Massive Marvellous Multiple Marble Machine

T3C6

MACQUARIE
University
SYDNEY · AUSTRALIA

Project history

Date	Revision	Author	Description
09/08/2023	0	T3C6 Team	Initial report made including the structure and initial requirements and TPMs
14/08/2023	1	T3C6 Team	Further changes made to problem definition and scopes of work to submit for peer review
17/08/2023	2	T3C6 Team	Added more detail in the introduction
20/08/2023	3	T3C6 Team	Final changes made before submission
6/9/2023	4	T3C6 Team	Discussed feedback with tutor and implemented into design document
15/9/2023	5	T3C6 Team	Final changes made for the design document
20/10/2023	7	T3C6 Team	Initial changes made to testing Document
1/11/2023	8	T3C6 Team	Finalised Test results and finalised report

Definitions

Term	Definition
T3B1	Team 3 Box 1
FREQ	Functional Requirement
PREQ	Performance Requirement
IREQ	Interface Requirement
T3C6	Box 1 Communication team 6
T3S1	Box 1 Structure team 1
T3M3	Box 1 Motions team 3
Flipper	The gate system that prevents conveyor belt from having marble overflow

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1. Introduction

This document outlines the scope and requirements needed for a kinetic sculpture's timely and successful completion, focusing specifically on one component—a single cube or "box." This cube is a collaborative project requiring the expertise of three specialised engineering teams: Structures, Motions, and Communications. Each team is responsible for a subsystem within the cube, aligning with their respective engineering disciplines. The Structures team is in charge of the physical elements and integrity of the cube, ensuring it is both durable and aesthetically pleasing. The Motions team focuses on the kinetic aspects, engineering the moving parts to function smoothly and harmoniously. Meanwhile, the Communications team, where the emphasis of this document lies, is tasked with integrating LEDs into the cube, ensuring they coordinate effectively with the structural and kinetic elements.

By working in this cross-disciplinary setting, each team is allocated tasks that best match their engineering strengths, thereby optimising the overall quality and functionality of the cube. The collaborative nature of the project not only facilitates more efficient work

1.1 Project Scope

This document is a comprehensive guide detailing the software and hardware requirements essential for the development and functionality of the T3B1, a key component in the kinetic sculpture. By laying out these specifications, the document aims to establish a clear and focused set of goals for the project, acting as a roadmap for the team members involved. The requirements outlined here cover everything from the choice of materials and hardware components to the software algorithms and communication protocols needed for the T3B1 to operate seamlessly within the sculpture. Moreover, the design document holds significance as it lays out a step-by-step process that must be followed for the project to be successful. This includes milestones, testing phases, and integration points with the other subsystems—Structures and Motions—ensuring that the Communications team, or any other team working on the T3B1, has a clear directive from inception to completion. By adhering to this structured approach, the document aims to minimise ambiguities, reduce risks, and ensure that the project meets and exceeds the quality and functional expectations set forth by the School of Engineering.

1.2 Team Scope

Our team, primarily focused on the Communications aspect, has a multi-faceted role in developing the kinetic sculpture's cube, often called T3B1. Our core responsibility lies in coding the software that enables marble detection and signal transmission to the LEDs, dictating their behaviour based on marble movement or position. This software is crucial for the interactive and dynamic elements of the sculpture. In addition to our work on LED signalling, we are closely collaborating with the Motions team to integrate a mechanism known as the "flipper." This flipper is designed to interact seamlessly with the conveyor belt, a critical part of the Motions subsystem. We will ensure that the flipper meets all functional requirements, particularly in how it interfaces with the conveyor belt to manipulate the movement of the marbles.

Another subset of our responsibilities includes working on sensor-based systems that either allow or obstruct marbles to change their paths, enhancing the interactive nature of the sculpture. We will also contribute to the functionality of the motors that power the conveyor belt, ensuring that they operate reliably and efficiently. On the other hand, Group B1_S_1, the Structures team, will focus on the box's structural aspects. Their work will encompass the installation of various fixings and the creation of the path that the marble will follow, ensuring it meets all guidelines for durability and aesthetic appeal. By clearly delineating these roles, each team can focus on its areas of expertise while collaborating effectively to produce a cohesive, functional, and engaging kinetic sculpture.

1.3 Problem Definition

The School of Engineering aims to install a kinetic sculpture at the entrance of its main building to serve as a visual and symbolic representation of the institution's commitment to creativity, ingenuity, and engineering excellence. The sculpture will consist of multiple interacting cubes, each designed and produced to meet specific measurements and criteria provided by the client, the School of Engineering. The objectives of this project include creating a visually impactful sculpture that captures immediate attention, embodies high engineering standards in its design and functionality, allows for interactive or harmonious movement between the cubes, and symbolically represents the School's mission and values. The producers responsible for the cube components' design, manufacturing, and testing of the cube components will work closely with the School of Engineering, which will provide the required criteria and offer design approvals. The expected outcomes of this project are educational enrichment, inspiration for clearly delineating these roles, and enhanced public relations for the School of Engineering. The timeline for this project includes phases for conceptualisation, design, client approval, fabrication, and testing, leading up to the final installation of the sculpture.

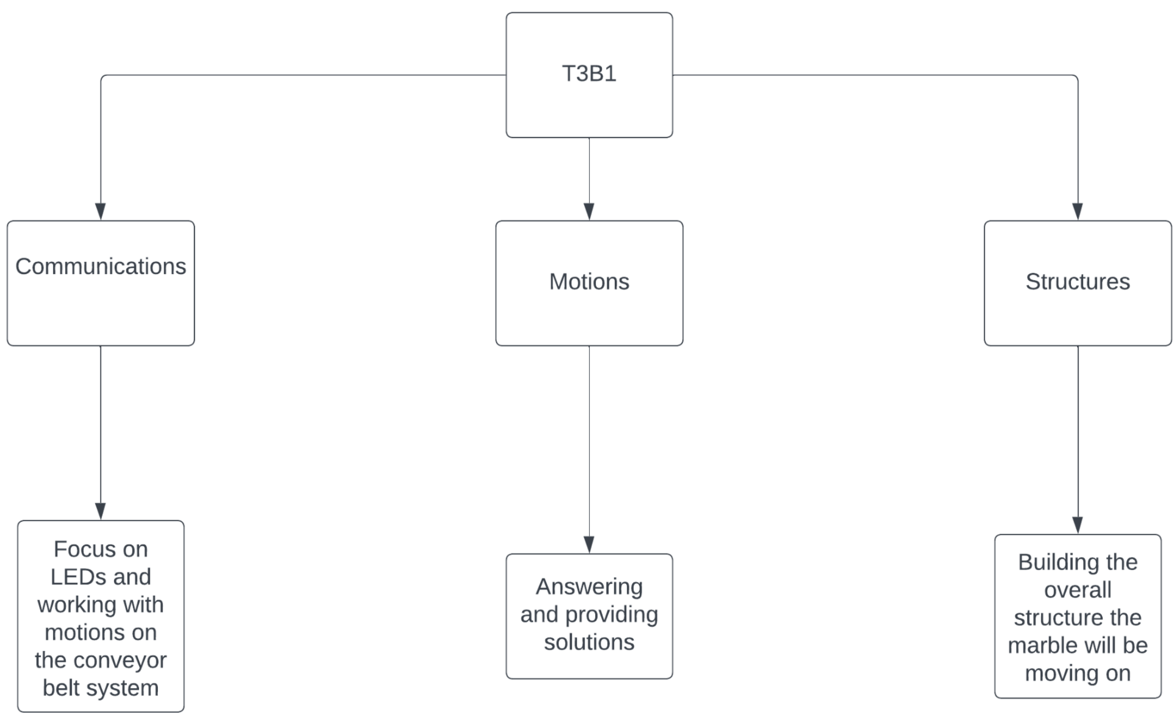
Table 1.3.1: Constraints

ID	Name	Description
C01	Time Constraint	The Entire project must be complete in 16 weeks
C02	Design Constraint	The design must adhere to the requirements set by the customer
C03	Budget Constraint	The entire design must not exceed $100
C04	Dependency Constraint	The Comms team must wait for Other teams to complete the bulk of their work.
C05	Workers Constraint:	The comms team has meagre numbers compared to other teams and other teams in other groups.

1.4 Subsystems

The communications team plays a specialised yet vital role, focusing exclusively on a single cube within the sculpture. While the Motions and Structures teams handle the kinetic and physical aspects of the cube, the Communications team is tasked with integrating LEDs and ensuring their effective coordination with the other subsystems. The LEDs serve as aesthetic elements and indicators or interactive components, potentially reflecting the cube's state, movement, or interaction with its environment. Working closely with the Motions and Structures teams, the Communications team ensures that the LED functionalities are seamlessly integrated into the overall design, adding a layer of visual and interactive complexity to the cube.

Fig 1.4.1: Flowchart of how the teams are created and their functions



2. Scope of Works

The Scope of Works section is a pivotal part of the project documentation, outlining the agreed-upon tasks, responsibilities, and expectations that will define the project's success upon completion. It is a binding agreement between the involved teams and stakeholders, ensuring everyone is aligned regarding objectives and deliverables.

2.1 Deliverables

Statement of Work

- The Statement of Work is a cornerstone document that formalises the project's overall scope, objectives, and commitments. It is an official communication medium between all parties involved, providing a detailed breakdown of the tasks, timelines, and resources allocated to each team and subsystem.

Design review

- The design review entails a comprehensive presentation of the project's current state, where domain experts and team members can offer constructive criticism and feedback. An early design will be presented for the coding aspect, as shown in **Fig 4**, to enable stakeholders to assess its functionality, efficiency, and adherence to project goals.

Testing document

- The testing document is a critical document that goes beyond just listing test cases; it outlines the function, performance, and interface requirements that the project must meet. Each requirement will be accompanied by testable statements to verify its successful implementation. Furthermore, the document will include an unbiased review of the design, highlighting its strengths and areas for improvement to ensure that the project aligns with the quality standards.

Design document

- This document will serve as a comprehensive guide to all code, interfaces, and communication protocols used in the project. It will provide a deep dive into the technical aspects, including a UML diagram to visualise the architecture and relationships within the codebase.

Final product

- A video presentation demonstrating the product in action will showcase the project's culmination. This video will provide an end-to-end view of the product, highlighting its subsystems, their integration, and how they collectively contribute to the kinetic sculpture's functionality and aesthetic appeal.

2.2 Inclusions and Exclusions

Table 2.2.1: Inclusions and exclusions table

Type	Description
Inclusions	Presenting a definite set of LEDs and their digital layout
	Carrying out the majority, if not the entirety, of the programming for all components and electronics.
	Consulting regularly with team B1_M_3 over the following tasks; - Stopper and Motor implementation and programming - Testing and investigating the performance of all electronic components
Exclusions	Assembly of the following features; - Cube structure - Cube layout - Component materials
	Proposing the Bill of Materials
	Placement and arrangement of all components, including electrical
	Producing the final design of the cube

3. Requirements

Reviewing the work outline, a list of requirements is compiled to provide details and traceability of how the final design will meet the client's expectations. Functional Requirements highlight all mandatory behavioural descriptions necessary for the box to perform. Performance Requirements aim to optimise potential solutions by considering quantifiable technical measures (TPMs) and nonmeasurable design elements. Interface requirements come from how the different systems interact with one another.

3.1 Functional requirements

Table 3.1.1: Functional Requirements

Requirement ID	Requirement	Requirement details	Priority
FREQ1	Exit speed	The marble entry and exit speed should be the same	Low
FREQ2	Hold time	The flipper must be able to hold the marble in place for at least 0.5 seconds	High
FREQ3	LED response	All LEDs will respond to the state of the machine/marble	Med

3.2 Performance requirements

Table 3.2.1: Performance Requirements

Requirement ID	Requirement	Requirement details	Priority
PREQ1	Flipper speed	The flipper must be able to release the marble quickly	Low
PREQ2	Overflow prevention	The cube must be able to handle the marbles entering at a rate of 1 marble per second	High

3.3 Interface requirements

Table 3.3.1: Interface Requirements

Requirement ID	Requirement	Requirement details	Priority
IREQ1	LED scrolling	The LEDs along the belt should be able to indicate the progress of the marble moving along the belt.	Low
IREQ2	Marble entrance and exit:	The sensor should detect if a marble enters the machine.	Med
IREQ3	Flipper detection:	The LED at the flipper should indicate if a marble is present and if it is waiting to be released.	Med

4. Conceptual Design

The main 'problem' area and the area with the most design alternatives is the 'Wheel' (originally the 'Flipper'). It is a high-traffic, complex, and relatively small moving component. Several issues arose from this area, the first being with the vertical 'flipper', which would work and is possible in every regard except for the unavoidable chance of jamming due to its downward motion on the marble.

This led to considering an alternative component for controlling the marbles entering the conveyor belt, which focused more on feeding them into the conveyor belt rather than stopping them. This component is known as the 'Wheel'. It sat off the ramp the marbles used to enter and would catch them in grooves. It would then move upwards and dump the marble onto the conveyor belt. This wheel would only be able to carry two marbles at a time, which would control the amount of marbles entering the conveyor belt.

Unfortunately, this leads to spatial issues with the diameter of the wheel. Now, it is in danger of breaking the constraints set by the customer as the entry hole to the machine is 40mm with 27.5mm of actual workable space. Within this space, the entry ramp still needs to tilt downwards, which leaves the wheel's diameter too small and determined to be infeasible without changing the design.

A subtype of the 'Wheel' is the horizontal wheel. It is functionally the same as its supertype but turned 90 degrees so that the motor is perpendicular to the conveyor belt, either above or below the wheel. This alternative design, however, comes with issues. Since the marble no longer leaves the wheel by being forced out by gravity and dumped onto the conveyor belt, the bottom of the notch that allows marbles into the rotation is tilted so that if left still, it would roll out on its own. The entry ramp would need to be steeper so the marbles have enough time to get into the wheel. Not to mention the issue of a buildup of marbles. In that case, the marble would not have enough speed to get into the wheel and, therefore, get stuck. This design also worsens the space issue as the entry ramp needs to be steeper, making the conveyor belt even closer to the ground. This alternative is less desirable than the others but remains an option if specifications such as entry hole height increase.

A new design was drafted to ease the strain on the whole system and one without the risk of jamming or breaching specifications. This alternative was called the "45° Ferris Wheel". It was two pieces of solid material with one hole on top and one hole on the bottom, each on opposite sides of the Ferris wheel. Inside would be three moving fins. The marble would enter the hole between the fins and move upwards towards the other hole, whilst the hole it entered would be covered by the solid part of the fin, preventing another from entering. It would then fall through the exit hole on the bottom side onto the conveyor belt. This design alternative was sound and solved the problem of space and jamming. However, this required a complete redesign of the wheel and would take more time and effort to get working correctly.

Note: Motions did not supply diagrams/drawings of these alternate designs.

5. Detailed design

In the detailed design, a comprehensive analysis of the marble machine will be conducted, primarily emphasising its software architecture. While the core focus remains on these digital parameters precisely, the codebase responsible for the LED control algorithms and the structures and motions will also be discussed to give a holistic understanding of the machine. These include the structural engineering specifications and the kinematic properties that govern marble movement. Our engineering team is executing the project strictly adhering to the guidelines and subsystem requirements defined by T3C6 and T3M3, ensuring alignment across software and hardware dimensions.

5.1 Assumptions

The design shall assume the following is true:

- The power source is continuous and produces a steady stream of electricity at 12v.
- There is only one Arduino unit that controls all the subsystems and components.
- There will be no external influence or interaction except for the power provided externally.
- Furthermore, according to the above statement, the program is expected to function correctly without assistance.
- All cables will not have any difficulty connecting the components together; as such, they will not need to be accounted for in this section.
- There is ample space and mounting for all components to be implemented appropriately.

5.2 Structures

As outlined in the conceptual design documentation, the Structures Team's primary responsibility centres on the enclosure's fabrication and structural integrity, commonly referred to as "the box." This responsibility encompasses not only the material selection and assembly of the box but also the strategic placement and secure mounting of critical components. Specifically, the components requiring meticulous mounting procedures include the wheel assembly, the conveyor belt mechanism, and both the entrance and exit ramps. For a visual representation of these components and their planned locations within the box, refer to **Fig 5** in the accompanying illustrations.

5.3 Motions

The Motions Team is primarily responsible for overseeing the marble's overall kinematic behaviour within the system. A significant area of focus for this team is the wheel mechanism, which is critical for preventing any potential buildup of marbles—a scenario that could lead to system failure. Additionally, the team is actively involved in optimising the marble's transition onto the conveyor belt and in selecting and controlling the servo motors that power this conveyor system.

5.4 Code

Due to Arduino's use of the C++ programming language, the entire program will be programmed in C++. The Arduino is expected to control all subsystems, which function separately from one another; hence, a single program where a cyclic layout will loop through all subsystems and update them one at a time will be put in place.

As such, the program cannot use delay functions, as a delay in one subsystem will also cause a delay in all the other subsystems. We can solve this issue by giving subsystems their clock, at which they can carry out their functions should the clock reach 0. **See Fig 6** for the provided diagram.

5.5 Component list

The design for all subsystems is expected to use the following components.

Table 5.5.1: Component List

Component ID	Component name	Amount
COMP01	IR sensor	3
COMP02	LED bulb	3
COMP03	LED strip	1
COMP04	Continuous motor	1
COMP05	Adjustable stepping motor	1

5.6 Subsystems

Table 5.6.1: Subsystem List

Subsystem name	Components used	Description	Designed by
Entrance LED	COMP01 COMP02	Placed at the entrance of the cube, the LED will light up when a marble triggers its IR sensor.	T3C6
Exit LED	COMP01 COMP02	Functions identically to the entrance LED, with the difference that both the LED and its IR sensor are placed at the cube's exit.	T3C6
Wheel LED, Belt scrolling LED strip, and wheel motor (combined)	COMP01 COMP02 COMP03 COMP04	Functions identically to the subsystems above. However, the IR sensor is placed at the gate, and the IR sensor will trigger 2 additional components along with the LED. When activated, the LED strip will send an LED 'pulse' that will follow the marble as it progresses up the conveyor belt. When activated, the wheel will rotate 60° to collect one marble and eject it onto the belt.	T3C6 & T3M3
Belt motor	COMP05	Unlike the other subsystems, the Belt motor will not take any input from any sensor and will spin continuously and at a fixed rate.	T3M3

*See **Fig. 7 and 8** for the LED flowcharts*

6. Technical Performance Measures and Testing

TPM Code	TPM Name
TPM01	LED scrolling calibration
TPM02	Entry Motion sensor

TPM Code	TPM01
TPM Name	LED scrolling calibration
TPM Purpose	To ensure that the scrolling of the LEDs along the belt align with the marble's movement
Source Requirement	RC3. RC10
Risk Level(High, Med, Low)	Low
What should be measured?	The rate at which the LED pulse travels up the belt
How should it be measured?	There will be a test, which will use a timer to measure the time taken for both the marble and the pulse to reach the end.
How often should we measure it?	This test will be carried out with every subsequent change to the machine to ensure that the feature remains functional as intended.
Measures of Success	If the LED pulse reaches the end of the belt within 20 ms earlier or later than the marble
Measures of Failure	If the LED pulse reaches the end of the belt over 20 ms earlier or later than the marble
Possible Causes of Failure	● The program is not calibrated to the scrolling correctly ● The wires are improperly secured and connected ● The sensor fails to detect the marble

TPM Code	TPM02
TPM Name	Entry infrared/light sensor
TPM Purpose	To detect the entry of marbles entering the machine
Source Requirement	RC6. RC7.
Risk Level(High, Med, Low)	Low
What should be measured?	Does it detect whether or not a marble enters?
How should it be measured?	By how many marbles it detects over how many marbles enter in total. Marbles detected/total marbles
How often should we measure it?	The test should be carried out after any changes in the physical positioning or code changes. To ensure that the changes do not hinder or cause a failure in performance.
Measures of Success	If the sensor constantly detects all marbles entering the machine.
Measures of Failure:	If the sensor fails to detect a marble.
Possible Causes of Failure	● The wires are improperly secured and connected ● The sensor is incorrectly or poorly mounted ● The sensor is too far away.

7. Design Traceability:

The traceability section within a design document plays a pivotal role in maintaining project progress and ensuring the alignment of design requirements. Its role mainly monitors various project components, encompassing requirements, design elements and implementation steps. Keeping constant track of whether project requirements are met is essential to keep within the scope and budget of a project.

Table 7.1.1: Traceability Matrix

Requirement	Description	Team	R	D	I	Fulfillment
REQ01	The infrared sensor must detect when a marble enters the machine.	Comms	X	X		The Sensor is to be placed close to the entrance so that the system can detect and register an entering marble.
REQ02	The Marble flow-control Module must control the flow of marbles to be that of a rate of 1 marble per second.	Motions /Comms	X	X		A ‘Wheel’ placed at a 45-degree angle will pick up the marble on its low end and drop it out at the high end through a hidden hole (see design specifications)
REQ03	The LEDs should illuminate the interior of the machine and ‘follow’ the path of the Marbles while they are in motion	Comms	X	X		LEDs to be added along the path the marble takes such as the entry ramp and the conveyor belt
REQ04	The marble enters the hole at a lower point that it’s designated exit. Therefore, the Marble must be assisted in its exit.	Struct/ Motions /Comms	X	X		Using a conveyor belt powered by motors that the marbles are fed onto allows the marbles to start at a lower point and still exit at a higher point.

REQ05	The Conveyor belt must be able to handle the load of six marbles on it at once without a decrease in performance.	Struct/ Motions	X	X		The Conveyor belt has six ‘teeth’, which can hold a maximum of six marbles at a time. The Motors being used have a ‘factor of safety’ well over what is required and will not be affected by a slight increase in weight.

Sign	Meaning
R	Requirement; this column indicates whether this is a requirement
D	Design, this column indicates whether the requirement/component has developed a detailed design specification or plan that outlines how you will fulfil a specific requirement
I	Implementation, this column indicates whether the requirement/component has been implemented. For example, written the code, developed the software, or built the system components required to meet the specific requirement.
X	This mark is used to signify that the requirement specified in its respective row has been completed to the stage specified by the column.

8. Testing

<table>
<tr><td>Name</td><td>Test Input ‘0’</td></tr>
<tr><td>Requirement(s)</td><td>REQ01: The infrared sensor must detect when a marble enters the machine.</td></tr>
<tr><td>Procedure</td><td>A Marble will be rolled between the sensors. Observers will then check to see if the motor activates. This occurs when 0 is returned inside the code which in turn occurs when a line of sight between sensor modules is broken. Therefore the sensor detected the marble</td></tr>
<tr><td>Risk</td><td><table>
<tr><td>Type:</td><td>Motor-related injury</td></tr>
<tr><td>Probability</td><td>Low</td></tr>
<tr><td>Severity</td><td>Low</td></tr>
<tr><td>Mitigation</td><td>Users will keep hands away from motors while the test is in session.</td></tr>
</table></td></tr>
<tr><td>Result</td><td>The detection rate was inconsistent, and the location of the testing environment is believed to influence the result. The test was able to detect input consistently in one environment, but when moving to another environment, the test failed continuously.</td></tr>
<tr><td>Measures of success</td><td>A consistent success rate of 90% and above is considered acceptable, as a minor backlog can be handled by the system. For example, the system can, at the very worst, handle a backlog of three marbles. So two failures are considered acceptable as to allow for a small factor of safety.</td></tr>
<tr><td>Measures of Failure</td><td>A consistent score of below 90%, this means backlogs are going to become extremely common, and the chance of a jam is high.</td></tr>
</table>

<table>
<tr><td>Name</td><td>Correct delay length and timing</td></tr>
<tr><td>Requirement(s)</td><td>REQ01: The infrared sensor must detect when a marble enters the machine.</td></tr>
<tr><td>Procedure</td><td>Line of sight will be broken between the two sensor modules with an object. Once the object no longer obstructs the view between the sensors, the Observers will check to see if the correct length of delay occurs before motor activation</td></tr>
<tr><td>Risk</td><td><table>
<tr><td>Type:</td><td>Motor-related injury</td></tr>
<tr><td>Probability</td><td>Low</td></tr>
<tr><td>Severity</td><td>Low</td></tr>
<tr><td>Mitigation</td><td>Users will keep hands away from motors while the test is in session.</td></tr>
</table></td></tr>
<tr><td>Result</td><td>The time between the motor movement and marble detection was consistently 1 second. This was confirmed with both the simulation on Arduino and the physical Arduino unit, with the components installed.</td></tr>
<tr><td>Measures of success</td><td>A success rate of 90% or above is considered acceptable. If the correct delay is observed before the activation of the motor, this means there will be or close to a seamless transition for the marble to enter the next stage of the system.</td></tr>
<tr><td>Measures of Failure</td><td>Below 90% is considered a failure. If the incorrect delay is observed, the marble must wait at the entrance to the next stage of the system before being allowed entry</td></tr>
</table>

<table>
<tr><td>Name</td><td>Sensor Distance</td></tr>
<tr><td>Requirement</td><td>REQ01: The infrared sensor must detect when a marble enters the machine.</td></tr>
<tr><td>Procedure</td><td>The two sensor modules will be held in place by an object/axis where they face each other. They will then be incrementally moved further apart and observed whether or not they still give accurate readings.</td></tr>
<tr><td>Risk</td><td><table>
<tr><td>Type:</td><td>Heat/burn-related injury</td></tr>
<tr><td>Probability</td><td>Low</td></tr>
<tr><td>Severity</td><td>Low</td></tr>
<tr><td>Mitigation</td><td>Users will keep hands away from sensors while the test is in session and will be wearing proper PPE if positional correction is needed.</td></tr>
</table></td></tr>
<tr><td>Result</td><td>The sensors were able to remain effective at a range beyond 10cm. The receiver sensor also had a maximum angle tolerance of 1 degree, when aligning with the emitter sensor.</td></tr>
<tr><td>Measures of success</td><td>Correct sensor readings of 5 cm distance apart are considered acceptable, and 10 cm is considered successful.</td></tr>
<tr><td>Measures of Failure</td><td>Anything less than 5 cm is considered a failure and may require design change.</td></tr>
</table>

<table>
<tr><td>Name</td><td>Correct LED Pattern</td></tr>
<tr><td>Requirement</td><td>REQ03: The LEDs should illuminate the interior of the machine and ‘follow’ the path of the Marbles while they are in motion</td></tr>
<tr><td>Procedure</td><td>LEDs will be fitted to easily observable surfaces. The input ‘0’ will be passed by marble. Observers will then check to see if the LED ‘follow’ the marble. This is, to a degree, down to observers discretion.</td></tr>
<tr><td>Risk</td><td><table>
<tr><td>Type:</td><td>Heat/burn-related injury</td></tr>
<tr><td>Probability</td><td>Medium</td></tr>
<tr><td>Severity</td><td>Low</td></tr>
<tr><td>Mitigation</td><td>Users will keep their hands away from LEDs while they are on and wear PPE to avoid possible burns. They will also allow LEDs to cool</td></tr>
</table></td></tr>
<tr><td>Result</td><td>For single marbles and less than 4 marbles, the LEDs were able to trace the path of the marbles correctly. However, when inputting multiple marbles, the LEDs began to behave erratically when 4 or more marbles were present. Results were obtained via a simulation conducted with TinkerCAD, as the components were not yet ready to test.</td></tr>
<tr><td>Measures of success</td><td>If the Observers determine that the pattern was satisfactory 70% of the tests, the LEDs are considered acceptable</td></tr>
<tr><td>Measures of Failure</td><td>If the Observers determine that the LEDs were unsatisfactory more than 30% of the time. The test is considered a failure, and the LEDs should be adjusted.</td></tr>
</table>

9. Design Review

Even when producing the product, it is crucial to confirm that the product not only satisfies all requirements provided by the customer but also to identify potential issues and seek feedback. This will be carried out in this portion of the document, the design review.

The design review will focus on alternative approaches to the technical aspects of the marble machine, more specifically the software architecture, as well as components influenced by the software system when necessary. Possible improvements to the existing design will also be discussed.

9.1 Alternative Designs

Given the current requirements and the same assumptions specified in **5.1**, there are a number of alternative designs and decisions that could have been devised;

LEDs for indicating marble count

To satisfy the requirement FREQ3, the alternative to scrolling LED strip subsystems could include an LED subsystem that changes its colour or brightness depending on the number of marbles in the backlog. While this design could minimise the component cost and complexity, this would require a method of counting the number of marbles, which would be too reliant on the sensors not only being able to detect individual marbles but to also distinguish between entering and exiting marbles, which would be unfeasibly difficult to implements.

Scrolling LED strip

Instead of timing the marble's ascent manually in the software, the LED strip could synchronise with the marble on the belt by giving each LED its own sensor. This would increase the reliability of the subsystem, as it would require less manual adjustment and be easier to implement, however would also greatly increase the cost of the design, as multiple sensors will need to be purchased and used.

9.2 Possible Improvements

In the case that the time frame of the project was increased, there are a couple of changes that could have been made.

Testing Quality and Quantity

The number of test cases and the amount they were tested is an area of development that the team agrees would be focused on in the event of a pushed-back deadline. Most of the components that Comms could test relied on the completion of work from other teams. However, tests were still carried out on individual components such as the sensors, motor and LEDs to ensure that the code was reliable. The team unanimously agrees that the amount of testing is satisfactory accounting for the circumstances.

Additional feature

Given the event of a deadline pushback, another feature that the Comms team would like to have implemented was communication with the subsequent Marble machine. This would have increased the overall complexity but also could optimise marble flow between machines. Although this idea has less priority than the additional testing.

Sign-offs

	Name	Team Accepting	Requirements	Team Responsible	Providing Team member Sign off	Accepting Team Member Sign Off
1	Movement of the ball	T3C6	IREQ 1	T3S1		
2	Structure of Box	T3C6	FREQ 1	T3S1		
3	Mounting of box	T3C6	FREQ 3	T3S1		
4	Positioning of sensors	T3C6	IREQ 2	T3M3		
5	Programming of sensors	T3C6	IREQ 2	T3C6		
6	Circuit Diagram	T3C6	IREQ 1	T3M3		
7	LED Design	T3C6	IREQ 3	T3C6		
8	Flipper Location	T3C6	IREQ 3	T3M3		

References

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6VH1ANEJbQVpPKXjtGC-TjF4p54ddwtBg5A1XBjZBjs-77vc4hGEVaMOsUEfg-QnfLgSqJ1rm2L
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Appendices

FIG 1: Arduino that will be used

FIG 2: IR Sensor to use for the flipper

FIG 3: Type of LED that will be used

FIG 4: Prototype code for the lighting.

```
#include <Adafruit_NeoPixel.h>
const int CONTROL_PIN = 7;
const int LED_COUNT = 8;

int state[LED_COUNT + 1];
int updateSpeed = 30;
int clockSpeed = 4;
int inputState = 0;

int clock = clockSpeed;

//Debug declarations
const int INPUT_PIN = 2;
const int OUTPUT_PIN = 13;
boolean lock = false;

Adafruit_NeoPixel NeoPixel(LED_COUNT, CONTROL_PIN, NEO_GRB + NEO_KHZ800);

void setup(){
  Serial.begin(9600);
  NeoPixel.setBrightness(255);
  NeoPixel.begin();
  //Debug input
  pinMode(OUTPUT_PIN, OUTPUT);
  pinMode(INPUT_PIN, INPUT_PULLUP);
}

void loop(){
  //Input detection and locking
  if(digitalRead(INPUT_PIN) == 0){
    inputState = 1;
  }
  //Printing and displaying all values
  for(int i = 0; i <= LED_COUNT; i++){
    Serial.print(state[i]);
  }
  Serial.println();
  //
  clock--;
  if(clock <= 0){
    clock = clockSpeed;
    //Updating
    for(int i = LED_COUNT; i >= 0; i--){
        state[i] = state[i - 1];
        }
    inputState = 0;
  }
  //Displaying
  for(int i = 0; i < LED_COUNT; i++){
        if(state[i + 1] == 1){
          NeoPixel.setPixelColor(i, NeoPixel.Color(255, 255, 255));
        }
        else{
          NeoPixel.setPixelColor(i, NeoPixel.Color(0, 0, 0));
        }
        NeoPixel.show();
  }
  state[0] = inputState;
//  Serial.println(clock);
  delay(updateSpeed);
}
```

FIG 5: Technical drawing of entrance bay

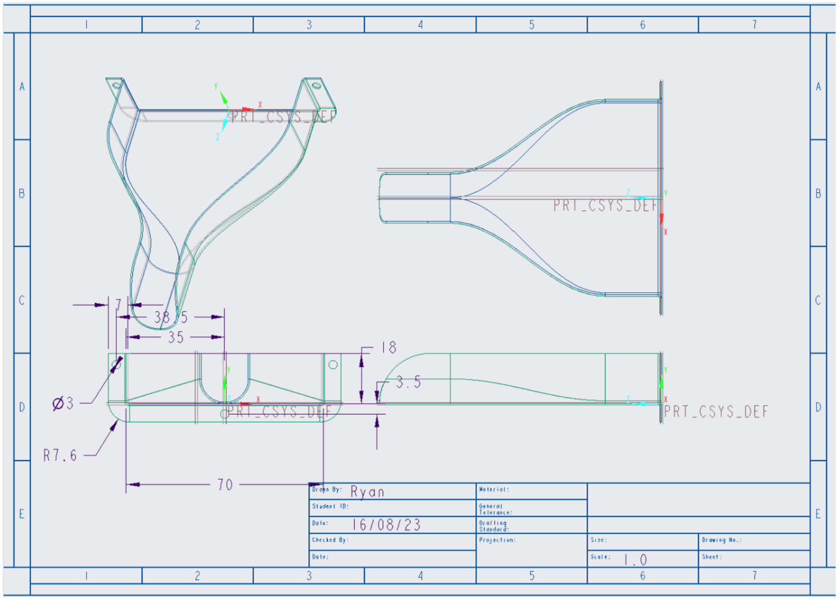

FIG 6: Flowchart of the program that controls all subsystems

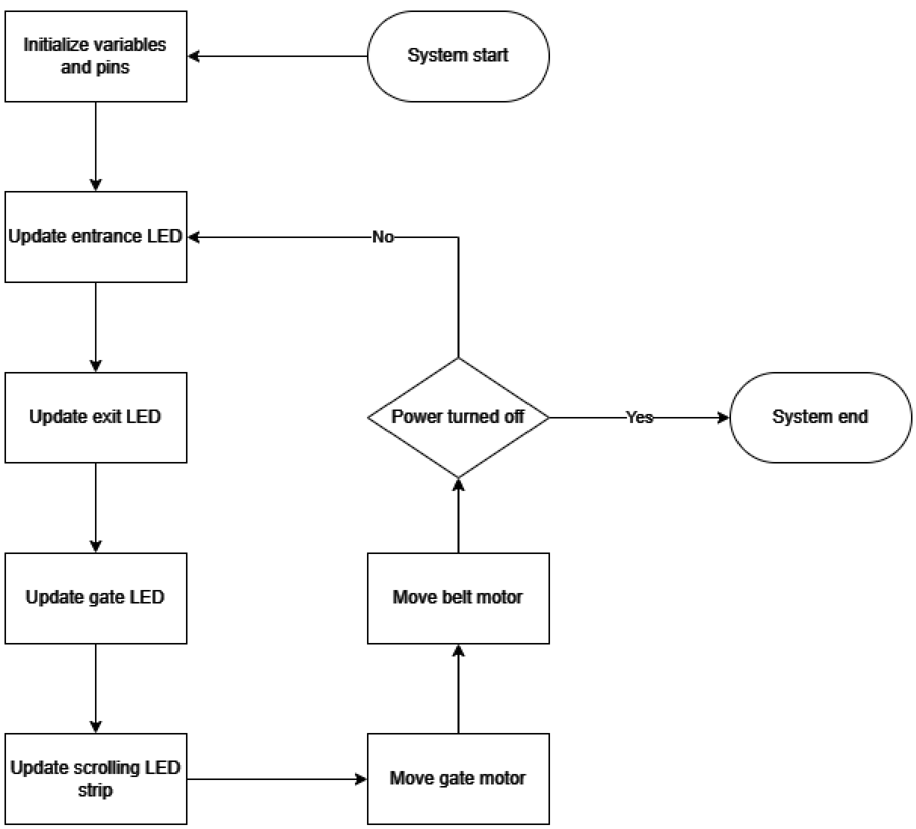

FIG 7: Flowchart for the LED scrolling subsystem

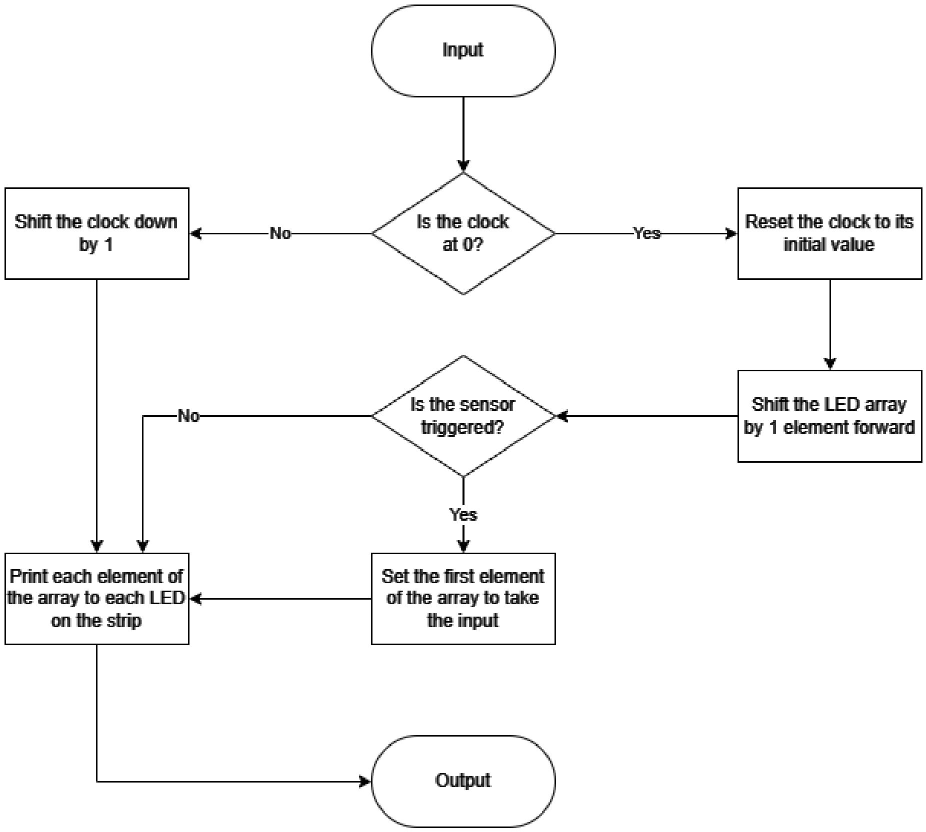

FIG 8: Flowchart for the entrance and exit LEDs