RANES Design Pitch

Project: ***Safe Water for All***

Team 1078E

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Executive Summary

Yemen is currently facing the world's worst humanitarian crisis. There is a lack of clean water and food insecurity, leading to outbreaks in diseases and starvation. A civil war has been going on in the country for over 7 years, which results in the continuous destruction of aid supplies and infrastructure. With the country predicted to run out of water in the next decade, solutions to their water crisis are needed now more than ever. The team has been tasked with the goal of creating safe water for the Yemeni population in their capital, Sana'a.

Agriculture was identified as a high consumer of water and an area where the team's design work could make a difference. The team narrowed down the scope to water filtration and water conservation through efficiency increases. After this, a requirements model with criteria and constraints was established. This requirements model conformed to the hierarchy of objectives – broken down into high-level and detailed – that were established following consultation with 6 of the UN SDGs: No Poverty, Zero Hunger, Good Health and Well-being, Clean Water and Sanitation, Responsible Consumption and Production, and Partnership for the Goals.

Due to the food and water crises faced in the country, the team has focused their solution on improving water quality and efficiency in irrigation systems. A common farming practice in Yemen is to flood the field with water; however, this leads to a large consumption of water. The prototype targets water efficiency by implementing a two way valve system that can control the amount of water that is dispersed to a field using surge irrigation techniques. A motor controls the opening and closing of two valves, which is timed based on soil moisture sensors. There is an inlet for water and two outlets for the irrigation system in two fields. The overall design solution also involves the use of a sari cloth filter to reduce the amount of bacteria present in the water supply. When creating this solution, other considerations were made such as energy usage, portability, and access to materials. Throughout the design process 3 key design decisions were made: prioritizing water efficiency over water filtration, creating a two valve mechanism to better improve the water seal, and using a single motor to turn the valves in order to minimize the cost of the overall prototype.

Finally, the team outlines proposed outcomes that are not just the product to be designed, but also a comprehensive and holistic set of plans for steps going forward. These are meant to target the identified opportunity at the appropriate scope with the right partnership from within and outside the community to develop a long lasting, sustainable, equitable and effective solution to Sana'a's water crisis and improve the lived experience of the stakeholders. Water and food are essential to survival and with supplies dwindling in the country of Yemen, solutions such as ours are crucial to the survival of the population. Promoting the ideas of safe and sustainable water usage is imperative to the success of the solution and many efforts are already being made in the country to ensure a uniform understanding. With the implementation of the design there will be improvements on the overall health of the Sana'a population and efficiency of water usage.

1. Introduction to the Design

Yemen is currently facing the world's worst water crisis, catalyzed by declining groundwater levels, economic and political instability and disease outbreak. This opportunity's global context provider, Mona Mohammed, highlighted the stress placed on groundwater sources due to uncontrolled use. Although Mona emphasized the need to monitor water levels in wells, the team saw this challenge extend to a greater upstream problem of where and how the majority of water was being used. In Yemen, only 8% of water is used for domestic purposes including drinking water, whereas the agriculture sector uses 90% of Yemen's available water [1] with 40% of crops relying on groundwater for irrigation [2]. This industry, providing livelihoods for 73.5% of Yemeni households [3], most significantly depletes Yemen's groundwater levels. Thus, the team scoped the opportunity to address the unsustainable use of water in the agriculture sector.

The proposed design CleanFlo uses surge irrigation to reduce water use by up to 43% [4]. Currently the main methods of irrigation are spate irrigation, which floods the cropland with water diverted from a nearby river, and spring irrigation, which pumps water from the ground to heavily water soil. Surge irrigation is a more efficient method of irrigating plants that works with both spate and spring irrigation. Instead of watering the field all at once, the cropland is divided into two sections and water is alternated between them. This gives time for the soil to absorb the water, reduce water runoff, and control the rate of water infiltration. CleanFlo's value proposition is primarily to reduce water use, but the real value of the design is that it considers the cultural, personal and societal values and needs of the Yemeni farmers. The design does not ask farmers to completely change their agriculture practices, instead, it is a simple widget solution that can be easily incorporated into their current methods while significantly decreasing water use. To address the effects of civil, CleanFlo is a compact and portable device that can be easily transported if farmers must escape conflict.

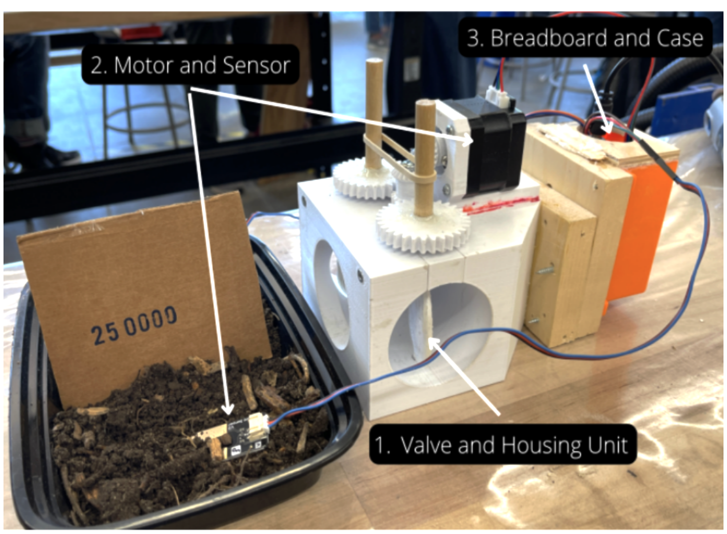

Figure 1a: High fidelity prototype of CleanFlo.

CleanFlo is composed of three key components (fig 1a). First, the housing unit uses two valves offset at 90° to divert water between the two sides of the field. This system is powered by a stepper motor that uses a system of gears to turn the valve. A soil humidity sensor is placed at the end of the field on each side of the divided land to ensure the whole field is well irrigated. The breadboard and case contain the electrical circuit that powers and controls the motor and sensors. Finally, a dashboard seen in fig 1b, will update users on the current state of the irrigation process and allow farmers to vary parameters related to the timing and duration of watering based on their land needs.

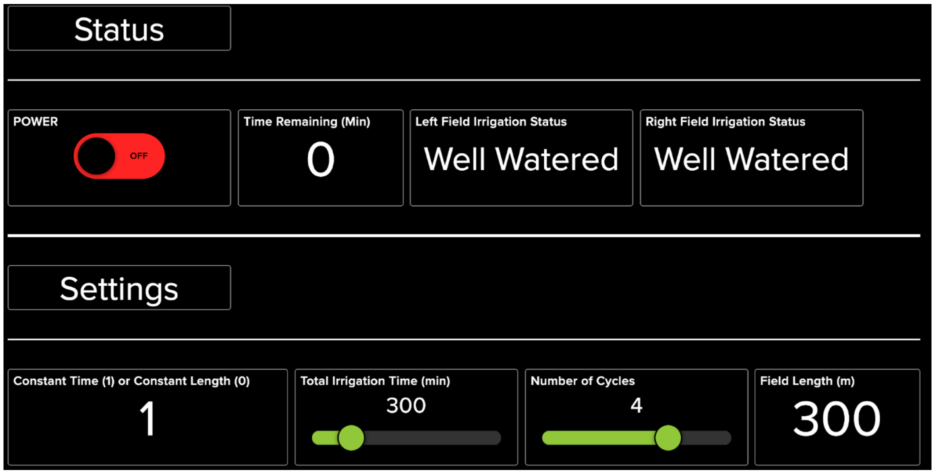

Figure 1b: IO Dashboard to control the power status and settings of the water irrigation system.

2. Background

2.1 Stakeholders

Three primary stakeholders have been identified: Yemen Farmers, their consumers, and the team. The farmers require a reliable source of water that will ensure the health of their crops. Their consumers need a source of food that will not cause illness. The team wants to create a design that will improve upon their lived situation while meeting the UN SDG goals. Two secondary stakeholders have been identified: the environment, and the UN WASH representative. The environment needs a design that will not cause harm. The UN WASH representative wants to improve the water quality for the people of Yemen.

This design will improve upon the efficiency and quality of water used to water the crops. This will provide value to the farmers and their consumers as it ensures there will be a source of water that can be safely consumed. The team and the UN WASH representative get to meet the goal of improving the stakeholders' lived experience. The environment is also considered as the proposed solution allows groundwater levels to be replenished and eliminates disease in the water supply.

2.2 Scope

There are several limits to the impact that can be cultivated in Sana’a regarding the water crisis due to the ongoing civil war and the extent of the team’s value chain. For instance, the proposed solution’s initial and continued implementation may be hindered by import restrictions and other bureaucratic impediments. Thus, there is no guarantee that the proposed solution will reach the hands of Yemeni farmers in Sana’a once it is mass-produced. Additionally, the water crisis in Yemen is multidimensional, spanning issues of water sourcing, monitoring, treatment, and conservation. Due to the team’s limited resources and capabilities, it is not possible to target all dimensions of the water crisis. The multidimensionality of the water crisis also prevents the design team from constructing solutions that are appropriate for all communities in Sana'a since their needs vary greatly and require solutions that reflect this diversity. As a result, the team has opted to design a solution that provides clean water and improves its efficient usage in existing spate or furrow irrigation systems used by Yemeni farmers.

Additional value, in the form of pain relievers, that this scope provides for Yemeni farmers and their consumers include improved food security and community health as increased water quality leads to the increased quality and quantity of the agricultural produce used to feed the city's population. Reduced water usage and water cleanliness will allow Yemeni farmers and their consumers to be more resilient toward water-related hazards such as droughts and to have sufficient access to safe drinking water as a result of increased water allocation towards drinking [5]. This provides value to the UN WASH Representative as it aligns with her goals of developing, implementing, and managing safe drinking water solutions in Yemen. Regarding the environment, clean water prevents the contamination of soil ecosystems [6] and reduced water oversaturation prevents the leaching of nutrients in soil ecosystems, which is conducive to Yemen's sandy soils [7,8]. Gain creators for Yemeni farmers include economic growth, from technological improvements and shifted attitudes toward new irrigation technologies, labour force growth, from advances in food security and community health, and increased human capital in the agricultural sector as more farmers will be trained and skilled in using these systems [9]. Another gain creator for Yemeni farmers is that the proposed design maintains the values of hard work and pride attached to traditional farming practices as only a small adjustment will need to be made to their current system (i.e., insertion of CleanFlo between pipe segments).

1 NO POVERTY	2 ZERO HUNGER	3 GOOD HEALTH AND WELL-BEING	6 CLEAN WATER AND SANITATION	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	17 PARTNERSHIPS FOR THE GOALS
Pain Relievers: improved community health and food security allow **farmers and their consumers** to meet basic needs. **Gain Creators**: increased labour force and human capital in agriculture contribute to advances in workforce skillset, which can help **farmers** in poverty break out of their cycle.	**Pain Relievers:** improved food security reduces hunger in **farmers and their consumers**. **Gain Creators:** increased labour force and human capital lead to increased income and purchasing power for **farmers and their consumers**. Makes food and water financially accessible.	**Pain Relievers**: Reduction of cholera and other water-borne diseases or contaminants in agricultural water and **soil ecosystems** contribute to a higher quality of life for **farmers and their consumers** in Sana'a. Progress towards "No Poverty" and "Zero Hunger" UN SDGs contributes to good health and well-being.	**Pain Relievers**: the **team**'s design solution space focuses on clean water and sanitation in spate irrigation systems used by **farmers**. Regarding future work, the cloth filter aspect of the proposed solution has applications for water filtration in **consumer households**.	**Pain Relievers**: There is a focus on minimizing water consumption in spate irrigation systems used by **farmers**. Implications include **farmer** education in responsible consumption and production and reductions in agricultural water consumption, allowing for increased water allocation towards drinking for **consumers.**	**Gain Creators**: the **team**'s collaboration with **UN WASH Representative Mona Mohammed**, the GSU peer, and the Praxis III FaCT to increase water efficiency and sanitation in spate agricultural irrigation systems is a form of global partnership in the sustainable development of Sana'a's agriculture sector.

Figure 2.2: *Team-generated table* establishing the relationship between value proposition, UN SDGs, and stakeholders [10].

2.3 Service environment

The proposed solution must work on a farm with an existing spate or furrow irrigation system. This particular farm is envisioned to have graded straight furrows with crops grown on the ridges. Existing piping from the irrigation system must be orthogonal to the furrows. Holes located along the pipe serve to flood water into the furrows, which infiltrate to transport water to the roots of the plants. The water must be supplied from another pipe attached to the aforementioned piping. The described environment allows the proposed design to be inserted between two pipe segments located at the halfway point of the crop field. Additional complications include weather damage and civil war attacks. Therefore, the proposed solution must be durable in withstanding debris buildup, wind, and water and must have the ability to be disassembled and portable to mitigate floods and allow for farmer evacuation amid war attacks.

2.4 Reference designs

Two reference designs were examined: a surge irrigation system (fig 2.4a) and a sari cloth filter (fig 2.4b). In Egypt, the Faculty of Agriculture at Kafrelsheikh University implemented a surge irrigation system to water maize crops in their Research Farm [11]. The goal of surge irrigation is to improve water use efficiency, which is low for traditional irrigation systems such as spate or furrow irrigation [11]. Surge irrigation achieves this goal by alternating and controlling the flow of water from one half of a crop field to the other half in timed cycles [12]. Water savings result from increased rates of water advancement down the furrow, a more uniform distribution of soil moisture along the furrow and throughout soil depth, and reduced losses from deep percolation and water run-off at the end of the field [12]. The structure itself consists of a water supply pipeline and an automatic surge valve (consisting of a butterfly valve, a programmable controller, a battery, and a solar cell recharging panel) located between two segments of a gated pipe [12]. Regarding functionality, the water supply pipeline transports water from a source to the surge valve, which diverts water in two directions through the butterfly valve plate and times diversions in cycles through the automated solar-powered timing system [12,13]. Diverted water reaches the furrows through the gated pipe [12,13]. When assessing its function, it was noted that for an inflow rate of 44 litres per minute and a furrow length of 20 meters, water savings increased by 19.14% [11]. Notably, a study conducted in Uzbekistan observed a 44% increase in water savings [14].

Bangladeshis use sari cloth to filter untreated water for drinking as they are unable to find and afford the materials required to build a fire for boiling untreated water in times of flooding [15]. Function-wise, a sari cloth is placed over the neck of a clay or metal-made water collecting pot, untreated water is then poured into the pot where it is filtered by the sari cloth. Concerning its microstructure, the pore size of one layer is 100-150 micrometres; however, this can be reduced to an effective pore size of around 20 micrometres when the cloth is folded into four to eight layers [15]. Under constant use, the thread of a sari cloth becomes softer and unconstrained. This leads to a reduction in cloth pore size and, in turn, more effective filtration [15]. A study by the University of Maryland and John Hopkins University found that a sari cloth filter could reduce the amount of cholera in untreated water by 48% in 65 Bangladeshi villages [15]. The study also concluded that a sari cloth can remove most phytoplankton, zooplankton (e.g., cholera), and particulates with a diameter greater than 20 micrometres from untreated water [15].

Figure 2.4a: Automatic surge valve, connected to a water supply inlet and outlet pipes [12].

Figure 2.4b: Sari cloth filter in use by a Bangladeshi woman [16].

2.5 Requirements Model

Objective 1: Must save water – *Design for Efficiency* – Farmers and Yemeni Government		
Objective 3.1	Metrics	Criteria
Increase the water efficiency compared to currently used irrigation systems.	Average percentage of water saved over water used per day of system operation.	More is preferred (Unit: $\frac{Litres}{Day}$).
Verification/Validation Process:	Measuring the difference in water required to irrigate a plot of soil using the widget versus conventional means.	
Objective 2: Must be accessible in terms of materials, implementation, and/or maintenance – *Design for Accessibility, Repairability, and Cost* – Farmers and Global Aid Organizations		
Objective 2.1	Metrics	Criteria
Reduce the number of costly parts in the design.	The cost of both the prototype and a total cost estimate of the full solution.	Cheaper is preferred (Unit: CAD).
Verification/Validation Process:	Calculating the cost of the design/prototype and confirming with the stakeholders that it is a reasonable price in Yemen.	
Objective 2.2	Metrics	Criteria
Reduce the number of materials that are not easily available in Yemen.	The number of components that are not commonly accessible in Yemen and for Yemen farmers.	Less is preferred.
Verification/Validation Process:	Confirming with the stakeholders whether a required material is accessible in Yemen.	

Objective 3: Must increase water quality for safe agricultural use – *Design for Safety* – Yemeni People		
Objective 1.1	Metrics	Criteria
Decrease the amount of harmful pathogens and compounds in water to safe levels.	Filtration of bacteria must abide by the WHO “Guidelines for the safe use of wastewater in agriculture” [17].	Less harmful pathogens remaining is preferred.
Verification/Validation Process:	Ensuring the water quality outputted meets WHO requirements and the farming standards for the stakeholders.	
Objective 4: Must not be more labour intensive than current practices – *Design for Efficiency* – Farmers		
Objective 4.1	Metrics	Criteria
Reduce the time and amount of work for farmers.	Time required to start and operate the system per day.	Less is preferred (Unit: Hours).
Verification/Validation Process:	Validating with Yemeni farmers that the required labour is feasible and less tedious than current methods.	
Objective 5: Must have crucial components be portable or replaceable – *Design for Portability and Durability* – Farmers and Yemeni Government		
Objective 5.1	Metrics	Criteria
Increase portability of irreplaceable parts in the designs.	Time required to assemble design.	Less is preferred.
	Compacted size and weight of design per m^3.	Less is preferred (Unit: kg/m^3).
Verification/Validation Process:	Verify that the design can be easily moved considering the size, shape and weight.	
Objective 6: Must be considerate with energy usage – *Design for Efficiency* – Farmers and Yemeni Government		
Objective 6.1	Metrics	Criteria
Minimize energy required to power the system.	Average power required to operate the system per day.	Less is preferred (Unit: Watts).
Verification/Validation Process:	Validate with stakeholders that the majority of farmers have access to the power needed for the design.	

**Yemeni People refers to those who will eat the food produced by the farmers and/or access the same water source and do a cascade effect, they are implicitly and/or explicitly considered in all objectives.*

Constraints

1. Must have a widget component.
2. Must not compromise the safety of any Yemenis people – *Design for Safety*.
    a. Must follow ISO Standards related to Ergonomics in the Agricultural Sector [18].

3. Prototype design must be less than $150.

3. Design Process and Key Design Decisions

3.1 Path to recommending the conceptual design

The path behind recommending the conceptual design was informed by the Project Management Plan (PMP). As part of the recommendation, several key design decisions were made for the mechanical and structural aspects of the design and the electrical and software components. For the mechanical components, the first key design decision was to use two valves instead of one. When first completing the CAD model using a single valve, it was found that the symmetric valve design would not be able to effectively seal either side due to the geometry of the spherical cavity used for the inner flow housing. Reflecting back, the team was anchored onto a single valve due to a consulted research paper on timed surge irrigation. Conclusively, the team consulted reference designs on 3-way butterfly valves from commercial sources before settling on using two valves.

The second key design decision was using a single motor. This decision was based on the PMP and team values of empathy and accessibility. Normally, using two valves would imply the use of two motors for completely independent controls. While this allows for more granular control and potentially safety, a single motor was chosen to reduce the cost associated with acquiring, powering, wiring, housing, and water-proofing; this aligned with team design goals of creating a design that was light and affordable. A single motor allowed the design to be accessible to more stakeholders by virtue of lower cost and power requirements.

On the electrical side of the design, the first key design decision was the use of a single small breadboard, which required using the space on the breadboard efficiently. This is related to the PMP as the team aims to create a durable and accessible design. In the context of this opportunity, compactness and portability were further emphasized. Another related key decision was the use of a single power input accomplished through the use of a voltage regulator so that the whole system could be powered at once and would require minimal external connections. Finally, the team's shared value of empathy and accessibility led to the decision of including a safety switch and visual indicator in the form of an LED so that the system progress could be easily tracked and would be safe to use for stakeholders.

For software, the first key decision was to use an IoT-based dashboard. Having worked with IoT in a previous widget lab, the team took advantage of the positive features seen, including accessibility and durability which ties into team values. The use of the IoT dashboard then gave rise to other key decisions in terms of using variable parameters which the farmer can input according to their respective needs to provide flexibility in the design, tying in with team values of accessible design.

3.2 Path to development of the prototype

Mechanically, the development process involved CAD modeling, based on research papers, and mechanical motion, simulated using motion links and joints in Fusion 360. Initially, the valves were planned to be assembled, with the inner shaft, faceplate and end cap being separate parts; however, it was realized that tolerances would have to be minimal, which was not feasible for 3D printing (fig 7.1). As a result, the entire structure was combined into a single part. The housing unit went through a few iterations, resulting in the final design in fig 7.2. The valves were optimized to be the thickest along the central shaft to repel the highest pressure. Regarding the gearing system, spur gears were selected from McMasterCarr. It was difficult to find a spur gear that would fit in the small space between two larger spur gears(fig 7.4). This prompted the design of a spur gear merged with a bevel gear, however, the spur part had difficulty catching the teeth of the larger spur gears attached to the valves. As a result, dowels were epoxied on atop the large spur gears. This was used to tension the valves together with rubber bands to allow for proper teeth contact between the smaller spur gear and the two larger spur gears.

The electronics were integrated into the main case by adding a wooden backbone for the case to be mounted on. A wooden lid, with a hole bored out for the cables, was used to waterproof electronics. The same hole was widened with a dremel to allow for power and data input for modifications. A flexible tube was used as a wire duct and routed the cables through it.

During final assembly, it was noted that the main issue in reliability was the M3 screw used to secure the bevel gear onto the motor driveshaft. The screw thread was cut and sanded down for clearance of the motor mount during rotation, which caused issues holding the bevel gear to the motor drive shaft. To resolve the issue, the bevel gear was hot-glued onto the driveshaft which was found to have superior reliability, hence completing the prototype.

Electrically, the path to the development involved important prototyping decisions which allowed for key insights into the overall design. The circuit design process was done with each component tested separately, where team members worked on ensuring the functionality of the different components separately to warrant an organized design process. When combining separate components of the circuit together, some difficulty was faced in getting everything to run. A multimeter was used to troubleshoot, and the problem was traced down to an issue in the common grounding between the external power source and the Arduino's ground. Abiding by the principle of compact design, wires were cut to appropriate lengths to minimize the area occupied. Wires, such as for the stepper motor and sensors, were kept in the form of jumper wires as these fit directly into the sensor inputs. For the switch and LED, soldering was used to create a reliable connection between the pins and the wires. When securing the circuit into the breadboard case, maintaining a clean layout of wires and using solder was helpful in identifying problems and provided flexibility in positioning the switch and LED (figs 7.3, 7.4).

Developing the software component of the prototype followed a similar trajectory to the hardware and was done in parts so that the functionality of each component could be verified along the way. A key decision made was in the IoT system. During testing, it was noticed that the wireless connection was unstable at times. An additional visual indicator was added through the onboard LED to keep track of the wireless connection status. This proved to be especially important when testing the system through the power source and without a direct connection to a laptop. The software also had to be tested in conjunction with the mechanical design by adjusting the stepper motor rotation power and number of steps.

3.3 Verification and Validation

For verification and validation, a series of tests were performed to determine if the prototype performed as was expected in a variety of situations. A leak test was conducted, where water was poured in from a high inlet to provide some velocity as it entered the flow housing and the valves were positioned to open one side and close the other. The amount of water that came out of each outlet was measured and a leak rating of 5% was reported. Calculations were performed using the Bernoulli and continuity equations to determine the torque that the motor could handle. It was reported that the motor had 100 times the necessary torque to hold the valve in place with the maximum flow rate of 17 gallons per minute for the given pipe. Further, an extended run of the farming cycles was stress-tested and found that it worked for the entire cycle, with waiting periods reduced for testing purposes; the prototype performed admirably, with no visible defects or damage after the long stint. In terms of the soil moisture sensors, testing was done using soil samples to ensure that the system was able to detect the appropriate water levels in the soil. The algorithm was verified using research on optimal surge irrigation timing.

3.4 Comparison to previous approaches

Compared to previous approaches considered in Section 2.4, the design is unique in several ways. While butterfly valves and automated surge irrigation controllers have been used by other designs, the team focused on having a compact, portable, and accessible design specifically for use in Yemen. Existing designs were extended and specifically tailored to the needs of stakeholders. The use of variable parameters and sensor data as part of the algorithm is another important distinction, one which derives from collective team values. In terms of the filter, the team built directly off of a design [15] that has already been tested under different conditions to ensure effectiveness and safety. Finally, the use of a single motor for the simultaneous control of two valves instead of two motors as in previous approaches is a design feature that allows for increased efficiency.

3.5 GSU interaction

The GSU collaborator provided the team with feedback for the Design Proposal. The feedback given was positive and did not incorporate any information on areas to improve. He identified successes in identifying primary and secondary stakeholders and constructing a value proposition for stakeholders. Further, he commented on the team’s ability to consider the environment and the difficulties it may pose with the proposed design. This positive feedback was incorporated into the prototype as the team continued to consider the value that their design choices were providing the stakeholders and the instability the country of Yemen faces. Ultimately, the feedback helped the team emphasize portability and water efficiency in the design to ensure they were providing value to the farmers and their consumers.

4. Final Design and Prototype

4.1 Validity of the design

The conceptual design presented in the previous section addresses the needs of the stakeholders in multiple ways. The design emphasizes efficiency, as it significantly reduces the amount of water used to water crops. This meets the needs of both the farmers and their consumers as the design allows efficient water usage that ensures the crops will thrive. This meets UN SDG goals 1, 2, 3, and 12. Further, the cloth filter allows pathogens to be mitigated from the water supply and ensures the health and wellbeing of the environment, the farmers, and their consumers. This meets UN SDG goals 3 and 6. The key components of the design are also portable considering the farmers' unstable environment due to the ongoing civil war. Finally, the overall solution does not increase labour for the farmers ensuring that it can be easily implemented into their existing piping systems.

4.2 Limitations and assumptions

Several limitations and assumptions have been identified with respect to the design and the prototype. Limitations include the availability and cost of the soil moisture sensors and the Arduino for people in Yemen. Also, the use of a power or battery source may limit the design due to a lack of resources and the cost of fuel. Assumptions include that the mass flow rate of their pipes is about the same as a typical garden hose. These numbers were used to calculate the torque for the motor and if the step motor would be sufficient for their scale of pipes. If their soil content is similar to the numbers used to calculate the timing for the opening and closing of the valves. That the design can be scaled to fit the dimensions of their pipes and that it can be easily reproduced. Finally, if the Arduino can make a reliable network for the design to have a dashboard that the farmers can interact with.

4.3 Prototype related to design

The prototype is a good representation of the final design concept at a smaller scale. On the mechanical front, it proves that actuating both valves with a single motor and a complicated gearbox is viable, reliable and capable of meeting requirements. However, for the actual design, the team hopes to use thermosetting resin instead of the thermoplastic resin used in the prototype. This allows for stronger, more precise manufacturing for the gears and valves. For the housing, wood is the ideal material as it is naturally found, easily procurable, cheap, durable and more water-resistant than plastic with print lines. However, there is concern about the wood softening under continued water exposure; this can be mitigated with a strong layer of paint to combat water exposure and assist in thermoregulation. Lastly, an added latex layer inside the cavity, secured by heat-treating latex film, will prompt superior water resistance.

Electrically, the components being used in the prototype will mostly remain the same in the final design concept. The motor in the final design will be a larger type of stepper motor which will require the control circuit to be modified for differences in the drivers and an increased power demand. The power source itself has currently been left as an open-ended aspect where different possibilities have been considered such as solar power, a source already used in Yemen. A breadboard has currently been used to implement the circuit; this will likely be in the form of a printed circuit board (PCB) in the final design for a more reliable and compact design. The possibility of including other microcontrollers specifically for these components has also been considered with the microcontrollers communicating among each other.

The prototype uses the Arduino Nano RP2040 connect microcontroller and CircuitPython for the software. In the final design, a different microcontroller may be used. This must be tailored specifically to the design and integrated into the PCB, which will likely require low-level programming. For the dashboard component, the Adafruit IO library was used, which provides an easy-to-use interface. In the final design, the dashboard may be on a local server, and this will require the team to design and program their own server with the relevant inputs and databases. Conclusively, the prototype has shown that these elements are feasible to implement at a smaller scale and thus have the potential to work as part of the final design concept.

4.4 Team collaboration

The team broke into two groups to create the mechanical components and the electrical side of the prototype. Riddhiman, Natacha, and Eve worked on the design, CAD, and assembly of the mechanical structure. Sophie and Ahmad created and tested the electrical component of the design. Throughout the design process, key design decisions were made as a team and were informed by research and the team's value proposition. Communication and planning were essential to ensure a uniform understanding of the design and that tasks were properly delegated to allow for internal deadlines to be met.

5. Conclusion

5.1 Refine value proposition

The current design has an emphasis placed on providing value in improving water efficiency and ensuring that the device is not more labour intensive. In future iterations of the design, the cultural aspect of Yemen needs to be considered more. This involves considering the materials available and how well the design can be implemented into their current traditional methods. This will provide value to the farmers in terms of accessibility and replaceability ensuring the longevity of the solution. The design will also be modified to make it cheaper, lighter, and have standardized parts. This will provide value to the farmers due to the economical instability the country is currently facing. Having parts that are affordable and can be easily carried is essential in their unstable environment.

5.2 Prototype supports the validity of design

The prototype, developed as a first iteration of the design concept, supports important aspects of the design through its functionality. Testing and validation have helped reinforce these while also identifying areas of improvement and next steps. The mechanical part of the design showed that the use of gears was successful in controlling both valves with a single motor with the intended degree of rotation. The motor torque was also sufficient to hold the valves still against the incoming water. Water testing the prototype showed that water majorly flows through the opened valve with a limited amount leaking through the closed side. Improvements in manufacturing can lead to greater effectiveness. The electrical and software aspects of the prototype showed that the chosen circuit components and power supply were functional and performed the desired control effectively. The IoT dashboard showed that the design is flexible in allowing various choices of parameters so that it can easily be adapted to different use cases.

5.3 Next steps

5.3.1 Superior manufacturing

Major issues include poor gear teething, poor fitting of parts, and poor durability. All are a result of poor manufacturing and 3D printing tolerances for the gears, valves and housing unit. This caused significant reliability issues for the prototype that required significant structural modifications. Superior manufacturing with tighter fits and tolerances that make fits more precise and leakproof will resolve the aforementioned problems.

5.3.2 Acrylic waterproofing for gearbox

The top gearbox and motor cannot be exposed. To combat this, an acrylic cover will be added onto the top with hinges to allow the user to see the system for easy and quick diagnosis. It also allows the user to quickly remove the cover and turn off the system manually. Safety releases will be used to fully close the housing on both sides.

5.3.3 Valve sizing changes

Emerson Vanessa Valves [19] are optimized to have a long lifetime while minimizing the stresses through supporting material. The valve faceplate is small with thick central shafts to anchor the valves, and the supports enable tighter fits. The final design is not required to seal a large area, thus design features of the Vanessa Valves could make the final design seal superior to that of the prototype. In addition, this allows the prototype to mitigate some stress that the valve faces, extending its life and reducing maintenance. Unfortunately, Vanessa Valves are not simple to implement due to its weight; however, structural and design insights could be applied to a second version of the prototype.

5.3.4 Dashboard to display

Currently, CleanFlo requires wifi access to display the current state and control the parameter inputs to the system using the Adafruit IO dashboard. The choice to use a wireless network was done due to the convenience and availability of the dashboard for prototyping. However, in Yemen's environment where less than 30% of the population has access to wifi [20], the dashboard would not be feasible in the design. Therefore, a future step in the design would be to use a local network or a screen and button mechanism attached to the design to receive and display information. This could be done using a screen and a local network generated from the Arduino itself thus eliminating the need for a wifi connection. Smart water meter displays and other devices already use buttons and displays to control the system making that aspect of the design believable.

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7. Appendices

7.1 Team Values and Members

7.1.1 Team Statement

As a team we value simplicity, empathy, and sustainability. We strive to create a design that can be easily implemented into our stakeholders' lives well still considering their cultural beliefs. It is also our aim to ensure we are meeting the UN SDG goals to assure an improved lived situation for our stakeholders. In our team setting, we create a supportive and collaborative environment where we encourage one another to explore unique ideas and work with people of different backgrounds. Organization is prioritized in our team to ensure deadlines are being met and that time is allocated for risk management. We use task trackers to account for team members' responsibilities and create meeting agendas to stay organized and on task. Risk is identified throughout our design process and as a team, we brainstorm ways to mitigate risk and try and implement ways of resolving conflict. We use our teams combined past experiences in coding, circuits, CAD, and design to create solutions that will meet and surpass our stakeholders' needs. Research is also important to our team as we value gaining a deeper understanding of our stakeholders' environment and identifying their greatest needs. We are motivated by learning and improving upon our current design. We try to identify ways to simplify our design to allow for easier integration into our stakeholders' lives, which also challenges us to think creatively. Our values, motivations, and past experiences make our team suitable to create a design that will provide value to our stakeholders and improve their lived experiences.

7.1.2 Eve Fletcher

Eve Fletcher has two main roles of Project Planner and Risk Coordinator. She is also responsible for timekeeping in meetings, editing documents, and coordinating the project. These roles contribute to the overall team productivity as she ensures that tasks are being allocated and that goals are being achieved. Eve values organization and ensuring that planning is undertaken to mitigate risks and understand issues that may arise. She greatly contributes to the team's success in meeting deadlines and ensuring that time is allocated for potential procurement delays. Eve also has experience with research and aims to understand the stakeholders' needs and outline potential challenges that may arise due to the given service environment. This helps the team prioritize certain aspects of the design that will provide more value to the identified stakeholders.

Eve's experience with leadership and the value of empathy align with the PMP. She strives to create an atmosphere that is inclusive and allows creativity to thrive. She tries to gain an understanding of her teammates' backgrounds and their beliefs to help aid in a positive team environment. By doing this she helps the team achieve their goals of an empathetic and collaborative environment. Eve is also motivated by creating a sustainable design that encourages a reduction in material usage and education in sustainable practices. This motivation helped her feel a vested interest in the success of the design and in ensuring that the UN SDGs were incorporated throughout the design process. Overall the team's goals, organization, and motivations ensured that a collaborative and productive environment was achieved that ensured value for the stakeholders was being prioritized and constantly considered in design decisions.

7.1.3 Natacha Hughes

Natacha has taken on the roles and responsibilities of the Design Engineer and Researcher. She is also responsible for coordinating component purchases, presenting aspects of the team's proposed design solution, constructing meeting minutes, and editing team documentation. Natacha values learning, challenge, and empathy. Her values coupled with team values of simplicity and sustainability particularly align with her responsibility as the Design Engineer as it motivates her to learn more about how CAD and different mechanical components can be used to construct a simple and sustainable design that meets stakeholder needs. Moreover, Natacha's experiences as a Policy Analyst and a Principal Investigator for two undergraduate student-led research projects in the Aerospace Policy and Law division of the University of Toronto Aerospace Team (UTAT) make her well-suited to technical writing, researching the stakeholders' environment and appropriate reference designs, and problem-solving when troubleshooting dysfunctional mechanical components from the proposed design solution. Natacha's technical experiences in the Liquid Propulsion Subsystem of the UTAT Rocketry Division, involving the construction of a preliminary transient model to tackle the inverse heat conduction problem, prove that she has capabilities to creatively and iteratively improve on current design features in a way that aligns with the team's formed requirements model.

Natacha's experience with research, technical writing, risk assessment, management, planning, and public speaking aligns with the PMP. She intends to standardize processes for document formatting and styling, team responsibility tracking, design progress tracking, and research to better manage and track the team's progress during all phases of the project. Additionally, she aims to foster an enthusiastic, inclusive, and open-minded environment when it comes to divergence, convergence, and iterative design in the prototyping stage so that the team may maintain healthy and fruitful interactions as well as offer support and learning opportunities to one another. Natacha is motivated to improve the lived experiences of others, with the hopes of making a positive contribution to their overall wellbeing. The alignment of her motivations with the team's goal of providing value to their stakeholders and improving their lived experiences allows her to maintain a spirited attitude and strong work ethic when accomplishing team tasks. All in all, the team's organization, goals, and motivation coupled with Natacha's roles, values, and experiences allowed for a collaborative, supportive, productive and positive learning environment, which contributed to the team's overall success.

7.1.4 Muhammad Ahmad Kaleem

Ahmad has two primary roles in the team, namely the Systems Engineer and the Facilitator. He is also responsible for cost coordination, fabrication liaison and note-taking for meetings. Ahmad values creativity and efficiency, especially for solutions, and this translates to the team's divergence and convergence phases for potential solutions. He also prioritizes mitigating potential biases which may arise in the design process and doing so has allowed for productive team discussions where all possible ideas are considered. Problem solving and open-minded thinking are also areas Ahmad focuses on and this has allowed the team to place an emphasis on a thorough understanding of the opportunity and stakeholders at hand through research and stakeholder interaction while ensuring that our proposed solution satisfies their requirements through a rigorous validation process.

Ahmad's experience with software and hardware through projects and work at a makerspace aligns closely with the PMP. Here, he aims to share his previous experience to facilitate the design process while fostering an environment where shared learning takes place. He has also used his technical knowledge to help evaluating different risks through the design process such as the feasibility of aspects of the prototype. Overall the team's goals, organization and motivation in conjunction with his roles and values ensured an efficient and productive working environment while simultaneously contributing to the team's overall success in terms of completing tasks and meeting deadlines culminating in an effective final design concept.

7.1.5 Riddhiman Roy

Riddhiman has two primary roles in the team: Design engineer and fabrication liaison. In addition, he worked as a researcher and presenter amongst other roles in the team to help the team achieve its goals while keeping its values in mind. Riddhiman enjoys challenging design and tasks, and hopes to continue learning and developing himself and those around him as he works in a strong team to succeed in the face of challenges. Riddhiman sees himself as a strong mechanical designer and engineer, specialising in making things move in new and unique ways to achieve objectives in a clean, efficient yet effective manner. He seeks to go above and beyond for all parts of his assignment to make his team, stakeholders, but most importantly, happy and content with his work. His handbook outlines as much.

His work on this project started with the CAD modelling for the valves, which he designed from scratch applying course knowledge. He quickly developed CAD skills, working with multiple files and parts to create complicated assemblies. He also helped Eve with designing the flow housing and worked with Natacha to come up with the gearbox assembly on the top to actuate the whole system. His eye for details helped identify potentially crippling issues early on and helped to fix them to develop the successful prototype. Physically, he was also a very quick learner, learning how to use a variety of tools such as drills, drill presses, band saws, dremels and others to become to primary mechanical designer on the team, working in all sorts of fabrication scenarios to allow the team the flexibility it needed to make quick fixes like the dowels atop the spur gear on the valves with a rubber band to tension them together and ensure better gear contact.

In short, Riddhiman did his best to satisfy his roles all around the team to develop a strong prototype that validates and verifies our ideas in the context of our community and stakeholders leveraging his experiences while expanding his skillset.

7.1.6 Sophie Sun

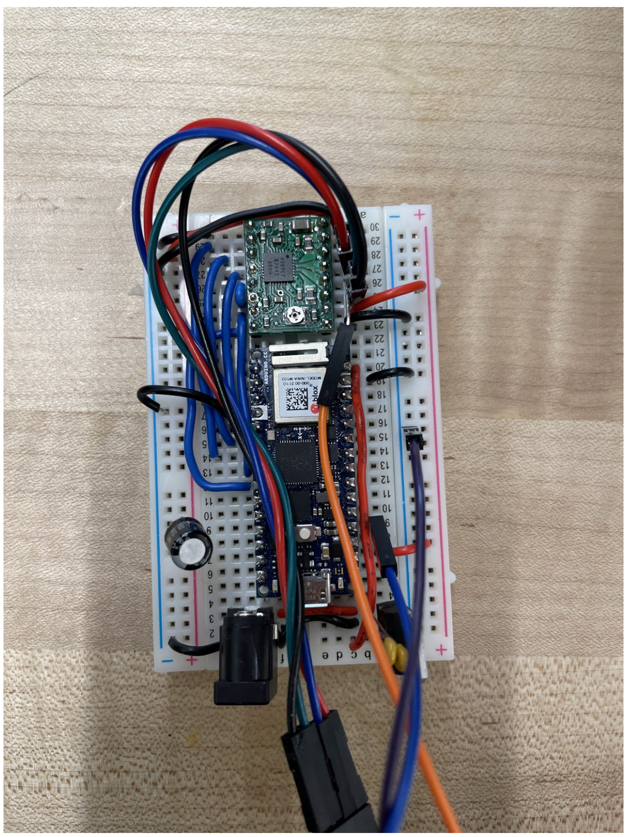
Sophie has two main roles of System Engineer and Issues Coordinator. She is also responsible for global context and peer liaison to foster a positive team environment and build a strong relationship with Pierce, the GSU student.

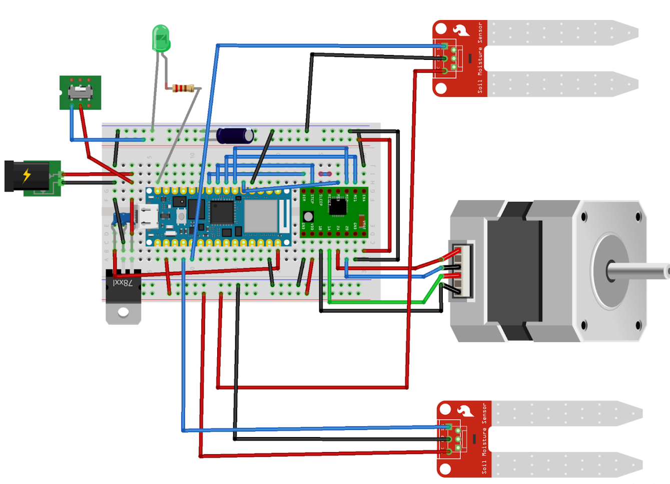
As the issue coordinator, Sophie works to identify potential problems and risks early to effectively address them. Most importantly, when building the high-fidelity prototype, the team encountered multiple design and timing challenges. Sophie worked to find a balance between the time spent versus the performance of the prototype to ensure the team could learn the most from the physical model without sacrificing other aspects of the project and team member's schedules.

In line with the team value of simplicity, Sophie believes that oftentimes the greatest designs are the least complicated. She translates this into her role as a system engineer by focusing on compact and streamline designs of the electrical and software components for CleanFlo. With past experience in research and software development focused on accessible medical technology, Sophie wanted to ensure any technical components of the design are easy to use and attainable for the stakeholders in Yemen. To do this she contributed extensively to the research behind Yemen's current environment, the needs of the stakeholders and how to minimize the resources required to perform the same function. She is extremely passionate about electrical and software but more importantly she focuses on how these skills can bring impact and value to others. She chose to guide the team towards designs that may not have the most challenging technical components but addresses the UN SDG and the needs of the stakeholders. In conclusion, Sophie's values closely aligned with the team values and goals, as a result she is able to motivate herself and the team to work together and create the meaningful design CleanFlo.

7.2 Bill of Materials

Excel Sheet of Bill of Materials: Project Budget and Procurement - Bill of Materials.xlsx.





7.3 Image Gallery

The images are labelled in the following order:

Top Left - 7.1, Top Right - 7.2,
Middle Left 7.3, Middle Right 7.4
Bottom left 7.5