Deliverable D – Conceptual Design

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Abstract

This report builds on the previous analysis of client constraints by defining the design criteria for the device. It outlines key considerations such as material selection, weight, cost, and dimensions, ensuring the design meets functional and safety requirements. Additionally, commercially available models are evaluated for their effectiveness, highlighting areas for improvement. This analysis establishes a foundation for optimizing the device while maintaining feasibility and compliance with industry standards.

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1-Introduction

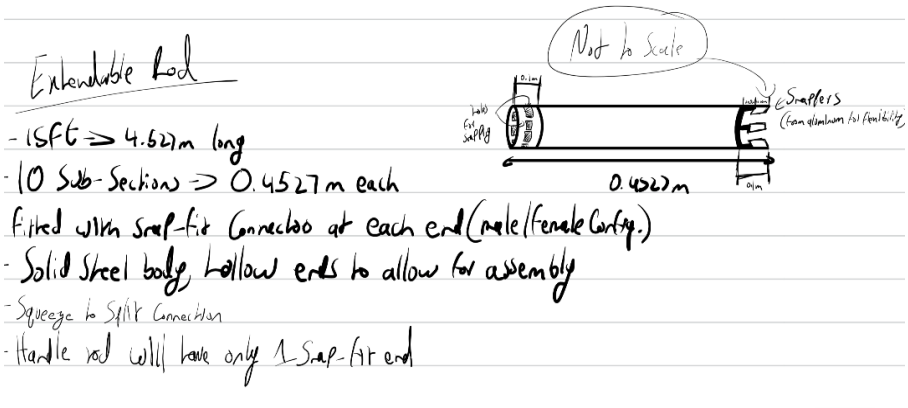
In engineering design, establishing clear criteria based on the needs of the client is essential for having a final product that is optimized and effective. This report focuses on the design criteria received based on the client meeting with CNL and on benchmarking products that have similar objectives and setting target specs, which will guide the development of a successful product. Benchmarking allows the project to have realistic yet competitive target specifications that meet the level of quality of already existing designs in the industry. This process involves analyzing existing designs, identifying the pros and cons of each design, and determining what aspect needs to be different in the new design. This approach ensures a final design that meets both the technical and practical needs of the client while maintaining efficiency, feasibility, and innovation.

2.0 Design Concepts:

2.1 Visisht Kaushik

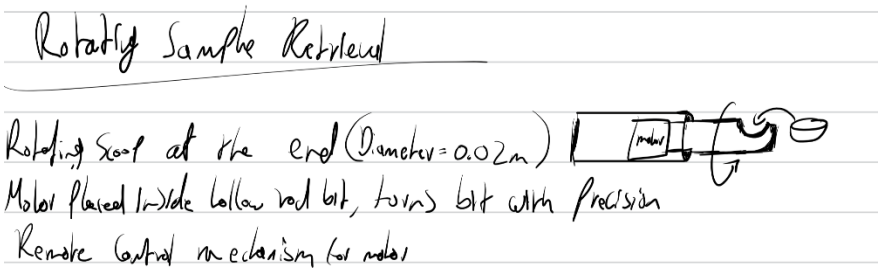
Extension Device

- Modular, snap fit sections (secure and good structural integrity)
- Easy to transport and customizable length
- Heavy and takes time to assemble
- Requires frequent maintenance



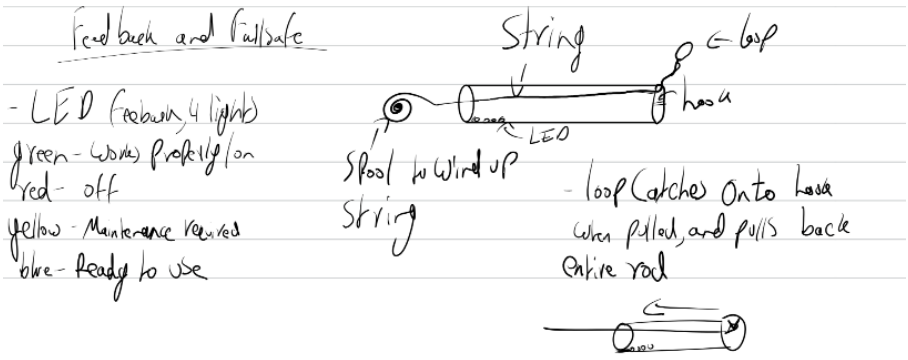
Sample Retrieval and Containment

- Secure retrieval of sample
- Simple to use and understand
- Can adapt to different sample sizes if required
- Requires high precision
- Can wear out fast
- Manual operation required

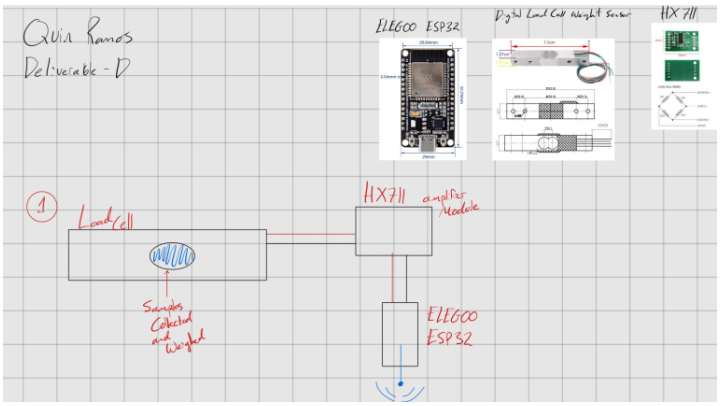


Feedback and Failsafe Systems

- Reliable failsafe, real time feedback
- Failsafe doesn't rely on power, ensuring it can still work in outage situations
- Feedback can use a lot of power



Quin Ramos

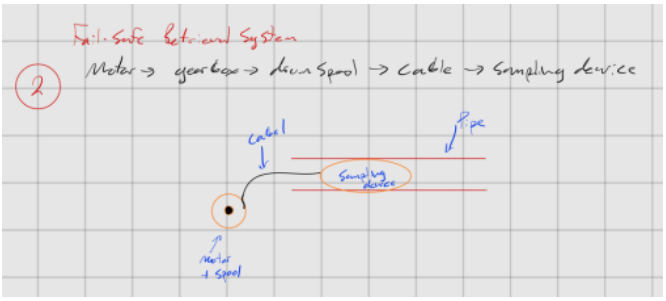


Weight Detector:

Concepts Considered:

1. **Load Cell with HX711 Amplifier (Final Choice)**
    a. **Benefits:** High accuracy in weight measurement, real-time data monitoring, and reliable sample validation.
    b. **Drawbacks:** Requires calibration and stable power; can be sensitive to vibrations.
2. **Optical Sensor for Sample Level Detection**
    a. **Benefits:** Simple, non-contact method; no need for precise calibration.
    b. **Drawbacks:** Can struggle with detecting small or fine metal particles, may require additional processing.
3. **Capacitive Sensor for Sample Mass Estimation**
    a. **Benefits:** No moving parts, works for non-metallic samples as well.
    b. **Drawbacks:** Affected by environmental factors like humidity; less precise than a load cell.

Final Decision: The **Load Cell with HX711** was chosen for its **precision and compatibility with wireless transmission**.

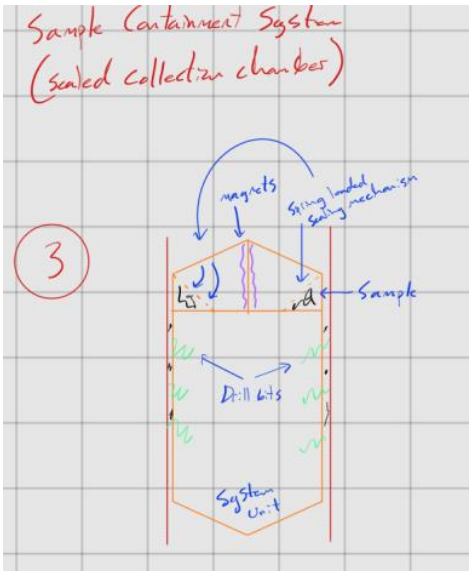


Failsafe

Concepts Considered:

1. **Motorized Cable Retrieval with Clutch System (Final Choice)**
    a. **Benefits:** Allows automatic retrieval, prevents excess tension on the tool, and enables operator control.
    b. **Drawbacks:** More complex, requires power and a robust mounting system.
2. **Spring-Loaded Retraction System**
    a. **Benefits:** Passive system that does not require power; simple and lightweight.
    b. **Drawbacks:** Limited control over retrieval speed; cannot adjust tension dynamically.
3. **Manual Hand-Crank with Locking Gear**
    a. **Benefits:** Does not require power; provides full control to the operator.
    b. **Drawbacks:** Requires constant manual effort, making it impractical for long retrieval distances.

Final Decision: The **Motorized Cable Retrieval with Clutch System** was selected due to its **reliability and automation**.



Storage Capsule

Concepts Considered:

1. **Sealed Vacuum Chamber with Locking Lid (Final Choice)**
    a. **Benefits:** Provides an airtight, contamination-free environment; ensures sample integrity.
    b. **Drawbacks:** Requires precise sealing mechanisms; additional complexity in manufacturing.
2. **Magnetic Seal Chamber**
    a. **Benefits:** Quick and easy to open and close, no physical wear on seals.
    b. **Drawbacks:** Potential leakage if not properly aligned; may not work well in all environments.
3. **Sliding Gate Mechanism**
    a. **Benefits:** Simple mechanical design, easy to operate.
    b. **Drawbacks:** Risk of sample loss if not sealed properly; may require additional force to operate.

Final Decision: The **Sealed Vacuum Chamber** was chosen for its **reliability in maintaining sample integrity**.

Ian Kahuro

Operation Handle:

- D-shaped handle used during operation; it is connected to the inner shaft.
- Inner shaft which spans the length of the device which has 360 degrees of freedom (freely rotates).
- Made from lightweight material (plastic, wood, aluminum etc.) or can be 3D printed.
- The tool's operation will be strictly mechanical by rotating the shaft and the scraping mechanism will collect the sample from the surface of the pipe.

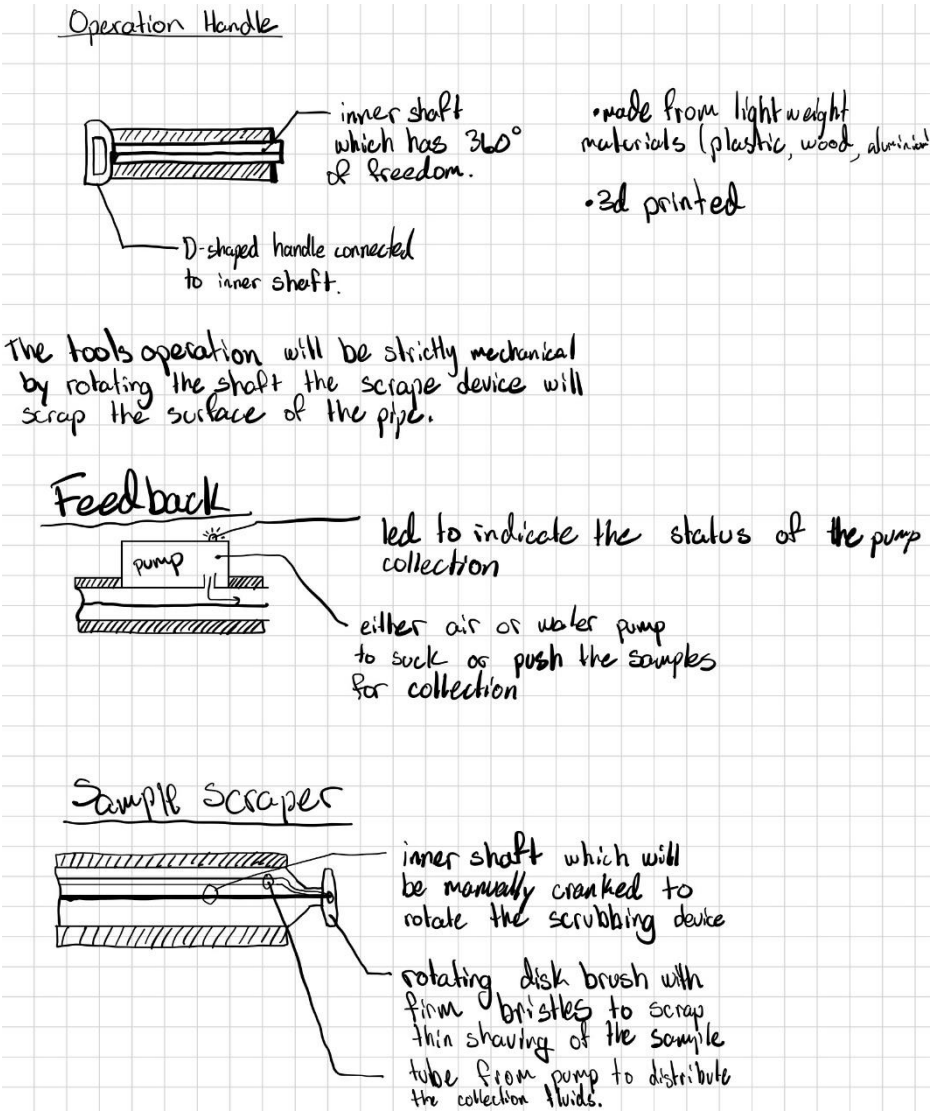
Feedback + Collection Mechanism

- The pump will use either air or water to flood the tube or suck out the scraped samples for collection within.
- The pump will have a small tube where the fluid of choice will be transferred to the sampling area.
- There is an LED on the pump mechanism to indicate the status of collection.
- The collection bay will be a clear container where the samples will be deposited and measured.

Sample Scraper

- Inner shaft which will be manually cranked and rotate the scrubbing device
- The scrubbing device is a rotating disk brush with firm bristles to scrap thin shavings of the sample from the tube

- Small thin tube from the pump to distribute the collection fluids



Concepts Considered.

- For the handle other variations such as a hand crank, a knob or turn dial were a few of the options considered but the D-shaped handle is preferred due the two applications of the force possible by the operator.
- The pump collection mechanism was one of the main ideas I wanted to include which will allow for effortless collection of samples. Other ideas included a mesh net or sweeping mechanism to retrieve the sample, but they were not as robust as the pump.

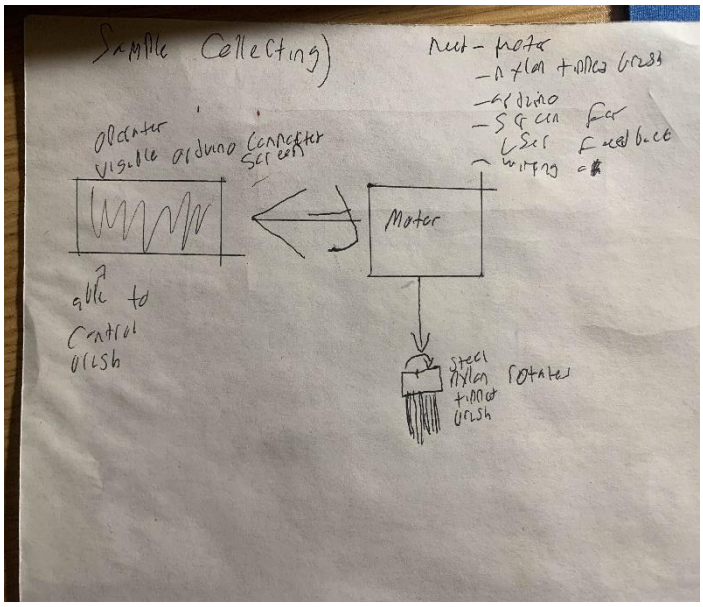
- For the feedback system we will use as many transparent materials as possible so there will always be visual feedback. As well as an LED to indicate the status of the samples, collections, etc. Other methods were considered such as various sensors or cameras, but we are constricted with the cost.
- For the sample scraper, instead of a disk brush a lever with steel wool was among the options considered but for the sake of simplicity, a hard bristle brush can do the job.

Caleb Gilbert

Main System

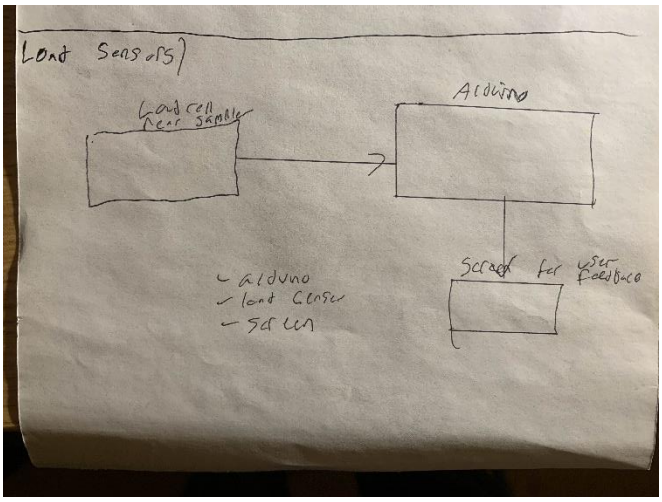
- **Pipe** – 15m length, 4cm diameter, PVC, or aluminum
  - PVC
    - Pros: Lightweight and inexpensive, easy to work with
    - Cons: Less durable under heavy stress
  - Aluminum
    - Pros: Strong, durable, and lightweight.
    - Cons: More expensive, harder to work with
- **Sub Systems**
  - Should be Arduino connected, when possible, for feedback and notifying the user on the status on the device

Capture and removal Mechanism



- A rotating brush – nylon bristles
    - Pros:
        - gentle on pipe, less likely to cause damage- more effective if deposits are loose
        - Cheap
    - Cons: -may suffer with tougher deposits
    - -requires power or a manual system
- A spring loaded, magnetic scraper
- Initially inside pipe, extends upon user interaction. Retracts upon completion to sit inside pipe.
    - Pros:
        - Better at tougher deposits
        - Adjustable pressure with user
        - Grabs the samples and attached them to scraper, reducing sample loss
    - Cons:
        - Harder on pipe
        - blades may wear out and need replacing
        - removal from scraper required

Weight detection mechanism

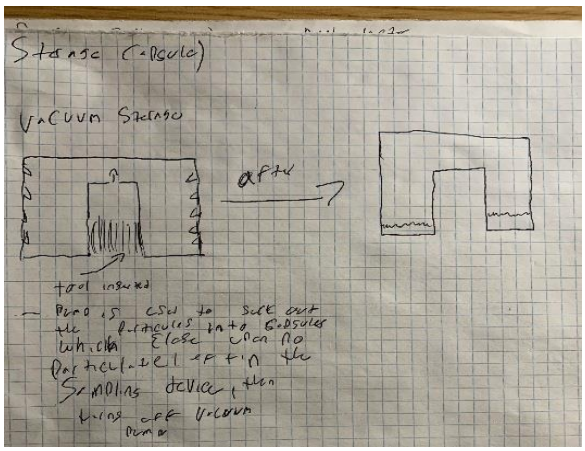
- 

  - Should be Arduino connected, sends to screen for user updates and able to show user when to stop collection
  - <u>Load Sensors</u>
    - Pros:
      - able to be connected to the Arduino to update user
      - Cheap- under 20 dollars for 4
      - Precise
    - Cons:
      - Need power and calibration

  - <u>Spring Sensors with displacement measurement</u>
  - Attached onto extraction device to test for displacement
    - Pros:
      - Simple design
      - Easy interface with Arduino
    - Cons:
      - Less precise than the load cells
      - Also requires calibration

  - <u>Pressure sensor:</u>
    - Pros:
      - Easy to install and integrate with the Arduino
    - Cons:

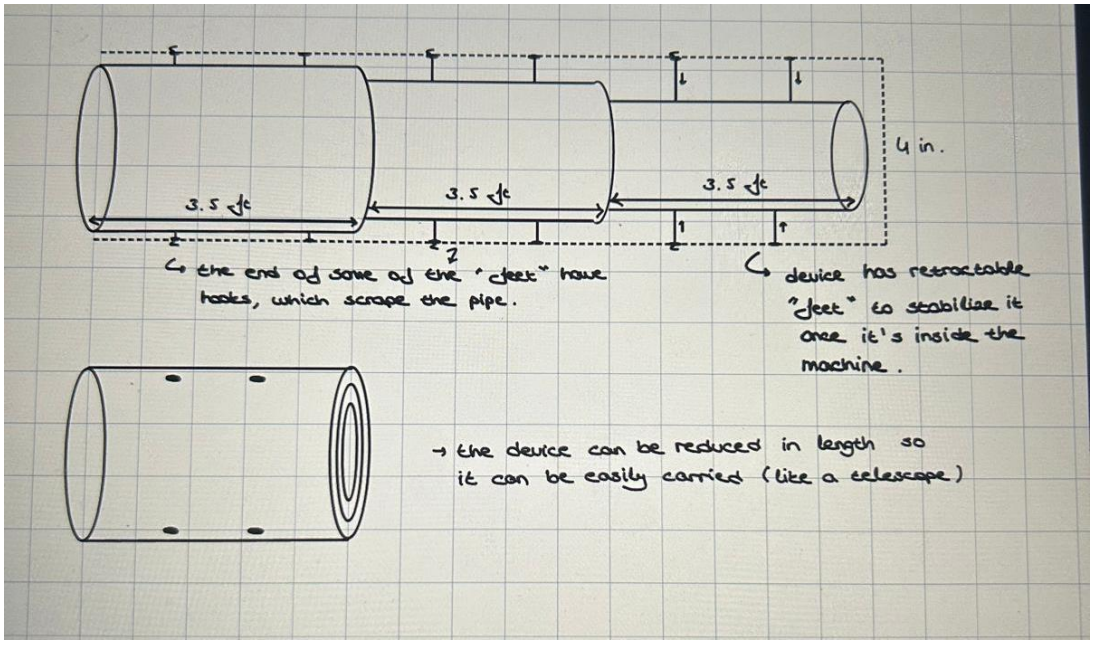
        - Needs to be in the storage area rather than the scraping area
        - Calibration is required
        - Dependent on power
        - Less precise than load cells
- **Sample containment system**



- Vacuum sealed container
    - using a vacuum system to suck the samples off the collection system to be sealed, safe from harming the collectors
    - Pros:
        - Efficient at collecting small dust particulates
        - Airtight
    - Cons:
        - Dependent on power
        - Intricate design is needed depending on sampling method to ensure that most material is collected
- Magnetic Containers.
    - Uses magnets to take the samples off the sampling device
    - Pros:
        - Simple and effective at removing the particulates and getting stored in the storage container
    - Cons:
- Cartridge containers.

- Takes samples off the sampling device and stores them in a cartridge which closes upon sampling device exciting the cartridge, preventing exposure.
- Pros:
  - Should automatically seal upon removal of sampling device
  - Modular Design. Able to take many samples with swapping out cartridges
- Cons:
  - May require power to seal automatically
  - Complex system for automatic sealing

Berke Dai



Design 1:

Main Body

- **D-Shaped Handle**

    - Pros: Easy to use efficiently with reasonable scraping force with little no stress.
    - Cons: Uses mechanical force so very dependent on the operator
- **Inner Shaft**
    - Pros: Simple and cost-effective way to transfer the scraping force along the length of the device
    - Cons: May be difficult to run the full length of the device, and may not provide enough force (may be resolved using gear systems)

  Subsystems
    - **Sample Collection**
        - Pros: Effective on measuring the amount of sample collected without damaging the integrity of the sample.
        - Cons: May be difficult to wire/integrate into the system, along with being somewhat costly.
    - **Storage**
        - Pros: Clear case for an easy visual of the sample in real time, while maintaining the integrity of the sample.
        - Cons: May be difficult for weighing.
    - **Weight Detection**
        - Pros: Using a sensor to measure the weight makes it easier to do autonomously and minimizes the handling of the product.
        - Cons: May be inaccurate with such a small load unless we use a more precise one which can ramp up costs.
    - **Feedback**
        - Pros: With the load sensor we can measure the weight of the sample during the collection process
        - Cons: Inaccuracies with the sensors or difficulties with the technical wiring of the sensors and microcontrollers

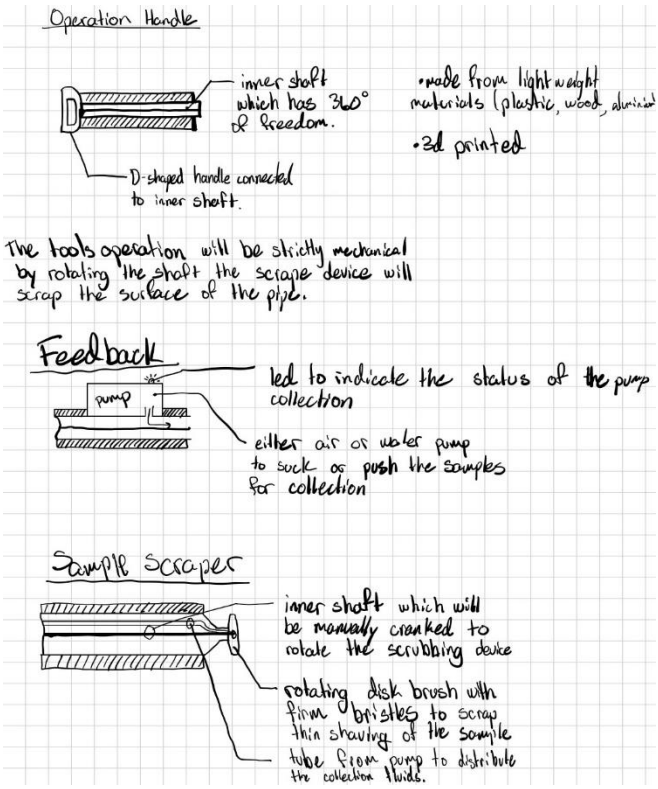
Estimated Cost:

6V/12V/24V DC Vacuum Pump, Mini Air Pump ~ 15$

Forney 72739 Wire Wheel Brush, Coarse Crimped with 1/4-Inch Hex Shank, 4-Inch ~ 8$

Arduino Mega 2560 Rev3 ~ 40$

Along with supplementary materials and manufacturing costs we estimate about 90-100$.



Design 2:

Main Body

Rotating Sandpaper Cylinder (Sampling Drum)

- A hollow cylindrical drum wrapped in abrasive sandpaper scrapes fine metal particles off the pipe wall.
- The drum has machined divots or shallow recesses (~2 mm depth) where the loosened particles accumulate.
- Rotates at a low but controlled RPM (~30-50 RPM) to gradually collect and trap material.

Motorized Drive System

- A low-speed, high-torque brushed DC motor (6V–12V, ~10-20 W) drives the cylinder.
- The motor is directly connected to the drum via a simple gear or belt system.
- Runs off a compact battery pack, providing enough power for a single operation cycle (~15-30 min).

Fail-Safe Retrieval System

- The system is attached to a manual or motorized cable retrieval mechanism.
- Once sampling is complete, the unit is pulled back via the retrieval cable.
- The sample remains securely stored in the drum divots until it reaches the operator.

The **pipe acts as the guiding structure**, ensuring proper positioning of the sampling tool within the system.

- Pros:
  - Provides stability for the sampling tool.
  - Minimizes movement and misalignment, ensuring even abrasion.
  - Guides retrieval system, preventing unnecessary strain on the cable.
- Cons:
  - Friction may cause drag, increasing motor power demand.
  - Tight clearances require precision alignment for proper tool insertion and removal.

Subsystems

- Sample Collection - Hard Sander Brush Scraper
  - Pros:
    - **Simple design:** Low moving mechanical parts reduce complexity.
    - **Durable:** Hard bristles can withstand repeated use.
    - **Effective scraping:** Ensures sample consistency.
  - Cons:
    - **Limited adaptability:** May struggle with varying pipe surface textures.
    - **Manual force required:** Unlike powered methods, scraping efficiency depends on physical force.
    - **Bristle wear:** Frequent use causes gradual degradation.
- **Insertion & Positioning:**
  - The unit is inserted into the pipe via a guiding extension rod or retrieval cable.
  - The operator manually positions it at the target sampling location.
- **Sampling Process:**
  - The motor is activated via a simple switch, spinning the sandpaper drum.
  - As the drum rotates, abrasion removes metal particles, which then settle into the divots.

        - The divots passively hold the sample in place due to surface tension and particle adhesion.
    - Fail-Safe Retrieval System
        - **Motorized:** A small reversible DC motor with a clutch system enables automated retrieval.
        - **Fail-Safe Clutch Mechanism:** Prevents excessive strain on the cable or system lock-up if the tool gets stuck.
        - **Cable Attachment:** The sampling unit is securely connected to the retrieval system via a stainless-steel loop or bracket.

Overall:

Sampling Process

- Motor is activated manually, spinning the sandpaper drum at a controlled RPM.
- Metal particles are loosened through abrasion and collect in divots.
- No vacuum or forced air is used, reducing power consumption and unnecessary complexity.

Pros:

- Low power requirements, maximizing battery efficiency.
- Mechanically simple, reducing failure points.
- No additional air or suction system needed, making the design compact.

Cons:

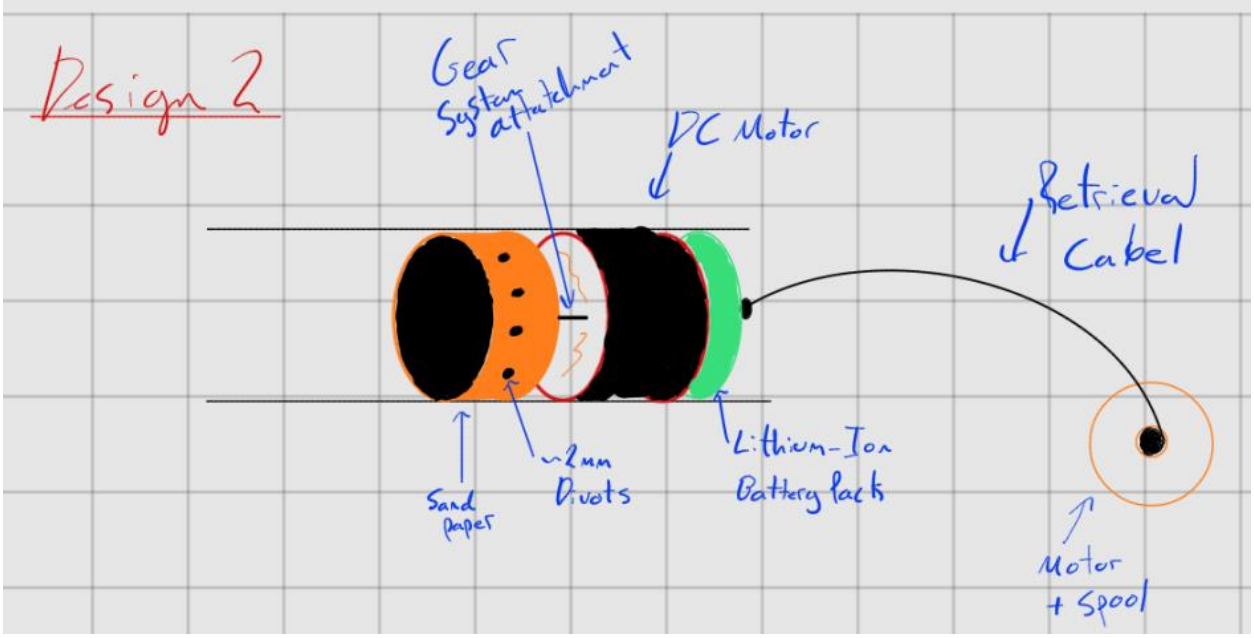
- Divots may lose material during retrieval due to vibration.
- Sampling consistency depends on drum speed and surface condition.
- May require an additional retention method (e.g., mild electrostatic charge or sticky coating).

Estimated Cost **Breakdown:**

Component	Estimated Cost (USD)
Low-speed DC motor (10-20W)	$10-$20
Sandpaper-wrapped rotating drum	$5-$15

Battery Pack (6V–12V Li-Ion)	$15-$30
Switch & Basic Wiring	$5-$10
Retrieval Cable (Fail-Safe System)	$20-$50
Total Estimated Cost	**$55-$125**

Full Design 2 Concept:



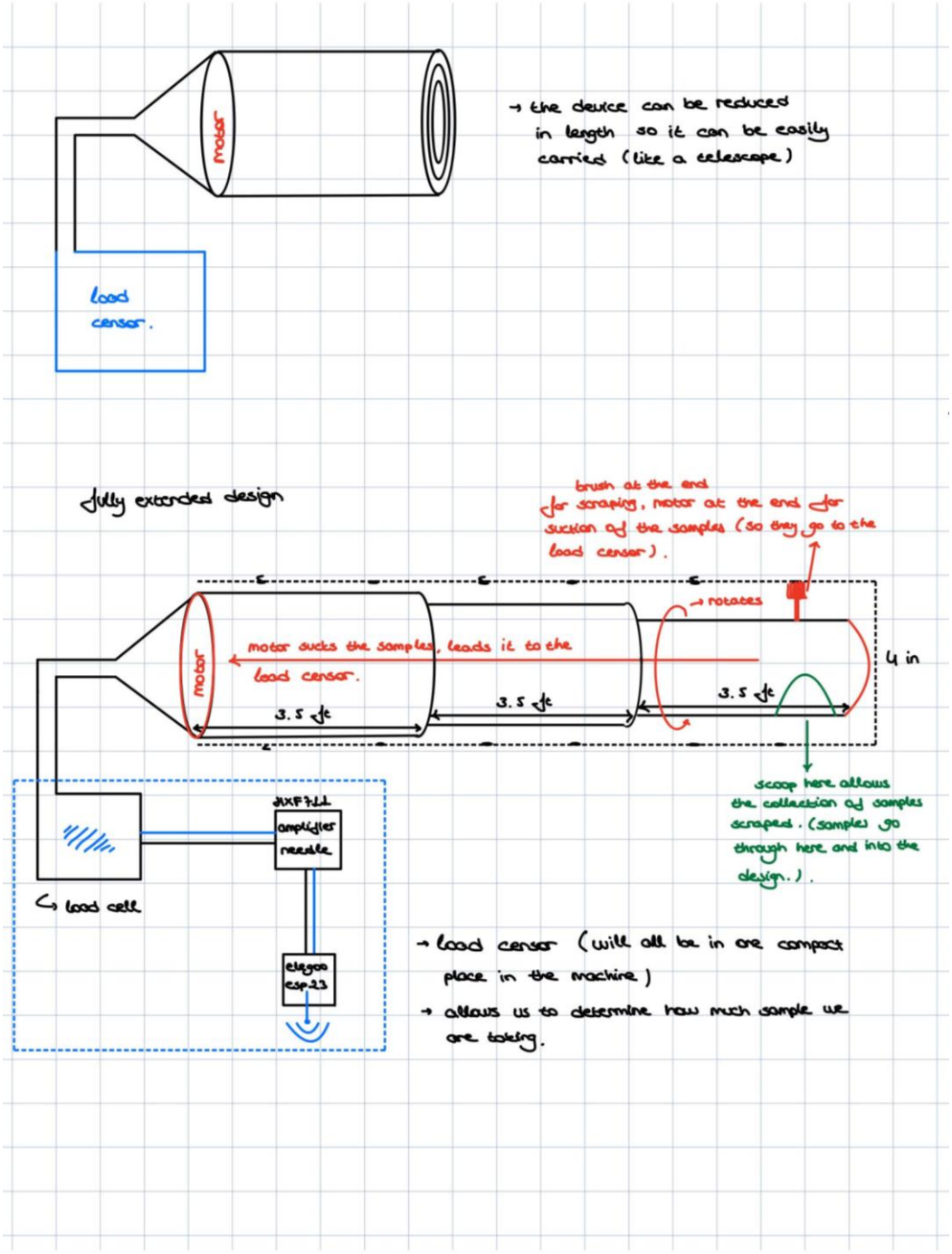
Design 3:

Main Body

- Handle: D- shaped handle
- Pipe: Collapsable for easy transport
    - Pros:
        - Able to be carried easier, as well as take up less space
    - Cons:
        - Needs to be able to accommodate the scraper as well as the various electrical components

    Subsystems
    - Sample Collection: Brush with Nylon Bristles
        - Pros:

        - Little damage to pipe, inexpensive to replace,
        - Non sparking.
        - Light weight.
    - Cons:
        - May struggle with tough deposits.
        - Needs power or may need to be manual.
- Storage: Vacuum Storage
    - Pros:
        - Able to collect small particles easily
        - Airtight
    - Cons:
        - Might clog with an abnormal large sample
        - Dependent on power
- Weight Detection: Load Cell with HX711 Amplifier
    - Pros:
        - High accuracy in weight measurement
        - Real-time data monitoring
        - Reliable sample validation
    - Cons:
        - Needs both power and calibration
        - It might be costly (relatively for the project)
- Feedback: load sensor relayed data to a laptop
    - Pros:
        - Provides real-time feedback to the operator
        - Alerts when full
        - Should be easy to integrate
    - Cons:
        - Requires calibration and power
- Fail Safe: Motorized Cable Retrieval with Clutch System
    - **Pros:**
        - Allows automatic retrieval, prevents excess tension on the tool, and enables operator control.
    - **Cons:**
        - More complex, it requires power and a robust mounting system.



Final Selection

Design/Specifications	Design 1	Design 2	Design 3
Cost	~$90	**$55- -$125** $	~$150

Weight	< 15 lbs	<20lbs	< 15 lbs
Material	Aluminum/Steel	**Aluminum**/Steel	Steel/Aluminum
Shaft	Rod with D-Shaped handle		Telescope/collapsible rod
Scraping Mechanism/ Collection Mechanism	Clear case under a rotating brush which scrapes the pipe	Rotating Sandpaper Cylinder (Sampling Drum) with divots to collect samples	Rotating brush with a catch scoop underneath
Dimensions	15 foot shaft, 3 inch diameter pipe	15 foot shaft, 3 inch diameter pipe	15 foot shaft, 3 inch diameter pipe
Special Features	Load sensor/ vacuum tube on collection mechanism, power, external power switch	Divots in the rotating sandpaper cylinder collects the material without using a vacuum tube, minimizing electricity needs. In the event of an emergency, the device is also able to use a motorized cable with clutch system to retrieve the sample without endangering the operator.	Load sensor, Collection Scoop, external power switch
Failsafe	No	Yes*	Yes
Feedback Mechanism	Load sensor	No	Load sensor/weight detector

4-Conclusions

After evaluating multiple design concepts, the chosen design (3) is a telescoping/collapsible rod with a rotating brush and catch scoop underneath, made of steel/aluminum, weighing less than 15 lbs. with an approximate cost of $150 (tentative). This design includes a 15-foot shaft with a 3-inch diameter pipe, a load sensor, a collection scoop, and an external power switch. Compared to a fixed-length rod with a static scoop, which is simple and cost-effective but lacks adaptability, or a lightweight composite

material with a manual brush, which is easy to handle but lacks durability and efficiency, this design offers the best balance of functionality, durability, and efficiency. The telescoping feature allows for easy storage and adjustable reach, the rotating brush enhances material collection, and the catch scoop reduces manual effort. While the cost is slightly higher and it requires an external power source, the benefits justify the investment. Alternative designs were considered but discarded due to their limitations in reach, usability, and efficiency. This final selection ensures feasibility within the constraints of time and budget while maximizing performance and durability.

5-References.

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