IoT Passive Monitoring for Assisted Living Homes

Design Document

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1. Introductory Material

1.1 Acknowledgement

Our team would like to thank Andrew Guillemette and Dheeraj Nalluri for their guidance and assistance throughout our project. Andrew was crucial in helping obtain parts for the project and conducting research with local assisted living homes. Our team would also like to extend our thanks to Dr. Goce Trajcevski who helped with our research by finding articles related to our project and contributed feedback and constructive criticism on our documentation.

1.2 Problem Statement

The families of elderly people often have a hard time keeping track of their elderly family member's health, in order to get them the care they need. In an effort to maintain their independence, elderly people often lie or mislead their family to keep them from worrying about their health. If they are not doing well and need medical attention, it is imperative that the family is able to get them that attention in a timely manner. In the case where the elder has misled their family, it is nearly impossible for the family to even know that such medical attention is required.

We are proposing a new product to designed to solve this problem. Essentially, we want to use passive, non-invasive sensors to collect and store data about the elderly persons habits. In order to help the family know if their elderly relative is doing well we will collect data about eating/drinking habits, sleeping habits, and personal hygiene. This data will be analyzed to see if the elderly relative is staying within normal ranges, and the family will be notified if, for example, the elderly relative stops eating. With the family notified of developments like this, they can get their elderly relative timely medical attention.

1.3 Operating Environment

The end product that we are working on will be used indoors and will not be exposed to any extreme temperatures. Our sensors will be placed in either assisted living homes or residential homes, so they will need to be able to withstand the normal wear and tear of similar objects in homes.

- **Door Sensor:** We will track when a person eats by using door sensors. The door sensors will be placed on refrigerator and pantry doors or even cabinets doors for cabinets containing dishes for eating. The data of these doors opening and closing can be interpreted to show when a person is eating. The exact door sensor we have picked out can be found here: https://www.adafruit.com/product/375. We chose this sensor because it operated as desired and integrates well with the rest of the sensors.

- **Flowmeter:** A flow meter will be used to monitor water flow for the purpose of drinking,bathing, and restroom habits. Based on how long there is flow, we can determine whether or not an event occured. The flowmeter that we have picked out can be found here: http://www.hobbytronics.co.uk/yf-s201-water-flow-meter. This sensor was chosen because it performed the desired task, required only a basic setup, and worked well with the other sensors.

- **Load Cell:** We will use load cell sensors to keep track of toilet usage. The load cells will be placed under the toilet seat and will be able to detect when a person sits on the toilet seat, in theory they will also detect how much waste has left the persons body. We are also considering attaching a flowmeter to the toilet to help account for the case of a male urinating standing up. The load cell we will use can be found here: https://www.sparkfun.com/products/10245.

- **Ballistic-Cardiogram:** Another health variable we want to track is how much sleep a person is getting. To collect that data we will use a ballistic-cardiogram: https://www.murata.com/en-us/products/sensor/accel/sca10h_11h/sca11h. This sensor was chosen because it is the only sensor that has these capabilities currently on the market. The BCG can be simply placed underneath a mattress and will collect respiratory and heart rate data, which will help in the analysis of how much sleep and the quality of the sleep a person is getting.
    - Due to issues acquiring the BCG, practical testing of the BCG will be postponed until the second semester.

- **Integration:** The ballistic-cardiogram is wi-fi enabled and thus can send the data straight to the server. All of the other sensors will be wired into raspberry pi zero W. The raspberry pi zero W will send the collected data on to an in-home server hosted on a raspberry pi 3. The in-home server will then encrypt and send the data on to the cloud server.

1.4 Intended Users and Uses

The end users will consist of an elderly person being non-invasively monitored, and a caring relative of theirs being notified of any problems. The sensors will not be interacted with- as they are passive monitoring sensors. Relatives of those living in the homes or caretakers will be the intended users of the interface we create. These users will monitor trends from the tenant's data and be alerted of any irregularities that may warn of an underlying health issue.

1.5 Assumptions and Limitations

In the process of developing this project, it has become necessary to make several assumptions.

- Assumption 1: There will be wifi in the home/install location. This assumption was made because our alternative, Bluetooth, may not work in every scenario due to the limited range Bluetooth has in comparison to wifi.
- Assumption 2: This product would not be used outside the United State. This assumption is made to streamline our project:
  - The only Medical Regulations that would need to be followed are those of the United States.
  - Building materials and styles or methods target only the United States (e.g. Voltage/outlet differences). Those assumptions are based on the fact we are creating it in the United States, in the future the product could be updated to be sold internationally.
- Assumption 3: The sensors will be installed in an environment with only 1 subject.

Limitations:

- The sensors must be passive and non-intrusive.
  - This limitation was initially placed on us by the client, but was later rescinded. We chose to keep this limitation, as the majority of the project had taken place under this limitation.
- Limited to using Android for the initial version of the mobile app.
  - We have had significant issues utilizing cross-platform development software, and thus decided to develop solely for Android, to meet our delivery date. Cross-platform functionality has been pushed tentatively to the next semester.
- A limited number of sensors can be connected to each raspberry pi.
  - Purely a physical limitation.
- Minimal number of wires and complexity of the wiring involved.

1.6 Expected End Product and Other Deliverables

The end product will be a platform that consists of: a cloud server, data collection, and a mobile application. These will be delivered by April 23rd 2018 to our client.

In order to collect data, we will create a simulated environment and install the sensors designed to passively track when a person eats or drinks, uses the bathroom, takes a shower/bath, and sleeps. Further detail on the types of sensors involved can be found in the operating environment section.

The cloud server will used to store and analyze the collected data sent from node servers. We are using Amazon Web Services for this project, because of our prior experience with the platform. For the first semester, we will be using AWS's Relational Database Service to store the data collected by the sensors, and Android Studio to create the app.

The application displays the data as it is stored in the DB. The user's home screen has a list of all the residents that are tied to that user's account. For each resident the user is able to view the most recent events for each type of sensor. The menu on the bottom of the screen allows the user to navigate between each data type and view the recent events in a list. Each event in the list has the name of the device that event came from, as well as the relevant data that is stored in the database such as the time and duration for door events.

In the second semester we will work on analyzing collected data so that it is useful in identifying health risks. To do this, we plan to work with a professional statistician, which will be organized by our client. Once the data is interpreted, the mobile application will be extended to to visualize the data in a more intuitive way.

2. Specifications and Analysis

2.1 Proposed Design

There are several ways to implement this project. These include: sensor monitoring, camera monitoring, or having a live-in-caretaker. Each of these solutions would allow for relatives of elderly subjects to know more about the state of the subjects health. For the sake of this class and having a project to complete, the last option of a live-in-caretaker is out of the question, not to mention grossly inefficient. This left us with cameras and sensor monitoring.

After several discussions with the client, it was determined that using cameras would be too invasive for comfort and the idea was cast aside leaving us with just sensor monitoring. This option in itself left us with several directions in which we could go; namely, whether or not to use a wearable monitoring device. Initially, the decision was made to not use a wearable. This decision has since changed but will not be affecting prior design decisions, as the project was well underway before we were informed of this change.

We selected sensors (see section 1.3 for more information and justification) that will allow us to monitor the areas of opening and closing of doors in the kitchen, sink usage for the purpose for getting a drink, bath and shower usage, toilet usage, weight, and sleep habits. We chose to monitor these specific factors at the request of the client. These sensors will provide an environment for evaluating the portion of our project's functional and non-functional requirements in terms of monitoring.

Each sensor is connected to a Raspberry Pi Zero W that sends sensor information to a local server being hosted on a Raspberry Pi 3. The local server will be responsible for encrypting and sending data to the cloud.

The cloud platform is used to store and analyze data in addition to using machine learning to attempt predictions of major health concerns. Cloud platform information and justification can be found in section 1.6.

Finally, there is a mobile Android application for data visualization. The app starts by having the user log in, allowing them to see information about an individual to which they are authorized. Throughout the first semester we will focus on ensuring feasibility of our implementation and thus have raw data that is collected by the sensors available for the mobile app. The focus of the work in the second semester will shift to having approaches that will process/integrate the information in a more meaningful manner that will have increased significance to the user.

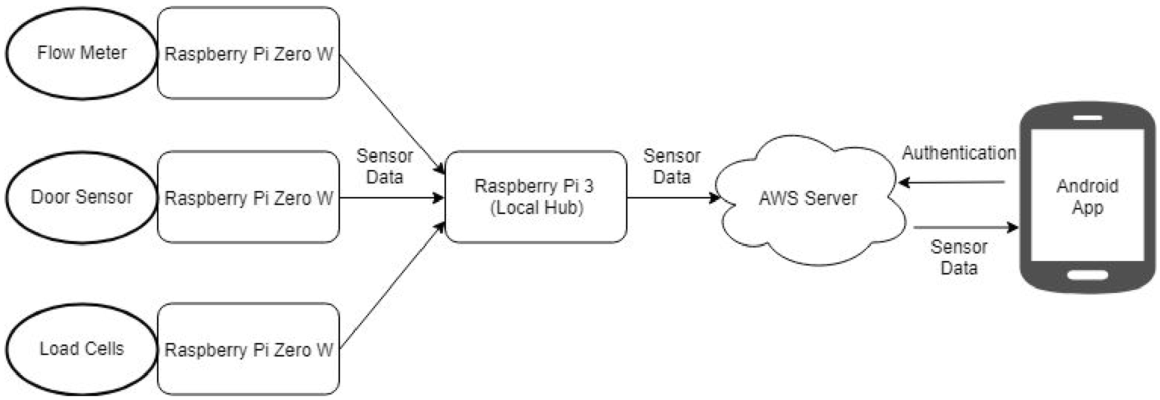

Fig 1. System Data Flow.

2.2 Design Analysis

The design stated above is a good proof of concept but it will need to be extended to be marketable. The current sensors accurately collect information in their area, however more types of sensors may be necessary to create a more accurate depiction of a user's health. This design is fairly simple in theory and is very easy to use. Additionally, some sensors will need to be calibrated to correctly measure the flow of a liquid or the exact weight.

The weaknesses of our solution include:

- Imprecise
  - The sensors merely give a stream of data, it is up to our interpretation that states if events occur; if our interpretation is flawed, the whole system can be flawed.
- Potentially infeasible to install
  - Depending on the area layout, the wired sensors may prove problematic to install: e.g. concealing the wires, routing the wires.
  - Necessary power supplies may not be readily available in ideal locations: e.g. some sensors/pi hubs may be located far from an outlet.
- More types of sensors are may be necessary
  - There may not be enough information to get an accurate idea of the individuals health
  - More information would always be better

The strengths:

- Cost-effective
  - This project specifically targets a Minimum Viable Product: we seek to accomplish our solution using as little capital as possible

- Modular
  - Based on our designs: each pi has a “loadout” applicable for certain areas, e.g. a bathroom or kitchen loadout. Thus a loadout is independent of others and is easily scalable.
- Easy to use
  - The Android app consists of a login/signup screen and a screen to view sensor data

3. Testing and Implementation

3.1 Interface Specifications

To test the sensors, our team constructed test environments to gather test data. As the door sensors operate on simple magnetic contact, no special environment is required: we simply disconnect and reconnect the pieces. Our plan for the load cells was to attach the cells to a toilet seat, and ensure the configuration and weight led to accurate readings. Flowmeter testing required the most in-depth build, as we would need water to flow through to test the readings. (See Fig 2.)

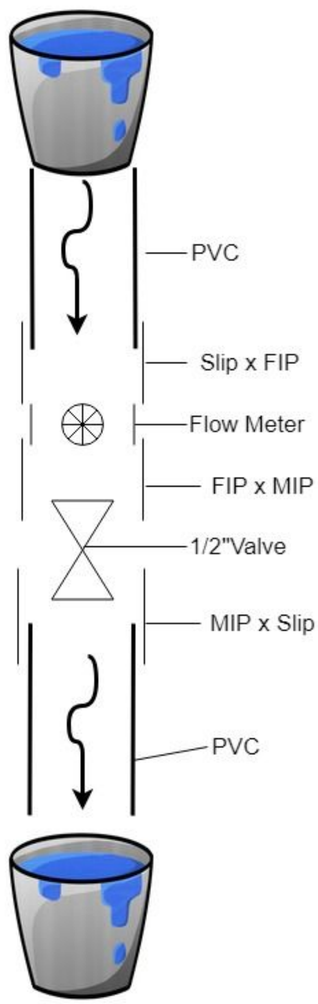

Figure 2. Flowmeter testing apparatus

The prototypes for the sensor testing are hardware interfaces used for initial tests. During the summer, our Client will go to assisted living homes and test the sensors while gathering real data to test the Cloud storage. There is no need for testing interfaces for other areas of the project as we will be able to test using the products themselves and mock data.

3.2 Hardware and Software

The hardware and software each have significant hurdles that will need to be overcome in order to implement testing of the systems. In terms of hardware we will need a test environment to collect data from:

- The Sensors performing the data collection
- The Raspberry Pi units aggregating the data
- The Cloud backend storing the data.

In terms of software we have successfully stored information all of the sensor data in a SQL database. For this semester we plan on displaying the raw data via an Android application. The data visualization will take the form of a spreadsheet-like document for this semester. Next semester we will begin to analyze the data, and give derived meaning that will be displayed in the Android application. We will need to write software to facilitate both gathering data from the sensors onto the Raspberry Pi's, and transmitting that data to the local server. Additional software will be developed on the local server to handle these transmissions, and pass the data to the cloud server.

3.3 Functional Testing

- For the hardware component of our project, it is important to simulate a test environment for our sensors.
    - As mentioned in 3.1, the door sensors have simple operation, merely connecting and disconnecting the parts will suffice. We will ensuring the door sensors are able to accurately detect a open/close event, as well as the time that the event occured.
    - We set up a testing apparatus for the flowmeter (Fig 2). We will ensure that the flowmeter can detect the flow of water, and calculate the flow rate with that information.
    - Lastly, we plan to simulate a toilet seat for load cell testing. We will ensure the proper load and load balance is read.

- The second part of hardware testing pertains to placement of the sensors around an assisted living facility. The client plans on finding a facility in which we can place the sensors around the living facility and get a feel for where we would place these sensors around the actual environment this summer. This in-home testing will also help to test the sensors more in depth than the prototypes that we have created and tested on.

- For software testing we plan on implementing a test script that will send data to the local server that would resemble that of the sensors. We can then set up queries to the cloud database to ensure that the information was sent and stored correctly.

- The final part of our software testing plan will be testing the mobile application platform to ensure that the HTTP points can be hit and successfully deliver the required information.

3.4 Non-Functional Testing

- Amazon Web Services provides a tool that allows us to see the metrics of our online services. This way we can constantly view the performance of the services and see where there are any bottle necks. We will also make use of AWS's Firewall Service and attempt various penetration tests. We could then derive where we need to strengthen security.

- For Non-Functional Testing of the sensors, we plan on both taking sensors away from the system as well as adding new sensors to it. This way we can check the systems behavior for when there is either data that is lacking from the system or new data being added. By doing this we will know how our system responds to the addition or removal of a sensor and how we can better automate such events.

3.5 Process

The first method we thought of after hearing the problem was to use cameras to collect data. Unfortunately, this method was quickly decided to be not viable for several reasons, chief of which was the violation of privacy to install cameras in a person's home. Our client agreed with this assessment and led us in a brainstorming session to find less invasive ways to passively collect health data.
The next idea we had was to use a wearable sensor to collect data as one of our primary sensors. The client was also not enthusiastic about using a wearable sensor, and asked us to focus on other solutions. The reasons for it included trying to keep the sensors as non-invasive as possible, as well as try to minimize costs. Later, our client decided that wearables could be a reasonable solution to track falls. Despite us not currently implementing wearables in our solution, we are implementing our current solution in a way that allows for wearables to be added.

Our current solution consists of:

- a flowmeter to measure drinking water intake
- door sensors on pantries and refrigerators to measure food intake
- flow sensors and a load cell on the toilet to track bathroom habits

We chose these specific sensors after several weeks of research into sensors. After securing funding for the prototype we put the sensors through testing as described in Section 3.3.

3.6 Results

Currently, sensor testing has been successful. The flowmeter and the door sensor are able to send meaningful data to their connected Raspberry Pis. These Raspberry Pi's are able to send their sensor information to the local Raspberry Pi hub. In turn, the hub is able to connect to the AWS server and store information from the door and flow sensors.

The Android app currently consists of a login screen, a registration screen, and an user screen. The user screen has a home tab and a tab dedicated to each of the sensors (including the BCG and load sensor). Through the registration screen one is able to create an account that is stored in the server. Once an account has been created the user will be able to login and see all current sensor data.

Finally, the AWS backend is able to receive sensor information from the local server via a JSON object sent to the appropriate REST endpoint mapped to the AWS API Service. The mobile client will then be able to hit the REST endpoints with requests, and receive JSON objects containing the correct information to populate the mobile client.

4 Closing Material

4.1 Conclusion

The elderly currently have two options, get a live-in nurse, or move to a nursing home to live out the rest of their days. Our plan is to create an internet of things that will allow for remote monitoring of their health. This will create peace of mind for family members as well as be able to provide some insight to a doctor should one be necessary. Our solution will consist of sensors sending data to a local server. This server will perform any formatting or interpretation of the data and will then send the data to the cloud server for analysis. The cloud server will have to handle requests for that information and will have to send it in such a way that the application will be able to display it textually or graphically.

Next semester, our team will be creating a prototype of a mock living environment to better test our sensors. We will then apply data analytics tools to this data, specifically to form trends and recognize anomalous behavior. In the event of such anomalous behavior, we will ensure a notification is sent to the appropriate user(s).

Further, our next semester plans include adding additional sensors to our solution, as well as improve the UI/UX of the Android application. Lastly, our team will look further into the security of our solution as a whole. As we mentioned throughout, our project deals extensively with health data, and as a result we will need to ensure our solution complies with HIPPA regulations. With that in mind, data encryption and user authentication will be a major focus for our team next semester.

By implementing this solution to the growing problem of people getting old, we hope to improve the quality of life and happiness of our elderly loved ones as they move from this life to the next.

4.2 References

Context-Aware Wireless Sensor Networks for Assisted Living and Residential Monitoring - IEEE Journals & Magazine, ieeexplore.ieee.org/document/4579768/?reload=true.

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4.3 Appendix