House Health Monitoring Proposal

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I. Introduction

Houses face many types of issues like gas leaks, fires, floods, and mold, which cause damage to the house leading to a decrease in value [1]–[3]. Unlike a smartphone or a modern car, current house constructions lack a mechanism to detect and monitor this information. This information, such as knowing if water damage has occurred, can improve the value of the house by proving that issues have not occurred or were taken care of quickly by the homeowner. Although there are several devices available to detect specific problems, none of this technology is integrated as a single system in houses today.

In order to detect and monitor all of these problems, this project proposes a collection of sensors and a head unit, called Preserve Home Pro. The goal of the system is to measure, record, and display important active and historical data, giving a homeowner valuable information to help maintain and protect the value of their home. The Preserve Home Pro will be designed as a semi-permanent system that will last up to thirty years. The system will also communicate information through a closed network without requiring internet. Combining these concepts, this project proposes an advanced solution to house health monitoring.

II. Formulating the Problem

A current market for this type of system does not exist. Since many homes face issues with gas leaks, fires, floods, and mold, actively detecting these issues could be beneficial in preserving a homes value [1]–[3]. The Preserve Home Pro will be designed as a semi-permanent system with multiple sensor modules that would detect and log these threats to a house.

A. Background Information

1) Fire Module: The three most common causes of house fires are cooking, heating equipment, and electrical fires [4]. The current temperature sensors available in the market are designed to regulate and display the temperature within your house. This may be useful for individuals who wish to manage or monitor the temperature of a specific room, but it is not suitable for detecting fires and increasing the worth of your property. According to an article on NCERT Point, drywall starts to burn at around 176 degrees Fahrenheit [5]. Adding a temperature sensor, that could detect a minimum of 176 degrees Fahrenheit, to various walls in a home would allow the Preserve Home Pro to track if there has ever been a room in the house that has ever caught fire and how hot the fire got. The system would then log the temperature level of the fire and the room that the fire occurred in the home. If the fire sensor was to be damaged from the fire, then there would be a clear indication that their was a fire in the house. Having this information logged in a system could be beneficial to homeowner to prove if there has ever been a fire in their home, potentially raising the value of it.

2) Water Module: From 2001 to 2018, there was an average of 67,915 flood insurance claims per year according to data from the Insurance Information Institute [6]. Even levels of 1 inch of water can cause thousands of dollars of damage to the home [7]. Adding flood sensors at various locations and heights on the wall would allow the Preserve Home Pro to track if there is water actively sitting in the home and how high the water level is. The system would then log the water level height and how long the water was in the home. There are existing “smart”, water detection systems on the home automation and monitoring market that alert if water is detected. These are great for detecting small leaks around a home, but they cannot give an accurate view of the depth of water in the home. Being able to show if a house had flood damage could increase the value of the home and give the buyer peace of mind.

3) Gas Module: Extending the issues that need to be addressed are the preventative measures that detect the home’s integrity against the dangers of gases and smoke. The gases that are commonly found in homes can lead to hazardous conditions for the homeowner. According to Redfin, ”58 percent of homes across the country use natural gas to heat their homes, amounting to 42 percent of total residential energy consumption” [8]. Some gases that are likely to be found in a house are methane, hydrogen sulfide, and carbon oxides [9]. These gases can leak from blocked air vents, cracked pipes, dry plumbing, clogged drains, and loose toilets [9]. Along with gases, the smoke from a fire can cause damage to houses and the well-being of the homeowner. ”There are more than 1 million house fires in the United States each year and more than 3,000 people will die each year as a result of fires” [10]. The sensor will detect gases and smoke allowing the homeowner to find gas leaks and prevent extreme fire damage.

4) Mold Module: Approximately seventy percent of homes have some level of mold growth. While some mold might be harmless, others can be very dangerous if exposure occurs [11]. Mold will grow in places with high moisture levels, such as roof leaks, windows, or pipes. Mold particularly grows well on wood, ceiling tiles, cardboard, and paper products [12]. Molds gradually destroy the things they grow on. You can prevent damage to your home and furnishings, save money, and avoid potential health problems by controlling moisture and eliminating mold growth [13]. Exposure to damp and moldy environments can pose many different health risks to the people and environment [12]. The objective of implementing humidity and temperature sensors into the Preserve Home Pro is to potentially prevent and alert homeowners of possible mold growth and high moisture levels.

5) Wireless Connectivity: In order for each of Preserve Home Pro's sensors to work, each sensor needs to be able to communicate with the head unit. For digital communication, there are a handful of ways that the sensors and the head unit are able to communicate with each other. The two main types of digital communication are wired and wireless connections. Wired communication for computers includes coaxial, ethernet, fiber-optic, and twisted pair to name a few. Coaxial cables are thick, multi-wire cables that are used in high bandwidth and high connectivity use cases. Ethernet cable is an unshielded, copper-based, twisted-pair cable that's typically used for networking. Fiber-optic cable is a group of plastic or glass fibers in a plastic casing that transmits information using light. Twisted pair cable is a shielded, copper based cable that is typically used in older local area networks[1]. Unfortunately, one downside of wired connections is the physical connection of the wire cannot be broken for continual communication. This also means wires need to be routed between each module and the head unit. In order to accommodate more flexibility of installation locations a different means of communication is needed.

Wireless communication allows for computer communication to occur without having a physical cable attached [2]. Most people interact with several types of wireless communication like wifi, cellular networks, and bluetooth on a daily basis. Since wireless communication allows for more flexible deployment and usage of networks, this allows the Preserve Home Pro system to be easily deployed in a newly constructed house. Wireless communication also allows for more potential locations for the install of Preserve Home Pro's sensor modules, which also allows for more potential sensor modules to be installed within a house. The installation of more modules gives the homeowner more opportunities of sensing potential problem areas in the house that a wired connection may not allow for.

6) Power System: For powering the system, wall power from a house can be used as the main power. Using wall power from a house allows for each module to stay powered as long as an outage does not occur. To account for power outages, a backup battery system could be used to ensure the system continues to function. An article from Scientific American States, "Between 2013 and 2021, the average duration of a power outage in the U.S. grew from approximately 3.5 hours to more than seven hours, according to EIA data. The frequency of outages increased from 1.2 to 1.42 events per customer per year" [16]. The longest anywhere in the U.S. has gone without power is two weeks [17]. Since all of the problems the system detects can still occur during a power outage, a backup battery would ensure the credibility of the system in preserving the home value.

B. Stakeholders

This project has internal and external stakeholders. The internal stakeholders will have access to the GitHub repository and the progress of the team as necessary. There are also meetings with the project supervisor to help with the process of the project. The ECE department is another internal stakeholder since they are providing the funding. All requests for funding will be signed off by the project supervisor.

- **Internal Stakeholders**
  - Project Team
  - Project Supervisor (Jesse Roberts)
  - ECE Department (Funding)

The external stakeholders have been interviewed for specifications. They also have access to the progress of the project as necessary. Homeowners are a stakeholder in this project because this system was designed to prove that the issues listed above have not occurred, potentially raising the value of their home. Home inspection companies are a stakeholder because this system would be able to help them with their jobs by making it easier to see some active data about a house. Insurance companies are a stakeholder because the Preserve Home Pro provides the information that insurance companies are interested in for insurance purposes like damages to the house that would cause an insurance claim. Damages such as water, mold, fire, and gas leaks are large causes of insurance company expenses, and fixing the problems early saves them money.

- **External Stakeholders**
  - Home Owners
  - House Inspection Companies
  - Insurance Companies

C. Specifications & Constraints

The following are specifications and constraints given by the stakeholders of the project:

1) The Head unit shall know what sensor is sending data to it, the sensor's location, and be able to differentiate from other sensors. This originated from the team supervisor.
2) The Head unit shall be able to display and log active and historical data from sensors. This originated from the project team and team supervisor.
3) Head unit shall be able to detect if the fire module temperature is at 176 degrees Fahrenheit or higher and display a warning [5]. This originated from the project team based on the fact of the drywall ignition level.

4) The Head unit shall be able to receive data from the water module to display a warning if water is present and the total water depth. This originated from the project team.
5) Head unit shall receive data from the gas module and follow OSHA standards for ammonia, propane, and carbon oxides (50 ppm, 1000 ppm, and 50 ppm respectively over an eight-hour window) [18]. This originated from the OSHA standards for the project.
6) Head unit shall be able to interpret, from the received data, that mold could form if the humidity levels exceed 50% and temperatures range between 55 degrees and 85 degrees Fahrenheit for a minimum of two days [19]. This originated from the project team based on the conditions in which mold can grow.
7) Head unit shall be able to receive the sensor name, number, data type, and raw data. This originated from the team supervisor.
8) Shall be a semi-permanent system that will last for up to thirty years. This originated from the team supervisor.
9) Shall have a backup power system that will allow the system to function in case of a primary power outage for up to two continuous weeks. This originated from both a standard and the team supervisor.
10) Shall fully function without having to regularly change batteries in sensors or head unit. This originated from all external stakeholders and the team supervisor.
11) Sensor modules shall not be placed in a way where they cannot wirelessly communicate with the system. This originated from the project team and broader implications.
12) Modules shall not be a distraction for a homeowner, and not be directly visible. This originated from all external stakeholders and the team supervisor.
13) The Water module shall be able to detect multiple water levels and determine if water is present. This originated from the project team.
14) The Mold module shall be able to detect the current temperatures and humidity levels in an area and send it to the head unit. This originated from the project team.
15) The Gas module shall be able to detect ammonia, propane, and carbon oxide. This originated from the project team and the insurance companies.
16) The Fire module shall be able to detect the temperature of the sensor and send the data to the head unit. This originated from the project team.
17) System shall not require an internet connection to work and communicate with the head unit and sensors. This originated from homeowners, insurance agencies, and the team supervisor.
18) Sensor communication shall send the sensor name, number, data type, and raw data to the head unit. This originated from the project team.
19) System shall not collect additional data that is not required for sensor functionality. This originated from all internal and external stakeholders and from broader implications.
20) System shall follow all IEEE Code of Ethics and common standards. This originated from the IEEE Code of Ethics.

D. Standards

Listed below are the potential standards and regulations that are to be followed for completing the project:

IEEE Code of Ethics - This standard is a set of guidelines on how each team member will conduct themselves and hold the team accountable for the betterment of one another, the team, and the safety of the public [21].

UL 2075, 1.1 – 2021, Gas and Vapor Detectors and Sensors - This standard applies to detectors and sensors of toxic and combustible gases and vapors that can be fixed, portable, or transportable. They are designed according to the National Electrical Code, NFPA 70. The detectors consist of electrical components and sensing mechanisms to detect gases or vapors and include a connection to a power source and signaling circuits [22].

47 CFR 15.212 - Single modular transmitters consist of a completely self-contained radio frequency transmitter device that is typically incorporated into another product, host or device. Split modular transmitters consist of two components: a radio front end with antenna (or radio devices) and a transmitter control element (or specific hardware on which the software that controls the radio operation resides). All single or split modular transmitters are approved with an antenna. All of the following requirements apply, except as provided in paragraph (b) of this section [23].

IEEE 802, 2020 – Networking standards - a collection of networking standards that cover the physical and data link layer specifications for technologies such as Ethernet and wireless [24].

NFPA 715, 4.1 -2023, Fundamentals of Fuel Gas Detection Systems – This standard will demonstrate adherence to fundamental requirements for fuel gas detection systems in chapter four of NPFA 715 [25].

IRC R314.1, 2018 - Building Planning for Smoke Alarms – This standard will be implemented to comply with NFPA 72 and section R314. It covers placement, installation, interconnection, combination alarms, and power sources [26].

IRC R315.1, 2018 - Building Planning for Carbon Monoxide Alarms – This standard will be implemented for adherence to this section. It covers new construction homes, repairs, placement, combination alarms, interconnection, and power sources [27].

NFPA 70 (NEC), 2023 – Electrical standards – This standard will be a benchmark for safe electrical design, installation, and inspection in order to protect people and property from electrical hazards [28].

E. Survey of Potential Solutions

The overall build of this system will consist of a head unit module and multiple sensor modules. The head unit module will consist of a screen that will log and display information given by the sensor modules. The head unit will process the input from the sensor modules and output it to the screen in a way that is easy for the user to understand. Each sensor module will consist of the sensor itself and have wireless transmission capabilities. Wireless transmission will allow the sensor modules to be placed in ideal areas of the house relative to what the sensor does. The head unit module and each of the sensor modules will be powered by the home's electrical wires with a backup battery in the case of a power outage.

Temperature sensors are electronic devices that can sense the temperature of their surroundings and convert this information into electrical data for monitoring, recording, or signaling temperature changes [29]. There are various types of temperature sensors with different purposes. A contact temperature sensor makes direct contact with an object to measure its temperature, while a non-contact temperature sensor usually uses infrared sensors to measure temperature [29]. There could be applications where both of these sensors would work for the incorporation of a temperature sensor into a home, but to ensure that the sensors are not visible a contact temperature sensor placed in or behind the drywall would work better. Figure one illustrates the difference between a contact temperature sensor and a non-contact temperature sensor.

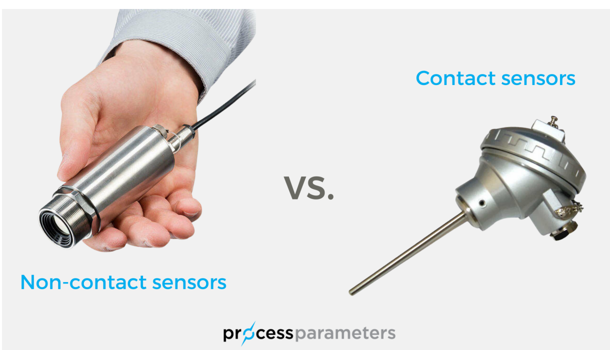

Fig. 1. Non-Contact vs. Contact Temperature Sensor [31]

Water level indicators are commonly available in the market, including resistive, capacitive, ultrasonic, and float sensors [32]. Resistive and capacitive sensors detect changes in conductivity and dielectric constant respectively, and provide output as voltage [33]. Ultrasonic sensors emit high-frequency pulses that reflect off the water surface and return to the sensor. These sensors are costly and require mounting above water [34]. Float switches have a mechanical switch that opens or closes an electrical circuit. The float rises with the water level and activates the circuit when it reaches a set height [35]. For this project, a resistive or capacitive sensor would be ideal as it can accurately track the water level.

Gas leak detection systems utilize a combination of sensors and control equipment. The sensors detect gas presence in the air, while the control equipment processes the sensor data and triggers an alarm or response in case of a gas leak [10]. There are various types of sensors available for detecting gas leaks, such as electrochemical, infrared, catalytic bead, and metal oxide semiconductor sensors. Electrochemical sensors are highly sensitive and detect toxic gases like Carbon Monoxide. They work by sensing electrodes in the air and sending an electric current to sound the alarm. Infrared technology uses transmitters and receivers to accurately measure gas levels in the air and sound an alarm when high concentrations are present. Catalytic bead sensors utilize a platinum-treated wire coil and identify combustible gas in the air by oxidizing the coil upon contact with the gas, tripping an alarm. Metal oxide semiconductor sensors detect gas based on a change in electrical resistance [36], [37]. Among all gas sensing materials, MOS sensors perform better due to their unique structures, physical, and chemical properties. MOS-based gas sensors can detect gases even in ppt range, whereas other sensors can only perform in ppb or ppm ranges [38]. Choosing the correct sensor is crucial for the system and the house's health. Figure two shows the comparison of gas detection ranges among different sensors.

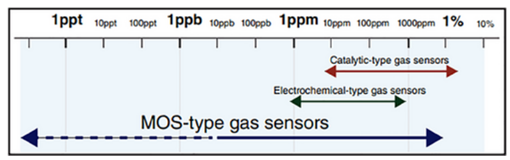

Fig. 2. Sensing range comparison of catalytic-type, electrochemical-type, and MOS-type gas sensors [38]

To measure the percentage of relative humidity levels in the air, humidity sensors are used. There are several types of humidity sensors available in the market, but most of them are not designed to preserve a home's integrity. Capacitive sensors are commonly used, and they work by measuring the humidity levels using a thin strip of metal oxide between two electrodes. The capacitance of the oxide changes with the relative humidity in the atmosphere. Resistive and thermal sensors are also used to measure humidity levels [39]. Mold tends to grow when the humidity levels are between fifty to sixty percent. It is ideal to keep the humidity levels between thirty to fifty percent to prevent mold growth [12]. By incorporating these sensors into the Preserve Home Pro, homeowners can keep track of the humidity levels over time and get alerts when the levels are too high. This will help alert homeowners to take action to reduce the moisture levels in their homes, which can create a favorable environment for mold growth.

For Preserve Home Pro's sensors to function, they require communication with the head unit. Digital communication can occur through wired or wireless connections. Wired communication includes coaxial, Ethernet, fiber-optic, and twisted pair cables. Coaxial cables are thick and used for high bandwidth and connectivity needs. Ethernet cables are unshielded, copper-based, and typically used for networking. Fiber-optic cables transmit information using light through plastic or glass fibers in a casing. Twisted pair cables are shielded, copper-based, and used in older local area networks. However, wired connections have the disadvantage of requiring a physical connection that cannot be broken for continual communication [40].

Wireless communication allows for computer communication without a physical cable. Examples of wireless communication include WiFi, cellular networks, and Bluetooth. All types of wireless communication use non-visible frequency bands to transmit and receive data across different non-visible wavelengths [41]. Wireless communication enables non-direct connections, unlike wired networks, which allows the Preserve Home Pro sensors to be installed in hard-to-reach areas for long-term use.

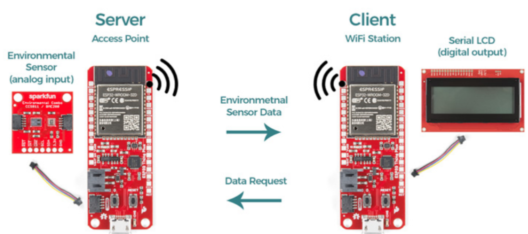

Fig. 3. Closed network wireless communication between modules [42]

There are three common kinds of rechargeable batteries: Nickel-Cadmium, Nickel-Metal Hydride, and Lithium Ion. Nickel-cadmium has a lower voltage and needs to be fully charged and discharged for optimum performance. Nickel-metal Hydride can be partially charged and discharged without drastically affecting its capacity. They are more expensive, however. Lithium-ion shares traits of both as they can have more voltage and they do not suffer as much capacity degradation [43]. The project will need a battery that has a large capacity to allow the system to operate for up to two weeks and a battery that will not degrade quickly.

F. Summary

In summary, the objective of the project is to create a system that will measure, record, and display data to a head unit. The homeowner will have access to both active and historical data through a user-friendly head unit, helping to maintain the value of their property. The project will meet all specifications and constraints provided by the stakeholders while also meeting all safety standards and regulations.

III. The Proposed Solution

A. Unknowns

When creating a system there are unknowns that will be hard to determine while in the proposal phase. One of these unknowns would be the total amount of sensors that will be used for each house. The amount of sensors that will be necessary in a home will depend on the size of the house and the layout, and it will not be possible to know this information until the system is implemented into the house. Not knowing how many sensors a house would need would also create the unknown of the final cost of implementing the system in each house. Both of these unknowns will have a solution when the team knows the information about the house that the system is being implemented in.

B. Measures of Success

The measure of success will be the ability of the system to properly measure and record data from the sensors and output it to a head unit that displays all of the data. If the system can properly display and log information allowing the user to view and browse through the data, then the head unit will work as intended.

Another measure of success will be the accuracy of the sensors in the system. The sensors can be tested by doing a number of experiments, such as putting the sensors through the specified constraints. Buying sensors with tighter specifications on what they detect will allow for increased accuracy that is intended for the system to be a success.

Another measure of success will be that the system will not be a distraction to the homeowner. The sensors will be placed in a way where they will not be visible to a homeowner, so that would remove the idea of them being a distraction. The head unit will be implemented in the homeowner's wall making the system not noticeable except for the head unit giving the user the data that the system will provide. Combining these two ideas will ensure that the system will not be a distraction for the user.

The final and most important measure of success will be the ability of all the sensor modules to work in conjunction with one another. If the system is able to differentiate the location of and data of sensors, it can give a more detailed view of what is happening inside the house.

C. Broader Implications & Responsibilities as Engineers

Due to the limited time and budget allocated to this project, there are multiple broader implications. Broader implications are the potential effects that the system could cause. Firstly, it may interfere with nearby radio frequency devices. Secondly, there is a fire risk if any backup batteries become damaged. Additionally, false positives may be triggered due to sensor wear or damage. Also, one concern from the stakeholders is unnecessary data recording and sharing. It is essential that the system will not record conversations or cause any insecurities to the user. Finally, given the installation process, it may be difficult to determine the level of effort required to do maintenance on the sensors if necessary.

It is the responsibility as an Engineer to create products that do not harm or distract humans. Homeowners often worry about their privacy when it comes to similar systems [44]. To address this concern, the design team wants to assure homeowners that only they can access information about their homes unless they authorize someone else. Homeowners also worry about spying, monitoring, and security when it comes to sensors in their homes [44]. To address these concerns, the team assures homeowners that Preserve Home Pro uses a closed local network for added security.

It is important that the design team follows the ethics and responsibilities of an engineer. These concerns were listed above in the constraints of the project.

IV. RESOURCES

A. Team Skills

In order to develop a home health monitoring system, a diverse set of skills is necessary. These include wireless power, wireless communication, low-power embedded systems, and circuit analysis and design. Each member of the team possesses expertise in multiple skills, listed below, that will be essential for the successful completion of the project.

- Jackson Woodard
  - Circuit analysis and design
  - Programming
  - Soldering
- Nate Campbell
  - C++
  - Power management
  - Arduino management
- Dylan Robbins
  - C++
  - Embedded Systems
  - Soldering
- Luke Carson
  - Power Management
  - Quality/Code Compliance
  - Analysis and Design
- Cole Cooper
  - Wireless communications
  - Computer-aided drawing design
  - Power management

B. Budget

The expected budget for the project is \$500 - \$600. The figure shown below is the full list of everything that the design team is expecting to spend on the project.

Budget

Components	Price(USD)
Wireless Transmitters	$40
Wireless Receivers	$10
Backup Battery Chargers	$75
Batteries	$100
Microcontroller	$75
Screen	$50
Sensors	$45
Printer Filament	$20
Wires	$10
Electronic Components	$20
Unknown(15%)	$67
Total	$512

Fig. 4. Proposed Budget

C. Expected Timeline

The expected timeline for the project is around one year. Figure five displays a Gantt chart that shows all of the design team's expected completion dates. The team plans to have everything built, utilized, and tested by May of 2024. Each team member will code, create, and test a module and then discuss their findings with the team for future considerations if necessary. The head unit, wireless communication, and power system modules will be completed together as a team. Considering the concepts above, it will be possible for the team to complete this project in the given time.

V. CONCLUSION

In conclusion, the team outlines the development of a closed local network, semi-permanent system aimed at monitoring and logging information from sensors to safeguard a home's health and integrity. With a particular focus on newly built homes for seamless installation, the team aims to equip homeowners with an easy-to-use interface for tracking their home's well-being. By facilitating data communication through a dedicated local network to a central head unit, the team believes this innovative home health monitoring system holds significant potential for success. The team is committed to carefully selecting sensors, ensuring network reliability and security, and delivering a user-friendly interface. With careful consideration of data storage, power management, scalability, maintenance, and regulatory compliance, the team is confident in creating a valuable and enduring solution that preserves home value and enhances peace of mind for homeowners.

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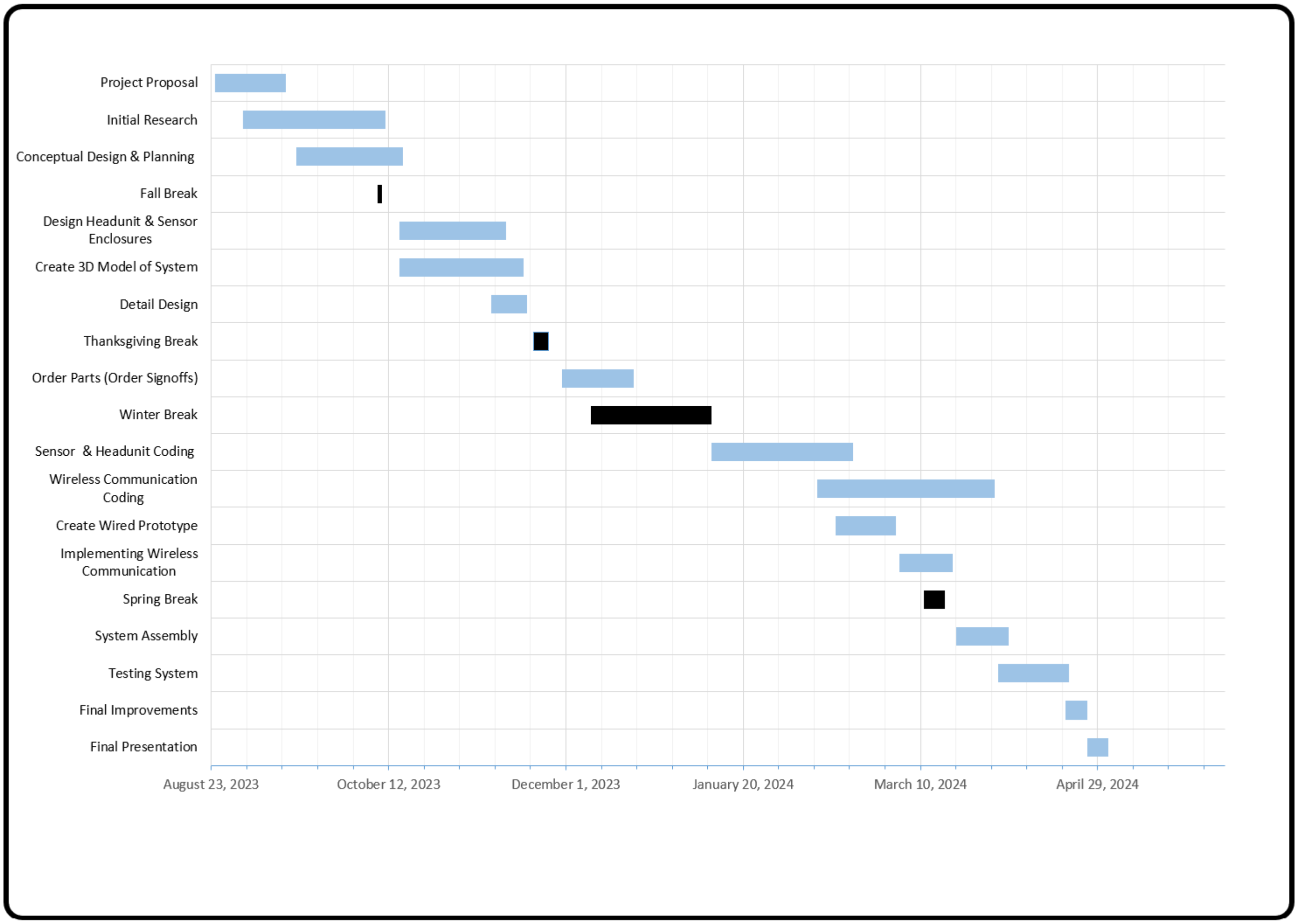

Fig. 5. Expected Timeline