ECE 491 – Senior Design I

Preliminary Project Proposal

Smart Assistive Living Environment (SALE) Project

Christopher Caruso, Padmanabh Kaushik, Calum McConnell, Nicholas Sorak, Scott Torzewski, Hernan Tovar-Molina, Priscilla Wu

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Introduction

Smart homes and smart home devices are a growing sector in the electrical and computer engineering field. Lafayette College's Department of Electrical and Computer Engineering (ECE) requested the 2025 senior class to design and/or integrate user-friendly devices that create a cost-efficient smart living environment for older adults or people with disabilities. This project will allow the senior design team to better understand the Internet of Things (IoT) and gain experience doing research and development in a team setting.

The final product of the senior design process is a Smart Assistive Living Environment (SALE) system. The goal of the system is to help residents in the smart home manage daily tasks, stay connected with friends and caregivers, and live more independently. The system must have a way for residents with dysfunctional hands to interact with the system, necessitating an alternate input device (to replace the mouse or keyboard). The SALE system consists of four elements: a Hub, a Smart Mobile Device (SMD) with apps, a set of smart devices, and a Remote Support Station (RSS). The Smart Mobile Device will accept input from Kick Buttons, which we've chosen as our alternate input device.

To ensure that the system works in the real world, the SALE system must be Matter-compatible. Matter is an industry-unifying protocol/standard that facilitates reliable, secure smart home connectivity. More information about Matter can be found in the Existing Standards section. In addition, the system shall be cost-efficient, and members must propose and work within a budget approved by the ECE Department.

Existing Standards

Numerous standards already exist for the creation of smart homes. The primary one that will be driving this project is the Matter standard, which describes a communication protocol between controllers and devices that allows for any Hub to control any device. The standard, however, does not specify a transportation method for data to physically move through space. There are two generally supported options: a standard WiFi network, with a centralized router, or a mesh network following the Thread protocol. The Matter and Thread protocols are specified by a pair of industry groups, the Connectivity Standards Alliance (CSA) and the Thread Group, respectively. WiFi is specified by the Institute of Electrical and Electronics Engineers (IEEE). All the standards are available for free, though the Thread and Matter standards require agreeing to an EULA to access.

Additionally, there are several open-source software suites that are useful for the design of an integrated smart home. Home Assistant is an open-source program designed to run on a Hub and provides automation, multi-protocol support, integrations, and more. There are related projects, such as open-source voice assistants, which will also be integrated.

Related Course Concepts

In Solid State Devices and Solid State Design with Professor Wey, we gained hands-on experience with designing and building circuit boards. For instance, we designed and built protoboards in the laser-sound board project and the amplifier project. We will need to design at least one PCB for this project, so our experience with protoboards will aid in learning how to design PCBs.

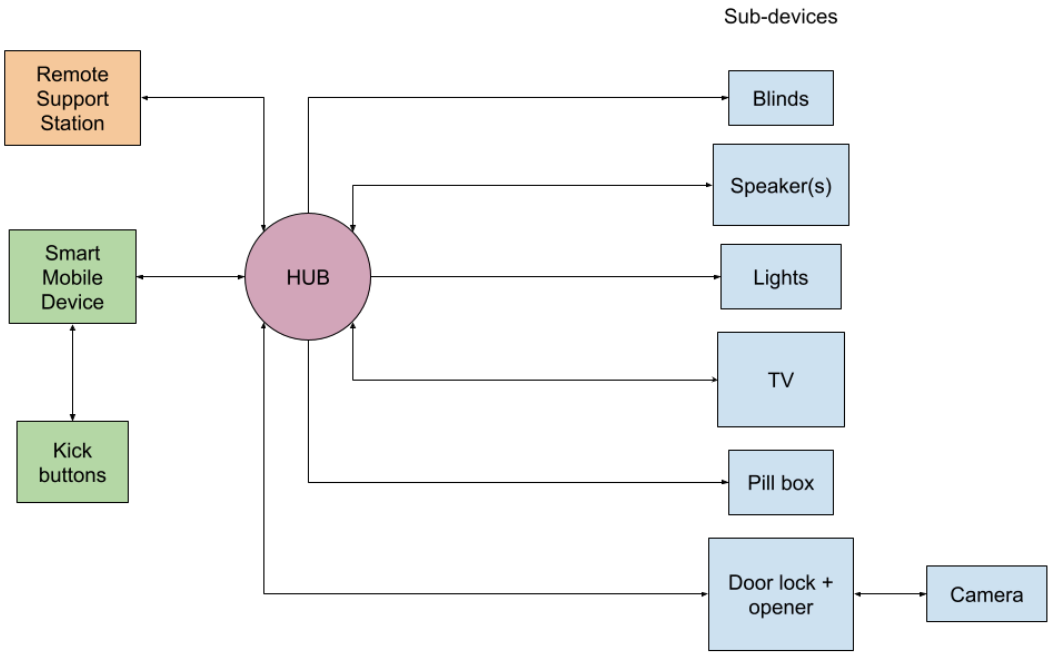
In Embedded Systems with Professor Nestor, we performed many labs where we had to design the hardware and software to control a larger system such as a calculator and a pong game. More specifically, we had to design the circuit using online applications like KiCad and build it using a breadboard. Additionally, we had to write a program to control the system and integrate the two to achieve our desired outputs. These skills will prove very useful when we have to program the smart Hub and integrate it with the other devices, as well as designing the circuitry for the various devices.

In Data Structures and Algorithms, we gained experience creating more complex programs. This will prove useful since the SALE system will require us to program many of the devices.

Some concepts we may need to learn as our project progresses include those related to mechanical engineering, as only two individuals in our group have experience in that field. For devices like our blinds, door opener, and pill box, we may need to research mechanical engineering principles to come up with our implementation plan. Additionally, we may need to complete more research on PCB design, and wireless/wired communication protocols.

High Level Design

System Block Diagram



Smart Hub

The Smart Hub will serve as the center of the SALE system. It will connect to every other device, and will coordinate all actions taken by the system. It will be made based on the Home Assistant software suite, which provides many of the basic features such as automations and matter compatibility. It will communicate with the sub-devices of the smart home via the Matter protocol; it shall support multiple of the different transport techniques under that protocol (such as WiFi, Zigbee, and Thread). The Smart Hub will also be responsible for data logging and voice processing, as well as maintaining configuration about the home's state. Lastly, due to its central role, the Smart Hub must have a battery backup, and maintain itself via software updates.

The Smart Hub will be implemented using the open-source Home Assistant software suite. This suite can be run on numerous host computers; however, there are some premade modules available. Research will need to be done to determine which pre-made module and configuration options shall be acquired, or if a custom design is needed. Voice assistant processing is also available via open-source software. By using open-source components, the team has the flexibility to modify and extend them as needed or necessary for the project, and can furthermore contribute those improvements back to the central repository.

Requirements:

1. The Smart Hub shall be able to record actions taken to files.
2. The Smart Hub shall be able to record data from various sensors/inputs to files.
3. The Smart Hub shall have enough storage for 30 days of files.
4. The Smart Hub shall be able to remove old data automatically as required by space.
5. The files on the Smart Hub shall be able to survive power loss.
6. The Smart Hub shall have password protection in order to access.
7. The Smart Hub shall have encrypted connections used for all signals.
8. The Smart Hub shall have Smart Mobile Device and Remote Support Station pairing.
9. The Smart Hub shall have backup battery power for at least 90 minutes.
10. The Smart Hub shall be able to track battery power from software
11. The Smart Hub shall have the Ability to unpair from devices

12. The Smart Hub shall pair to matter devices.
13. The Smart Hub shall utilize a Home Assistant to send matter commands.
14. The Smart Hub shall be powered via connection to an outlet.
15. The Smart Hub shall include a system status consisting of an RGB display, where different colors indicate whether the system is functioning properly or not.
16. The Smart Hub shall have a physical on/off switch on the device.
17. The Smart Hub shall have the ability to connect a keyboard and screen to the system for debugging.

Smart Mobile Device (SMD)

The Smart Mobile Device (SMD) shall allow the resident to use all the features of their home through various means of input to accommodate disability, including custom kick button inputs and voice commands. The device will be battery-powered and can attach to a wheelchair for mobile control.

The Smart Mobile Device will consist of a tablet with a mount. The screen will have a custom interface design to be easy to use for a person with disabilities. It will have a keyboard and microphone to allow the device to intake voice commands and make video calls via the Smart Hub. The tablet will have a biometric scanner to allow the resident to easily login while still being password protected.

Requirements:

1. The SMD shall send audio from the internal microphone to the Smart Hub for voice assistant features.
2. The SMD shall handle commands from Kick Buttons.
3. The SMD shall use Linux/Android GUI tools to make a user-friendly GUI.
4. The SMD shall have a custom downloaded app from playstore/internet/website.

5. The SMD shall be protected by a password which will be entered through the Kick Buttons.
6. The SMD shall have a biometric alternative to log into the Smart Home app.
7. The SMD shall be battery-powered.
8. The SMD shall be easy to use.
9. The SMD shall have a camera.
10. The SMD will be able to be attached to a wheelchair.

Kick Buttons

The *Kick Buttons* will be designed for residents who have partial mobility of their legs and can use their legs to kick objects. The kick button panel will have 5 Kick Buttons, allowing the resident to control the entire home automation system using them. We will be creating this kick-button system for someone who uses a wheelchair and has limited leg motor control. The buttons will be designed so that the caretaker can shift their location (by sliding) to a position that is convenient for the resident.

Requirements:

1. The Kick Buttons must be easy to activate, requiring minimal force to be kicked.
2. They shall be mounted on a raised platform that can be positioned within easy-kicking. distance from the resident's wheelchair.
3. The buttons need to provide feedback, such as lighting up, whenever they are kicked.
4. The buttons must transmit data wirelessly to the connected smart mobile device.
5. The resident shall have the ability to adjust the position of the buttons on the platform.
6. The power usage for the buttons shall not exceed 12 V or 2 A.
7. The buttons must have an emergency power backup, such as a battery power line.

Remote Support Station (RSS)

The Remote Support Station shall allow the caregivers or family members to communicate with senior and/or disabled residents and support them without affecting their privacy. The station will require the resident's permission to perform certain tasks such as start a call or access all the functions of the Smart Hub, but shall allow for emergency overrides.

The Remote Support Station will consist of a Personal Computer (PC) that runs Windows and a downloadable app. The downloadable app will be built off of open-source Home Assistant Windows Apps available on GitHub.

Requirements:

1. The support staff shall be able to use the RSS to call the resident and vice versa.
    a. The support staff and resident shall both be able to start and end a call.
    b. The support staff and resident shall be able to select a video or voice call.
    c. The call shall require approval from the person receiving the call before the call starts to stream audio and/or video.
    d. The receiver shall be able to select whether or not to have their camera on.
    e. The support staff shall be able to initiate an emergency call that does not require resident approval.
        i. The emergency call shall announce itself on the resident's end as an emergency call.
    f. The RSS shall keep a record of call time and length and send it to the Smart Hub.

2. The support staff shall have ready access to a number of support options via the Smart Hub.
    a. The support staff shall be able to lock and unlock the door from the station.
    b. The support staff shall be able to set reminders for the resident.
    c. The support staff shall be able to access medication records logged by the pillbox.
3. The RSS shall require resident approval to have additional access to the Smart Hub beyond the options enumerated in the requirement above.
    a. In order to request additional access, the RSS shall require the support staff to provide user authentication.
    b. The resident shall be able to select if the additional access is one-time or permanent until changed.
    c. The resident shall be able to revoke the additional access.

Smart Light

The Smart Light shall allow the resident and their caregiver to control the lighting of the smart home via a connection to the Smart Hub. This device will allow the resident to tailor their environment to their comfort with as little physical hindrance as possible.

The Smart Light will consist of a standard lightbulb socket connected to the Smart Hub using a wire. The resident will be able to easily turn the light on and off from the Smart Mobile device using the kick button inputs. The caretaker shall be able to easily switch the bulb in the event that it gets out. The light will be completely safe and not cause any overheating or fires.

Requirements:

1. The Smart Light shall have limited heat output to avoid starting fires.
2. The Smart Light shall be wirelessly toggled through the Smart Hub.
3. The Smart Light shall have the ability to change bulbs without replacing the full smart device.
4. The Smart Light shall be able to be controlled through kick button inputs.

Smart Door Lock

The Smart Door Lock will secure exterior access to the home, with two access methods. The first will be remote unlocking through the Smart Mobile Device. Once the button on the display is pressed, the electronic lock will release. The second way to control the Smart Door Lock will be a keypad located outside the door. Caretakers assigned to this resident will have access to the password in case the remote unlocking is malfunctioning, or there is an emergency. Once the door closes, it will lock automatically.

Requirements:

1. The door shall only unlock/lock with resident approval via the smart Hub and from caretakers assigned to the resident.
2. The system shall be able to withstand constant usage of door opening and closing.
3. The system shall utilize an electronic keypad located on the outside of the door.
4. The system shall utilize remote locking and unlocking via the smart Hub OR contain a button located by the floor for the resident to press with their foot to unlock the door.
5. The keypad system shall contain a camera, microphone, and speaker so the resident can see and communicate with people outside the door.
6. The door shall automatically lock after it is closed.
7. The system shall incorporate a backup power system in case of power loss.
8. The system's primary source of power shall come from batteries.
9. The lock shall function as a proper lock so that it stays locked if repeated attempts are made to open the door incorrectly.

Smart Door Opener

The Smart Door Opener will be able to open and close a door when directed to by the smart mobile device. Selecting the “open” or “close” buttons on the display will cause the door to open or close. It will consist of a motor and a piston. It can be mounted on existing doors to add accessibility, allowing the user to navigate their home independently. The sensor placed on the inside door will provide safety for the resident, as it will stop the door from closing if something is obstructing it.

Requirements

1. The system shall be able to withstand constant usage of door opening and closing.
2. The Smart Hub shall be able to open/close the door wirelessly.
3. The system shall open and close the door at a reasonable speed so that the resident can quickly exit in an emergency.
4. The system shall not inhibit the door opening manually if it is not functioning properly.
5. The mechanism shall not block the entry way.
6. The system shall contain a sensor on the opening mechanism so that it does not close in case a person becomes stuck in it.
7. The system shall incorporate sound alerts when the door opens and closes via the smart speaker.

Smart Pill Box

The Smart Pill Box will be designed to organize the resident's daily medications. Each day of medications will be combined in a single compartment and dispensed as a group. When it becomes time for the resident to take their medication, the Smart Pill Box will send a voice notification through a smart speaker. The Smart Pill Box will dispense the pills as the resident approaches it and puts their hands under the collection area. Additionally, the Smart Pill Box will notify the caregiver whenever the pills have been dispensed and when the medications need to be refilled.

Requirements:

1. The Smart Pill Box must activate the Smart Speaker (through the Smart Hub) at a set time, notifying the resident that it's time to take their medication and specifying what the medication is for.
2. It shall have the capacity to hold multiple types of medications.
3. The Smart Pill Box must send a notification to the caregiver once the medication has been dispensed.
4. It shall also communicate to the caregiver when it's time to refill the medications.
5. The caregiver shall be able to enter the medication data into the Remote Support Station to set up the Smart Pill Box.
6. Access to the Smart Pill Box medication data on the Remote Support Station/Hub must be password-protected.
7. The Smart Pill Box shall be able to be positioned at an appropriate location and height to dispense pills to the resident in the wheelchair.

8. The Smart Pill Box must be manually openable by a caregiver in the event of a malfunction.

Smart Speaker

The Smart Speaker will be an essential component of our SALE home system, designed to stream audio from our Hub (including medicine notifications, doorbells, or music selected using the smart mobile device). It shall be easily configured by the resident, specifically the volume control, and will be the conduit through which our home system communicates with our resident. Additionally, the smart speaker shall listen to voice commands from the resident and send the audio to the Smart Hub for interpretation.

Requirements:

1. The Smart Speaker shall be controlled by a Matter compatible control system.
2. The Smart Speaker shall connect wirelessly to the Smart Hub.
3. The Smart Speaker shall have a volume control system accessible through the smart mobile device.
4. The Smart Speaker shall send a notification to the Smart Hub when an error occurs.
5. The Smart Speaker shall be easily accessible/controlled using the Kick Buttons and voice control.
6. The case of the Smart Speaker shall be durable and good-looking.
7. The Smart Speaker shall be able to stream audio to and from the Smart Hub.
8. The Smart Speaker shall be sufficient enough for FM-quality sound.
9. The Smart Speaker shall be able stream from pandora/internet radio, and play audiobooks.
10. The Smart Speaker shall play error messages (if any). There shall be an option for the resident to disable the feedback messages.

11. The Smart Speaker shall play messages when actions are undertaken through the smart mobile device.
12. Speaker shall be loud enough to hear across the room.
13. The Smart Speaker shall be powered via a standard room outlet, with connections to the main power line as well as to the backup line.

Smart Window Shades

The Smart Window Shades component of the SALE home system will essentially be integrated with controls intended to unburden the resident. The resident will be able to conveniently adjust their preferences for lighting with simple, straightforward controls. The shades will be sheets of translucent cloth that block out most of the light.

Requirements:

1. Simple controls; with a push/touch shall open or close.
2. Smart Window Shades shall be connected with the Smart Hub wirelessly.
3. Smart Window Shades shall have manual mechanical control as an alternative.
4. Wired aspects shall be secured and out of reach/away from the resident.
5. The resident shall be able to raise/lower the Smart Window Shades by interfacing from the Smart Mobile Device.

Smart TV

The Smart TV will provide added convenience to the resident by providing functionality through the Smart Hub to control a home entertainment unit. Thus, the SALE home system will utilize a TV with a Roku player streaming box, and the Smart Hub will be able to control both the native TV settings and preferences as well as the Roku. The Smart TV control will be accomplished via an infrared home-built remote controller, which will emulate both the Roku and TV remotes.

Requirements:

1. The resident shall be able to control the Smart TV via voice, Kick Buttons, and Smart Mobile Device. This might include the following:
    a. TV power on/off
    b. TV volume control
    c. HDMI Input
    d. Navigate TV native preferences and settings (e.g. picture quality)
    e. Roku control (seamlessly navigate to different Roku applications as well as operate within those applications)
2. The Smart TV shall send notifications to the Smart Hub when following error occurs:
    a. Lost HDMI connection
    b. TV unexpectedly turns off
    c. Poor internet connection
3. The Smart TV shall be easy to control via voice control.
4. The Smart TV shall be powered via a standard room outlet, connected to the main power line.