OPEnS Pyranometer: IoT Solar Radiation Sensor
Project Requirements

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Abstract

The IoT solar radiation sensor, referred to as the pyranometer, is to be a wireless and open-source solar radiation sensor that integrates into the OPEnS Lab IoT architecture. The goal of this project is to create a completely open-source pyranometer that is comparable to commercial-grade pyranometers that can cost thousands of dollars. The pyranometer will be able to sense and record some combination of UV, IR, and visible spectrum solar radiation hitting the pyranometer and transmit the data to a remote data hub. The pyranometer will record accurate data, last weeks in the field on battery power, and be able to survive most climates.

Contents

1 Revisions

Section	Original	New
Functional Requirements	Using two sensors to gather data	Using three sensors to gather data
Physical Characteristics	Teflon is a needed material	• TCA9548A is as a needed material • SI1145 is a needed material • Adalogger Featherwing is a needed material • 3.7v Lipo battery is a needed material • Acrylic domes are a needed material • Teflon is not a needed material

2 Introduction

2.1 System Purpose

Pyranometers already exist, but they are expensive and do not integrate into the Loom architecture being used in the OPEnS lab. More specifically, open-source pyranometers exist, but they are typically poorly documented, not wireless, and not validated against comercial-grade pyranometers. Researchers need an open-source pyranometer that can be made inexpensively, wirelessly communicate with the Loom system, and be able to withstand a wide range of climates. As of now, the only way to acquire a wireless pyranomter is to buy it, and this project looks to eliminate that requirement by allowing scientists to assemble their own pyranometer using open-source CAD files, open-source software, and a microcontroller. Scientists will be able to assemble the pyranometer, place it in the field, and watch data be gathered in real time from any device with internet connectivity; all of this at an affordable price.

2.2 System Scope

The system to be produced is titled "OPEnS Pyranometer: IoT Solar Radiation Sensor".

This system will detect a combination of UV, IR, and visible spectrum solar radiation. The solar radiation will be translated into W/m^2 and then uploaded to a Google Spreadsheet in real time. The data acquired will be accurate, with an R^2 value greater than 0.8. The system will be able to withstand high temperatures, be weatherproof, and be able to remain in the field for weeks at a time. The software and files required to build the system will be free and open-source, and documentation will be available to help users build the system. The system will be easy to integrate into the Loom architecture, and the system will notify users when the pyranometer has gone offline or otherwise stopped communicating with the data hub. The system will not be solar powered, and batteries will need to be recharged periodically.

At the highest level, scientists will be able to gather real-time solar radiation data from a remote device. The pyranometer can be left in the field for weeks at a time, and scientists will be able to continually see the data being acquired. This will help scientists study how solar radiation effects the environment as well as how it effects climate change. Scientists will be able to download open-source CAD files to 3D print the housing structure for the pyranometer. The software will also be able to be freely downloaded and flashed onto a microcontroller. Documentation will exist to guide users to assemble the pyranometer and synchronize it with the Loom system. Users will then be able to deploy the system and immediately begin using it. The pyranometer will be easy to assemble and deploy. The data gathered from the system will be accurate with an R^2 value greater than 0.8. The system will be able to withstand high temperatures and be otherwise weatherproof. In the case that the system does go down, users will be notified immediately. The system will be able to last weeks at time, with batteries being periodically recharged.

2.3 System Overview

2.3.1 System Context

The pyranometer requires users to set up the sysetm in an area where they wish to acquire data. The pyranometer will then take solar radiation and convert it into W/m^2 and transmit it to a data hub. From there, the data hub will upload the data to a Google spreadsheet where users will be able to interpret and use the data.

2.3.2 System Functions

Per our client's request, we are exploring three different designs. In one design, the pyranometer will be able to take in solar radiation and convert it into heat using a black body object. Then a thermal sensor will read the change in heat and pass the data to a processing chip. From there a microcontroller will translate the data into W/m^2. The raw analog data is useless to researchers, so the translation into W/m^2 is necessary for usability. Our second design will be using a photo diode to take in light directly. A light diffuser will be used to evenly spread out the light onto the diode. The diode will output analog data that will need to converted to digital data. Again, we will have to use a microcontroller to translate the data into W/m^2. The final design will use a lux sensor. The lux sensor is similar to the photo diode, but it reads UV, IR, and full spectrum radiation separately. The solar radiation data will be translated to W/m^2. Each pyranometer design will be able to read a combination of IR, UV, and visible spectrum. The data will be transmitted wirelessly and in real time to a data hub. The entire system will also be integrated into the Loom IoT architecture.

2.3.3 User Characteristics

The user will be able to configure our sensor using the open source software provided and calibrate it to their specifications. When turned on, the pyranometer will instantly process data from any source of solar radiation and transmit it to a data sheet in real time. The user should be able to use deploy the pyranometer to all kinds of environments and still gain accurate and consistent data. The user will be notified when the pyranometer goes into an offline state and it should not be difficult to fix the pyranometer or replace parts.

2.4 Definitions

Loom: Software architecture surrounding OPEnS sensors
W/m^2: Watts per meters squared; the standard unit of measurement for solar radiation
Weatherproof: Capable of withstanding rain, high temperatures, low temperatures, wind, and be waterproof.

3 System Requirements

3.1 Functional Requirements

There is no material that lets UV, IR, and visible spectrum solar radiation through; meaning that at least one form of solar radiation will not make it through the dome and reach the sensor. Multiple materials will be needed to get readings from the three types of solar radiation. Three sensors will be needed, one behind acrylic and the other two behind glass. One sensors will detect UV radiation, one sensor will detect visible spectrum radiation, and the third sensor will detect IR. Our processing chip needs to be able to read data from all three sensors and accurately combine the data to report the total W/m^2 hitting the black-body object. The structure surrounding the sensors, microcontroller, and batteries needs to be weatherproof in order to withstand various climates. The radio that sends data to the data hub needs to reach at least ten kilometers in various climates, and the antennae needs to be weatherproof. The batteries should be able to last a few weeks and be easy to recharge. The optical black object that traps heat needs to be black enough to accurately report the amount of solar radiation hitting it. Finally, data needs to be translated from analog voltage to energy (W/m^2).

3.2 Usability Requirements

The effectiveness of the Pyranometer will be measured by the accuracy of the data it produces, its survivability in the field, its ability to transmit data wirelessly, and its ability to stay on for long periods of time. To test the data accuracy, we will compare the data of our pyranometer with the data of a commercial-grade pyronometer. To test surviveabilty, different climates will be simulated using greenhouses and sprinklers. Testing how long the pyronometer will last is as simple as leaving it active and timeing how long it takes for it to die. We can test the range of the radio by moving the pyranometer further and further away from the data hub and noting the limit of the radio's range.

3.3 Performance Requirements

The pyronometer, once built, should be "plug and play". Once it is deployed and turned on, it should sense varying levels of solar radiation and be able to accurately report changes in solar radiation over time (changes in overall solar radiation and changes in specific types of solar radiation). The pyronemeter is expected to be weatherproof, and thus go undamaged when deployed to the field. While deployed, the pyranometer's power supply should last a minimum of three weeks. It is expected that the pyronometer is uploading data non-stop while deployed, no matter the time of day or weather conditions.

3.4 System Interface

The interface for the pyranometer will include an intuitive way for users to power on the device. The online interface will be a Google Spreadsheet that updates periodically with data from the pyranometer.

3.5 System Operation

The pyranometer will be well documented and users will be provided with thorough, easy to follow instruction on how to assemble and deploy the pyranometer. The pyranometer should be "plug and play", in that it will work properly once it is deployed and turned on. One of the main goals for the pyranometer project is to have it be easy to assemble, so a simple design and thorough instructions will make the pyranometer easy to build and use.

3.6 System Security

Keeping OPEnS lab projects secure is a top priority, so chips that do not support full operating systems will be used to control and operate the pyranometer. The microcontroller that operates the pyranometer will not support SSH (secure shell) and should be difficult to hack. The data reported by the pyranometer will be uploaded to Google sheets via a PushingBox API that translates the data into HTTPS.

3.7 Physical Characteristics

The only constraint on weight, volume, and dimension is that it is able to carried by one person. The system is meant to be built and configured inside a lab with access to a 3D printer. The pyranometer is meant to be deployed in an outdoor location that is in range of a Loom data hub. The materials used are custom PCB, an Adafruit TSL2591, a Thermopile TMP007, an Adafruit SI1145, an Adafruit TCA9548A, an Adalogger Featherwing, an Adafruit Feather-M0, a 3.7v Lipo battery, an antennae, ABS plastic, acrylic, and glass. The parts are not interchangeable, as the software is written for specific hardware and the materials block specific solar radiations. The enclosure and domes are to be 3D printed, and the glass and acrylic should not have to be shaped in any way.

3.8 Environmental Conditions

The pyranometer will be deployed outdoors, so it will be subject to all natural environmental conditions. This includes wind, rain, and various temperatures. Wind has the potential to blow the antennae off, low temperatures can skew thermopile data, and high temperatures can cause overheating. Measures must be taken to prevent all of these from happening, as any of them can ruin the effectiveness of the pyranometer. The pyranometer utilizes several electronic parts, so any water leaking into the pyranometer will cause significant damage; thus the pyranometer will be made waterproof and the hardware will be coated with a waterproof substance.

3.9 Information Management

The optical black within the material absorbs solar radiation in the form of heat. A thermopile reads the change in heat of the optical black and outputs analog voltage. The microcontroller translates the analog voltage into W/m^2 and sends the data to a data hub over radio. The data hub expects W/m^2 data. Additionally, the other two sensors record UV, IR, and visible spectrum data and send it to the microcontroller. The mincrontroller translate the raw data into W/m^2 and sends it to the data hub.

3.10 System Lifecycle Sustainment

To realize a quality system, the pyranometer will have to be tested. The best tool to review the system is an industry-grade pyranometer that our open-source pyranometer will be compared to. We will compare the data from the two pyranometers to be able to determine how accurate our pyranometer's data is. We will use a greenhouse and sprinklers to simulate various weather conditions. Before integrating the system into Loom, the data from the pyranometer will be uploaded to an SD card and analyzed. Having everything be open-source, people will be able to continually improve the software and design.

4 Verification

There are four areas to verify: quality of data, survivability, data transmission, and portability. To test quality of data, we will take a commercial-grade pyranometer and gather data samples. That data will be compared against the data taken with our pyranometer to determine the accuracy of the data. Each pyranometer will be used in the same controlled environments to help ensure accuracy.

Survivability involves the pyronometer being weatherproof and being able to last at least 3 weeks in the field. To verify how long the pyranometer can remain actively deployed, we will work with the OPEnS staff to perform a draw test and estimate the longevity of the pyranometer. The estimated time of life must be at least 21 days. To verify surviveability, we will simulate different environments. To simulate a hot and humid environment, we will place the pyranometer in a greehhouse, and to simulate rain we will place the pyranometer in the midst of a sprinkler system.

To verify data transmission, the pyranometer will wirelessly transmit data at gradually increasing distances (intervals of one kilometer). This will verify that wireless data transmission is functional, and it will give an upper bound to the range of the wireless transmission. This will verify the range is long enough (at least ten kilometers).

Portability refers to ease of use and deployment. To verify this, we will give a user an assembled pyranometer and deployment documentation. We will observe how they are able to follow the documentation and if they are able to successfully deploy the pyranometer and get data readings.

5 Appendinces

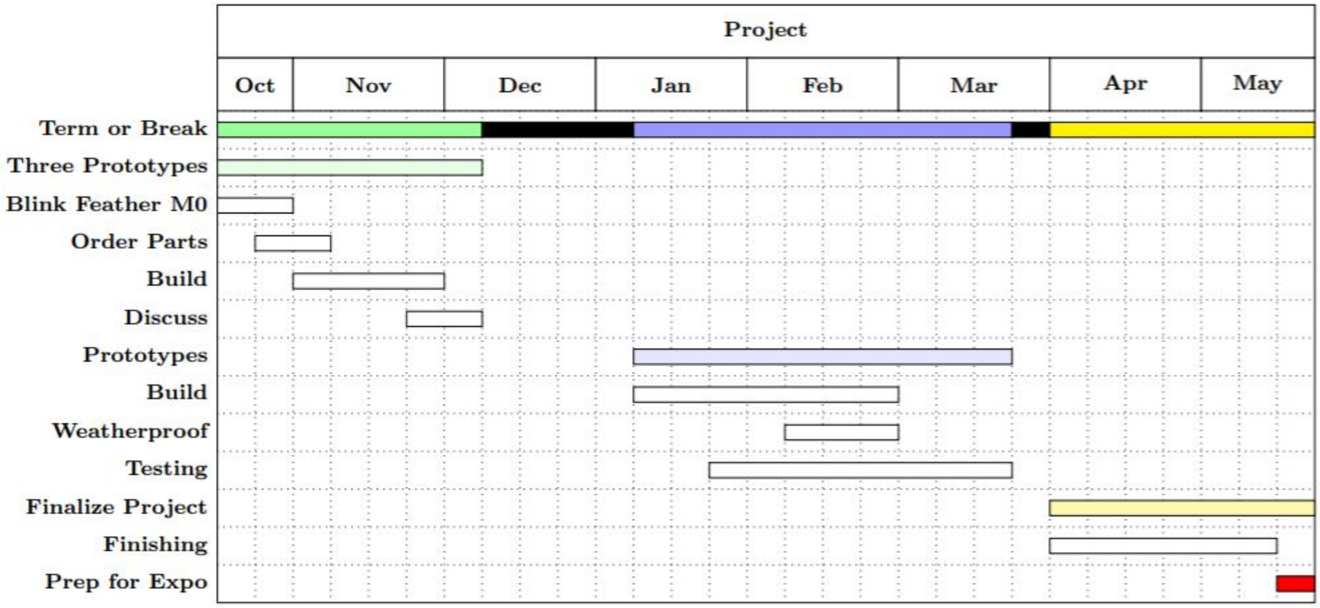
5.1 Assumptions and Dependencies

It is assumed that the pyranometer will be used to integrate with Loom, as such the radio will be programmed to communicate with a Loom data hub.

5.2 Acronyms and Abbreviations

OPEnS: Openly Published Environmental Sensing; the lab that is developing the pyranometer
CAD: Computer-aided design; design files used in 3D printing
IoT: Internet of Things; wirelessly interconnected systems

6 Gantt Chart



CS Capstone Design Document

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OPEnS Pyranometer: IoT Solar Radiation Sensor

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Abstract

The wireless, open-source pyranometer project has more to do with hardware than software, thus the design views discussed deal with hardware and physical materials. The project is being sponsored by the OPEnS lab at Oregon State University and there are two stakeholders, Dr. Chad Higgins and Dr. Chet Udell. The pyranometer is to become a part of the environmental sensing collection in the OPEnS lab; it is therefor critical that the pyranometer be able to withstand multiple environments. Most of the physical elements in the pyranometer will relate to weatherproofing or heat regulation in some way and both are crucial in keeping the pyranomator running and reporting accurate data. The pyranometer uses a thermopile, a lux sensor, and a UV sensor to report solar irradiance, so any extra solar energy entering the pyranometer will skew the data. If the data reported by the pyranometer is inaccurate, the pyranometer is rendered useless, thus ensuring accurate data is important part of the design. Each design decision in no way hinders data accuracy, and anything possible is done to potentially increase data accuracy.

Contents

1 Revisions

Section	Original	New
2.4.3 Data Transmission	Mentioned that we assume the user has a hub, but we do have code up for the hub.	Code for the hub is now included in our software package .
3.2 Scope	Only mentioned 3D printed objects and some low-cost electronics.	Added that a few other materials are needed that are not electronics or 3D printed.
3.4 Authorship	Only mentioned the team members, Chet Udell, and Chad Higgins.	Added John Selker and other OPEnS staff to acknowledge their help as well.
4.1 Black Body Object: 3D Printed ABS Dome	• Dome is made of PLA • Dome is not being vapor-finished	• Dome is made of ABS • Dome is being vapor-finished
4.2 Power Source	• LoRa chip and two thermopiles are being used to gather and send data • Battery costs $50-$75	• A Feather M0 with built in LoRa is being used for data transmission • One thermopile, a lux sensor, and a UV sensor are being used to gather data • Battery costs $30-$50
4.3 Data Transmission: LoRa Radio	Using a seperate LoRa chip for data transmission	Using a Feater M0 with built in LoRa for data transmission
4.4 Data Logging: Adalogger	SD card is strictly used for testing	SD card is now used as a data backup for when the pyranometer is in the field
4.6 Weatherproofing Housing Structure: 3D Printing and a Resin	Hardware is not being made waterproof	All hardware is being coated in a waterproof resin
4.9 Dome Structure	Dome is made of acrylic.	Acrylic dome is now being purchased directly.
5 Conclusion	There is a separate compartment for the LoRa chip and there are two thermopile/black-body compartments	• LoRa compartment has been removed • One thermopile compartment is being replaced with a lux/UV sensor compartment
6 Glossary	Definitions for vapor-finish and lux sensor are no present	• Vapor-finish definition included in Glossary • Lux sensor definition included in Glossary

2 Introduction

2.1 Project Description

The overall project is a wireless, open-source pyranometer. A pyranometer is a device that detects solar radiation and reports a W/m^2 value based on the total amount of solar radiation hitting the device. Open-source pyranometers exist, but they are generally poorly documented and are not wireless. This pyranometer will be easy to set up due to good documentation and will be wireless.

2.2 Stakeholders

2.2.1 Dr. Chet Udell

Our primary client, Dr. Chet Udell, is the director of the Openly Published Environmental Sensing (OPEnS) lab. The OPEnS lab is the primary sponsor of our project and our pyranometer will become one of the many OPEnS lab wireless devices.

2.2.2 Dr. Chad Higgins

Dr. Chad Higgins is an associate professor in the College of Agricultural Sciences, specifically in the College of Biological and Ecological Engineering. Dr. Higgins conducts many ecological studies and a pyranometer will be especially helpful for such studies. He wants the pyranometer to be accurate and easy to assemble.

2.3 Design and Stakeholder concerns

The main concerns are cost to build, easiness to build, and accuracy of data. One of the main purposes of the open-source pyranometer is to have it be cheap and easy to build by anyone with access to a 3D printer. Researchers and scientists should be able follow the documentation for the pyranometer and construct it without any headache. The data reported by the pyranometer needs to be reliable, otherwise it is useless. A fourth concern is the pyranometer's surviveability; the pyranometer needs to be weatherproof and the power source needs to last at least a few weeks.

2.4 Design Viewpoint Descriptions

2.4.1 Black Body Object

The black body object is what the thermopile senses in order to report the total solar radiation hitting the pyranometer. The object is meant the absorb solar radiation and emit IR radiation, which is detected by the thermopile and used to report the total solar radiation hitting the pyranometer.

2.4.2 Power Source

The power source is what supplies power the pyranometer. The power supply must be wireless and be able to sustain the pyranometer for weeks at a time.

2.4.3 Data Transmission

Data transmission refers to how the pyranometer wirelessly sends data back to the user. It is assumed that the user has a data hub or receiver that the pyranometer sends data to. There will be some directions towards building a hub, but there will not be a housing structure for said hub because it requires an Ethernet connection.

2.4.4 Data Logging

Data logging is how data from a sensor can be recorded. In this case, it refers to taking the sensor data and turning it into something useful.

2.4.5 Housing Structure

The housing structure is the 3D printed object that will contain all of the hardware and protect the hardware from wind and water.

2.4.6 Weatherproofing Housing Structure

Weatherproofing the housing structure refers to keeping the pyranometer safe from the elements. These include water, and wind.

2.4.7 Analog Translation

Analog translation is the method of converting the data gathered by the sensor in to usable data. For our project we want the data to be converted into units W/m^2.

2.4.8 Light Diffuser

The light diffuser will be used to assist the sensor. It will evenly spread light onto the sensor to give consistent and acurate data.

2.4.9 Acrylic Dome

The acrylic dome is used to protect the thermopile while still letting light through. Acrylic is able to let IR and Visible light pass through, which is perfect for the thermopile.

2.4.10 Glass Sheet

The glass sheet is used to protect the UV and lux sensors while still letting light through. Glass is able to let UV and Visible light pass through, which works well for bot the UV and lux sensor.

3 Project Identification

3.1 Date

The pyranometer project was assigned to the group on October 8th, 2018. It will end on the Engineering Expo hosted by Oregon State University in May 17, 2019.

3.2 Scope

The pyranometer will be able to measure solar radiation and convert it to W/m^2. It will then transmit that data to a Google spreadsheet using the LOOM IoT architecture. The goal of this project is to create an open-source and low-cost pyranometer that is comparable to acommercial grade pyranometer. The project will also be open-source by adding any code added to the LOOM system on GitHub. All of the technology used to create the pyranometer should be available to any other lab or Maker Space. It should be able to be recreated with a 3D printer and access to funds to buy a few low-cost electronics and other materials that cannot be printed. The materials that are not 3D printed or electronics are also low-cost however. The benefit of creating something open-source is that it can be built all over the world. This is helpful because measuring solar radiation is good information around the globe. One use for this sensor is to use it for agriculture. Plants need sunlight to survive and using a pyranometer to know how much sunlight a particular area is getting is good information.

3.3 Issuing Organization

OPEnS lab is the primary sponsor of the wireless open-source pyranometer project, with Dr. Chad Higgins supplying the idea of the project. Once the project is complete, the pyranometer will become a part of the OPEnS collection of open-soure sensors.

3.4 Authorship

The authors and editors of this project are Brooke Weir, Garen Porter, and Alejandro Tovar. Suggestions, guidance, and recommendations made by Dr. Chad higgins and Dr. Chet Udell have influenced design decisions and edits made to most written documents for the pyranometer project. John Selker at Oregon State University has also made recommendations to the team. Other members of the OPEnS lab staff were helpful in creating the pyranometer.

3.5 Context

There is a need for an open-source pyranometer that is wireless and well documented. Existing open-source pyranometers are either poorly documented or wired, so researchers who are looking for an open-source pyranometer that is well documented and wireless have no options. The wireless open-source pyranometer project will fill this need and look to serve researchers who need a cheap, wireless, and easy to assemble pyranometer. Most wireless pyranometers are expensive, and the open-source nature of this project will make the pyranometer much cheaper (only cost of materials and assembly need to be accounted for).

4 Design Views

4.1 Black Body Object: 3D Printed ABS Dome

A thermopile, which is what is going to be used to report total solar irradiance, is a device that reads the temperature of an object using a die with a known temperature. More precisely, the thermopile reads the IR emanated from an object to calculate the object's temperature. To get accurate readings, black objects with high emissivity values need to be used.

4.1.1 Design Concerns

The first concern is material cost and availability. Ideally, a cheap object with high emissivity should be used. The first material recommended by our client is Teflon, which is cheap and has an emissivity value of 0.92 (fairly high). Teflon, however, leads to the second concern; the object's ability to be shaped and formed. Teflon is a hard plastic that can only be shaped by a laser cutter and is not easily formed into shapes other than a sheet. Thermopiles work best when pointed at an infinite plane, and the best way to implement an infinite plane is to place the thermopile inside a dome, where the dome is the black body object. It may be possible to form Teflon into a dome shape, but it would be exceedingly difficult. An alternative, and what is now perceived as the best option, is to 3D print a dome out of Acrylonitrile butadiene styrene (ABS) and paint the dome with Black 2.0. ABS is a popular plastic in 3D printing and its surface is able to be painted. ABS is inexpensive and 3D printing a dome structure will be easy and the dome can be made with any desired dimensions. Black 2.0 is the blackest and mattest paint available for purchase. A tube is about $20 and will make the emissivity of the ABS about 0.99. The third concern is the texture of the plastic dome. The rough surface may affect the emissivity of the dome. We plan to vapor-finish the ABS dome to make the surface even and smooth.
A fourth concern is the accuracy of the data; which is directly related to the emissivty of the black body. The higher the emissivity of the object the higher the accuracy of the data. The emissivity of black ABS is about 0.92, but when the ABS is coated with Black 2.0 the emissivity increases. The emissivity of ABS by itself is high enough to where a user would not *have* to paint it, but it would be best if users did use Black 2.0 to paint the ABS.

4.1.2 Design Elements

There are three required elements for the optical black object; a coil of black ABS; a 3D printer; a tube of Black 2.0 (optional); and a CAD design of the dome. The CAD file will be used to tell the 3D how to construct the dome. Once the dome is finished printing, it can be painted with Black 2.0 to achieve the highest emissivity possible. There needs to be a small slit on one side of the dome that allows the wires coming from the thermopile to pass under. The dome will be inserted into the base of the housing structure with the thermopile underneath. The dome should simulate an infinite plane that allows the thermopile to get the most accurate readings possible.

4.1.3 Design Relationships

The black object directly effects the thermopile and the housing structure. The dome is inserted into the base of the housing structure and it must fully encapsulate the thermopile. The optical black object is a crucial element in ensuring accurate data is read from the thermopile.

4.1.4 Design Rationale

Ideally, an infinite plane with an emissivity value of 1 would be used as the optical black object. A dome surrounding the thermopile will accurately simulate an infinite plane, and coating black ABS with Black 2.0 will give as high an emissivity value as possible at a reasonable price. Vapor-finishing the object should give a consistent reading from a smoothed surface. This approach to the optical black object should result in the most accurate data readings possible.

4.2 Power Source

A large part of this pyranometer project is to make it wireless, which primarily means the pyranometer needs a wireless power source. There are several different possible routes to go, and different users may have different preferences. For the OPEnS open-source pyranometer, lithium batteries will be used, but the documentation will mention possible alternatives (solar panel, generators, etc.).

4.2.1 Design Concerns

The main concern with the power source is how long it will last. The power source itself is the main factor in battery life, but the efficiency of the code in the microcontroller and how many sensors are connected to the microcontroller must also be considered. The current design has a thermopiles, a lux sensor, and a UV sensor being connected to the Feather M0 microcontroller. All three of these take little power. LoRa is not power intensive by nature, and the three sensors take readings every few seconds and are put in a low power state between taking readings.
It was decided that lithium-polymer batteries would be used to power the pyranometer. An initial concern was ease of use, and it is very easy to hook up a lithium battery pack to a Feather M0 (as simple as plugging a wire into a pin). Other implementations, such as a solar panel or thermoelectric generator, had a much more involved setup. The OPEnS lab already has lithium battery packs purchased, so no additional money needs to be spent on lithium batteries. For users outside the lab, the battery packs will cost between $30 and $50 dollars, but they are rechargeable and should last several weeks or months. There is a large discrepancy between the low end and high end of the estimated life of the batteries. This is due to the code efficiency playing a large role in how long the batteries will last, and it is difficult test the code's effect on the battery without deploying the pyranometer to the field and timing how long it lasts.

4.2.2 Design Elements

For the power source there is only one design element, and that is the battery pack itself. The pack that OPEnS lab uses is a collection of six "AA size" lithium batteries. Other OPEnS projects reportedly last a couple months per charge, but it varies depending how well the code is written and how many sensors are a part of each project. The batteries are rechargeable and have a relatively low discharge rate (meaning not much charge capacity is lost per recharge) and can be recharged a few hundred times before needing to be replaced.

4.2.3 Design Relationships

The project as a whole will not work without a power source, but the power source itself only effects the Feather M0 microcontroller and the housing structure. The housing structure needs to adequately protect the lithium batteries from any form of weather, and any heat coming from the batteries needs to be isolated from the three sensors. This entails having the lithium batteries being enclosed by walls. The power source needs to adequately supply power to the Feather M0 so that it may perform its functions for long periods. As long as the lithium batteries keep the Feather M0 running for long periods of time and the lithium batteries are adequately protected; the batteries are performing their job.

4.2.4 Design Rationale

Various power sources were judged based on three criterion; cost, ease of use, and average life. Lithium batteries are expensive initially, but can be reused over and over, so the overall cost is relatively low. Lithium batteries are long lasting in two senses; each charge of a lithium battery pack lasts a long time and the batteries can be reused over and over giving them a long overall life. Finally, lithium batteries are easy to use; simply plug them into the Feather M0 to power it, and plug them into a charging station to charge them. The pyranometer documentation will recommend a battery pack to buy, so users should be able to order the batteries and begin using them immediately. The housing structure will have an enclosure to set the battery pack in, with the goal of the enclosure to minimize the heat impact of the batteries. The ease of use, longevity, and value of lithium batteries make them the ideal design choice for the pyranometer project.

4.3 Data Transmission: LoRa Radio

The purpose of using LoRa radio with the pyranometer is to wirelessly transmit data over long distances. LoRa is a wireless communication technology that consumes low amounts of power while being able to transmit data or long distance; the caveat is that LoRa operates under low bandwidth, thus limiting the amount of data that can be sent.

4.3.1 Design Concerns

There are several concerns when implementing LoRa radio, first of which is keeping power consummation low. LoRa, by nature, consumes low amounts of power compared to other data transmission methods (Wifi and Cellular), but to further assist with power consumption the *rocketscream/Low-Power* Arduino library will be used. The library assists with power management by frequently putting the Feather M0 in a lower power mode.

A second concern is keeping the pyranometer structure weatherproof. Using LoRa radio requires use of an external antennae, which means that an antennae needs to protrude out of the housing structure. To make this protrusion possible, a hole will need to made in the housing structure. The hole will need to be just wide enough to fit the antennae, and a resin will be applied around the hole to help seal the crack between the antennae and the housing structure.

A third concern is ensuring the antenna connector stays attached to the Feather M0. A Feather M0 with integrated LoRa is going to be used so that a fourth chip does not have to wired to the Feather M0. The connector that connects the Antenna to the Feather M0 is less than ideal. Keeping the Feather M0 and antenna attached is crucial to get real time data, so we will be hot gluing the connector to the Feather M0.

4.3.2 Design Elements

The specific Feather M0 that is to be used is an *Adafruit Feather M0 with RFM95 LoRa Radio - 900MHz*. The antenna to be used is a 900Mhz Antenna with an SMA connector. The SMA connector will make it easy to attach the antenna to the outside of the housing structure. The antenna will be connected directly to the Feather M0 with no intermediate chip needed. The connector will be hot glued to the Feather M0 to ensure the connector does not get disconnected whilst in the field.

The *LOOM LoRa API* will be used to setup and configure the LoRa radio with the pyranometer. The API has implementations for receiving and sending OSC bundles (data packets containing sensor readings). The LOOM LoRa API makes use of the following APIs and libraries: *adafruit RadioHeaad, GreyGnome EnableInterrupt, FabioCuomo FabioCuomo-DS3231, rocketscream Low-Power, CNMAT OSC*, and *EnviroDIY Arduino-SDI-12*. Each library is made specifically for use by Arduino microcontrollers, and each library assists or enhances the LoRa radio implementation.

4.3.3 Design Relationships

The wireless transmission, both the non-physical and physical aspects, relate to the housing structure, black body objects, and Feather M0. The housing structure will need a hole cut where the radio antennae needs to poke out of, and the hole needs to be properly sealed to keep water from entering. The Feather M0 will need to be configured to send data packets over LoRa radio to a LoRa receiver. The LOOM API has a configuration file that will need to be set to use LoRa as its wireless transmission medium. With the configuration file correctly configured, the readings from the three sensors will need to be organized into OSC packets (this is all done by the API). The only code that will need to be written is a call to the LoRa send function (the function will be called in the main loop every few seconds).

4.3.4 Design Rationale

LoRa radio is the best option for data transmission due to its low power consumption and high range. There is an existing API already implemented in LOOM to make LoRa easy to implement. Many other OPEnS IoT devices use LoRa as well, so there are LoRa receivers already set up and there are examples to follow. As long as the housing structure is designed carefully, the weatherproofing and data interference concerns can be negated.

4.4 Data Logging: Adalogger

LOOM will be used to log data from a sensor onto either a spreadsheet or a micro SD card. When configuring the LOOM system for the pyranometer, LOOM can either put the recorded data on a micro SD card or transmit it to a Google spreadsheet. To upload to a Google spreadsheet, the pyranometer will send data to a hub over LoRa. The hub will then upload the data to a Google Spreadsheet using PushingBox. In this section, the SD card route using the Adafruit Adalogger will be examined.

4.4.1 Design Concerns

The major concern with the Adalogger is that the information recorded on the SD card will have to be manually taken from the sensor and uploaded to a computer. Having to manually move the data will not be helpful for a sensor since they are meant to be left outside for a long period of time without human involvement. Also, an SD card can only hold so much data. The SD card will mostly be involved during the testing of the sensors so this concern is valid. Once the project is finished, the main method of getting data from the pyranometer will be receiving it over LoRa, but all data will written to an SD card on the pyranometer. The locally saved data will act as a backup in case LoRa fails.

4.4.2 Design Elements

The Adalogger can be hooked up to a multiplexer that is also connected to the Feather M0 and a sensor. The Adalogger can take the data from the sensor and put it on a micro SD card. The micro SD can then be taken out and read using a computer.

4.4.3 Design Relationships

The Adalogger will be connected to the multiplexer and Feather M0. The multiplexer is what connects the sensor to the Feather M0 and Adalogger. The Adalogger will take the data that the sensor gets and put it on a micro SD card.

4.4.4 Design Rationale

The purpose of the Adalogger is to give a quick way to get data from a sensor for testing. Testing is an important part of making sure that the data the pyranometer senses is accurate. Using the Adalogger is a good way to get the data and determine if it is correct. Additionally, the adalogger will be used to store a backup of all recorded data.

4.5 Housing Structure: A 3D Printed Design

The housing structure will enclose the sensors, microcontroller, and battery. It will be 3D printed with a space for an antennae to poke out.

4.5.1 Design Concerns

A concern for the housing structure is to fit all the electronic pieces within the structure while not cramming the electronics too closely. This is important so that the sensors do not pick up heat from other electronics, which may interfere with the data. The Feather M0, battery, and any other electronics will have to maintain some distance from the other sensors (particularly the thermopile). Otherwise the data will not be accurate.
Another concern is the hole where the LoRa antennae will poke out of the structure. It leaves a space in the housing structure where the elements can affect the electronics more easily. Rain or wind can enter the structure and skew the data as well as damage the hardware. The resin applied to the 3D printed structure should prevent such damage from happening, but it is best to close any gaps and alleviate the possibly of a breach.

4.5.2 Design Elements

The housing structure will be 3D printed and then coated with a resin. To create the structure, CAD will be used to create the design and one of the three 3D printers available at the OPEnS lab will be used to print it. The structure will then be coated in a resin to help weather proof the structure. The antennae for the radio will be added to the housing and have a resin applied to minimize the space where the elements can enter the pyranometer. Additionally, the hardware will be coated in an acrylic substance to make them waterproof. In the case that water does get inside the structure, the hardware should be safe.

4.5.3 Design Relationships

The housing structure has a relationship with all other components of the pyranometer since it will contain all of them. All of the parts of the pyranometer, except the radio antennae, will be contained within the housing structure. The radio antennae will be partially enclosed in the structure.

4.5.4 Design Rationale

The purpose of the housing structure is to have something to surround all of the electronics so each unit is portable. It is there so that there are no loose electronic pieces. The housing structure also protects the electronics from the elements. The housing structure allows the components to be put together and called one single sensor.

4.6 Weatherproofing Housing Structure: 3D Printing and a Resin

Weatherproofing the housing structure for the pyranometer is important to protect the electronics and to obtain accurate data. The structure itself will be 3D printed with a radio antennae sticking out of the structure. The structure will have to be protected from the elements as well as insulated to get accurate, reliable data.

4.6.1 Design Concerns

There are several concerns for weatherproofing the housing structure for the pyranometer. The first concern is to prevent water damage to the sensors inside the housing. Water can break the hardware and render the pyranometer nonoperational. There will be some areas where the possibility of water damage is be higher. One such area is where an antennae will protrude out of the housing structure for the LoRa radio. Preventing water damage is crucial to keep the battery, Feather M0, and other electronics working. Another concern with waterproofing the housing structure is to protect the sensors that depend on heat to read data. Heat comes from the sunlight coming in, but also wind and ambient heat affects the temperature. The housing structure should be insulated from wind and other types of heat.

4.6.2 Design Elements

The housing structure will be 3D printed. There are ways to 3D print the housing structure to make it more waterproof. The first way to do so will be to print thick layers [4]. This will reduce the overall amount of layers which will decrease the areas that water can slip through between layers. The second way to do so will be to print the housing structure with 100% infill [4]. The third way to do so will be to print several perimeters to enclose the electronics. Having smaller structures enclosed within another structure will add to the number of layers water will have to go through to damage the electronics. It can also help insulate the electronics from wind and heat.
Beyond 3D printing the structure in particular ways, another way to weatherproof the housing structure is to coat it in a resin. Applying a resin to the 3D printed structure will fill in the gaps between the layers. The resin itself will be resistant to the elements and help the overall structure from being damaged.

4.6.3 Design Relationships

Weather proofing the housing structure has a relationship with everything inside the structure. It will have to protect everything inside from wind, rain, and ambient heat. Specifically, weather proofing will interact with the LoRa radio antennae since the antennae will have to protrude outside of the housing structure. Otherwise, the housing structure will protect the Feather M0, sensors, battery, and black body object.

4.6.4 Design Rationale

The purpose of weather proofing the housing structure is to protect the electronics from the elements such as wind, rain, and heat. This is necessary to keep the pyranometer running. Each component, aside from the black body objects, inside the structure will be small electronics. Those pieces will be susceptible to water damage. Protecting against wind and heat will protect the electronics from experiencing extreme temperature fluctuations and will help record accurate data.

4.7 Analog Translation

Analog Translation is the process of converting solar radiation into some form of usable data. For this project we want to be able to read in solar radiation as W/m^2. The micro-controller needs a way to achieve this translation. There are some hardware that can simplify this task, but they can be expensive. For our purpose, using open source software and modifying it for our needs will be best suited for this project.

4.7.1 Design Concerns

The written and modified code will need to be simplified and well documented for other users to understand. Once we can get our code to compile and translating data, we will need to run tests to determine the accuracy of our translations. The code will also need to be compatible with the chip of the micro-controller and to maker sure we don't overwork the chip with the program.

4.7.2 Design Elements

The micro-controller will be programmed with our translator to read in data as heat. Then using a physics equation that will need to be derived, the program should be able to take in the data the micro-controller is reading and convert it into data with units W/m^2. The data will then be ready to be sent and logged on a spreadsheet.

4.7.3 Design Relationships

The translation program will be compiled and downloaded onto the chip of the micro-controller to perform it's calculations. It will get the data that was gathered from the sensor and convert it into our desired data in W/m^2 units.

4.7.4 Design Rationale

Using open source software is better for this project because it is being integrated into an open source data hub. The goal of the project is to get a solar radiation sensor onto the Loom git hub repository for others to use. It is cheaper than having to buy dedicated hardware that can do this translation for us.

4.8 Light Diffuser

The light diffuser is a piece of material that will spread light evenly onto the sensors. This part of the device plays an important role in the accuracy of our sensor. The light transmittance efficiency of the diffuser will play a big role in the design of this part. The light transmittance efficiency is a rating of how much light passes through an object.

4.8.1 Design Concerns

Some concerns will be material of the diffuser and the thickness. It needs the right amount of light transmittance. The sensor is like the human eye, too much light and it will be blinded by bright light, but too little light and it will be difficult to see. We need the right amount of light to pass through our diffuser. We don't want to overstimulate the sensor or not have enough. The material will determine how much light and what kind of light can get through. Thickness will also determine how much light will pass through. Price of the material is also a concern that will need to be taken into account.

4.8.2 Design Elements

Our ideal diffuser will have a surface called a Lambertian surface. A Lambertian surface is the ideal surface for diffusing light. The idea is that the brightness of light is the same regardless of the observer's angle view. If our diffuser has this kind of effect, then we can evenly distribute light for an accurate reading. We plan on using our diffuser as both a diffuser and to play small role in protecting our sensor. The diffuser will be dome-like to account for all angles of sunlight.

4.8.3 Design Relationships

The diffuser will have to be big enough to cover our sensor. This is to get the most out of the sensor. The size and shape of the dome will need to fit on top of the structure and cover the sensor. We will have to make sure that this piece maintains our goals of weather proofing the device.

4.8.4 Design Rationale

The diffuser needs to be able to distribute light as evenly as possible to give our sensor consistent data. It will also need to let in the right amount of sunlight so the sensor doesn't get overstimulated or have too little to work with. A dome shaped structure is needed to cover the sensor as well as to fit in the housing structure design. The dome will be made out of acrylic plastic. Acrylic allows IR radiation through and is durable to the environment.

4.9 Dome Structure

The dome structure is what will overall protect the sensor as well as act as the diffuser. It will need to be durable and be able to let sunlight in. As well as meet the weather proofing goals since it is an outer layer of our device. For the dome structure, the material will be made out of a purchased acrylic dome. The dome will actually be a double dome with a larger acrylic dome over a smaller acrylic dome.

4.9.1 Design Concerns

Some concerns include cost, durability, and light transmittance efficiency. The material used will need to have a low cost to keep our device from being too expensive. The material will also have to be durable to survive long periods of time in any environment it is used in. Since this will cover our diffuser, we need to maker sure light can pass through and enough light passes through to the diffuser. This will play a role in the accuracy of the sensor.

4.9.2 Design Elements

The dome structure will be bigger than the diffuser in order to cover and protect it. The material will be acrylic. The dome structure will have the same shape as the diffuser for this design.

4.9.3 Design Relationships

The dome structure is used to protect the diffuser, the smaller acrylic dome, and the sensor. It will help isolate external heat change caused by wind. It will need to fit with the housing structure as well. Since it is a part of the housing structure it will need to be weather proof just like the rest of the structure.

4.9.4 Design Rationale

Acrylic material will be used for this dome structure. It is more durable than glass, and less heat conductive. This is important because the sensor will read in heat, and any external heat can lead to errors. Acrylic is also cheaper than other viable materials, making it the better choice in terms of cost. The material also has a high light transmittance and lets in the most amount of different wavelengths of sunlight. The thermopile needs to read IR, and acrylic is good at letting IR through.

4.10 Glass sheet

Whereas the Acrylic dome is used to cover the thermopile and black-body, as glass sheet will be used to cover the UV and visible spectrum sensors. Glass is able to transmit UV and visible spectrum light, thus being a good material to place over the UV and visible spectrum sensors. Acrylic domes cannot be used to cover these two sensors because acrylic is not effective at transmitting UV light.

4.10.1 Design Concerns

The design concerns include cost, durability, and light transmittance efficiency. The material used needs to be cheap, durable, and easy to acquire. The material is not only responsible for transmitting light, but it is also responsible for protecting the sensors. Thus, the material needs to be water proof. A resin cannot be applied to the material because the resin would change the light transmission, so the material must be inherently waterproof. This particular material will be placed over the UV and visible light sensors, so the material must be able to transmit UV and visible light.

4.10.2 Design Elements

According to Dr. Higgins (one of the stake holder for our project) the material covering the UV and visible light sensors can be flat rather a dome shape. With this mind we found that a glass sheet will server the most effective material.

4.10.3 Design Relationships

The glass sheet is related to the housing structure, UV sensor, and visible light sensor. The top of the housing structure will need a square hole that the glass sheet can fit over to allow light to hit the sensors. The sensoros will need to point toward the glass to allow the maximum amount of light to hit the sensors.

4.10.4 Design Rationale

The UV and visible light sensors do not rely on heat to get their readings, so the heat conducting properties of glass do not matter. Glass is the cheapest material to acquire that transmits both UV and visible light, and glass is readily available in small sheets. Due to glass being easy to acquire, its ability to transmit UV and visible light, and it's low cost, it is the ideal material to place over the top of the UV and visible light sensors.

5 Conclusion

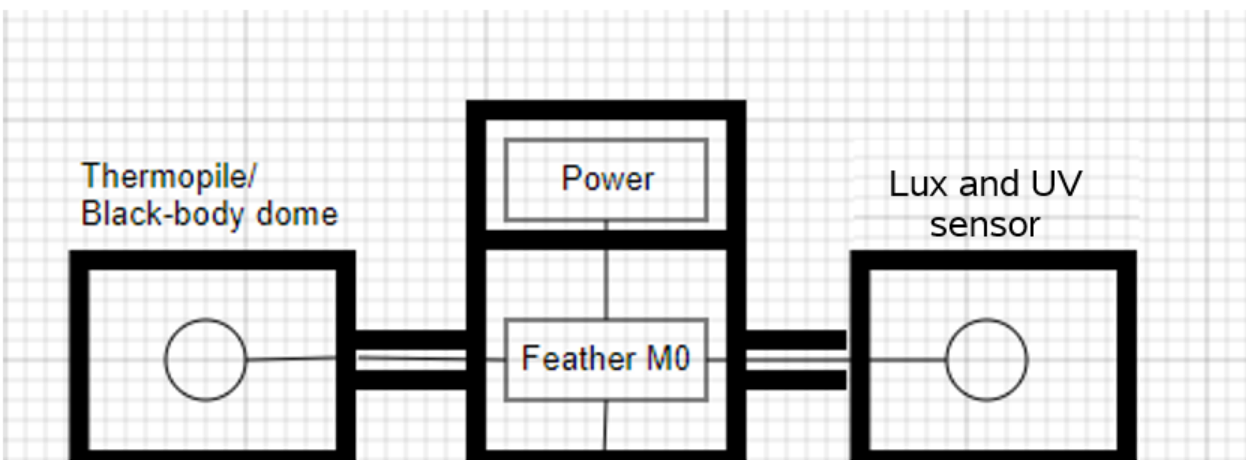

Figure 1: Top-down design of the open-source pyranometer.

Figure 1 shows the current design of the open-source, wireless pyranometer. The design is heavily influenced by various design concerns, such as data accuracy, cost, and ease of assembly. Each hardware piece is put behind a 3D printed wall, and the sensors (and surrounding black-body dome) are put behind two walls to limit any excess thermal energy from interfering with the sensor readings. Each wall will have a small slit for wires to go through, but each hardware piece should otherwise be separate from each other. Having different "compartments" for each hardware piece should make assembly easier, as users will simply need to place each hardware piece in its respective slot. The entire structure, as well as the dome surrounding the thermopile, will be 3D printed to limit cost. A second 3D printed structure will be placed over the top of the base to protect the hardware from the environment in order to keep it weatherproof.

A common theme throughout the various designs is keeping pyranometer safe in the field (deployed in the environment) and ensuring the data it reports is accurate. All of the OPEnS sensors are meant to live out in various climates and the pyranometer is no different. In each design decision, weatherproofing and data accuracy were considered to help ensure that the pyranometer is reliable in most environments. Besides keeping the pyranometer weatherproof and ensuring accuracy of data, ease of assembly and price are two important factors considered in each design decision. Everything that can be 3D printed is being 3D printed to keep cost down and make assembly easier. For the parts that cannot be 3D printed, such as the acrylic domes, the best value parts are chosen. The design decisions made should lead to a pyranometer that can survive in most environments, be easy to assemble, be inexpensive (relative to other wireless pyranometers), and produce reliable data.

6 Glossary

Black 2.0: *The blackest paint available to the public; created by Stuart Semple and inspired by Vantablack [1].*

Emissivity: *An objects ability to emit thermal radiation (IR).*

Feather M0: *A small, lightweight microcontroller developed by Adafruit.*

Infrared (IR): *A form of electromagnetic radiation emitted from heated objects.*

Lambertian Surface: *A quality a transparent object may have. Where the brightness of light passing through is the same in any angle it is viewed at. This is regarded as an ideal diffuser*

Light Diffuser: *An object that can evenly distribute light passing through on a surface.*

Light Transmittance Efficiency: *A rating on the percentage of light that can pass through an object.*

Lithium-ion battery: *A rechargeable battery that generates electricity via the movement of positively charged lithium ions.*

Long Range (LoRa): *A wireless communications technology developed by Semtech [2]*

LOOM: *An IoT system designed by the OPEnS lab. It seeks to make the process of creating IoT devices simple.*

Lux sensor: *A sensor that measures luminous flux, namely how the human eye perceives visible and infrared light.*

Pyranometer: *A device that detects solar radiation and reports the total solar irradiance in* W/m^2.

Open-source: *Refers to software and code being freely available to the general public.*

Openly Published Environmental Sensing (OPEnS): *An organization sponsored by Oregon State University dedicated to creating open-source environmental sensors using modern technology.*

Resin: *A material that is insoluable to water.*

SD card: *A type of portable memory card.*

Thermopile: *A device that converts thermal energy (IR) into electrical energy (volts) and reports the temperature of an object.*

Vapor Finishing: *A process of heating acetone into a gas onto ABS plastic. This heats the plastic to slightly dissolve and smooth the printed object.*

3D Printing: *A method of layering plastic into a three dimensional object based on a model.*

7 References

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