House Health Monitoring Proposal

Jackson Woodard, Dylan Robbins, Nathaniel Campbell, Luke Carson, Cole Cooper
Electrical and Computer Engineering Department
Tennessee Technological University
Cookeville, Tennessee
jrwoodard44@tntech.edu, dcrobbins42@tntech.edu, nmcampbell43@tntech.edu, lmcarson43@tntech.edu, cacopper44@tntech.edu

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, like 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 being built into homes as they are constructed for detecting potential issues.

Preserve Home Pro measures, records, and displays important data about a home. This system gives a homeowner valuable information to help maintain and protect the home. The system has been created as a semi-permanent system to be incorporated into new home constructions to give the home many years of valuable information about that home. The system is able to keep track of all of this information by using a closed network that does not require an internet connection.

II. Formulating the Problem

A current market for this type of system does not exist. A similar comparison would be the market for smart home automation and monitoring, however, these products cannot be fully integrated into a house and show the overall history. The Preserve Home Pro would be a semi permanent system that would be embedded in a house from the day it is built to the day it is torn down. The system also would not require anything that a new homeowner would have to purchase. It would also be designed to run off of the house's electricity with backups in place in case of any power outages.

A. Background Information

The Preserve Home Pro comes with multiple sensors that are paired with a head unit. This head unit features a screen that shows real-time and historical data about the house. The unit is designed to be installed flush with the drywall, providing a streamlined look and easy accessibility for the homeowner. Additionally, it would wirelessly connect to all sensors in the house to collect and display data.

1) Temperature Sensor: House fires are an issue everyone should be able to prevent if possible. The three most common house fires are cooking, heating equipment, and electrical fires [4]. When a home inspector is looking at a house, they usually look for things that could cause a fire but if a temperature sensor was installed in the house, it could warn the homeowner that sections of their house have an elevated temperature before a fire could form [5].

The intended goal of the Preserve Home Pro temperature sensor is to be able to detect when a particular area of a house or building has reached an unsafe temperature level. This would be useful for a homeowner to tell if a section of their house is overheating, allowing them to act before a fire or something else occurs. Another purpose of the temperature sensor is to allow home inspectors to have easier access to all temperature data, and the history, throughout the entire house in one place. Finally, it gives people in the market for a new house the ability to look at the house's history to see if there has ever been a fire or any other heat-related problems. There are multiple different temperature sensors already on the market to detect temperature, so achieving the goal would be feasible.

2) Flood Sensor: 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/Smoke Sensor: 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. There are vast types of gases that are commonly found in homes that lead to hazardous conditions for homeowners or the destruction of it. "Most homes primarily use natural gas for heating, cooking, and drying clothes," notes Pete Deininger from Breck Life Group. 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 more common gases that are likely to be found in a house are methane, hydrogen, 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) Humidity Sensor: Mold and moisture are most common in homes and buildings and owners may never know these are present until it is too late. Roughly seventy percent of homes have some mold in them. 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 [11]. High moisture and mold counts can cause structural and foundational damage to the home which can degrade the health and integrity of the home. These factors could also pose health risks to the environment and people exposed. The objective of implementing humidity sensors into the Preserve Home Pro is to potentially prevent and alert homeowners of possible mold growth and high moisture levels.

5) Wireless Connectivity: A challenge that has faced mankind has been the sharing of information. One of the first recorded instances of humans storing information comes from over 5,000 years ago in Mesopotamia [12]. Throughout the centuries the logging of information has become a very important day-to-day task. From the invention of writing to the invention of the internet, humankind has created and continues to innovate the sharing of information. However, not only humans need to communicate. Many modern inventions, like smart home sensors, also need to communicate. Existing smart home devices currently use WiFi to connect to the internet to share the information recorded by each sensor in smart home ecosystems like Google's Nest and Amazon's Ring. One of the most important parts of Preserve Home Pro's implementation is that no existing WiFi or internet connection is needed for the system to work. Preserve Home Pro can communicate using its closed wireless network.

There are different ways to communicate between multiple sensors and their final destination. Wireless mesh networks are designed to be used in situations where the network structure does not allow each node to be within the range of its final destination. Within this network, it can connect separate sensor networks, sensor nodes to a monitoring platform, or provide sensor-to-sensor communication [13]. Using the mesh system would eliminate the factor of being out of wireless transmission range. This would allow smooth communication between each device back to the final destination, or head unit.

6) Backup Battery System: "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" according to an article from Scientific American [14]. The longest anywhere in the U.S. has gone without power is two weeks [15]. Implementing a backup battery system with the capacity to last two weeks and the ability to have two charge/discharge cycles per year would be more than enough to allow this system to function. Some manufacturers estimate an average lithium polymer battery can last for around 300 to 500 charge cycles before its capacity drops to approximately 80% of its original capacity [16]. Estimating this system would only use a maximum of two charge cycles per year, it could last well over thirty years.

B. Goal of the Project

The following is the goal of the project:
- A semi permanent system that actively monitors and logs the health of the house that will add value and prolong the life of the house.

C. 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.

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

D. Specifications

The Preserve Home Pro will meet specifications derived from stakeholder inputs. The system will continue to work without external power for up to two weeks. A period of two weeks of internal power is what is the highest average period in the United States for a home to be without power [15]. It will work without an existing WiFi network. Although most homes in the US have broadband access, 42 million Americans still do not have broadband internet access [41].

Just because a household does not have internet, should not prevent the implementation of Preserve Home Pro. The system shall help detect various types of issues that lead to the damage of a house. These measured indicators are high temperatures over 150 degrees Fahrenheit, high humidity over 50 percent, the collection of water in the house, and dangerous air particulates like mold or carbon monoxide. It also will be a semi-permanent installation to new home constructions, allowing for a long service life over 20 years from installation.

E. Constraints

The Preserve Home Pro will meet constraints derived from stakeholder inputs. Preserve Home Pro will not violate the guidelines laid out in IEEE 802.11, NEC 70, IEC 60950-1, and 47 CFR 15.212. Each sensor module's battery backup will not require replacement within ten years of installation at minimum. Preserve Home Pro will not record any information that is not necessary for the system's measured indicators of high temperatures over 150 degrees Fahrenheit, high humidity over 50 percent, the collection of water in the house, and dangerous air particulates like mold or carbon monoxide.

F. Standards

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

IEEE 1924.1-2022, IEEE Recommended Practice for Developing Energy-Efficient Power-Proportional Digital Architectures - A set of guidelines is presented in this recommended practice for the development of energy-efficient and power-proportional digital architectures so that energy is only consumed when computations are underway and energy is reduced in the non-operating state. The purpose of this practice is to provide guidelines for the designers and developers of digital architectures for creating power-proportionality at different levels of the system [17].

IEC 60950-1 - The standard is applicable to mains, or battery-powered information technology (IT) equipment and office machines with a rated voltage not exceeding 600 V. It is intended to prevent injury and damage to persons and property from such hazards as electric shock, fire, dangerous temperatures, and mechanical instability [18].

47 CFR 15.212 - Single modular transmitters consist of a completely self-contained radiofrequency 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 [19].

NFPA 715, 1.1.2*-2023, Installation of Fuel Gases Detection and Warning Equipment - This standard shall cover the selection, design, application, installation, location, performance, inspection, testing, and maintenance of fuel gases detection and warning equipment in buildings and structures [20].

NFPA 715, 3.3.2.3 -2023, Installation of Fuel Gases Detection and Warning Equipment, Multiple-Purpose Alarm – This standard follows an alarm that incorporates detection capabilities for more than one hazardous condition, such as fire, fuel gas, or carbon monoxide [21].

NEC 70, 110.1-2023, General Requirements for Electrical Installations – This standard covers the general requirements for the examination and approval, installation and use, access to and spaces about electrical conductors and equipment; enclosures intended for personnel entry; and tunnel installations [22].

NEC 70, 702.1 – 2023, Optional Standby Systems – This article standard to the installation and operation of optional standby systems. The systems covered by this article consist of those that are permanently installed in their entirety, including prime movers, and those that are arranged for a connection to a premises wiring system from a portable alternate power supply [22].

NEC 70, 800.1 – 2023, General Requirements for Communications Systems – This article standard covers general requirements for communications systems. These general requirements apply to communications circuits, community antenna television and radio distribution systems, network-powered broadband communication systems, and premises-powered broadband communication systems, unless modified by Articles 805, 820, 830, or 840 [22].

IEEE 802.11 – 2020, Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks – These technical guidelines will serve as a family of standards for implementing communication for wireless LANs or known by consumers as Wi-Fi. This specifies the interface that enables over-the-air signaling between two or more wireless clients. It serves as the main bearer of communication for various electronic devices [23], [24].

G. Survey of Potential Solutions

The overall build of this system will consist of a head unit module and multiple sensor modules. The main module will consist of a microcontroller connected to a screen that will log and display information given by the sensor modules. The main microcontroller 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 a microcontroller with wireless transmission capability. 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 [25]. 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 [25]. According to an article from Master Mechanical, current air conditioner temperature sensors in homes use infrared radiation [26]. To measure the temperature in a room instead of just an object, it is more practical to use a non-contact sensor. Figure one illustrates the difference between a contact temperature sensor and a non-contact temperature sensor.

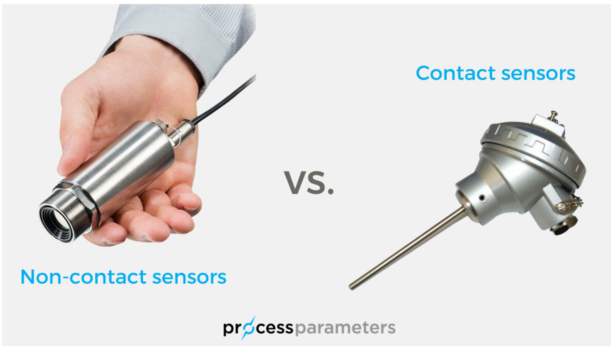

Fig. 1. Non-Contact vs. Contact Temperature Sensor [27]

Water level indicators are commonly available in the market, including resistive, capacitive, ultrasonic, and float sensors [28]. Resistive and capacitive sensors detect changes in conductivity and dielectric constant respectively, and provide output as voltage [29]. 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 [30]. 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 [31]. 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 [32], [33]. 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 [34]. 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.

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 [35]. 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 [11]. 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.

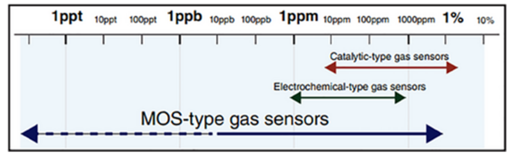

Fig. 2. Sensing range comparison of catalytic-type, electrochemical-type, and MOS-type gas sensors [34]

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 [36].

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 [37]. 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.

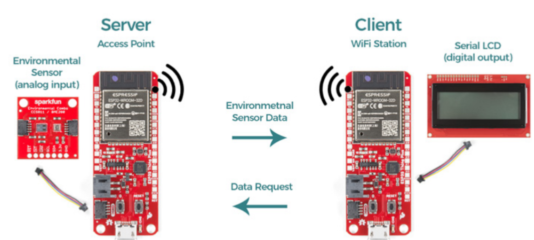

Fig. 3. Closed network wireless communication between modules [38]

There are 3 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 [39]. The project will need a battery that has a large capacity to allow the system to operate for up to 2 weeks and a battery that will not degrade quickly.

H. Challenges

Some of the challenges that have occurred for the team are lack of experience, misunderstanding of the objective, limited budget, and limited time. One challenge that could occur later is creating a backup battery to power the system when there is no power.

I. 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 must meet all specifications and constraints provided by the stakeholders while also meeting all safety standards and regulations.

III. The Proposed Solution

A. Unknowns

There are several things that are still uncertain and can only be determined once the system is constructed and implemented. One unknown would be that we do not know the layout or size of the house where the sensors are being installed. Another unknown would be we do not know the surrounding environmental signal interference, like WiFi networks or power lines, and how that would affect the sensors. Likewise, the system could also cause interference to other devices.

B. Measures of Success

The measure of success will be the ability of our system to properly measure, record, and display the data from the sensors and output it to a head unit that displays all of the data. The head unit can be tested by connecting the sensors to it and seeing how it looks visually on the screen. If the data on the screen is hard to understand, then we would have a clear understanding of what needs to be fixed in the coding of the display.

Another measure of success will be the accuracy of the sensors in the system. This can be tested by using preexisting sensors for each sensor we have included in our system and testing the output of our sensors to the output of the preexisting sensors. The purpose of testing all of the sensors is to ensure that the system is outputting accurate data for the homeowner to see and respond to if necessary.

The final and most important measure of success will ultimately depend on achieving the project goal. To test the sensors, we plan to create a demo house where they can be implemented and evaluated. The head unit must display both real-time and historical data and be user-friendly in order to reach our goal. If everything functions as intended, our system may increase the value of a house.

C. Responsibilities as Engineers

As engineers, it is our responsibility to create products that do not harm or distract humans. Homeowners often worry about their privacy when it comes to systems like ours [40]. To address this concern, we want 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 [40]. To address these concerns, we assure homeowners that Preserve Home Pro uses a closed local network for added security.

It is important that we follow 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 we are 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 our expected completion dates. The team plans to have everything built, utilized, and tested by May of 2024.

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 and builders alike.

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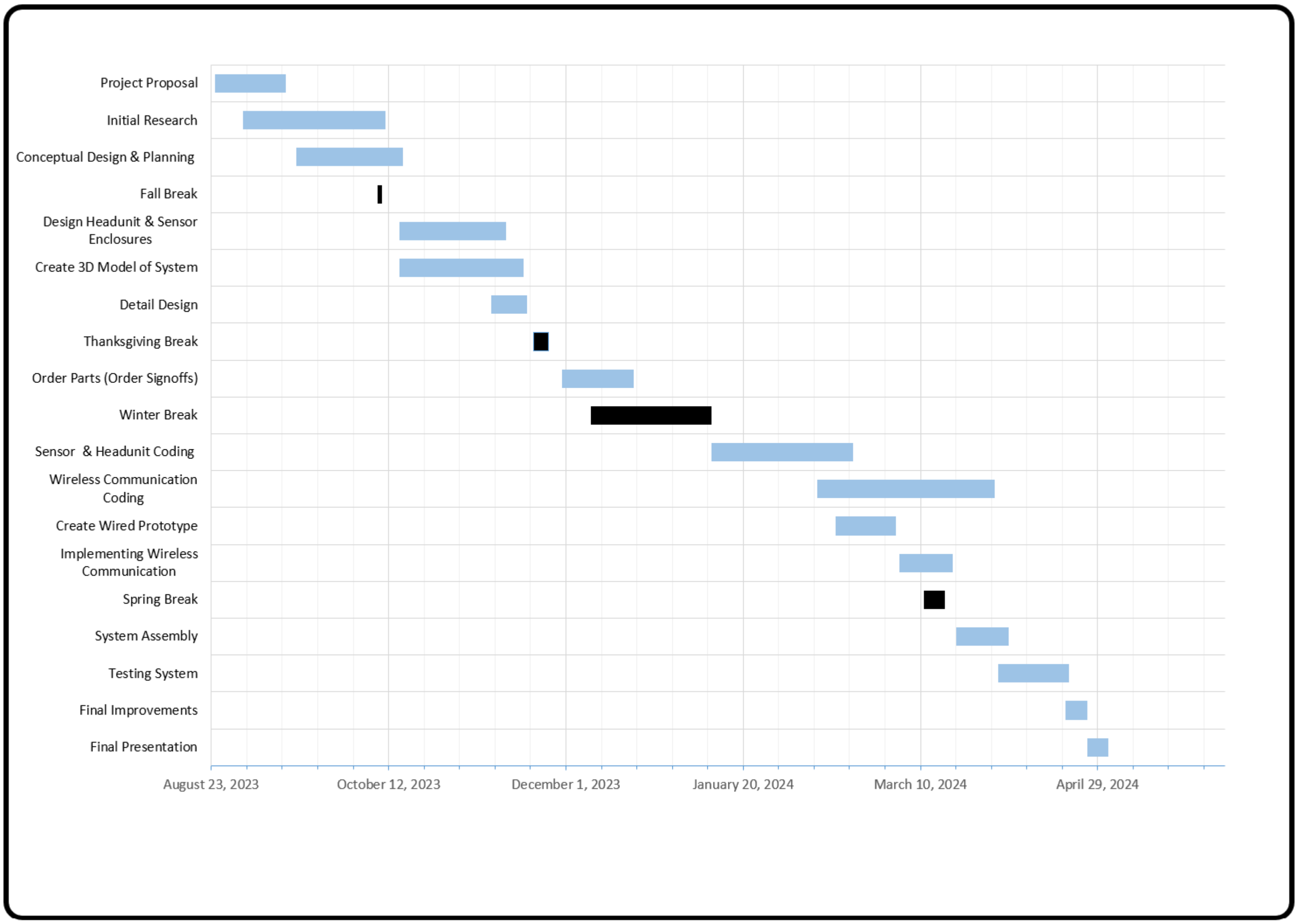

Fig. 5. Expected Timeline