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Feedback

Neatly done Project Proposal.

Approved

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To be completed by the student							
PROJECT PROPOSAL 2021				Project no	HG2	Revision no	0
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Project title: **3D cube-world construction robot**							

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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: Conroy	Study leader signature and date: 2021-05-19

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 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 localisation 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 minimises 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 to receive 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 (FU2.5) 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 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 (FU3.3) 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 FU3.5 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

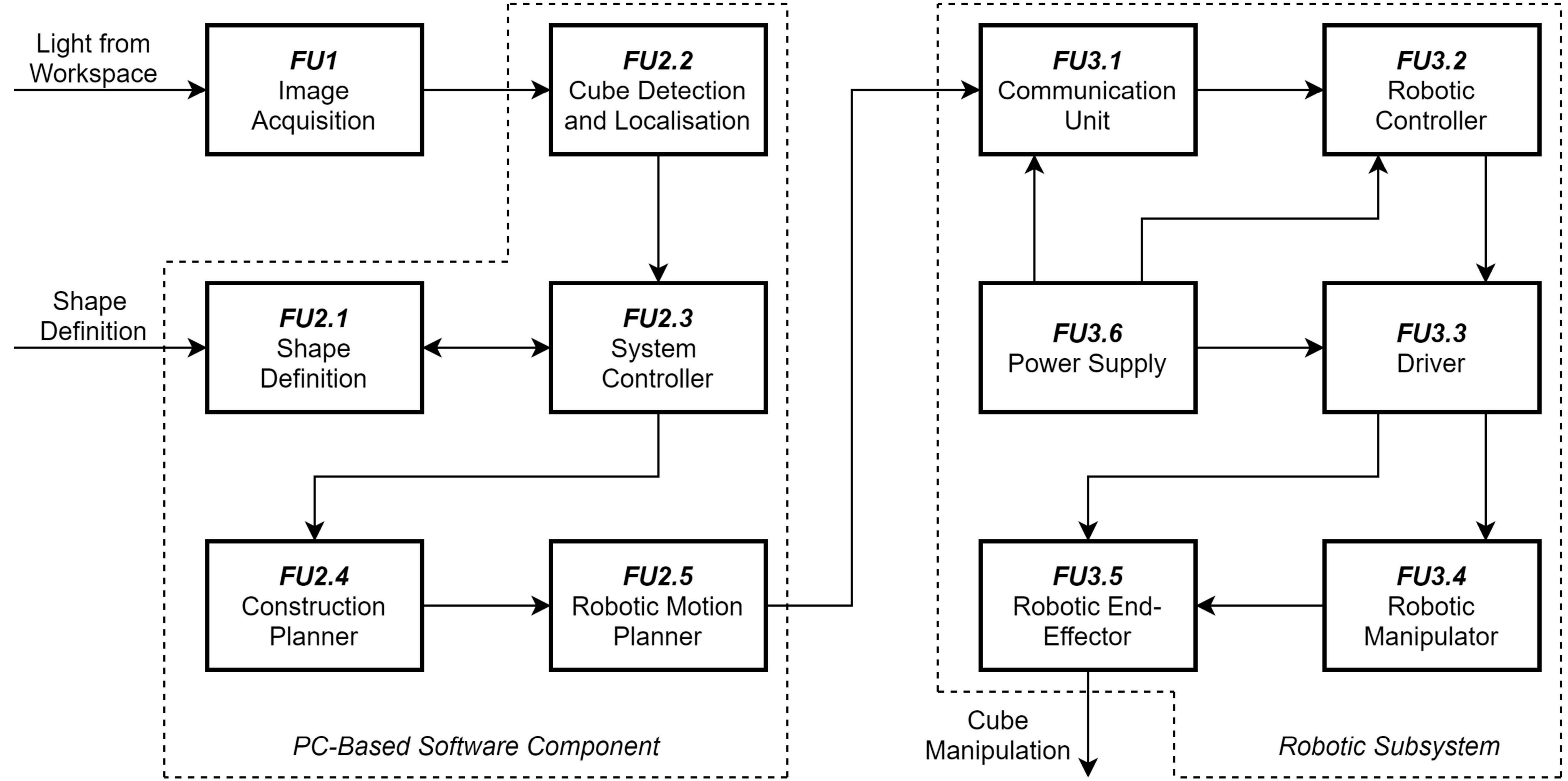

Figure 1. Block diagram showing the proposed functional structure of the system.

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. <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.	The system should construct novel and moderately complex 3D shapes using small cubes.	The GUI should allow the user to define a wide range of 3D shapes to be constructed.	The end-effector should be able to grip a cube, maintain its grip during motion and release the cube.
2. What is the <u>target specification</u> (in *measurable* terms) to be met in order to achieve this requirement?	The system should handle shapes up to at least 4 cubes in height containing up to at least 30 cubes where each cube has a face parallel to the base plane. The system should handle equal size cubes with a side length between 10mm and 15mm.	For each constituent cube in the shape, the GUI should allow the position of each cube to be specified along each Cartesian axis with at least 1mm resolution as well as the rotation of each cube about the z-axis with at least 1 degree resolution.	The end-effector should maintain the cube in its grip when the robotic manipulator is at maximum acceleration. The end-effector should be able to maintain the cube in its grip for at least 20 seconds continuously.
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)	The shape specifications are based off the requirements for a pyramid with a 4x4 base and allow for a variety of 3D shape arrangements of varying complexity to be constructed. The cube size is based off a qualitative interpretation of the term small.	Allowing the position of each cube to be specified with 4 degrees of freedom with the stated resolutions facilitates relatively precise control over the 3D shape definition. This allows a wide range of different shape definitions.	The greatest force exerted on a constant mass occurs at the point of maximum acceleration which is the most-likely grip failure instant. 20 seconds was based off twice the average time components are held for in similar existing systems.
4. How will you <u>demonstrate at the examination</u> that this requirement (point 1 above) and specification (point 2 above) has been met?	The system will construct a selection of 3D shapes satisfying the shape specification using a set of cubes all having the same side length in the specified range. Each construction will either be demonstrated live or using a time-lapsed video.	A pre-defined arbitrary 3D shape that contains the positional and rotational details at the specified resolution will be input into the GUI and the captured shape will be rendered as a 3D graphic to confirm the correct shape was captured.	The system will execute a demonstration sequence in which it grips a cube and moves between the extremes on all axes for a period of at least 20 seconds before releasing the cube.
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.*	The high-level structure of the overall system to construct the shapes will be designed. The software component that plans the construction and robotic movement will be developed from first principles and be executed on a PC.	The GUI structure, logic and flow will be designed. The 3D render of the captured shape will be designed from first principles with only calls to a low-level graphics API. A PC will be used for the processing platform for this component.	The mechanical component of the end-effector mechanism and its attachment to the robotic manipulator will be designed from first principles.
6. What are the aspects <u>to be taken off the shelf</u> to meet this requirement? If none, indicate "none"	The construction cubes and PC will be taken off the shelf.	A GUI framework will be used to provide the base window for the GUI as well as to provide the basic GUI components. The PC will be taken off the shelf.	The motor that actuates the end-effector as well as the appropriate motor driver will be taken off the shelf.

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.	The robotic manipulator should accurately translate the end-effector in 3D space and rotate it about its vertical axis.	The computer vision component should detect and localise the construction cubes in the workspace to facilitate re-gripping dropped cubes and identifying damage to the 3D shape under construction to signal a construction halt condition.	The system should detect when a cube is unintentionally dropped by the end-effector.
2. What is the target specification (in *measurable* terms) to be met in order to achieve this requirement?	The robotic manipulator should have a repeatability of at least 2mm for each Cartesian axis and a repeatability of at least 5 degrees for the rotation about the z-axis.	Only the cubes whose faces are visible from a vertical perspective need to be detected and localised. Cubes that need to be gripped should be localised with a positional accuracy of 2mm and a rotational accuracy of 5 degrees about the z-axis.	The system should detect a cube has been dropped before the end-effector grips the next cube to be placed.
3. Motivation: *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)	The repeatability needs to be a relatively small fraction of the cube size to ensure minor positional placement variations do not significantly compromise the basic 3D shape. Similar reasoning applies for rotational repeatability.	Only cubes visible from the vertical perspective are required to identify 3D shape damage that prohibits further placement or are candidates as dropped cubes. Dropped cubes need to be localised with an accuracy similar to the robotic repeatability.	The dropped cube may be required as support for the next cube to be placed. Therefore, it is important that the system deals with the dropped cube situation (either by re-gripping the cube or replacing it if absent) before the next cube is placed.
4. How will you demonstrate at the examination that this requirement (point 1 above) and specification (point 2 above) has been met?	The robotic manipulator will be instructed to travel from the origin of its coordinate system to an arbitrary point on each axis 5 times with the maximum deviation measured. This will be repeated in the z-axis rotational coordinate system.	The system will be instructed to detect and localise cubes with 5 different positions and orientations. The detected orientations and positions will be displayed on the GUI and compared to the corresponding physical measurements.	The end-effector will be instructed to drop the cube it has in its grip. The system will proceed as normal until it detects that the cube has been dropped. At this point, the system will show a GUI notification indicating a dropped cube was detected.
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.*	The mechanical component of the robotic manipulator will be designed. The firmware to control the robotic manipulator will be developed from first principles and will be executed on an embedded platform.	The algorithms required to process the images, detect the cubes in the images and localise the cubes will be developed from first principles. The algorithms will be executed on a PC.	The firmware to monitor the dropped cube sensor and the system control software that determines the response to the dropped cube will be designed and run on an embedded system and PC respectively.
6. What are the aspects to be taken off the shelf to meet this requirement? If none, indicate "none"	The motors to drive the robotic manipulator's movement as well as the motor drivers will be taken off the shelf. The microcontroller will be taken off the shelf. The robotic subsystem's power supply will be taken off the shelf.	The camera hardware and firmware required to capture the images will be taken off the shelf. The PC will be taken off the shelf.	The sensor required to monitor for a dropped cube will be taken off the shelf. The microcontroller will be taken off the shelf.

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.	The system should work under laboratory conditions.	The image background should be controlled.	
Field condition specification. What is the specification (in measurable terms) for this field condition?	The ambient lighting level should be approximately 500 lux.	The immediate background of the construction cubes in the captured images should be non-reflective and of a single hue.	

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, 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 theoretical knowledge relating to robotic systems will have to be aquired. One subtopic 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.
- Knowledge of techniques relating to 3D computer graphic rendering needs to be acquired to implement the 3D shape renderer in the GUI.