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DESIGNING AN AUTOMATED REFILLING TIKI TORCH SYSTEM

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ABSTRACT

One of the primary problems with citronella torches used to deter mosquitos and other pests is the tedious and often dirty process of refilling the oil. The goal of this project is to develop an automatic refueling system to simplify the process of refilling oil and provide the user with a remote monitoring and control functions in an effort to manage many torches over a larger area. The project has created a system to control fluid flow into the torches and a rudimentary interface for basic monitoring of torches.

KEYWORDS – DESIGN, REFILLING SYSTEM, TEST, TIKI TORCH

BACKGROUND

The Bug Torch system attempts to solve the problem of maintenance of existing pest-deterring citronella torches. Refilling torches is a very messy affair and the torches themselves rarely last more than one season. The goal of this project is to produce a system that will not need to be replaced every season and has a more convenient and cleaner refilling process. This system ideally should be customizable to any residential landscape. The customer put forth several general requirements for the overall function of the system, most notably the system having the capacity to run 20 torches at the same time, a per-torch build cost of $25 USD, a central controller application with several functions including monitoring of oil levels, and a strict guidelines that underground electrical cabling is not to be used to avoid expensive installation. The list of general requirements was prioritized during a discussion with the client and detailed in Table 1.

Category	Customer Rqmt. #	Importance	Description	Status
Aesthetic	A1	9	Torch is visually appealing	-
	A2	9	Suppress pump noise	-
Ease of Use/Installation	E1	3	No underground wires	-
	E2	3	Central fuel resevoir	-
	E3	1	Automatic ignition	-
	E4	3	Supported smartphone/tablet app	-
Function	F1	9	Fuel lasts 8 hours without human interaction	-
	F2	3	Scaleable to 20 torches	-
	F3	1	Scaleable beyond 20 torches	-
	F4	9	Measures individual fuel levels	-
	F5	3	Refills torches evenly	-
Durability	D1	9	Capable of remaining in the ground year-round	-
	D2	9	No routine maintainence	-

Table 1: *Prioritized List of Requirements from Client*

Requirement #	Importance	Source	Discipline	Engineering Requirement (metric)	Unit of Measure	Marginal Value	Ideal Value
S1	9	A1	Mechanical	Minimize modifications to the torch appearance	cm^2	30	0
S2	9	A2	Mechanical	Plumbing does not make auditory disturbance	dB	50	30
S3	9	F4	Electrical	Detects high/low fuel level	Binary	1	1
S4	3	F1	Computer	Low sampling rate	Samples/min	1	1/5
S5	3	E1	Computer	Torch communicates wirelessly over acceptable distance	Meters	200-300 Meters	1km
S6	3	F1	Electrical	Power lasts without user interference	Days	~30	~365
S7	3	F1	Electrical	System consumes low Power	mAh	15000	30000
S8	3	F1	Electrical	System uses low voltage electronics	V	12	3.3
S9	1	F1	Mechanical	High reservoir fuel capacity	L	Run 20 torches for 8 hours	Runs 24 hours without refill
S10	1	F2	All	Size of four to twenty torch systems	#	4	20
S11	3	D1	Mechanical	System withstands multitude of weathering	Binary	1	1
S12	3	D1	Mechanical	Strength/stability	N	3000	7000
S13	3	D1	Mechanical	Resist extreme heat/cold	°C	-10 to 120	-30 to 150
S14	3	D2	Mechanical	System does not leak fuel or allow water penetration	IP rating	50	70
S15	9		All	Meets resdiental codes/laws/etc.	Standards	-	-
S16	1		All	ADA, EPA, OSHA, IEEE, ASME, etc. Standards	Standards	-	-

Table 2: *Engineering Requirements*

Constraint	Description
Time	Meeting times, length of project, full time students
Money	Project budget, desired desgin cost per torch
Power	Batteries, solar, ground wire, wireless
Regulations	ADA, EPA, OSHA, IEEE, ASME, etc. Standards
Residential Plan	different sizes of backyards and different types of housing
Modality	Patent linearity
Experience	Only ~1yr in respective fields (Besides guides)
Available Tools	Easy user installation
Safety	Need to be careful of dangers in design and manage environmental risks
Temperature	Electronics can function in heat/cold. Torch does not get damaged.
Sound	Torch system creates minimum noise polution

Table 3: *Project Constraints*

Some requirements are substantially less defined, so it was necessary to convert them into engineering requirements. This allowed for a means to objectively evaluate whether the team achieved the requirements or not, listed in Table 2. The metrics as well as the marginal and ideal values for each of the engineering requirements are also specified.

Additionally, the team discussed constraints and tabulated in Table 3. Some of the constraints imposed upon the project included but not limited to restrictions on vendors for ordering parts and restrictions imposed by the COVID-19 pandemic.

Design

The client provided the team with an existing torch set which served as a framework for the development of the project. The set featured torches which would be connected in series to a central oil container and a small pump to move oil through the system. Additionally, some valves to allow oil to enter the local reservoir of the torches were provided, though these were not used in the final design.

The design features an automatic refueling sequence that will function without any human input, and a Wi-Fi driven integrated app for the customer to manage the system (enable, disable refueling, monitor fuel levels, etc.). Oil is stored in a central reservoir, pumped through a check valve and through a length of tubing to the torches connected in series. Each torch comes with its own internal oil tank and the team used a mechanical float valve to make sure the internal tanks do not overfill. An externally mounted capacitance sensor is used to determine when the oil pump needs to be run to refill one or more torches. The torches are linked to a central application via Wi-Fi and are capable of displaying current fuel levels and other usage statistics. Details of designing each of the individual subsystems are described below.

Valve

To prevent overfilling of the torch reservoirs, the team developed a mechanically operated valve to restrict fluid flow when the local oil reservoir has filled to the desired level, the valve operates by a simple ball bearing that floats to the top of the valve when submerged in oil, preventing further flow. The first iteration of this design was

operated by a lever arm but the bulky assembly and many failure prone moving parts lead to a simpler design where the float was enclosed in a housing that prevented it from drifting away. We were supplied a valve by our client as a foundation for our design however it was not adequate for preventing oil from flowing past the desired level.

Level Sensor

The central electronic controller is an Espressif Systems ESP-32 microcontroller which is capable of Wi-Fi and Bluetooth communication with a small footprint and built-in oscillator to assist in detecting oil level in the local storage container of the torches. The ESP-32 was chosen as the choice of microcontroller because of its small build form and capabilities with Arduino which has a lot of different useful libraries that facilitated the process of coding the web server along with utilizing the capacitive sensor. The level sensor was a capacitive tape that was taped on to the body of the fuel tank on the torch. Attaching a wire to the capacitive tape and connecting that to the pin on the ESP-32 allowed a value to be read as the fuel level changed. Additionally, a charged wire was stuck into the fuel tank so when the oil level rises and eventually touches the charged wire, it would cause a jump in value that the ESP-32 can detect as a change and decide if it should turn on or off the pump.

As for the coding of getting the ESP-32 reading a value from the capacitive tape was fairly simple. The specific ESP-32 that was used, ESP32-DevKitC-VE, had compatibility with a capacitive sensor. All that was needed to be done was call a function *"touchRead(pin_for_sensor)"*. This function detects the value of the capacitive sensor and returns it back to the user which was used to send it over to the web server.

Solar Charger

To eliminate the number of wires used throughout the system, a solar subsystem used to generate power for the ESP-32 microcontroller for each of the individual torches. The subsystem is composed of three small solar panels arranged atop the torch and equilaterally spaced. A constant issue with using solar power is the intermittent behavior of generating power and therefore needed a battery and battery charger for backup. Based on the voltage behavior of the ESP32 microcontroller, we need to supply at least 3.3V to the microcontroller and estimate the minimum power required to ensure they operate consistently for at least 8 hours. Unfortunately, solar power is intermittent and only produces power when the sun is shining. When designing we took into consideration days where the torch would not be able to generate enough power and would need assistance from a battery to power on the microcontroller. The battery was then sized up to from 20mAh to 1200mAh, so that the torch could theoretically run for more than five days straight when the battery is fully charged.

A voltage regulator circuit was also critical for the design. The solar panels available off the shelf each can supply 8.29V. They were arranged in series on which were then connected to the battery charge followed by the voltage regulator circuit to adjust the voltage to approximately 3.3V. Preliminary testing yielded results which did not adequately power up the microcontroller in full and part-sun. Voltage at the microcontroller only achieved 2.5V maximum. Therefore, the regulator circuit was removed from the assembly and retested. Voltage values were greater than 3.3V and could power up the battery and microcontroller.

App Design

he The app design for this was a simple web server where the user can manually control the pump and also see the fuel level that is seen from the level sensor. It utilizes multiple ESP-32s, one for the server and all the other ESP-32's for the clients. The server creates its own Wi-Fi access point and the clients and mobile device can connect to it through Wi-Fi. The server had to handle 4 different functions. They were ON, OFF, GIVE_CLIENT_ID, POST_SENSOR_DATA. The ON and OFF command turns on and off the pump. The GIVE_CLIENT_ID function gives a client ID to the client ESP-32's so it can keep track of each individual torch's values. The POST_SENSOR_DATA function handles getting data from the client ESP-32's. It would receive information from them and the web server would handle that information and decide to turn on or off the pump.

The client mainly sends over data to the server and asks for an ID. It only utilizes two different functions: POST_SENSOR_DATA, GET_CLIENT_ID. The client would read the sensor data and take an average of 5 readings and the average must be within a certain range to send it over to the server. This allowed for a consistent reading sent over to the server. The GET_CLIENT_ID asks the server to get a client ID. The special feature is that the client also sends over the processor chip ID which is unique to the board so the server can also keep track of that data and see if the device had previously connected and can just give back the already assigned ID.

Supporting Feasibility Evidence

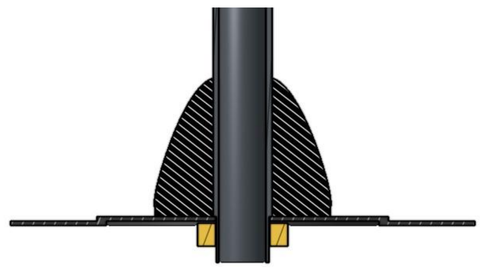
Torch body redesign

During the design process, the team noticed some irregularities in the pipes and base that make up the torch body; the welded piece of pipe that connected the base of the torch to the body was rarely at a ninety-degree angle due to welding and grinding issues, and multiple pipes were found to be slightly bent or otherwise misshapen. These two factors would cause the torch to tilt at a precarious angle, possibly allowing the torch to leak from the tank, or even completely fall over. Upon further inspection into solving the tilting issue, a greater issue arose; if the torch leaned too much or was bumped into, the threads that joined two pipes whole completely shear (1.a). This was due to the construction of the pipe itself; while the pipe itself was made from stainless steel, threaded aluminum inserts were fixed into each end of the pipe with masking tape.

The team worked with Gary Hodenius, the MSD machine shop specialist to design a new torch base and body. For the base, it was decided to remove the welded pipe from the cover and instead add a flange on the outside to create a ninety-degree angle with the pipe, with a threaded nut fastened on the inside to hold everything together (1.b). For the pipe itself, the team went with a thicker walled aluminium pipe of the same diameter, that was to have the threaded connections machined directly into the walls. Due to shipping time and large costs the team was unable to purchase the necessary pipes to construct a complete torch system, but a test piece of aluminium was machined to the proper dimensions and stress tested under conditions similar to a fully constructed torch (1.c).

(1.a) Sheared Insert

(1.b) Threaded Aluminium



(1.c) Base Flange

Figure 1: *Torch Body Redesigns*

Citronella oil testing

The project needed to meet several criteria to be considered a success (detailed in Table [INSERT NUMBER/LETTER]. The most challenging aspects to satisfy were related to ensuring consistent oil flow up the torches without overfilling the torches' local reservoirs, this would pose a serious safety risk and required a substantial number of attempts to control without breaching the constraint forbidding the use of underground electrical cables to power sensors. The easiest method to control the flow of fluid would have been to install an electrically operated solenoid valve to open when more oil is needed and close when the local reservoir is full, however this came with a large energy overhead which the team was unable to account for, being limited by the low power and weather-dependent solar panel mounted on the torch from which the team would run the electronics transmitting oil level information to the central controller as well as the small battery's limited storage capacity concealed within the torch.

Ben Kemnitzer proceeded to develop a lever arm mechanism connected to a float to seal the local reservoir after it had filled, however the number of moving parts in the assembly was cause for concern over general degradation after being exposed to citronella oil and the elements over significant periods of time (2.a).

(2.a) Valve Design v1 (2.b) Valve Design v2 (2.c) Valve Design v3

Figure 2: *Improved Valve Designs*

. The future attempts refined the concept of an unpowered valve based around a float that seals the oil inlet once the reservoir is sufficiently full, these variants had only one moving part and while corrosion may still present a significant problem in the long term the team has deemed this issue to be out of scope of the project due to limited material selection (2.b/c). The material for the mechanism cost was approximately $2 USD which is far from ideal, however these parts were custom-printed and a larger scale production model should be substantially less expensive.

The other substantial mechanical problem the project faced was acquiring an oil pump capable of moving oil over one hundred feet with enough energy to also overcome approximately five feet of vertical distance to the top of the torch reservoirs. For simplicity, prior to testing the team made the assumption that if the pump were powerful enough to work with the last torch of the series (which would also be the furthest away), then it should be functional with all torches connected in series before it. Jason attempted to create a mathematical model of the system; however the team was unable to determine a means of simplifying the equations without completely ignoring frictional losses in the flexible tubing used in the system or losses associated with pump inefficiency which the team was unable to accurately measure. The resulting model would have been non-representative of reality due to the numerous assumptions which needed to be made and was therefore discarded in favor of an experiment where the pump could be tested directly.

Over the course of testing the team primarily experimented with water as the liquid flowing inside the system. Starting with a simple aluminium bowl and some copper tape the first real sensor prototype was formed. By wiring the microcontroller to this with intent to catch changes in capacitance the team was able to detect the level of the torch tank. The data returned from this event is a binary value of low(zero) or full(one). To decide this state the team thought the best way was to use a threshold value for the measured capacitance. If the system saw the reading cross this threshold the state of the tank would change from full to empty and vice versa. This data is then transferred over wireless connection to the gateway at the central reservoir and pump. The gateway could then process this information and decide whether to toggle the pump on or off.

Unfortunately, when the team received approval to use the oil it was all but too late. The expectation was that the system would function even better with the swap from water to oil. But, it appeared that oil acts more like an insulator for charge than it does a conductor. This resulted in the loss of the ability to detect the aforementioned binary tank state. To fix this issue given more time the team would have liked to construct a custom tank that would be able to detect these changes.

Results

During initial tests it became apparent that there were some quality control issues with the torches the team was supplied with, though this had little impact on our system testing it should be noted that some of the torches displayed substantial bending after being left against a wall for a few weeks, prompting questions about the durability of the frame that, while not relevant to the automatic refueling system directly, likely could have serious impacts to long term operation of the system.

Additionally two torches sustained damage prior to the beginning of full system tests, rendering them unusable for testing. The threaded pipe inserts had sheared off leaving the torch stand vulnerable to tipping with almost any force applied, a moderate wind gust would likely be sufficient to topple the torch. Our solution to this problem was to rebuild the poles and machine the threads directly into the pole instead of using a flimsy insert to connect the torch pole to its base.

Tests with the ESP-32 showed the microcontroller was able to successfully connect to a simple web server and perform basic functions i.e. turning a light simulating the main pump on and off. When connected to the solar power source, the team was unable to consistently activate the ESP-32 due to insufficient energy generation and low voltage. Removing a voltage regulator from the circuitry was sufficient to improve energy transfer, allowing the ESP-32 to be connected to by Wi-Fi.

The custom valve consistently disables substantial flow once the fluid level in a container exceeds the desired level. However, it does suffer from a slow leak, likely due to significant imperfections caused by the low precision of the 3-D printer used to make the parts. The test consisted of pumping water into a container through the valve until flow ceased, a valve provided by our sponsor and a modified variant were also tested in the same manner, but both valves failed to adequately restrict the flow of water and the container continued to fill beyond the level the valve should have closed at. In a production model scenario the leak would be a serious cause for concern as a leak that persists long enough could cause the torch oil tank to overflow and spill oil onto the ground, a very substantial fire hazard. Production models would require substantially tighter tolerance controls to avoid this risk but given the low tolerance control the team had over the custom printed parts we believe this risk is not going to remain present in a production-quality model.

Final testing of the system revealed a slew of important results. These results came from the Environmental Health and Safety departments approval to use citronella oil. Previously, the team experimented on the integrated system with water. From those tests each of the systems reacted as expected. The level sensor was able to discern the states of low and full allowing the wireless network to communicate this information to the gateway. The gateway then processed this information and toggled the function of the pump system thus automatically refueling the individual torch tanks. Unfortunately, the results with oil were much less promising. Unlike with water, the system could not detect the change in states from low to full. The ramifications of this event are directly related to the pump control. If the system cannot detect the level then the pump will remain in the active state shortening its lifespan greatly. Although, with the help of the valve the tank will not overflow.

Conclusion, and recommendations

Through design and testing we were able to develop a robust prototype for your model which achieved some of the major requirements such as not using wire to communicate between the pump and individual torches, a preliminary app design, and an improved value. In developing our system, we have discovered some critical information regarding the clients existing system such as defective torch bodies. Although using citronella oil was not initially a requirement from the multidisciplinary design, it is very important to our client and to our team to develop a feasible design over the course of the semester. With some of the difficulties we experienced with the torch body, torch tank, and citronella oil, we now understand the importance of materials and the impact they have on system development.

Several actions can be taken to combat these new issues which arose from the citronella testing. The first major change would be a custom torch tank design. This would allow for the construction of a simpler valve system less likely to leak. With this change the sensor could also be redesigned to allow for a greater level of accuracy and functionality especially with citronella oil. Detailed descriptions of these changes were handed off the client. Future iterations of the system would benefit from these changes. In short, the tank should be made from a material like PEEK plastic that could resist corrosion but allow for a sensor to detect the fuel level without contacting the fluid within. Also, the tank should have a removable lid that would allow the valve to be manufactured easier.

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