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Deliverable 6: Prototype I & Customer Feedback

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Abstract

Our team (Group 18) has been tasked with designing and building a device meant to retrieve a metal sample from a tube in a CANDU reactor. This sample will then be sent to a lab to test the integrity of the tube. This report delineated the project's design process, “Prototype”. This report details the development of our first prototype, incorporating client and peer feedback, which was used to design elements like collection, functionality, and rotation. Key improvements include reducing blade count for consistency, adding a fail-safe mechanism, and optimizing the rotation system. The CAD-modelled prototype helped assess dimensions and identify design flaws early.

Testing focused on structural stability, load capacity, and rotational precision, which were calculated mathematically under ideal conditions as a “sanity check”. Preliminary results confirm dimensional accuracy, though refinements are needed for material durability and automation. Future work will test electrical components, refine the blade mechanism, and ensure precise motor control, forming the basis for a fully functional final product. The project is ready to move onto the “Prototype 2” phase.

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1. Introduction

- 1.1 Purpose of the Report
  - The purpose of this report is to analyze the development of our first prototype. This will incorporate the client feedback and other group's feedback, assessing and analyzing critical elements of our design, and outlining necessary improvements by testing and validating.

- 1.2 Scope and Objectives
  - This report will cover the prototype's design, methods of testing, and the incorporated feedback. Specifically focusing on collection, functionality, and rotation, these are three critical components that will show whether the prototype will be functional/successful or not. This report will be a foundation for the next prototype, which will target more technical and electrical improvements and functionality.

- 1.3 Overview of the Design Process
  - The design process followed an iterative approach, which incorporated feedback from the client meeting and the peer feedback. Our initial concepts were re-evaluated, leading to the development of a proof of concept prototype, which will be tested for further improvements. The purpose of this prototype is to better visualize all the moving parts in the design, and get the final design consolidated and ready for physical testing.

2. Client Feedback and Design Improvements

- 2.1 Summary of Client Feedback

  The client feedback helped us ground our ideas and helped us think more realistically. During the meeting, we asked which of our ideas the client thought would work the best. The client liked the "V12" and the "encased dremel saw" ideas, however, each had its own flaws so he recommended a product that took inspiration from both of the designs.

- 2.2 Key Takeaways from Feedback

  We had to simplify our ideas. The client also clarified that it was unimportant whether our product would operate manually or automatically. He then suggested that we look into the material density and mass of our product's blades to ensure our sample collection was consistent. He also hinted that the sandpaper idea had very high risks because it would be harder to collect a consistent amount of sample as a powder. It was also mentioned that our design didn't have a fail-safe mechanism yet.

- 2.3 Implementation of Feedback in Future Design

3. Peer Feedback and Design Improvements

- 3.1 Summary of Peer Feedback

  To prepare for the second client meeting, we did a mock presentation for our peers to get their insights on our product and to gain inspiration from theirs. Their main concerns were that our scrape flap might not stay open and that our codes for the rotation of part C might be too complex.

- 3.2 Key Takeaways from Feedback
  Although our design had been simplified, this mock presentation proved that further simplifications can still be made. One was that we did not need 3 telescoping parts. And if we had 3 telescoping parts, they also did not need to be in descending order from biggest to smallest either. This opens up more ways to design the device so that the diameter of the device is big enough so the scrape flap wouldn't have to open as wide. After discussing the suggestions, we decided that making the sections smaller and more portable (and getting rid of section A) was the best course of action since it minimizes cost and "points of failure".

4. Prototyping Strategy and Objectives

- 4.1 Purpose of Prototype I

The purpose of the prototype was to fit all of our constraining parts on a CAD design. Since size was our main limiting factor, this prototype would determine the feasibility of the project.

- 4.2 Description of the Prototype

The prototype was a CAD proof of concept, which includes all the main parts of the device. Some notable missing parts are the following:

- Wheels: A set of 12 wheels, which fit around the circumference of the more narrow tube. These wheels will stabilize the system to allow the bigger tube (with the scraper) to rotate freely.
- Load Cell: Since the specific dimensions of the load cell have not been defined, it has been omitted in this design.
- Circuits: All cables have been omitted for simplicity

The CAD design can be found here:
https://cad.onshape.com/documents/44974b3466ab022eadd1a738/w/b515d53cc5e8b89d877f7e21/e/7132009a5afe6a1b01c1df9c?renderMode=0&uiState=67c52c343afff07c33ad43e9

5. Prototyping Test Plan

- 5.1 Objectives of the Prototype Testing
  - Evaluating the fit of different parts in the design, as well as consolidating our finalized product.
  - Identify potential issues early on and fix any problems before moving on to more advanced prototypes.
- 5.2 Key Performance Metrics and Measurement Criteria
  - Test 1: Design's dimensions fit, leaving room for wiring and possible adjustments.

- Test 2: Find the exact theoretical volume of debris collected (not mass, since we don't know the material).
    - Test 3: After a theoretical load evaluation, all of the systems remain stable (the axis of the motor doesn't break, the blade does not lodge the system on the outer tube, etc).
- 5.3 Stopping Criteria for Testing
    - All test results are boolean.
- 5.4 Expected Fidelity Level of the Prototype
    - High fidelity in terms of dimensions
    - Low-medium fidelity when calculating the loads, since it does not account for real-world variables (not as good as a physical prototype).

6. Analysis of Critical Components and Systems

- 6.1 Identification of Critical Components:
    - Scraping Mechanism:
        - Responsible for sample collection through scraping.
        - The material's composition and density, as well as the sharpness/design of the scraping mechanism, will affect the efficiency and durability by a significant amount.
        - Poor material choice can lead to wear, or breakage of scraping mechanism.
        - Might get lodged on the tube if the density is too low (unknown).
        - Might snap if the material is too brittle or thin (cannot be calculated since we don't know the material of the outer tube).
    - Grater Flapping Mechanism:
        - The flap of the grater will assist in stabilizing the collection.
        - The flap might not open consistently if the centripetal force generated by the rotation of the motor is not strong enough to overcome gravity.
    - Rotating mechanism:
        - Must ensure controlled motion of grater.
        - Stability is required to ensure constant and precise movement to be able to track the efficiency of the run.
        - A concern is the material not jamming in certain scenarios like, extended use or unexpected material density.
        - The Arduino must be properly coded to stop the motor in the upright direction, no matter how many times it revolves.

- 6.2 Engineering Analysis:
  - Material Integrity and Durability:
    - The scrapping mechanism must be designed to be resistant to wearing, and with a respectable lifespan.
    - Load capacity was measured to estimate the force limit required to meet as well as not surpass for optimal scraping.
    - We analyzed different materials based on their integrity, composition, and cost-effectiveness.(Steel, Stainless Steel, Aluminium, etc…)
  - Rotation Stability and Torque Analysis:
    - Rotation system was put through analysis to determine the torque requirements for optimal performance.
    - Friction coefficient calculations between parts coming into contact will be taken into account to minimize unnecessary resistance.
    - Rotation mechanism might require a bearing system to prevent misalignment and ensure consistency.
- 6.3 Expected Challenges and Risks
  - Ensuring Reliable Rotation and Smooth Operations:
    - Current observations show us that the rotation mechanism has fricitional inconsistencies and potential areas of concern due to pressure and force applied on specific parts.
    - Possible Solution: Use bearings which are lubricated and reduce the mechanical resistance in friction dense areas.
  - Minimizing Grater Wear and Maintaining Efficiency:
    - The current grater material is degrading faster than expected when running for extended periods of time.
    - Possible Solution: Observe and test other materials with higher wear resistance, while remaining within budget range. (Ceramic Coating, etc…)
  - Balancing Cost and Performance for Material Choice:
    - If we want higher performing materials that will logically increase costs.
    - Possible Solution: Use a cost benefiting analysis to determine the most logical trade-offs when it comes to durability and affordability.

7. Prototype Development and Testing

- 7.1 Materials and Construction Process
  - Done virtually on the Onshape CAD site.
- 7.2 Test Setup and Methodology
  - Careful design of the project at an ultra high fidelity, considering the parts we will acquire for the final prototype.
- 7.3 Experimental Data and Observations
  - The current tube sizing is precise, but section B might have to be readjusted if the Load Cell is replaced and the new part takes up more space than expected. If so, the length of part B will be increased to 10in.
  - The blade design will have to be refined to avoid bouncing or getting stuck. Further, in-depth testing will be done for Prototype 2.
- 7.4 Analysis of Test Results
  - Results where overwhelmingly satisfactory (dimensions). The rough calculations showed that under ideal conditions, each part of the system can take the expected loads with minimal wear and tear.

8. Updates to Target Specifications and Design

- 8.1 Updated Detailed Design
  - Refer to the CAD design above.
- 8.2 Bill of Materials (BOM) Adjustments
  - Deliverable F - Updated Bill of Materials (BOM)

9. Preparation for the Next Prototype

- 9.1 Key Improvements for Second Prototype

We have to build a prototype of the electrical systems and blades and see how that works first then we can analyze to look for improvements

- 9.2 Refinement of Prototyping Test Plan

  We have concluded on a blade design for our final product which is a scrape flap (like a cheese grater). When the sample is scraped, it will fall into the built-in container inside the device

- 9.3 Next Steps and Timeline
- Prototype 1: Proof of Concept (currently working on)
  - Test 1: Basic functionality tests; ensuring the prototype demonstrates core concept(s).
  - Test 2: Stability/Durability; ensures structural integrity, modularity, and that the structure holds up while scraping (manual scraping).

    - Test 3: Feasibility; will verify whether the design can be further developed or not. The "grater" will be tested to ensure the hatchet won't deform and the scraping mechanism in sound
- Prototype 2: Key Subsystem Development
    - Test 1: Load Cells; Ensure proper communication with Arduino board, and correct code, as well as correct measurements and displays.
    - Test 2: Rotary Device; Ensure the device is durable enough to maintain structural integrity and not snap.
    - Test 3: Hollow Slip Ring; Ensure it is compatible with all other parts of the device.
- Prototype 3: Full Functional Model
    - Test 1: Precision of collection; refine the mechanism to ensure maximum precision when collecting debris.
    - Test 2: Precision of rotary motor revolutions; ensure that the motor's rotation always ends with the "grater" facing up, within a small margin of error.
    - Test 3: Friction does not cause any significant wear and tear in any part of the system.

10. Project Timeline and Task Distribution

- ## 10.1 Task Breakdown and Team Roles

  Currently, the project tasks are allocated as follows:

  • **Sam:** Oversees the electrical systems.

  • **Sam, Deba:** Coding and debugging the control program for the prototype.

  • **Sam, Nick, Deba:** Work on the CAD design of the prototype.

  • **Ahmed:** Responsible for acquiring and preparing the tube for assembly and sourcing any other required materials.

  • **Louis:** Tracks the team's completed work, milestones, and overall progress.

  • **Louis, Nick, and Sam:** Collaborate on calculations to address theoretical challenges.

★ Note that this task list may be adjusted to ensure efficiency.

- ## 10.2 Project Milestones and Deadlines

    - Deliverable Deadlines:

        - Deliverable E - Project Plan and Cost Estimate (2/23/2025)

            - Finalize the project design for prototyping

            - Generate a cost estimate per prototype and for the entire project

        - Formulate an action plan and deadline for the construction and adjustments of prototypes.

    - Deliverable F - Prototype I and Customer Feedback (3/2/2025)

        - First prototype centered around the electrical system should be properly built and tested by the end of 2/28/2025

        - Any kinks with the prototype should be aptly addressed and an action plan should be generated for the following prototypes by 3/2/2025

    - Deliverable G - Prototype II and Customer Feedback (3/9/2025)

        - The second prototype focused on the structural integrity and mechanical systems should be built and tested by the end of 3/7/2025

        - The structural and mechanical designs of the prototype should be perfected and ready to move on to the third and final prototype, it should also be tested for compatibility with the prototype

    - Deliverable H - Prototype III and Customer Feedback (3/23/2025)

        - The third and final prototype needs to be tested for functionality, at this point in the development process only small adjustments should be made to either the code or certain small parts related to the electrical or mechanical systems.

    - Deliverable I - Design Day Presentation (3/26/2025)

    - Deliverable J Project Presentations

    - Deliverable K - User and Product Manual (4/4/2025)

11. Conclusion

- 11.1 Summary of Findings
    - The prototype 1 process has given us valuable insights into how we should carry out the rest of the project.
    - Peer and client input were put into consideration and improved our design.
    - All parts were found to be compatible.
- 11.2 Future Work and Considerations
    - Figuring out a way to build a physical prototype.
    - More research and benchmarking can be done for more inspiration and data.