DYNOSCAN 3D

Project Quality Plan (PQP)

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Version	Details Changed
V5	N/A
V6	Expanded on the evaluation of existing commercial solutions Amended the risk assessment to include software challenges Updated the Gantt chart
V7	Updated Gantt chart v2 Updated skills acquired and skills required table Amended the risk assessment to include electronics/control challenges Updated Product Design Specification – testing of scanner calibration
V8	Updated Gantt chart v3 Updated supervisor communication section to reflect new meeting dates Updated technical roles
V9	Updated Gantt chart v4 Updated training requirements to include software packages (Meshlab) Updated budget expenditure

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1 Introduction

3D scanning is an expedient way to translate a physical object into data that can be viewed using 3D modelling software and printed using additive manufacturing. Imperial College London's Dynamics Group requires an automated 3D scanning solution that can digitise medium-sized engine components and other industrial components.

Current commercial solutions are unsuitable to meet the requirements of the Imperial College's Dynamics Group as they are either exceed the initial stipulated budget of £1000 or are incompatible with larger and heavier objects. Other competitors are identified in Figure 1 and Table 1, such as the Scoobe3D [1], HandySCAN 700 [2], and the Peel 3D [3], however, these products all require manual scanning of the object which is generally time consuming. As such, the Dynamics Group have requested a solution that can be used to 3D scan medium sized objects with minimal operation, for less than £1000.

The main objective of this project is to develop a structural mechanism that houses a 3D scanner that can capture the digital data of an object from all angles. The scanning process should be automated and require minimal human interaction after initializing. The overall device should be able to be easily transported.

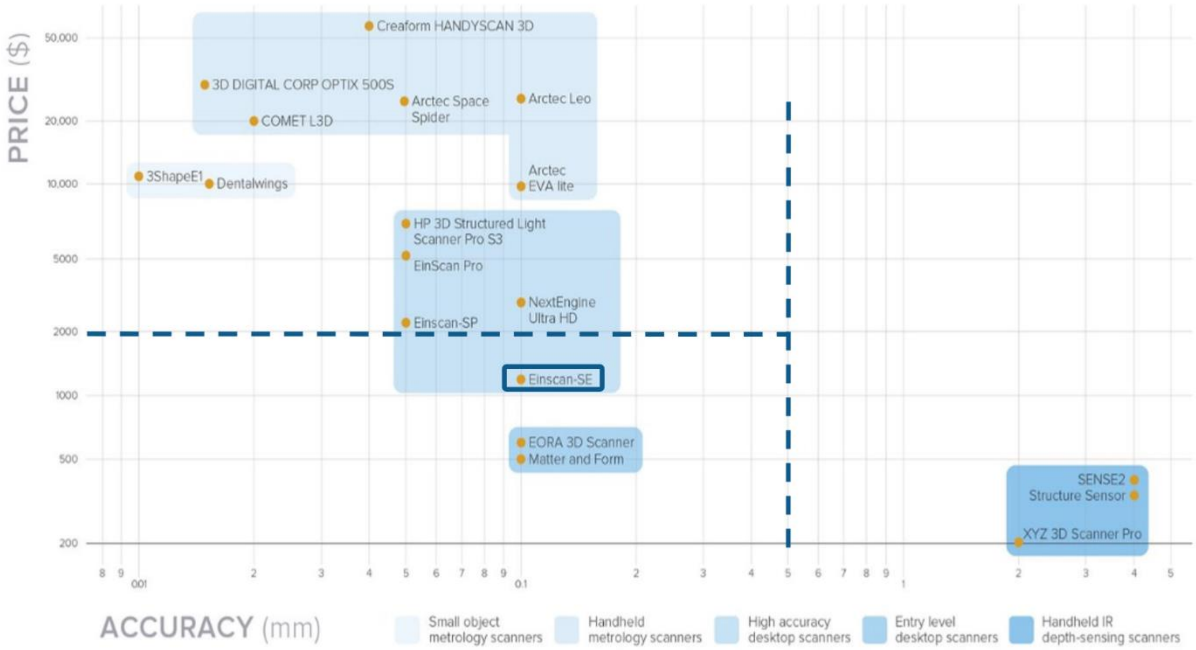

Figure 1: Market analysis plot of price vs. resolution of 3D scanning devices [4]

Table 1: Summary of commercially available 3D scanners

Product Name	Price	Features	Evaluation
Einscan-SE	£1,400	Structured Light Scanner 570x210x210 mm dimensions Can be used without turntable	5 kg turntable capacity Proprietary Software

		Scan time between 4-60 seconds Point distance resolution 0.17-0.2 mm 4.9 kg device weight	
EORA 3D Scanner	£455	Slit Laser Scanner Utilizes smartphone camera to scan 2.2 kg device weight High point cloud density that can be edited on smartphone or desktop Approximate resolution of 0.1 mm	5 kg turntable capacity Unable to scan objects larger than Ø (diameter) 300 mm Poor generation of watertight meshing Proprietary software
Matter and Form	£570	Laser Scanner 345x210x345 mm dimensions Approximate resolution of 0.1 mm 1.71 kg device weight	Extensive education resources for user operation Proprietary software 3 kg turntable capacity Cannot be used independently of turntable
GOM ATOS Scanbox 5	> £100,000	Structured Light Scanner Industrial Solution Point distance resolution of 0.05 mm	Proprietary software
Peel3D Scanner	> £5,900	0.95 kg device weight Handheld scanner 150 x 171 x 251 mm dimensions Point distance resolution of 0.5 mm	Proprietary software

2 Scope

2.1 Project Objectives:

The team is tasked to:

1. Design, make, and test a platform to 3D scan a stationary object.
2. Ensure that the platform must support up to 20 kg and be portable by 2 people or fewer.
3. Implement a modular scanner to produce 3D model.

2.2 Product Design Specification

Table 2 below summarises the pertinent requirements for the scanner.

Table 2: Product design specification outlining intended design aspects.

Aspect	Criteria	Evaluation
Customer Requirements		
General Description	A physical system that allows the user to scan and obtain a 3D model of a desired object.	N/A
Scan Space	Able to contain and scan an object measuring up to Ø 500x300 mm (height).	Design Review
Transportability	Portable by 2 people.	Check the total mass based on density and volume calculations

3D Model Resolution	Less than 0.5 mm.	Testing
Scan time	Total scan time to take less than 1 hour.	Testing
Scanning Software	Software must be accessible and modifiable without any prior purchase.	NA
Scanning Device Housing	Scanning device housing must be accessible for maintenance. Scanning devices should be installed in a modular manner to accommodate for future improvements.	Design Review Testing
Competition	Expensive commercial solutions (GOM). Cheaper hand-held scanners (Scoobe3D, Peel 3D, HandySCAN 700). Small-scale open source solutions (FabScan).	NA
Aesthetics	No exposed sharp edges to minimise injuries whilst handling product.	Design Review All edges to be chamfered
Operation		
Scanner Output	Data must be taken from the object from all angles and preferably stored in a suitable 3D modelling format.	Design Review Testing
Calibration	Calibration procedure only required if scanning device is replaced or the distance between camera and projector is changed.	Testing Evaluate 3D model dimensions against object of known dimensions
Scanning Device Position	Scanning device to be adjustable with respect to the platform in order to optimise scan results.	Testing
Setup Safety	Clear indication of machine state prior to placing object.	Design Review Ensure all wires are insulated during assembly
Operational Safety	No exposed wiring or moving transmission parts. Any intense light or laser sources must be shielded from the naked eye. Failsafe switch to kill operation. Temperatures to be kept within a safe range to prevent operator injury.	Design Review Visual feedback during operational testing
Control		
Environment	Scanner to be operated indoors with adjustable lighting to accommodate for optimal environment for scanning.	Running of scanner in ambient different lighting conditions
Operating Conditions	Scanning to take place in ambient conditions of room temperature and pressure.	Running of scanner in the aforementioned conditions
Aesthetics	A self-contained device with no external sharp edges.	Design Review
Life		
Service Life	5 years – Long enough for customer to make further modifications and upgrades.	Calculation of service life of parts under stress like bearings
Maintenance	Modular scanner that can be replaced. Scanning device lens to be accessible for cleaning.	Design Review Validated during assembly
Production		
Quantity	One product is required.	NA
Assembly	Manufacturable parts to be made in the Student Teaching Workshop (STW) (CNC milling, turning, laser cutting, welding)	Design Review

	Hackspace (3D printing). Must be manufactured and assembled using facilities available.	
Costs	Total costs including prototyping to be under £1000. Additional funds up to £1000 may be given to procure a more expensive optical scanning device.	Review of expenditure sheet
Standards		
Drawing Standards	BS 8888	Design Review
Lab Safety Standards	Induction provided by department to access Dynamics Lab. Induction arranged by group to access lasers. Supervisor clearance needed when working with lasers of class 3 and above.	NA

2.3 Justifications for Design Specifications

A suitable scan space was decided to allow for scanning of a medium-sized engine component or a large object of up to 500 mm diameter with a height of 300 mm. This was after consideration of the largest object the dynamics group needed to scan.

The design must also be light enough for two people to move it over a short distance. A study shows that for 95% of the human population, a group of 2 males or a group of 2 females should not be able to lift loads greater than 83 and 63 kg respectively [5]. Therefore, the conservative lower bound was taken and a safety factor of 2 applied to reach a 30 kg maximum weight threshold.

The scanner should also output the model in a suitable 3D modelling format so that file can then be easily manipulated using commercially available software such as Solidworks, which is used by the Dynamics group. Also, a resolution of 0.5 mm was chosen both by surveying commercial scanners at our project budget range and discussion with the Dynamics group for the tolerances required of the scanned objects.

Since future iterations and improvements of the scanning device are plausible, the design should accommodate for a modular scanning device housing and facilitate the ease of integration.

Calibration is required to determine the intrinsic and extrinsic parameters of any optical device, in order to obtain an accurate and complete replication of object. To facilitate ease of use, this procedure should be done as little as possible, optimally only when the positions of the optical devices such as the camera and projector are moved relative to each other.

Environment and operating conditions must be considered as it may affect scan quality. As the Dynamics lab is a closed environment, variable lighting conditions can be achieved, such as having a dark room or a brightly illuminated one. After the market survey of existing products, it was deemed unlikely that extraordinary luminosity is required.

2.4 Gantt Chart

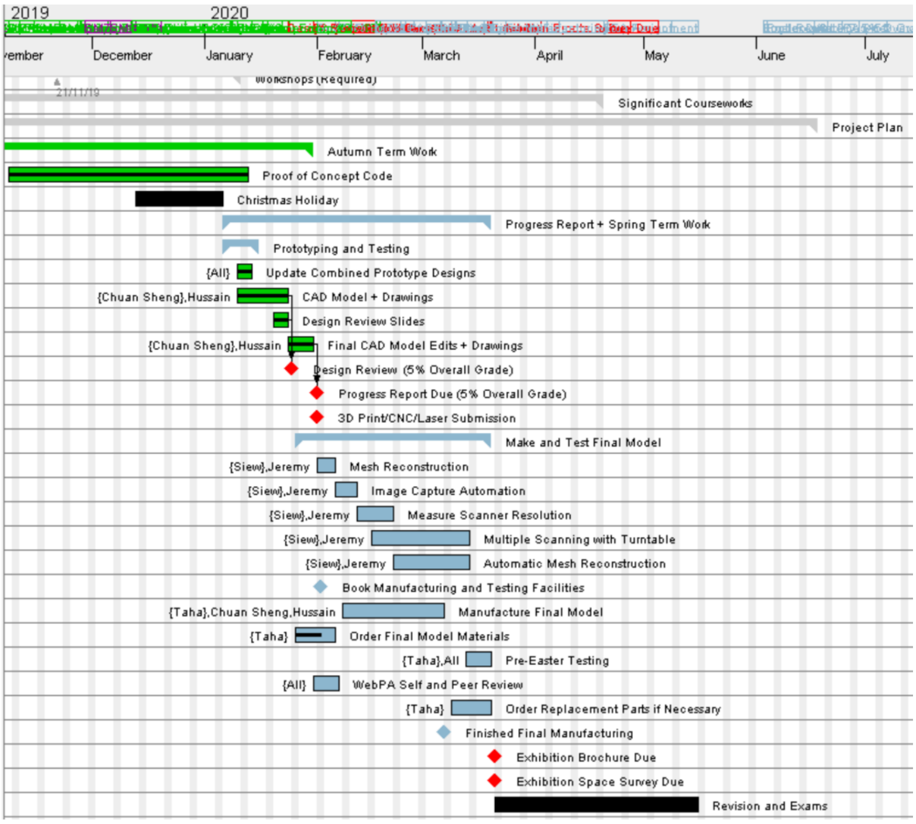

Figure 2: Forecasted Spring and Summer Term Workload and Crucial Deadlines. Gantt chart accurate as of 28/01/2020 [6].

Note in Figure 2, the 'Significant Courseworks' and 'Autumn Term Work' along with all the key milestones contained, have been collapsed in the top portion of the Gantt chart. This has been done to preserve the conciseness and legibility of the Gantt chart.

Table 3: Colour code to indicate nature of activity in Gantt chart.

Colour Code	Description
Green	Completed activities and milestones
Blue	Future activities and milestones
Black	Holidays/Low work periods
Red	Critical milestones

Table 3 shows the colour code that corresponds to the different activities in the Gantt chart. Tasks have been assigned to different group members, indicated by their names to the left of the activity. Furthermore, the individual in charge of an activity overall has his name inside a curly bracket. Slack has been accounted for in this Gantt chart by the space between activities. For example, in Autumn term during the December to January period, slack (denoted by a black block) was introduced between the embodiment designs and working prototype, due to the heavy workload from the Literature Research Project and Embedded C for Microcontrollers coursework and Christmas holidays which will limit how much work that can be completed. In

Spring term, slack was introduced by leaving a gap in between 'Order Final Model Materials' and 'Manufacture Final Model' to accommodate any procurement delays. Similarly, slack was introduced to accommodate for any manufacturing delays that may impact 'Pre-Easter Testing'.

However, an arrow linking two activities together indicates that the previous activity must be completed before proceeding onto the next activity. For example, RAFT and other induction activities must be completed prior to commencing embodiment prototyping as access may be needed to facilities that require training.

Table 4 shows a summarised history of changes made to the Gantt chart as the project progressed.

Table 4: Version history of Gantt chart

Version	Date	Details Changed
2	06/12/2019	Events Brought Forward: • "Manufacturing of Turntable and Transmission Prototype", "Testing of Turntable and Transmission Prototype" – As the design review has a greater focus on the mechanical aspects of the project, it was decided that the development and testing of the turntable prototype should be given priority. Events Added: • "Obtain Independent Design Review Tutor"
3	04/01/2020	Extended: • "Develop Code" – more time was necessary to create code that produced a working scanned image • "CAD Model + Drawings" – more time was required to make amendments to design and produce engineering drawings for Design Review Postponed: • "Design Review" – postponed to 24th January as that was the only available date where all 3 tutors were available Events Added: • "Update PQP", "Implement Motor Control", "Testing of Turntable Transmission Prototype", "Casing Design", "Scanner Housing Design", "Design Review Slides"
4	21/01/2020	Events Added: • "Mesh Reconstruction", "Multiple Scanning", "Automatic Mesh Reconstruction", "Measure scanner resolution", "Image Capture Automation" – the software aspect of this project was broken down into multiple key points

3 Budget

3.1 Initial Estimates

A budget of a £1,000 is allocated by the course supervisor for the entire device. A graphical breakdown of the proposed budget is in the pie chart below in Figure 3.

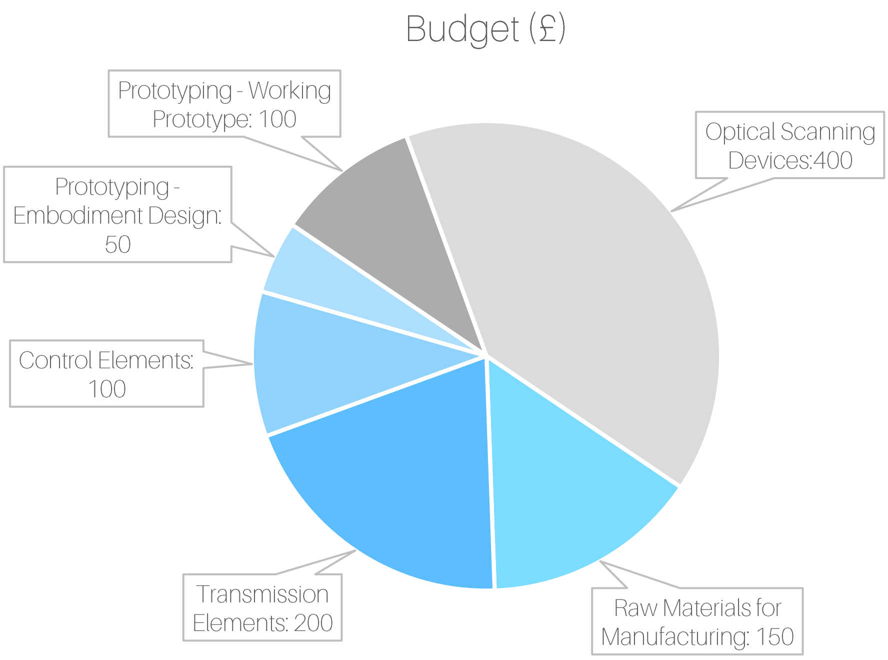

Figure 3: Pie Chart Showing Approximate Budget Breakdown.

As stated in the PDS, the 3D model requires a resolution of 0.5 mm, which in turn depends largely on the resolution and quality of the optical scanning devices. Yet, as such, components can reach prices far beyond the given £1,000; the upper limit of £400 is imposed such as to ensure that there are enough remaining funds for the other aspects of the project.

Transmission elements, such as motors, belts and pulleys, bearings etc. are expected to take up the second highest expense. The need for transmission elements would arise in moving and rotating parts such as a rotating platform for the scanning device, scanned object, or both. From a review of transmission elements from RS Catalogue [7], pulleys and bearings are expected to take up a significant portion of the cost, in order to satisfy the maximum weight requirement of the scanned object.

Control elements would include items like microprocessors, wires, and other electrical parts needed to achieve motor control. The bulk of the cost is likely to come from the microcontroller, which can cost up to £50 for a Raspberry Pi or an Arduino [7].

Raw materials include items like steel and aluminium shafts, laser cut acrylic boards, and 3D printed filaments. As these materials are relatively inexpensive [8], with little or no processing fee, a lower budget of £150 is allocated. This category is intrinsically linked to the prototyping costs, as raw materials such as 3D printing or laser cutting are often used to get an initial embodiment design. The use of existing optical devices such as laser pointers, projectors, and commercial cameras that the group already possess would also ensure minimal prototyping costs as resolution would not be a focus.

3.2 Updated Budget Breakdown 31/01/20

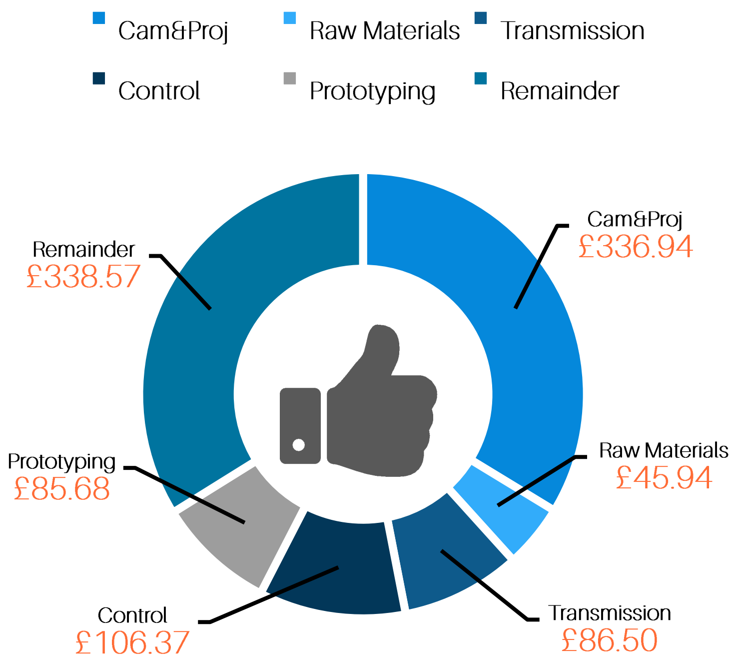

Figure 4: Pie Chart of Expenditure as of 31st Jan 2020

Figure 4 above shows the current budget expenditure as of the 31st of January 2020. Table 5 below also shows the expenditure compared to the initial approximation and that there is excess budget remaining to accommodate any unforeseen setbacks.

Table 5: Comparison of assigned budget and expenditure

Budget Assigned	Amount Allocated (£)	Spent (£)
Camera & Projector	400	336.94
Raw Materials	150	45.94
Transmission	200	86.5
Control	100	106.37
Prototyping	150	85.68
Remainder	338.57	0

4 Management Responsibilities

4.1 Team Roles

The administrative and technical roles are recognised as distinct, and thus each member assumes a role in each area as shown in Tables 6 and 7 respectively.

Table 6: Administrative roles and responsibilities for each group member.

Name	Administrative Role	Responsibilities

Siew Han	Document Control	Organise all documents and online files to maintain consistency among the group.
Jeremy	Deadline Manager	Ensure deadlines are met, update the Gantt chart, identify dependency events, and plan lead time.
Chuan Sheng	Team Liaison Officer	Contact the supervisor to set up meetings or to request assistance in accessing facilities as well as in any problems that may arise.
Taha	Budget Manager	Track all expenditures associated with the project to keep costs to a minimum and prevent exceeding budget of £1,000.
Hussain	Minutes & Room Bookings	Keep a log of all things discussed during meetings so that information in previous meetings can be referenced accurately. Rooms booked to provide an ideal working space.

Table 7: Technical roles and responsibilities for each group member.

Name	Technical Role	Responsibilities
Jeremy	Project Manager	Sets the overall direction for the project. Monitors progress and ensures key deadlines are met. Defines the project scope to an appropriate level. Delegates tasks based on competency and resources available.
Chuan Sheng	CAD Manager	Oversees the entire modelling process, ensuring communication between different members when modelling to minimize potential clashes. In charge of ensuring that engineering drawings are coherent and conform to the required engineering standards.
	Electronics and Control Lead	In charge of ensuring the implementation of motor control and other necessary electronics
Siew Han	Report Manager	Oversees the outline of the report. Ensures coherence in format and work done by members.
	Software Lead	In charge of developing and implementing the software that converts the data input from the scanner and projector into a 3D model
Taha	Procurement Officer	Sources for appropriate commercial components based on specifications required and ensures availability of parts according to the timeline.
	Manufacturing Lead	Sets out a manufacturing plan based on team capabilities and the part to be manufactured. Ensures all prerequisites (Drawings, bookings) are in place before the manufacturing session and is responsible for following up the entire process.
Hussain	Analysis Lead	Discerns relevant areas that requires structural and performance analysis, such as estimating the minimum width of bars or the stress concentration factors in a loaded structure. Sets the direction taken and delegates relevant portions to other members.

4.2 Supervisor Communication

During Autumn term, the team will meet the project supervisors, Dr. Loic Salles and Dr. Christoph Schwingshackl, tentatively every Friday, from 0900-1000 hours. For Spring term, the team will meet with the supervisors every Tuesday from 0900-1000 hours. If a change in timing or additional meetings are needed, our team liaison officer will make the necessary arrangements.

During these meeting sessions, we aim to:

- Report the project progression.

- Ensure project meets the requirements and timeline.
- To enquire and seek guidance from supervisors.

Singular or less complex issues can be resolved via e-mail communication by the liaison officer.

4.3 Conflict Resolution

Potential for intra-team conflict is to be minimized at the onset by factoring both the expertise and personal preferences of team members when delegating work. Considerations will have to be made for individual members' other commitments such as coursework and work schedules.

A potential source of conflict can arise from disagreements in decisions made. Such discontent can be avoided by members being clear on his/her intent before the conduct of tasks to catch any potential issues. Difference in opinions regarding technical matters can be reasoned out via discussion and if need be, by informal voting.

Even with these systems in place, conflicts cannot be eliminated due to other factors including low work commitment and/or quality, not meeting deadlines, or critical attitudes towards each other. The following plan outlines the escalation sequence taken to resolve any issues.

1. Discussion within the group
    - Manage and clarify expectations.
    - WebPA (Web Peer Assessment) and conduct of task assessment to keep members in check.
2. Discussion within the group and a third-party mediator (course mates).
3. Discussion with supervisors.
4. Discussion with Module Leader and Director of Student Experience.

5 Quality Materials

Table 8 below summarises the Quality Materials that are available.

Table 8: List of software, facilities and suppliers with an indication of how access is gained.

Type	Function	Name	Remarks
Software	File Access and Storage	OneDrive	Accessed via Microsoft Office 365
	Project Management	Microsoft Teams	Downloadable using IC login details
	Documentation	Microsoft Word Microsoft Teams	Accessed via Microsoft Office 365
	Engineering Models and Drawings	Solidworks	Accessed via Apps Anywhere / College computers.
	Numerical Calculations	Matlab Microsoft Excel	Downloadable using IC login details Accessed via Microsoft Office 365
	Analysis	Solidworks ANSYS FEA	Accessed via Apps Anywhere / College computers
	Dissemination	Microsoft PowerPoint Adobe Suite	Accessed via Microsoft Office 365
Facilities	Manufacturing	Student Teaching Workshop Imperial HackSpace	Monday – Friday: 0830 - 1615 1000 – 1800

	Testing	Mechatronics Lab	Monday – Friday: 0800-1800
Suppliers	Manufacturing Materials	Mechanical Engineering Stores	Ordered via Stores Requisition Form
	Electronic Components	RS Catalogue	Ordered via ICIS
	Optical Components	RS Catalogue ThorLabs OneCall	Ordered via ICIS

6 Quality Events

Table 9 below summarises the Quality Events that should improve the Design, Make and Test (DMT) project.

Table 9: Key events related to the project and respective dates.

Date	Event
2017/2018	STW Induction
02/10/2019	Introduction to the DMT Project
07/10/2019	Safety and Liability Lecture
18/10/2019	Quality Planning Lecture
4/10/2019 – 6/11/2019	Negotiation and Conflict Management Workshop
25/11/2019	Progress Management Lecture
08/01/2020 – 10/01/2020	Capistan Stakeholder Challenge

7 Documentation Control

Table 10: All documents required for the project to ensure effectiveness, efficiency and organisation.

Document Type	Description
Required Submissions	
Quality Plan	The current document, which defines how the team is to deliver the quality product by the stipulated deadline. The plan includes an outline of the project, the roles and responsibilities of individual members, and the systems in place to ensure quality and adherence to the project timeline.
Progress Report	A review of the current work done, re-evaluation of the proposed objectives and schedule, as well as a discussion of any problems encountered.
Final Report	A comprehensive documentation of the project, including project outcomes and results from testing.
Logbook	Individual book containing documentation on ideas, meetings, calculations, and other elements relevant to the project. Each logbook should contain information relevant to the role of the member in the project and be regularly updated.
Poster	An A1-sized landscape colour poster, to be mounted on a display board during the project seminar. This poster should succinctly display to an audience what was done and the results achieved.
Supporting Documents	
Bill of Materials	An inclusive list of all items to be used in the project. This should include brief descriptions of the item use, quantity, cost, suppliers, and potential alternatives. Unlike the expense list, this serves to contextualise and collate items needed for the projects.
Meeting Agendas and Minutes	Chronological documentation of all meetings and the content. This includes meetings with supervisors. Each entry should contain the date, members present, agenda, and the pertinent points discussed.
Expense List	A comprehensive list of all items purchased. This should include the quantity, price, date of purchase, means of purchase, and current status of the item. This document facilitates the accounting of budget.

Engineering Drawings	A series of images showing the relevant dimensions and tolerances of all parts to be manufactured or modified, conforming to the BS 8888 standard.
CAD (Computer Aided Design) Models	A folder of Solidworks model files forming a complete assembly of the physical project components
Task Allocation and Status Update	An interactive interface allowing easy entry and assignment of tasks, allowing real-time updates of progress.
Outdated Document Folder	A folder containing outdated files, as a record of the changes done throughout the project and for reference in case older information is needed.

To deal with changes and updates, a nuanced approach is taken, summarised by Table 10. For word documents such as the quality plans and reports, no new file should be created when adding information, as changes are clearly visible. However, if a drastic change to existing content is made, the new document should be saved as a separate file with a clear name and date of change. For example, if one member decides to modify the structure of a report, they should save it as "Report – Proposed Changes Mar 17" or as of the likes, to make the document's purpose clear.

For model files and engineering drawings, likewise, the creation of a file should not cause conflicts within existing assemblies. Changes, however, should be saved as a separate file, as before. Also, as these files do not allow multiple users working on them at the same time, any member that wishes to edit these files should notify the group when they begin and end so that no other member should attempt to access those files during that period.

This implies that whenever a member is editing a document, they should summarise the changes and update the group as soon as possible. In the case of major edits, the team shall convene to decide on a preferred version, and the defunct document is put in the outdated document folder.

All these documentation changes and uploads are to be done via the Microsoft Teams platform, whereby timestamps and a communication channel facilitates reduces the chances of miscommunication and ambiguity in the uploads or alterations.

To ensure clarity of work carried out, the use of Trello, integrated with Microsoft Teams, is used to record the assignment of tasks and track the progress of each team member.

8 Deliverables, Acceptance, and Dissemination

8.1 Deliverables and Milestones

The list of deadlines, deliverables, and milestones are listed in Table 11 below, along with the action required to actualise the deliverables.

Table 11: Description of each required submission.

Date	Item	Description and Purpose	Action Plan

25/10/10	Registration Form	Officialise the objectives of the project and members of the group.	Affirm objectives with supervisor.
01/11/10	Quality Plan	Outline the process of developing the project along with details on how to manage the group dynamics.	Peer and supervisor review.
31/01/20	Design Review	Critically analyse the design plans to assess whether manufacture will be successful.	All engineering drawings to be internally checked and approved.
31/01/20	Progress Report	Comprehensive summary of all work done so far so that the project can be completed by the deadline.	Periodic documentation of progress as well as weekly internal and supervisor meetings.
03/06/20	Final Report	Detailed account of every stage of the project to explain the process of development and final outcomes achieved.	Early allocation of work to group members related to their technical role in the project. Formatting and conventions to be agreed upon before embarking on the report. Individual sections to be internally checked.
03/06/20	Logbook	Notes of ideas, calculations, and a record of actions in the case that earlier work is needed as a reference.	Consistent documentation from all members. Logbooks to be periodically signed off by supervisors.
04/06/20	Poster	Display key features of the final product with explanations of the underlying mechanisms.	Survey of previous design and research posters

9 Design Testing and Evaluation

9.1 Prototyping

Often, prototyping is done as early as the brainstorming phase of the project in order to get a better understanding of what constraints are faced. For a 3D scanner, the possible insights from a prototype model are:

- Greater understanding on how scanning method and software influences the mechanical aspect of design.
- Identifying the areas that requires prioritising, such as the integration of hardware with software.
- Ensuring all assumptions made during early design and brainstorming remain valid in a real-world context.

From the initial market research, the form of scanning method used would greatly affect mechanical design. For example, a structured light scanner would require the optic sensor and projector be kept stationary, while a slit-laser scanner would require a laser slit to be drawn across the object being scanned. In the latter case, an additional actuator and transmission would be required.

A preliminary proof of concept prototype should thus explore the viability of the different scanning methods. Some metrics would be an ease of implementation, availability of software or code and the cost of the optical devices needed. Once a certain method has been decided upon, the mechanical design would then be updated based on any physical requirements.

Physical prototyping can be quickly and cheaply done with 3D printed or laser cut components, to get a better understanding of how the components are laid out spatially and catch any physical constraints overlooked during the preliminary design phase. However, with these plastic parts, some objectives regarding structural integrity cannot be tested, such as a maximum mass requirement or the ease of transportation.

A working prototype may be developed and tested which could consist of integrating the critical components previously prototyped to ensure that they work together in unison. This will be useful in determining any final changes that need to be made to CAD models and engineering drawings before the design review.

9.2 Final Evaluation

This will be the final test for the product and will be used to judge the accuracy of the scan. The method described below is a form of non-destructive testing and is as follows:

- A small turbine blade or engine component provided by the project supervisor will be placed in the device and scanned.
- The corresponding 3D scan of the turbine engine component will be obtained on a computer screen.
- The dimensions obtained from the 3D model will be compared with the actual dimensions of the blade and a percentage error will be calculated.

Additionally, a user experience test will also be done to ensure the product is ergonomically viable. Firstly, two group members of average physical strength will manually move the device 100m. Their comments will be used to judge whether the device can be easily transported. Secondly, external parties will be invited to try and move the device as mentioned above. This is to increase the sample size and eliminate any inherent biases with regards to the ergonomics of the device. Thirdly, external parties will also be invited to test the ease of use. Lastly, since it is likely the results arising from these tests will be subjective, a numerical scale will therefore be introduced to quantify the data.

10 Training Requirements

Table 12 lists and describes the training required to access the facilities required for the project.

Table 12: Required training to access facilities for project use

Training Type	Description

ME1 STW Induction	To equip students with the basic skills on how to operate the machinery present in the workshop (lathes, mills, saws etc.) as well as the appropriate safety precautions to take when working in the workshop.
Imperial College Advanced Hackspace Induction	To familiarise users with the standard operating procedures on safety and evacuation. Users will be given a brief explanation as to which machines are available (3D printers, soldering irons, vinyl cutters etc.) and how they operate.
RAFT (Risk Assessment Foundation Training)	The RAFT online course on safety related to working in labs/workshops, is to be completed by all members of the group. Members can be familiarised with the College's risk assessment process through the course's video scenarios. Conducting risk assessments and constructing a risk matrix in this course would also help in recognising substantial risks in the project.

10.1 Proficiencies

Tables 13 and 14 respectively show the required skills needed to actualise the project and the individual member's proficiency.

Table 13: Software necessary for design and programming purposes.

Required Proficiencies	Description
Solidworks	Used to 3D model the structural components of the project.
Matlab	Numerical solutions to solve stress analysis calculations and code to transform the data input from the scanning device into a 3D model.
Graphic Design	Image editing software is required to create a poster for the summer term poster presentation.
Finite Element Analysis	Numerical calculations and simulations to determine the structural integrity of critical and non-critical components. Identify any components which may undergo substantial loading.
Embedded C	Microcontroller language, commonly used for control of motors and actuators
Python	Used for image analysis and conversion of 3D scanner data into a model.
Meshlab	Used to process and edit 3D triangular meshes, which can convert point cloud files to 3D surfaces.

Table 14: Proficiencies in software already acquired and lacking by group members.

Proficiency	Siew Han	Jeremy	Chuan Sheng	Taha	Hussain
Solidworks	✓	✓	✓	✓	✓
Matlab	✓	✓	✓	✓	✓
Graphic Design	✓				✓
Finite Element Analysis					
Embedded C	✓		✓		
Python					
Meshlab					

Siew Han and Jeremy will be taking the ME3 Finite Element Analysis course during Spring term, which will bridge the proficiency gap identified in the table above. Furthermore, Chuan Sheng and Siew Han have completed the ME3 Embedded C in Microcontroller course during Autumn term and should have acquired most of the proficiencies required for this project. Meshlab or similar software will be required to convert the point cloud files, produced form the structured light scanner, to 3D surface meshes and can also be used to edit or remove unwanted data points to improve the 3D mesh quality. There are tutorials provided online that provide a walkthrough of how to use the software. Python will have to be learnt on a needs-basis through online tutorials or through other resources when working on the image conversion process. Hussain has signed up to the Nvidia Deep Learning course as well as the Data Science Society where he will have a chance to practice using Python. He has also had previous experience with Photoshop and GIMP but will need to remind himself of a few aspects.

11 Risk Assessment

11.1 Project Management Risk Assessment

Table 15 below shows the risks associated with the project and mitigating steps taken. The likelihood of occurrence is evaluated, as well as the chance of occurrence after mitigating steps are taken. All chances are on a scale of one to ten, with one being the least likely to occur, and ten indicating an almost certain chance of an incident happening.

The impact is also rated in terms of severity on a scale of one to ten, with a score of one having minimal impact on the project, and ten potentially delaying certain processes by a few months.

Table 15: Risks associated with the progress of the project.

Identified Risk	Likelihood of Occurrence	Severity of Impact and Consequences	Re-evaluated Likelihood of Occurrence and Alleviative Measures
Delay in Receiving Components	5	Manufacturing and prototyping phase is delayed. Possible increase in price for express deliveries. Impact - 7	Plan for slack in component delivery. Use Imperial College approved suppliers to increase reliability of receiving appropriate quality of goods. New Occurrence - 2
Personnel Injured During Manufacturing	4	Operating machinery to create parts for prototype/final product may result in injury. This will cause delays to manufacturing and overall progress. Impact - 8	Ensure that no lone working is carried out, manufacturing to take place in groups of 2 or more. Ensure a manufacturing plan is created and followed before manufacturing begins. New Occurrence - 2
Delayed Design Review	6	Delayed manufacturing timeline for final product. Impact - 5	Provide progress update during weekly supervisor meetings and raise any concerns early. Each member to identify possible sources of delays. New Occurrence - 2
Unavailability of members (due to schedules, illnesses etc.)	5	Delayed progress in the work delegated to that individual which would in turn delay the whole project.	Plan and coordinate members' schedules and assign back-up personnel for tasks. New Occurrence – 3

		Impact - 4	
Technical delays in software development/coding	8	Delayed or incomplete scanning prototype could delay the testing of the combined prototype (turntable transmission and scanner) Impact - 9	Plan for slack in learning and developing the software. Front-load the design and manufacturing of turntable transmission in Autumn term to free up team members to pursue software development at the start of Spring term. Assign 1 or 2 team members to focus entirely on software development New Occurrence - 4
Technical delays in implementing electronic components	6	Lack of experience setting up motor positional control can delay the testing of the turntable transmission Impact - 5	Front-load the design and manufacturing of turntable transmission in Autumn term to ensure that enough slack and lead time provided to implement motor control. Motor control to be implemented only after successful completion of Embedded C in Microprocessor module. New Occurrence - 3

11.2 Risks Associated with User Operation

While still in the initial stages of the project, some risks specific to certain manufacturing, assembly, or operating methods may not be relevant. However, an initial assessment of the more general hazards is discussed below in Table 16.

Table 16: Risks to the individual while handling product components.

Part	Hazard	Precautions Taken
Scanning Device	Eye injuries from looking directly at source	Ensure that no members are in the vicinity before turning on the device. If members are required to stand close to the source while working, safety goggles or shades should be worn to protect the eye.
Motor/Wiring	Electric shock Skin burns due to a hot motor	No exposed wiring. Motor housed properly. User does not come in physical contact with the motor during operation. Purchasing motors from reliable suppliers.
Casing	Sharp edges may result in a cut during operation or transport.	Chamfer all outer edges exposed to the user. Also, chamfer all internal sections that the user may encounter during operation.
Transportation	Back injuries, sprain, wrist injuries.	Establish a procedure to safely transport the product and ensure adherence by all group members. Ensure proper lifting technique used before lifting heavy objects.

If required by the client or other team members, a detailed HAZOP (Hazard and Operability study) analysis can be conducted on the entire operation once the final operating procedure and the detail design is confirmed.

11.3 Risks Associated with Manufacturing

Table 16 below shows the contingency plan for manufacturing, accurate as of 31st January 2020.

Table 16: Manufacturing contingency plan

	Intermediate & Base Plate	Pulleys	Frame	Scanner Mount	Base Plate
Action Plan	Obtain raw material Laser cut	Repurchase pulleys	Obtain raw material Laser Cut	Obtain raw material Laser Cut	Obtain raw material Laser Cut
Expected Time Delay	2 weeks	1 week	1 Week	2 weeks	2 weeks
Likelihood of Occurring	Low	Low	Medium	Low	Low
Impact of Initial Failure	High Delays product testing by 2 weeks	Medium Potentially additional cost of £49	Medium Potentially an additional cost of £40	Low Scanner testing can take place without mount	High Delays product testing by 2 weeks

- If lead times for laser cutting are too high, then parts can be manually milled and drill.
- All parts are planned to be manufactured by 20th February leaving 4 weeks for assembly & Final product testing before Easter holidays.

During the manufacturing process, safety hazards are also present. However, reasonable precautionary measures both by the college and the members of this group have been taken to mitigate any harmful circumstances that may arise. These include:

- Adequate training received by all members regarding usage of equipment available in the STW.
- Supervision of manufacturing technicians in the STW during the manufacturing process.
- Safety goggles, lab coats or boiler suits being worn by all members during operation.
- The RAFT online course on safety related to working in labs/workshops, attended by all members of the group.

12 References

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