**Ultrasonic and Photoresistor Plastic Quality Evaluation System with IoT Implementation**

**Widget Lab 3 - Assignment Work and Design Project Walkthrough**

1. **CONCEPTUAL DESIGN PROCESS AND SCOPING**

*Introduction*

In response to the opportunity of providing a reliable and convenient method of qualitative plastic sortation for processing in Ghana, the design team constructed a compartment of sensors to evaluate the condition of plastic through detecting opacity **[A.5]**. By ultrasonic sensors that register when an object is inserted, LEDs opposing photoresistors on the interior of a box-like structure detect the intensity of light through the object. Should the plastic achieve a certain level of translucency, the system will upload this information as “good quality plastic” to the IoT - which will communicate and record this information via the Cloud. With a rigorous system providing sensory data and intercommunication of results, accurate evaluations of plastic quality can be made.

*Scoping and Divergence Process*

Many considerations were discussed and made during the scoping process of this project. Chosen metrics of assessment, along with some approximations and assumptions, provided specifications to the boundaries of the opportunity.

Earlier design and divergence processes encompassed feverish and copious amounts of brainstorming. In hearing the stakeholder’s preference towards automation of their bottle collection and mesh-making process, the team leaned towards incorporating a more mechatronics-based prototype that focused on a solution which addressed processing rather than sortation. Preliminary designs (done prior to any of the widget labs) depicted a system to poke a hole and string through a bottle; linking them together in a mesh-style for structural use. This was later proven infeasible - as variables such as the strength of plastic and piston-based machinery that was required were either too difficult to calculate, had mechanisms that were unavailable through MyFab or were not the focus of skills developed in later Widget labs.

As mentioned in the design proposal, sketches that design for different ways of plastic sortation (drones, funnel, reading gun, mentioned in the design proposal) throughout this phase were explored; all of which were too complex and did not fit well enough into provided resources and undergoing learning. Eventually, the team pivoted from processing to a sortation solution that acted to evaluate the quality of plastic bottles collected by McKingtorch Africa. This created smaller variabilities and allowed us to implement our knowledge of sensor-actuator systems introduced in Widget Lab 2. Additionally, it was recognized that McKingtorch Africa currently does not have a computerized, automated system in place to determine the quality of cleanliness for water bottles that they collect; and thereby which ones are fit to use for installations.

Prior to developing our requirements table, the design team scoped in on certain assumptions and constraints around the bottles and power of our system. It was assumed that all bottles entering assessment are clear-colored **[A.1]** - as the team’s resources and testing did not have access to a complete population of colored water bottles to realize any error (or lack thereof) for sensing bottles of different colors (and whether color affected opacity enough to mislead the sensor of the bottle’s cleanliness). On top of that, dimensions of the bottles were assumed to be uniform as this simplified the prototype and created standard measurement expectations for building the case.

Additionally, the ultrasonic sensors were initially assumed to be accurate enough to detected irregularities of bottle dimensions within the structure - and thus associate the bottle with “crumpled” or “not crumpled” as another metric in quality determination. However, through testing and prototyping, this was not the case. The ultrasonic sensors appeared to have a distance measurement error of +/- 5 cm, which proved to be too great a margin for accurate detections of bottle indentations or deformations that varied around 3-4cm.

With these preliminary scopes established, the team was ready to develop the requirements table.

*Requirements Table*

|  |  |  |  |
| --- | --- | --- | --- |
| Objectives | Metrics | Constraints | Criteria |
| Meets Budget | Component Cost (CAD Dollars) | Less than $15 | Less expensive is better |
| Sensors that can apply metrics to the quality of the plastic evaluated. | Opacity of plastic (indicates how damaged/dirty the plastic is) - measured with LED/Photoresistor pairing. | System must be able to identify the presence (or lack thereof) of plastic in the system; done by measuring object distance with ultrasonic sensor. | Higher opacity = lower voltage of photoresistor = dirtier/damaged bottle = lower quality of plastic which is worse. |
| Record and representation of plastic quality data. | Yes or no - evidence of data represented graphically, by table, visually or otherwise | Must use an IoT to achieve this objective. | Yes is acceptable.  No is unacceptable. |
| Accurate Measurements | Uncertainty in Sensor Data | Ultrasonic sensor uncertainty should not be greater than the dimension of the bottle.  Photoresistor sensor uncertainty should accurately identify bottles versus complete opacity (like a human hand). | Less is better. |

*Convergence Process*

Converging on a final design that allowed an IoT system to interact with a physical, sensor-centred structure that interpreted quality of plastic based on opacity, the team developed rough 3D drawings to represent this idea. These interpretations can be seen in [**A.2]**; showcasing the breadboard housing the circuitry that powers the LEDs, photoresistors and ultrasonic sensors. The IoT itself was discussed through group meetings and a skeletal version featuring a UI for Widget Lab 2 was designed as practice[**A.3]**. It was decided through trial and error that the photoresistor will be set to identify readings of below a certain threshold when detecting the object interfering with the light from the LEDs. Lower readings will indicate higher opacity - sending information to the IoT for low plastic quality indication. The ultrasonic sensor will detect changes in object distance, which will be interpreted as plastic entering the system to be evaluated. All such information will be distributed to the IoT for graphing, analyzing with other devices (should they be implemented) and communication to the user.

1. **IMPLEMENTATION PROCESS**

The implementation of the design can be split into three subcategories that were focused on by individual group members: the structural components (woodshop work, assembly, and modeling), electrical components (wirings between sensors and breadboard, Arduino setup, LEDs, and circuit element connections), and software components (writing the code for instruction and information processing, thereby connecting the sensor information to the IoT, coding of the IoT). These sections will be discussed individually in the following text.

*B.1 Structural Design*

Some key base design features we included in our case are listed as:

* Pathways for connections of LEDs and sensors
* Big enough for a 19x6cm standardized plastic water bottle
* Covers the entire breadboard to hide wirings for aesthetics and increase the durability
* Sensor and breadboard stabilization

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Description automatically generatedThrough team discussions of divergence and convergence, we determined the key features needed to optimize the performance of our solution. For holding a standardized plastic water bottle, we built a 2-walled and overhang structure. The water bottle can be placed between the two walls and under the overhang. Each wall has an ultrasonic sensor facing inward to detect changes in distance (which will inform as to whether a bottle has been inserted). One wall will have a pair of LEDs, while the other holds a pair of photoresistors. With the insertion of a bottle, the plastic’s opacity will affect the photoresistor’s ability to register the LEDs; thus, changing readings to correlate with the quality of the bottle.

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Description automatically generatedFor the focus of this lab, we wanted to do a quick prototype to test the positioning of the sensors and their function. For the final stages of our solution, we will be drilling holes into the walls to place the sensors inside. In our prototype, the ultrasonic sensor was mounted on small wooden pieces through threading a small wire along the sensor and securing it to the wood with a hot glue gun. Such wooden pieces were necessary to ensure an even mounting ground (as the sensor had a connections port protrusion at the back that prevented it from sitting regularly on a flat surface – *Fig B.1.1*). But as the connections to photoresistor sensors and LEDs did not have this issue, they were taped onto the walls with electric tape for secure and easy modifications (*Fig B.1.2)*.

Figure B.1.2 – Exterior setup, with all wirings

Figure B.1.1 – Mounting of the ultrasonic sensor

Finally, to prevent wastage of materials, the breadboard was placed on top of the structure using the case from Lab 1. Wires easily exited the case through the ventilation openings. For future prototypes, insulative pipes will direct wires to circuit elements under the overhang for safety and organization.

Refractions that may occur from the light on the bottle due to the wrinkles or deformations were considered – as well as interference of light in the environment that could lead to inaccuracies in the sensors. Notably, deformations do not influence plastic quality determination. After our initial prototyping and code testing, ambient light from the surrounding has an unknown effect on the performance of the photoresistors. As such, we changed from a 2-walled structure to a 3-walled structure with a flap that opens and closes, allowing less light from entering the system from the surroundings.

The additional materials introduced to our structural components were electric tape, plywood (which had to be cut with the band saw and sanded for good measure), and glue – all accessible through MyFab. Of course, these are rough prototype tools necessary. When creating the final design (modelled in *Fig B.1.3*), A picture containing icon

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Description automatically generatedthe expectation is up to 3 pairs of ultrasonic sensors on either side and 20 pairs of photoresistor-LEDs setup per wall. Dimensions of system were discussed in **[A.4]**.

Figure B.1.3 – Structural 3D models of final design expectations (more sensors and LEDs)

*B.2 Electrical Components*

## *B.2.1 Components*

The electronic system components, along with their respective logic voltages and the number of units implemented, are listed in *Table B.2.1*.

|  |  |  |
| --- | --- | --- |
| *Table B.2.1*: Electronic system components | | |
| Component | Logic Voltage (V) | Quantity |
| Ultrasonic Sensor | 3.3 (digital) | 2 |
| Photoresistor | Continuous (analog) | 2 |
| Arduino Nano RP2040 | 3.3 (digital) | 1 |
| LEDs (red) | Continuous (analog) | 2 |
| 330-ohm resistors | Continuous (analog) | 2 |
| 1000-ohm resistors | Continuous (analog) | 2 |

## *B.2.2 System Summary*

*Figure B.2.1* contains the annotated circuit diagram for the whole system, along with views of the final circuit implementation.

Figure B.2.1: whole-system circuit diagram and implementation images. Left: TinkerCAD circuit diagram of the entire system. Top right: interior wiring and sensors. Bottom right: close-up of breadboard with wires.

|  |  |
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## *B.2.3 Design Decisions*

Photoresistors were chosen to measure plastic quality, as they can detect the amount of light absorbed by the PET. Any contaminating substances on the plastic bottle would increase the index of refraction of input, resulting in light scattering and interruption the flow of photons from the LEDs to the photoresistors. With less light transmitted, the resistance of the photoresistors increases. By setting a threshold voltage value in the code, the plastic can either be classified as “good” or “bad” quality.

*B.3 Software Development*

## *B.3.1 System Overview*

The system goes through three primary steps: 1. Data Sensing, 2. Data Assessment, and 3. Data Publishing. During data sensing, the ultrasonic input is assessed to check if plastic has been put into the system. Photoresistors measure the amount of light absorbed (or scattered) by the plastic. During Data Assessment, the average photoresistor values are compared to a pre-defined threshold, and a binary quality assessment is made (pending approval by the user). If the user approves the assessment, the data is sent to the adafruit.io feed “item-quality” **[A.6]**. This is then displayed on the Adafruit dashboard. *Figure B.3.1* shows the code process flowchart.

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Figure B.3.1: Code process flow chart

## *B.3.2 Development Process*

The code was developed by combining elements of the provided MQTT interfacing code with a separate codebase created to detect ultrasonic sensor data and photoresistor values. The Adafruit IO console was selected as a user interface method due to the low set-up time required to create a system that fulfilled our data storage objectives. MQTT was used as a communication protocol due to the extensive documentation about its compatibility with the Adafruit console.

## *B.3.3 Next Steps*

In the future, more advanced algorithms (like neural networks) may be used in the place of averaging to determine plastic quality from photoresistor input. Additionally, auto-calibration of the photoresistor thresholds (based on any ambient light and tested water bottle quality) may be used to improve efficiency of implementation.

1. **EVALUATION PROCESS**

During the testing and evaluation phase, a few scenarios of the design were tested. First, testing using the feedback from the ultrasonics sensors to determine the presence of the water bottle was done. After the ultrasonic sensor was properly wired and set up, a hand was inserted through the design to observe if feedback from the sensors is changing. This allowed us to evaluate the general functionality of the sensor’s ability to detect objects within the device. A water bottle was later introduced to determine and calibrate the range of sensor data to consider when the water bottle is present.

Additionally, we tested extreme cases to evaluate the basic functionality of the sensors. We used a clean clear bottle (considered good quality) and a human hand (considered non-recyclable). The photoresistors worked - they were producing drastically different values for the transparent bottle and the opaque hand. But the values produced by the ultrasonic sensors were not reliable as they were randomly varying by significant amounts. Therefore, we decided to use the ultrasonic sensors as a method of detecting whether a bottle was present in the device instead.

We then replicated the functionality of the sensors under more practical situations. Instead of testing the extreme cases of transparency, we tested different “levels” of opacity of the bottle by adding bits and pieces of tape to the plastic surface and seeing if the photoresistor value was changing. This test was successful as greater amounts of tape resulted in lower photoresistor values. We noticed that sometimes when the bottle was in contact with the ultrasonic sensors, they would be unsuccessful in registering the presence of the bottle and we realized that it would only work if there was space in between the bottle and the sensors. We therefore added two rulers at the base of the system that kept the bottle centered so that it wouldn’t touch the sensors on either side. Further structural components will be required in later stages to refine this design.

Finally, to test some real situations, we stained bottles with food to varying degrees and evaluated the results. Bottles that we considered to be more stained and therefore of poorer quality did receive lower values from the photoresistor and were therefore considered worse by the system as well. Setting an arbitrary threshold on the photoresistor value, the output of the code successfully informed us of whether a bottle was considered good or bad quality relative to the selected threshold. These results were then able to be viewed online in a graph via the Adafruit website platform.

Videos of tests of our final prototype can be found in the following SharePoint folder: <https://utoronto.sharepoint.com/:f:/r/sites/001T_FASEESCPraxisIIITeachingTeam-2022Winter-StudentWork/Shared%20Documents/2022%20Winter%20-%20Student%20Work/TUT1910/Team%201910C/Team%20Documents/Lab_Recordings?csf=1&web=1&e=pgoh6b>.

INDIVIDUAL CONTRIBUTION AND LEARNING PROCESS

Throughout this assignment, I primarily focused on the testing and evaluation process of design. I worked on developing a systematic method of testing the functionality of the system, ensuring that the design met all of the requirements and covered more peculiar/special cases. I helped with the debugging process as well. As an example, there was a situation where the photoresistors were producing drastically different values and I spent quite a bit of time trying to identify the source of the issue. In the end, it turned out to simply be because of a slight difference in the orientation of the photoresistors. Beyond the testing and evaluation process, I also made numerous contributions in the initial design process. For example, after performing research on plastic quality, I suggested the use of photoresistors as a method of quality assessment. I also suggested several ideas regarding the structural aspect of the design that stuck in the final prototype.

The main things I learned from my involvement in this lab were predominantly related to the Internet side of things. Having worked with code, electrical components, and sensors in previous labs, there was little that I was unfamiliar with when working on these portions of the lab. On the other hand, communication protocols and implementing WiFi connection were very unfamiliar topics for me and I needed to learn a lot in order regarding these topics when completing the lab. Also, having never worked with Arduinos before, I learned a lot about Arduinos as well in the process. As always, the primary sources that assisted in my learning were the datasheets provided in the lab instructions and the Internet. The Internet was particularly helpful in this lab since I read and watched many supplementary articles and videos that solidified my knowledge in topics I was unfamiliar with. Team members also helped with my learning process, trying their best to help explain concepts I didn’t understand.

Although most of what I learned through this lab was about WiFi connection and different communication protocols, I’m still much more interested in learning about the hardware related aspects of the lab, such as the circuitry and sensors. Beyond the Python code, breadboard wiring, and the use of 3D modelling software that I’ve worked with in previous university and high school courses, there was very little in this lab that reminded me of or related to other academic and professional experience I’ve had. As mentioned above, I had never worked on implementing WiFi connection or learned about communication protocols – much of this lab was completely new for me. In the future, I would definitely prefer to be more involved in the electrical aspects of the lab. I believe I greatly prefer working with hardware, software, microprocessors, etc. than working with the structural components and Internet related aspects.

WIDGET LAB 3 – STUDIO REPORT

1. **Inertial Measurement Unit (IMU):**
   1. The sensor measures linear and rotational force in each of the three spatial directions (x, y, and z) and outputs the linear acceleration and rotational velocity in each of these directions.
   2. The x-axis corresponds to the direction along the length of the Arduino (front is positive, back is negative). The y-axis corresponds to the direction along the width of the Arduino (right is positive, left is negative). The z-axis corresponds to the direction along the height of the Arduino (down is positive, up is negative).
   3. The sensor uses the I2C serial communication protocol.
2. **Microphone:**
   1. The MAG\_LOW and MAG\_HIGH values set the lower and upper bound values of the microphone input magnitude that is mapped to the LED PWM range.
   2. The RMS average of the microphone readings is taken to provide a more accurate reading of the perceived loudness of the audio.
3. **Adafruit IO:**
   1. The two MQTT topics that are used are the CPU temperature and LED.
   2. The Nano RP2040 both subscribes and publishes - subscribes to the LED topic and publishes to the CPU temperature topic.
   3. The two feeds do not affect each other since they’re separate input/output devices.
   4. The graph does make sense - the average temperature it reads is around 29 degrees Celsius which is close to room temperature.
4. **Sensor Addition to Adafruit IO:**
   1. We chose to use the thermistor as an additive sensor to our dashboard.
   2. Our team used a gauge to represent the feed from the thermistor.

CITATIONS

**[1]:** T. A. Team, “Accessing imu data on Nano RP2040 Connect: Arduino documentation,” *Arduino Documentation | Arduino Documentation*. [Online]. Available: https://docs.arduino.cc/tutorials/nano-rp2040-connect/rp2040-imu-basics. [Accessed: 27-Mar-2022].

**A picture containing tree, outdoor

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**[A.1]:** Structural water bottle element created by McKingtorch Africa which depicts the primary use of clear plastic bottles. This image encouraged the team to simplify and limit testing for only clear-colored water bottles in the prototype:

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Description automatically generated**[A.2]:** Product of convergence process when developing the final design. A rough 3D drawing model of the structural components:

Graphical user interface, text, application, chat or text message

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**[A.3]:** Product of convergence process in which an initial IoT user interface was madefor practice – pertaining to Widget Lab 2. The site interacted with the user through an input/output fashion.

Graphical user interface, text, application, chat or text message

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**[A.4]:** Conversation addressing the dimensions of final designs; especially in terms of sensors.

Diagram

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**[A.6]: A picture containing text

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