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Solution Design Description
on

Sandia Integrated Sensor

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November, 2018

Sandia Integrated Sensor: Solution Design Description

Background:

Today we live in a technology-driven world, where real-time sensing is feasible for a range of applications and environments. The data collected is invaluable, it can be used to improve future designs, enhance security, increase efficiency, assess health, and track performance, to name a few of the potential advantages of embedded sensing hardware. Sandia has many systems that could benefit from real-time monitoring at the system and component level.
Systems and components designed at Sandia are designed to function in an array of environments during their lifetime. Lifetimes range from a few days to tens of years. Sensors are sought that can detect a broad range of the environment space. Ideally, such sensors would be small, lightweight, low power, robust, and would operate both passively and actively. In the passive state the device would have minimal influence on the environment. However, in the active state the device would respond to the environment, such as, cooling device if it gets too hot or warming the device if it gets too cold.

Problem Definition:

The designed device must sense the environments within the specified ranges, listed in the table below. All sensors should be integrated using a Raspberry Pi Data Acquisition and Controller Pi-Plate card or something with similar capabilities. The sensors can be powered wirelessly or wired. The device must function without supplemental power up to four days. Fit within the mechanical envelope of a ¼ pie piece, with a 14.7 inch diameter and 6.5 inches tall. Table 1. Required sensing environments.

Environments	Operating Range
Vibration	20 to 5000 Hz
Light Irradiation	0 – 1000 W/m^2
Relative Humidity	5 – 90% RH
Liner Acceleration	0-10G
Orientation	Orthogonal coordinate frame
Proximity	0.028 m^2
Air Composition	O, H, CO_2, CO, N
Shock	0 – 10G

Stretch requirements:

• Actively respond to 1 to 3 of these environments (such as, cool device if it get hot, warmer the device if it get to cold, shading a device if exposed to more 100 W-m-2)
• Sense material changes with time (aging)
• Wireless capability
• Sense pH
• Synchronous sampling and timestamping

Standards & Socio-Cultural Constraints:

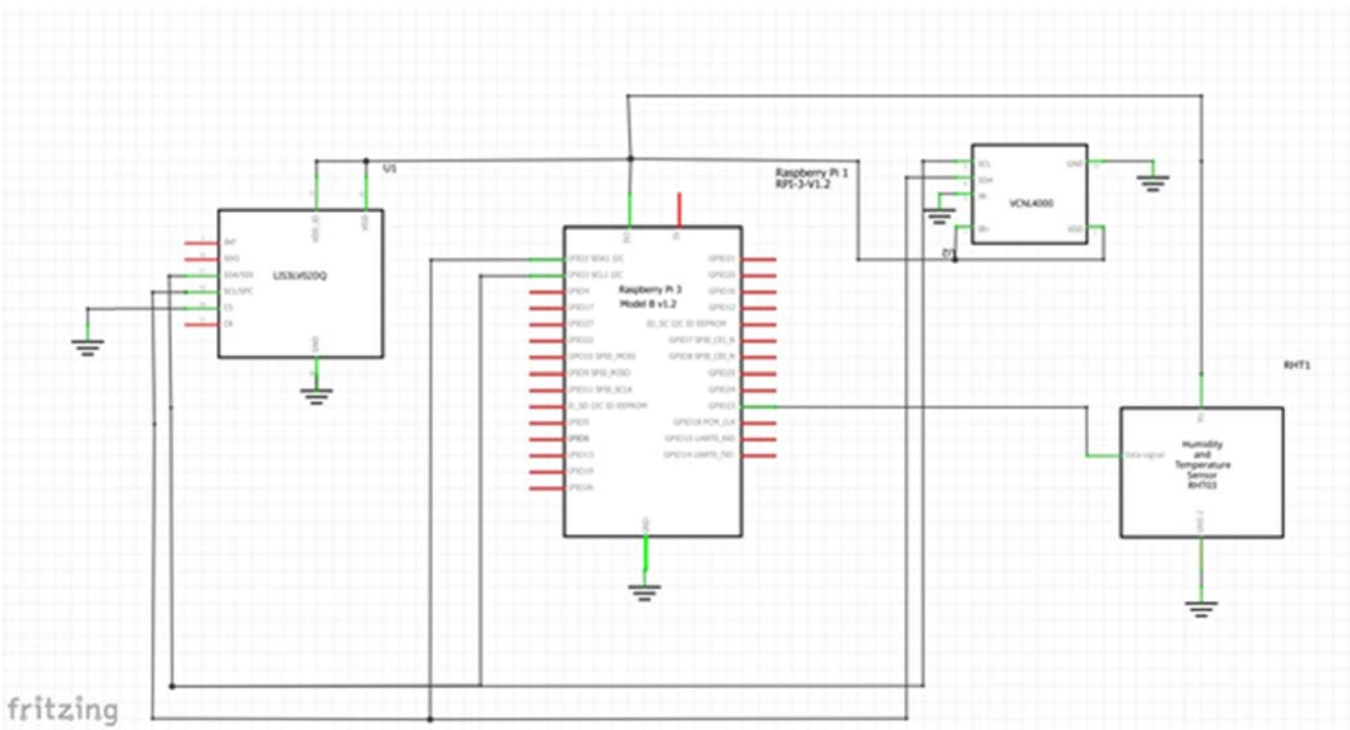
Even though this device will not be made for commercial use, it still needs to adhere to certain standards in order to ensure safety for the operator, the public and the proper functionality of its surrounding devices. These standards include:

1. CISPR 22
2. CISPR 24
3. FCC part 15
4. IEC 610000-4-2

Section 1: Individual Solution Designs

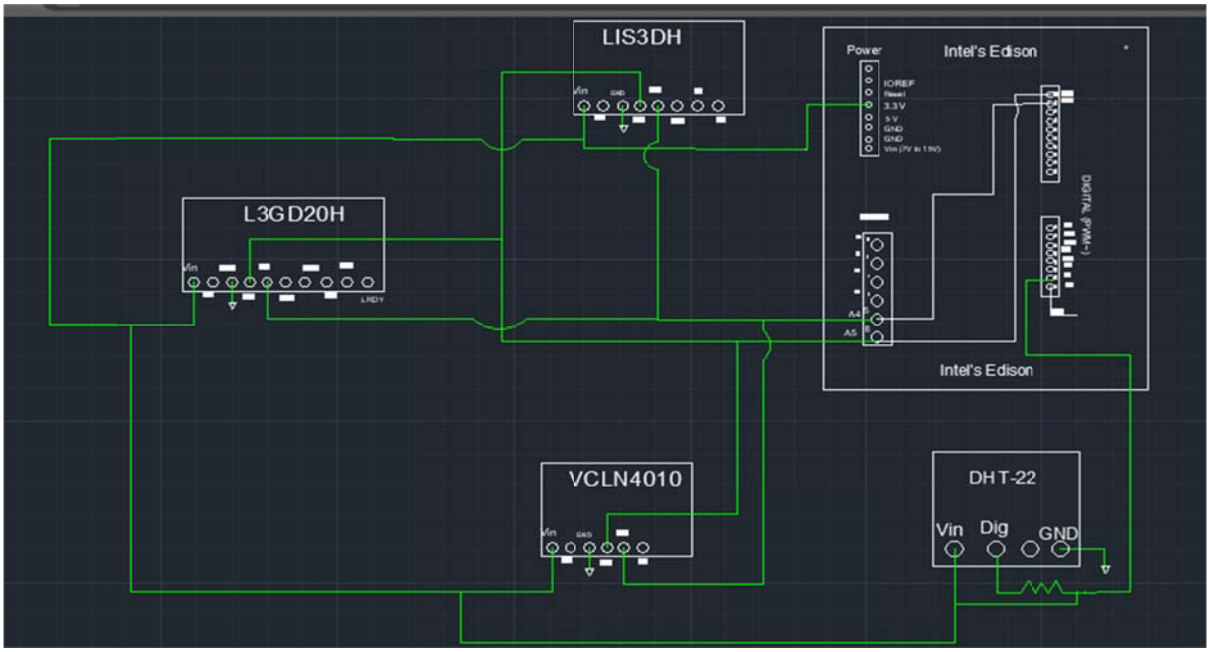
Schematic Designs:

Figure A: Hakeem Thomas Schematic Design



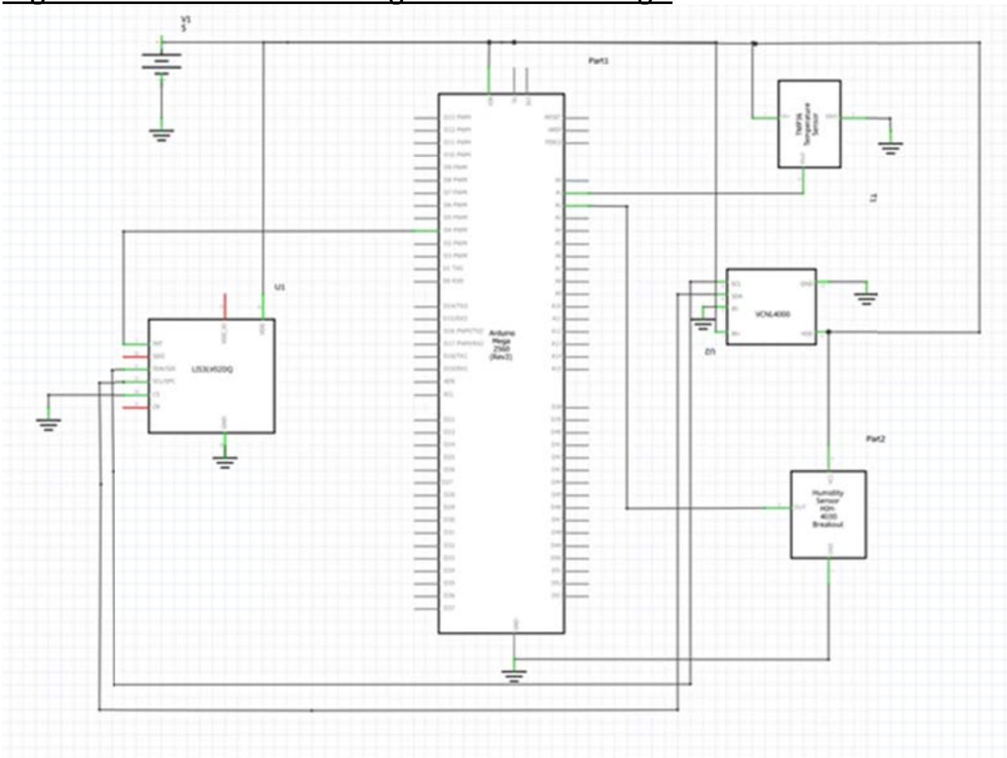
This design uses the Raspberry Pi 3 microcontroller. The entire circuit is powered by the 5V input port of the raspberry pi 3. All environmental variables are sensed by 3 sensors to minimize power consumption. The raspberry pi 3 comes equipped with wireless capabilities to transfer data to a data station wirelessly.

Figure B: Nadine-Marie Bell Schematic Design



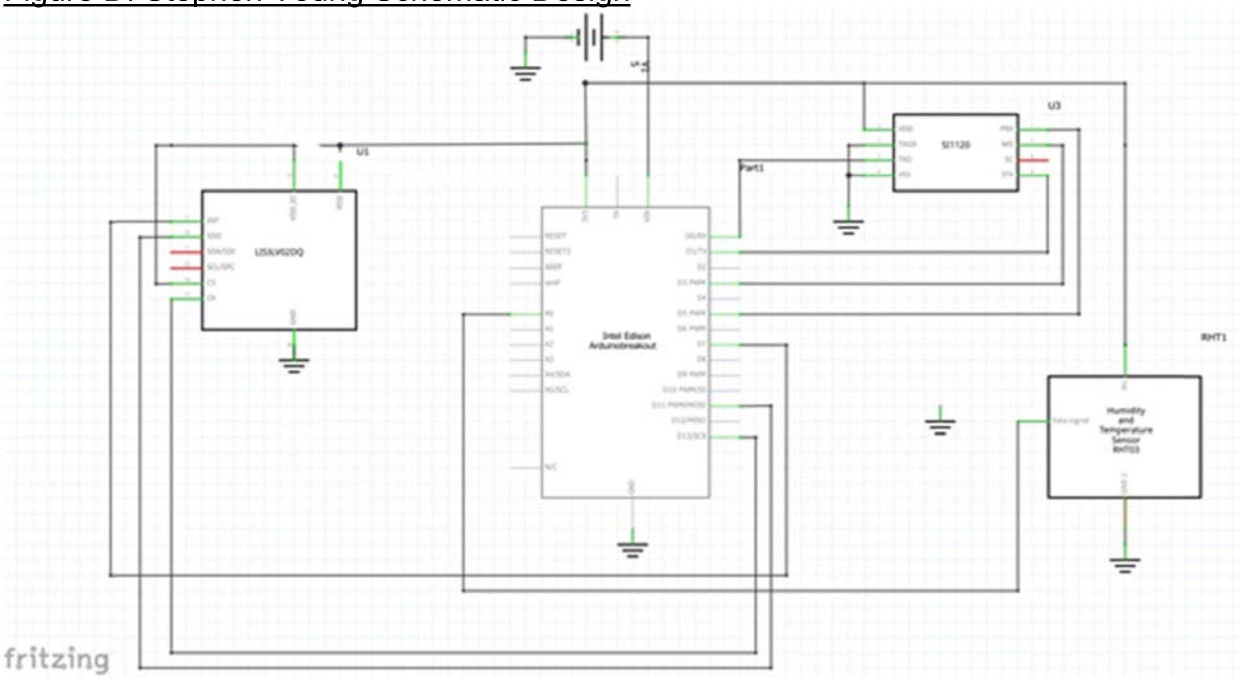
Sensor LIS3DH covers vibration, linear acceleration, and shock. The L3GD20H covers orientation. Sensor VCLN4010 is for light irradiation and proximity. DHT-22 covers temperature and relative humidity.

Figure C: Michelle Chastang Schematic Design



This design uses the Arduino Mega 2560 to power the sensors for this design. The microcontroller is powered by the external power source. The analog pin A1, is used to connect the analog pin on the TMP36 temperature sensor. The I2C Bus is shared for all components that require I2C connection. Therefore, the LIS3DH SDA and SCL pins are shared with the VCLN4000, the proximity and light irradiation sensor. The Humidity sensor is connected to the A2 pin on the microcontroller. This design is powered by a 5v battery source.

Figure D: Stephen Young Schematic Design

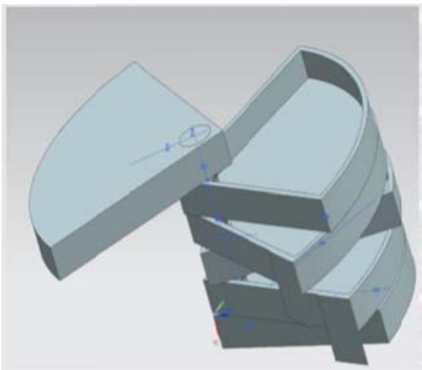


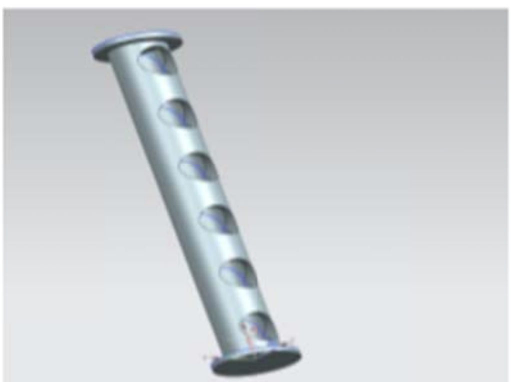
The Intel Edison reads values from the outlying sensors including sensors RHT03, SI1120, and LIS3LV02DQ. This design is powered by a battery source and the 7V power jack on the Intel Edison board, it has the flexibility to choose between the two sources. The sensors in this design are configured in a way that the can send interrupt signals to the microcontroller so that it can respond to the environment passively.

Casing Designs:

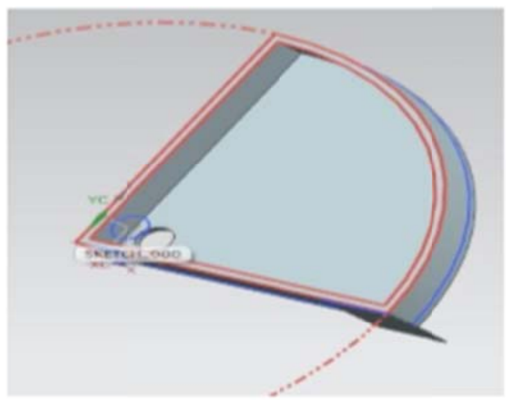
Four designs were generated for the mechanical envelope which would be the physical structure that will be the housing of the integrated sensor. With expertise from the mechanical engineering students, these designs were created.

Figure E:





- Hinge Wire Recess; for allowance of electronic component integration



Pie piece section of assembly

Figure F:

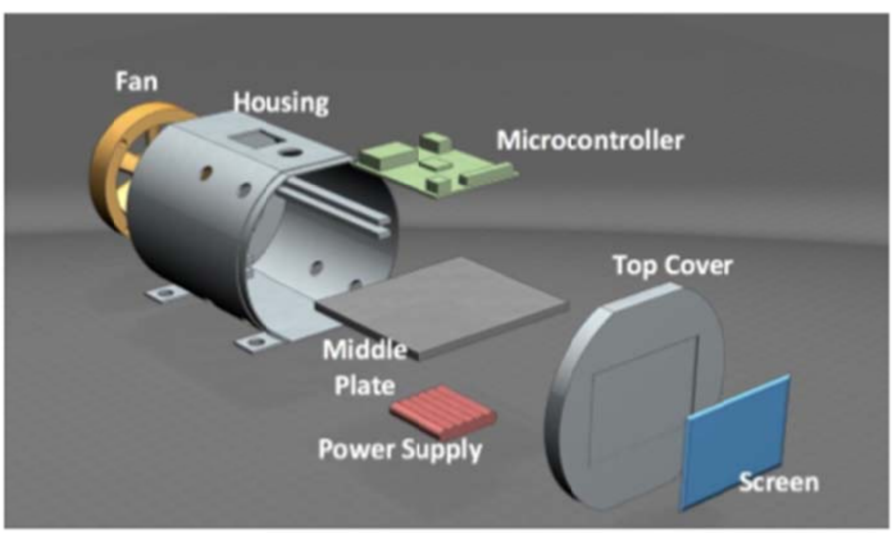


Figure G:

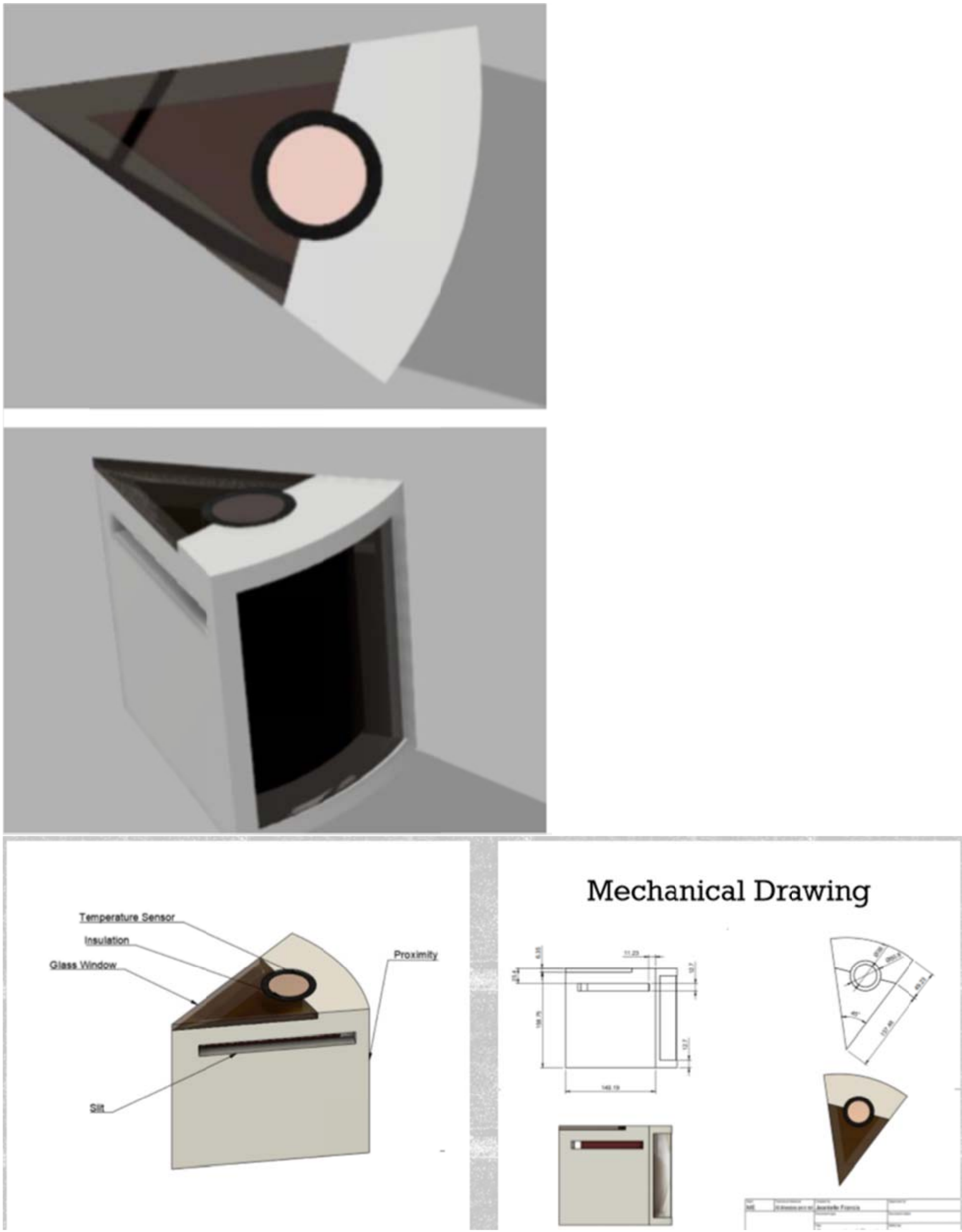

Temperature Sensor
Insulation
Glass Window
Proximity
Slit
Mechanical Drawing

Figure H:

Section 2: Description of Top 2 designs with Pros & Cons

Electrical Designs:

The following table shows the deliverables in each design. The top 2 designs that will help us meet the most requirements are chosen based on this information. High consideration is placed on size, power consumption, and compatibility with the mechanical designs and sensors used.

	Figure A	**Figure B**	**Figure C**	**Figure D**
Microcontroller Used	Raspberry Pi 3 microcontroller	Intel Edison	Arduino Mega 2560	Intel Edison
Power Required	2.5 watts	.32 watts.	External supply between 6 to 20 volts	.32 watts.
Dimension	85.60 mm × 53.98 mm × 17 mm	35.5 x 25 x 3.9 mm	53.3 mm (w)x 101.52 mm(l)	35.5 x 25 x 3.9 mm
Sensors required	3 sensors	4 sensors	4 sensors	3 sensors
Analog Input Pins	8 analog inputs	6 analog inputs	16 analog inputs	6 analog inputs

From this table we concluded that our top two designs were Figure C and D because Figure C uses an Arduino which contains 16 analog inputs, and figure D which uses the least power and is easy to program.

Figure C	**Figure D**
This design uses the Arduino Mega 2560 to power the sensors for this design. The microcontroller is powered by the external power source. The analog pin A1, is used to connect the analog pin on the TMP36 temperature sensor. The I2C Bus is shared for all components that require I2C connection. Therefore, the LIS3DH SDA and SCL pins are shared with the VCLN4000, the proximity and light irradiation sensor. The Humidity sensor is connected to the A2 pin on the microcontroller. This design is powered by	The Intel Edison reads values from the outlying sensors including sensors RHT03, SI1120, and LIS3LV02DQ. This design is powered by a battery source and the 7V power jack on the Intel Edison board, it has the flexibility to choose between the two sources. The sensors in this design are configured in a way that the can send interrupt signals to the microcontroller so that it can respond to the environment passively.

a 5v battery source.	
Pros •Less power consumption •Contains 4 different sensors to sense environments which can increase accuracy	**Pros** • Uses Intel Edison which is our desired microcontroller •Power source contained within schematic •Generate interrupts • Uses a battery • on board card read/write • Contains 3 different sensors to sense environments which can decrease power consumption • Wireless compatibility built in
Cons • Uses Arduino • Cannot use a battery •Low Memory; External storage model is needed •Cannot generate interrupts	**Cons** •More power consumption

Mechanical Designs:

Figure F	Figure E
▪ This build uses the entirety of the volumetric footprint prescribed by the requirements, as well as maximizes on space via the use of shelving. ▪ Only two sections of the pie piece may be additively manufactured due to their material. ▪ Design encompasses all sensors by having each in its own section specifically tailored toward its function. ▪ Light Irradiation: top shelf made of acrylic ▪ Vibration, shock, orientation & linear acceleration: closed aluminum box ▪ Temperature, Relative Humidity Air Comp: perforated pie piece to allow for air travel ▪ Due to lightweight, aluminum structure, design is robust enough to withstand 10G's of acceleration. ▪ Temperature strain is also negligible	• The design has an outer diameter of 6 inches and height of 6.5 inches, which fits with in the specified dimension. • The housing will be made from Sheet Metal. The capability to work with sheet metal is believed to be possessed by the university's labs and machine shops • The device has a unique shape that could potentially incorporate all the sensors in a smaller volumetric footprint • The design has cutouts and placeholders for various sensors • Due to the absence of extremely sharp corners, the device will have lesser regions of stress concentrations, thus increasing the robustness
Pros ▪ Easy access for viewing/altering/replacing mechanical and electrical components. ▪ Components can be assembled in an orderly fashion.	**Pros** ▪ Contains fan which will keep Intel Edison cool. ▪ Centralized microcontroller which requires less wiring. ▪ Maximizes space for occupying electrical components. ▪Comfortably fits Intel Edison
Cons ▪ Requires awkward layout of PCB and lots of wiring. ▪ Locking mechanism may not be fully secure. ▪The design have several moving parts which would need lubrication, which may affect sensor readings.	**Cons** ▪ Fan requires extra power ▪ Sizing limits space even further from pie shaped to cylinder

Section 3: Decision Matrix for Top Design Selection

Microcontroller Selection Process:

Originally, it was suggested that a Raspberry Pi be used for this project. However, it the **Intel Edison** proved more beneficial in meeting requirement/stretch requirements. Benefits of the Intel Edison specific to this project include:

- **Less power consumption** Edison uses 3.3V - 4.5V @ <1W, while Raspberry Pi uses 5V * 600mA (~3W).
- **Smaller dimensions** Edison is 60mm x 29mm x 8mm; Raspberry Pi is 85mm x 56mm x 19.5mm.
- **Bluetooth capability** Edison has Bluetooth 2.1/4.0; Raspberry Pi has none.
- **Wifi capability** Edison has Dual-band 802.11 (a/b/g/n); Raspberry Pi has none.
- **RAM Storage Capacity** Edison stores 1GB of data; Raspberry Pi stores 512 MB
- **GPIO** Edison has 70 pins on 0.4mm mezzanine header; Raspberry Pi has 27 pins on 0.1" headers.

Sensor List:

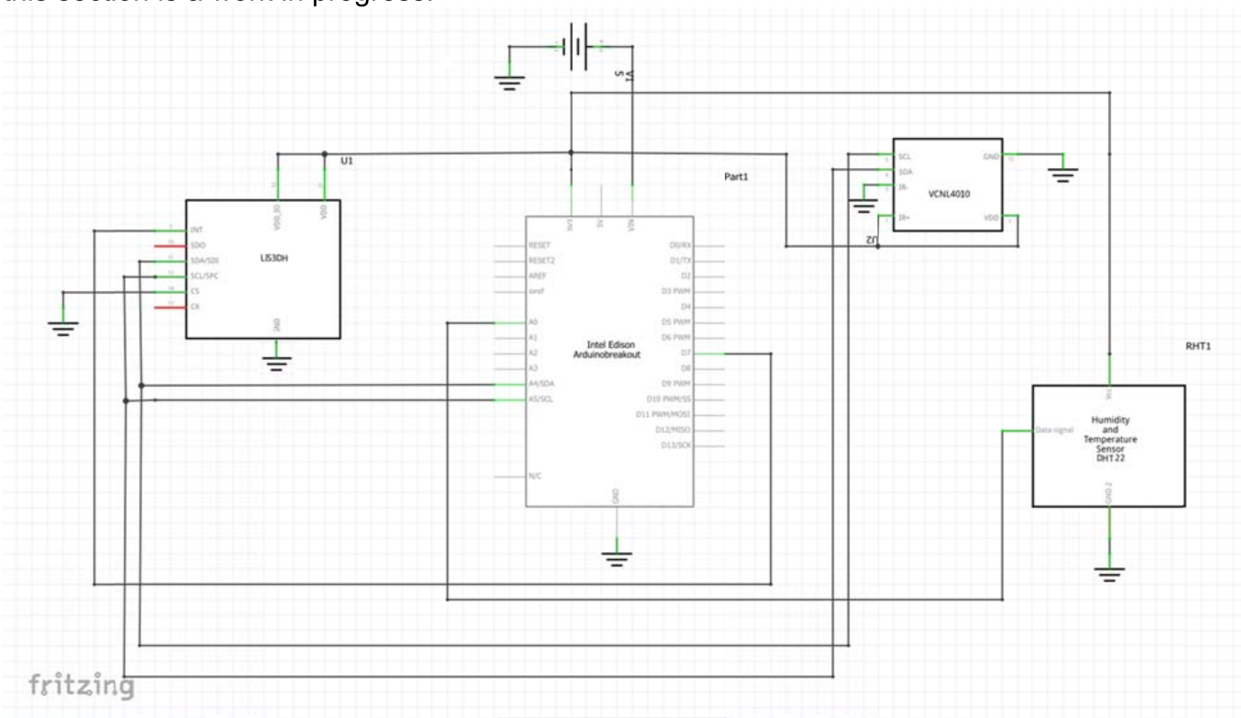
Environment	**Sensor Name**	**Range**	**Operating Temp (℃)**	**Cost($)**	**Supply Voltage (V)**	**Compatibility**
Vibration	LIS3DH Triple-Axis Accelerometer	1Hz-5kHz	-40°C to 85°C	4.95	1.7-3.6	Intel Edison
Light Irradiation	VCNL4010	1mm-200mm	-25°C to 85°C	7.50	2.5-3.6	Intel Edison
Temperature	DHT22	-40°C to 80°C	-40°C to 80°C	7.20	3.3-6	Intel Edison
Relative Humidity	DHT22	0%-100% RH	-40°C to 80°C	7.20	3.3-6	Intel Edison
Linear Acceleration	LIS3DH Triple-Axis Accelerometer	0G-16G	-40°C to 85°C	4.95	1.7-3.6	Intel Edison
Orientation	LIS3DH Triple-Axis Accelerometer	6D/4D Orientation Detection	-40°C to 85°C	4.95	1.7-3.6	Intel Edison
Proximity	VCNL4010	1mm-200mm	-25°C to 85°C	7.50	2.5-3.6	Intel Edison
Air Composition*	-	-	-	-	-	-
Shock	LIS3DH Triple-Axis Accelerometer	0G-16G	-40°C to 85°C	4.95	1.7-3.6	Intel Edison

Schematic Design:

After careful consideration of parameters such as: time, cost, compatibility, etc. the following schematic diagram encompass the overall structure of the electrical layout of the integrated sensor. The schematic diagram was straight forward, as the schematics for all sensors and the microcontroller being used were readily available and since there was little room for variability, only one schematic diagram was constructed.

Figure: Overall Schematic Diagram

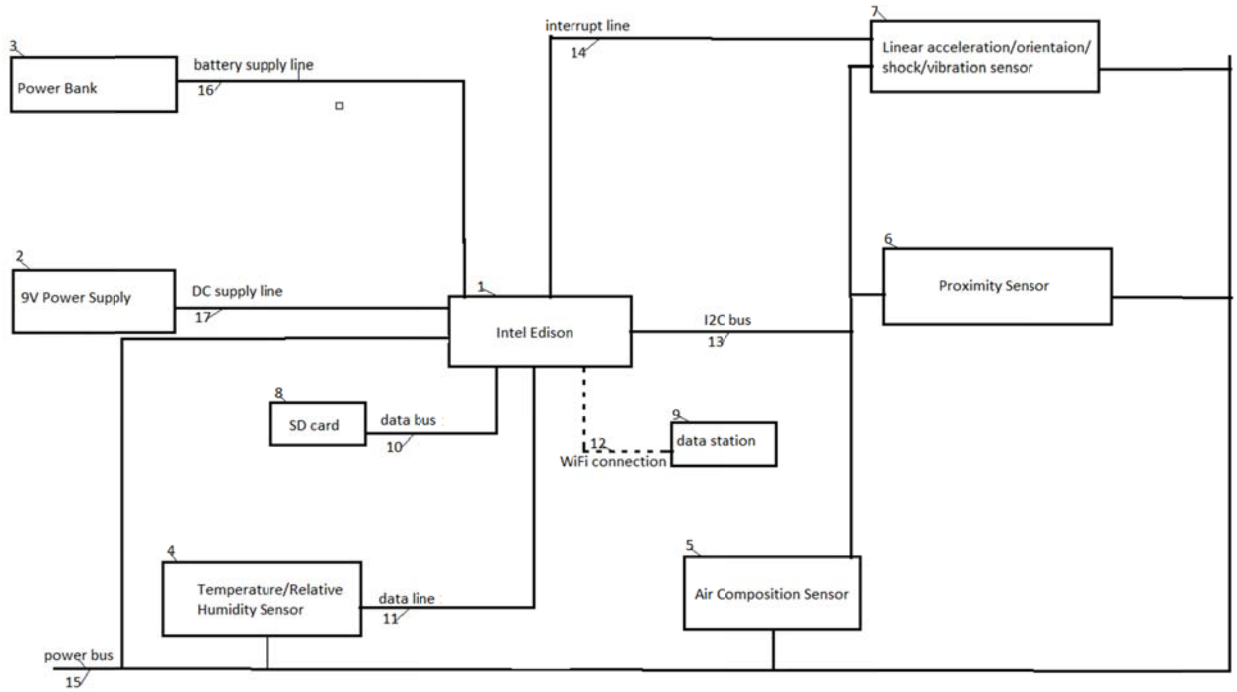
*The air composition sensor will be a module of multiple air composition sensors according to the requirements (see Environment Requirement table). A lot of the sensors are not analog, so this section is a work in progress.



DESIGN MATRIX FOR THE HOUSING

Topic (Weight)	Unacceptable (1)	Mediocre (2)	Marginal (3)	Acceptable (4)	Exceptional (5)	Poin
Volumetric Footprint	Entire Mechanical envelope not used, and all electrical components cannot be housed	At least 50% of the Mechanical envelope used and all electrical components can be housed	At least 75% of the Mechanical envelope used and all electrical components can be housed	Maximum use of the mechanical envelope but inner volume is not maximized	Maximum use of the mechanical envelope with ample inner volume for the electrical components	
Usage of Additively Manufactured Components	No components of the design can be constructed using additive manufacturing	Four (4) or more components cannot be constructed using additive manufacturing	Two (2) or three (3) components cannot be constructed using additive manufacturing	One (1) component cannot be constructed using additive manufacturing	Entire Design can be constructed using additive manufacturing	
Novelty	Design is not creative nor unique. Little or no grasp of problem. Incapable of producing a successful solution.	Device is either creative or unique. Some understanding of problem. Major deficiencies that will impact the quality of solution.	Device is either creative or unique. Overall sound understanding of the problem and constraints. No deficiencies that will significantly impair solution.	Design is either creative or unique. Clear and complete understanding of design goal and constraints.	Design is creative and unique. Clear and complete understanding of design goal and constraints.	
Sensor Integration	The design is incapable of sensing at least four (4) environments	The design facilitates the sensing of four (4) environments	The design facilitates the sensing of at least five (5) environments	The design facilitates the sensing of seven (7) or eight (8) environments	The design facilitates the sensing of all nine (9) environments	
Robustness	Design cannot withstand body forces. Material is porous and cannot	Design can withstand a body force of 9G or less Material is porous and can withstand 70°C	Design can withstand a body force of 10 G Materials is porous and can withstand 70°C	Design can withstand a body force of over 10 G. Materials are not porous can withstand 70°C	Design can withstand a body force of more than 10 G. Materials are not porous and can	

Section 4: Solution Design Description for the Top Design



Mechanical Design Used: Figure E

At the core of our design is the Intel Edison at component **1**. The Intel Edison (**1**) is connected to a power bank at component **3**, a 9V power supply at component **2**, and various sensors including a Temperature/Relative Humidity Sensor (**4**), linear acceleration/orientation/shock/vibration sensor (**7**), proximity sensor (**6**), and air composition sensor (**5**). All busses and data lines (**14, 13, 11**) coming from these sensors and the power supply lines (**16,17**) are read as input values into the Intel Edison (**1**). All of the sensors (**4,5,6,7**), are connected to a power bus **(15)** which takes power from the Intel Edison(**1**). The data collected from the Intel Edison(**1**) can be stored in an SD Card (**8**) through data bus **10**. The Intel Edison is also wirelessly connected to the data station through WIFI(**12**) at component **9**, which allows us to wirelessly store our data.

Conclusion:

In order to build our real-time sensing device to meet the requirements specified by Sandia National Labs, we will be using an Intel Edison microcontroller at the heart of the device due to its low power consumption, ease of programming and its wireless capabilities. We will also be using an array of 4 sensors in order to test 9 different environmental variables and we will be storing this information on a SD card on our microcontroller. Our design will also facilitate wireless transfer of data and power bank to meet requirements. We are still identifying some sensors and decisions will be made at a later date, we may need to mount ADCs in order to accommodate these new sensors.

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