of F3.5 changes in response to the signal it receives from FU3.3. FU3.5 is able to grip a cube when actuated and release it when not.

3.2 Functional block diagram

Figure 1. Block diagram showing the proposed functional structure of the system.

4. System requirements and specifications

These are the core requirements of the system or product (the mission-critical requirements) in table format IN ORDER OF IMPORTANCE. Requirement 1 is the most fundamental requirement.

	Requirement 1: the fundamental functional and performance requirement	**Requirement 2**	**Requirement 3**
1. Core mission requirements of the system or product. Focus on requirements that are core to solving the engineering problem. These will reflect the solution to the problem.			
2. What is the target specification (in *measurable* terms) to be met in order to achieve this requirement?			
3. Motivation: *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)			
4. How will you demonstrate at the examination that this requirement (point 1 above) and specification (point 2 above) has been met?			
5. Your own design contribution: what are the aspects that *you will design and implement yourself* to meet the requirement in point 2? If none, *remove this requirement.*			
6. What are the aspects to be taken off the shelf to meet this requirement? If none, indicate "none"			

System requirements and specifications page 2

	Requirement 4	Requirement 5	Requirement 6
1. Core mission requirements of the system or product. Focus on requirements that are core to solving the engineering problem. These will reflect the solution to the problem.			
2. What is the target specification (in *measurable* terms) to be met in order to achieve this requirement?			
3. Motivation: *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)			
4. How will you demonstrate at the examination that this requirement (point 1 above) and specification (point 2 above) has been met?			
5. Your own design contribution: what are the aspects that *you will design and implement yourself* to meet the requirement in point 2? If none, *remove this requirement.*			
6. What are the aspects to be taken off the shelf to meet this requirement? If none, indicate "none"			

System requirements and specifications page 3

	Requirement 7	**Requirement 8**	**Requirement 9**
1. <u>Core mission requirements of the system or product.</u> Focus on requirements that are core to solving the engineering problem. These will reflect the solution to the problem.			
2. What is the <u>target specification</u> (in *measurable* terms) to be met in order to achieve this requirement?			
3. <u>Motivation</u>: *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)			
4. How will you <u>demonstrate</u> at the examination that this requirement (point 1 above) and specification (point 2 above) has been met?			
5. <u>Your own design contribution:</u> what are the aspects that *you will design and implement yourself* to meet the requirement in point 2? If none, *remove this requirement.*			
6. What are the aspects <u>to be</u> taken off the shelf to meet this requirement? If none, indicate "none"			

System requirements and specifications page 4

	Requirement 10	Requirement 11	Requirement 12
1. Core mission requirements of the system or product. Focus on requirements that are core to solving the engineering problem. These will reflect the solution to the problem.			
2. What is the target specification (in *measurable* terms) to be met in order to achieve this requirement?			
3. Motivation: *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)			
4. How will you demonstrate at the examination that this requirement (point 1 above) and specification (point 2 above) has been met?			
5. Your own design contribution: what are the aspects that *you will design and implement yourself* to meet the requirement in point 2? If none, *remove this requirement.*			
6. What are the aspects to be taken off the shelf to meet this requirement? If none, indicate "none"			

5. Field conditions

These are the REAL WORLD CONDITIONS under which your project has to work and has to be demonstrated.

	Field condition 1	Field condition 2	Field condition 3
Field condition requirement. In which field conditions does the system have to operate? Indicate the one, two or three most important field conditions.			
Field condition specification. What is the specification (in measurable terms) for this field condition?			

6. Student tasks

6.1 Design and implementation tasks

List your primary design and implementation tasks in bullet list format (5-10 bullets). These are *not* product requirements, but *your* tasks.

- The mechanical structure of the robotic manipulator needs to be designed and constructed and its accuracy tested.
- The robotic end-effector mechanism needs to be tested with small cube manipulation and integrated with the robotic manipulator.
- Computer vision techniques and models for object detection and robotic localisation need to be researched.
- Many images need to be captured of the small cubes from various angles to design and develop the object recognition software.
- A shape definition GUI needs to be implemented and research needs to be performed for the selection of the most appropriate GUI framework and graphics API.
- A single piece of software needs to be developed that integrates the computer vision, GUI and robotic path planning functionality.
- A circuit for the robotic controller embedded system and its peripherals needs to be designed, constructed and integrated along with a power supply.
- A communication protocol needs to be developed for communication between the embedded system and PC.
- The most appropriate microcontroller for the robotic controller needs to be researched and selected and firmware needs to be developed for it.

6.2 New knowledge to be acquired

Describe what the theoretical foundation to the project is, and which new knowledge you will acquire (beyond that covered in any other undergraduate modules).

- Computer vision forms a large part of the theoretical basis for this project. The primary computer vision concept to be investigated is object detection as well as all the mathematical concepts, models and image processing techniques relevant to this.
- Robotic localisation involves the identification of the robotic system's location with respect to the environment. The theory associated with this in a 3D context will be investigated deeply to achieve as precise an alignment of the robotic end-effector with the cubes as possible.
- Robotics is at the core of this project and therefore a great deal of theory relating to robotic systems will have to be aquired. One sub-topic that will require investigation is robotic path planning which involves planning the actions of the robot optimally.
- This project involves a degree of mechanical design which will require the acquisition of knowledge in this domain to produce a mechanically precise system.
- The construction planner for the 3D shapes requires a theoretical background on modelling geometric systems and objects in three dimensions.