IoT Passive Monitoring for Assisted Living Homes

Project Plan

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HIPPA: Health Insurance Portability and Accountability Act of 1996

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 can often have a hard time keeping track of their elderly family members' health, in order to get them the care they need. Elderly people want their family to think that they are in good health, so they lie or mislead their family to keep them from worrying. If the tenant is not doing well and needs medical attention, it is imperative that the family is able to get the tenant that attention in a timely manner. In the case where the tenant 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 designed to solve this problem. Essentially we want to use passive, non-invasive sensors to collect and store data about the subjects 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 help for health issues.

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:** To track when a person is drinking we will put a flowmeter on the sinks. Based on how long the sink is on we can figure out what the sink was used for. 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 Ws. The Raspberry Pi Zero W will send the collected data on to an in-home hub server located on a Raspberry Pi 3. The in-home hub will then 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 22nd 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 be used to store and analyze the collected data sent from node servers. The cloud server will also include a database to store and access the data.

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 20 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 the analytics services provided by our cloud platform, and 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 an intuitive way.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

The final product will include several sensors placed strategically around a house to collect data on the health habits of the person living there. These sensors will send data to a local server, which will act as middleware to a cloud server. There the data will be analyzed for trends. When an outlier is detected (signifying a health concern) a notification will be sent to the mobile app to alert relatives or caretakers.
Most of the project is clearly feasible.

2.2 Functional Requirements

The project and system developed are required to

- Function passively; without any direct input from the subject being monitored.
  - The solution we have developed does this intrinsically.

- Sensors must be passive and non-intrusive.
  - Discussion of basic testing of sensors is in section 2.12.

- Collect data securely into some central location.
  - Our choice in cloud platform will be influenced by the availability of security services.

Tentative requirements include:

- Analytics performed on the data to determine trends.

    - This will be designed and tested during the second semester.

- A mobile application to alert user based on certain events, as found from the data.
    - Tests will be done to confirm that the app displays correct data from the cloud server.

2.3 Constraints Considerations

Constraints

- **Security requirements-** The final product should limit access to sensitive information about individuals to those who need it. Be that a family member, member of staff, or a doctor.
- **Testing-** Testing will be done on basic sensor functionality and extensive details about it can be found in section 2.12.
- **Cost-** cost is a consideration in all of our design choices in an attempt to make the most affordable end product in addition to the expense of hosting a cloud server with as minimal traffic as possible.
- **Software Licenses-** Because this product is likely to enter the commercial market, it is necessary to be sure that we have the right to use any external software libraries we choose.

Non-Functional Requirements

- System must record an instance of someone eating/drinking.
- System must record an instance of someone sleeping.
- System must record bathroom activity.
- App is responsive.
- Data visualization in the application.
- Secure in both data access and lower level system access.
- System can report the loss of a sensor.
- System can report the loss of power or a low battery.

Ethics

This project is developed to ensure ethical operation. Key focuses are ensuring anonymity, and protecting an individual's data as per HIPAA.

2.4 Previous Work And Literature

While this project is in its infancy, the idea is not. As such, our work is not based on a previous senior design project. However, it is important to look for existing research or implementations of this idea that are already on the market. These findings will help shape our design decisions as well as help to identify potential problem areas before they arise.

There are a few existing projects that attempt to capture the goal of this one. The existing projects have all included some type of wearable sensor(*Torres, Roberto L. Shinmoto, et al.*) to monitor various aspects of a person's health or their physical state. This project attempts to limit technologies of that nature but the information provided may yet prove useful.

A quite similar project we found is the Smart Home for Seniors by Qorvo. This project is similar to ours in terms of core concept and architecture. However, our project makes use of a wider variety of sensors, while Smart Home for Seniors makes exclusive use of motion detectors and open/close sensors.

2.5 Technology Considerations

Considering the passive nature of the sensors, it is important to preserve a degree of transparency such that the tenants of the assisted living facility don't feel as if their privacy is being invaded. This lead to the decision that the sensors we needed to select needed to be smaller and thus more easily concealed.

In this system there will be a large quantity of sensors sending information at any given time. This being the case, we decided that the best solution would be to have a local server at each facility or home. Thus the data flow would begin at the sensor, be sent to the local server and then relayed to the cloud server. The cloud server stores all of information for each individual sensor, as well as which tenant the sensors correspond to.

The method by which the sensors communicate will also be an issue to address in this project. We have chosen to go with wifi communication, as the sensors will have both faster communication times and simplified server communication. Using Wifi gives us the ability to send out a ping to a given sensor to ensure the sensor's continued functionality. The downside to using Wifi is the requirement of an internet connection at each facility or home.

An alternative to Wifi is ZigBee for communication between sensors. While Zigbee doesn't require a Wifi connection, communication to a local server is less efficient, and the ability to check a sensor's continued functionality is limited, relative to Wifi.

Finally, the issue of which cloud service to use in the end product. We initially decided on Microsoft's Azure Cloud platform. In our research, we found Azure to have many services that we could take advantage of in this project. These include: Cosmos DB, Stream Analytics, Machine Learning, HDInsight, Notification Hub, and App service. (For more in-depth explanation and interaction of these services, see Fig 3 in the appendix).

Our first alternative to Azure was Amazon Web Services. Having experience with AWS, we know that setting up a cluster, which is crucial for big data analytics, can be implemented easily and works well with Java, in the event we choose to use Hadoop for big data.

Our second alternative to Azure was Google Cloud. Having no previous experience with Google Cloud there would be a learning curve and is harder to secure than Amazon Web Service, which is important due to the fact that we are sending personal information across the network.

2.6 Safety Considerations

Due to the nature of passive sensors, there are virtually no physical safety concerns in our project. However, the quantity and nature of the data collected provides some potential privacy concerns. Thus, we will need to ensure the data transmission and storage is secure.

2.7 Possible Risks And Risk Management

A substantial risk with these passive sensors lies in edge cases where the data collected by the sensors is not useful. This could result from inconsistencies as to how tenants eat or differences in faucet usage that could lead to inconclusive data about drinking habits. Our team will have to consider all possibilities for these various edge cases to ensure that the sensors are collecting data that is meaningful and can provide insight to a tenant's health trends.

Another risk for our project is investors having different ideas or plans regarding software or hardware than we come up with for the project. Our project is in a unique situation: this project is potentially the flagship product of a new entrepreneurship. That presents specific challenges when it comes to capital that could dictate what our final product turns out to be. It was pointed out by our Client that our software solution could change if an investor comes onboard the project and needs to interface with a specific program. This would nullify some of the work we have put in to our original solution, and require us to start from scratch for some aspects of the project. Our team will need to stay prepared for risks such as these and be aware of other options than our current solution.

2.8 Project Proposed Milestones and Evaluation Criteria

The first key milestone is buying the sensors we propose. For the first portion of the semester we have been researching and compiling a list of possible sensors to use for the project. After comparing different sensors with similar functionalities to each other and finding the strongest candidates, we presented a finalized list of sensors we need for the project to the client with justifications of why they are the best and why they are necessary. The client will discussed the list with us and eventually approve a finalized list of sensors to buy.

The next step for the project is testing the sensors. A list of the chosen sensors can be found in 1.3. The initial basic testing plan for the sensors can be found in Section 2.12.

The next major milestone is successfully storing data from the sensors on our cloud server. For this to happen we have set the sensors up in a simulated environment. The flow sensor is fixed into a testing apparatus (Fig 2), the door sensors will be attached to cabinets in a kitchenette, and the load cell will be fixed under/within a toilet seat attached normally to a toilet. All of these setups will be within the same building where the client works. The objects the sensors are attached to will be used routinely throughout the day, with a analog log kept of the times they were used. The analog log and the cloud server data will be compared for discrepancies, and smaller tests will be proposed to isolate any discrepancies discovered.

The final milestone of the first semester will be when the application can update in effectively real time; showing the successful transmission from sensor to server to cloud to app. To test this, the app will be open and observed while the sensors generate events in their respective apparatuses.

2.9 Project Tracking Procedures

Our client presented us with a tentative schedule at the beginning of the semester. In our first meeting with the client we refined the tentative schedule and have been keeping up with it since. To keep track of progress we are discussing it in our meetings and it is recorded in our meeting notes as well as weekly reports. We intend to stick with our planned schedule and falling behind that schedule in any area will result in discussion about how to catch back up.

2.10 Task Approach

We place sensors in locations to observe daily habits:

- Door sensors are attached to cabinets, pantries, and refrigerators to monitor the tenant's eating habits.
- A flowmeter is attached to the sink the tenant uses for drinking water.
- A load cell is attached to the toilet seat along with a flowmeter attached to the toilet's water supply to monitor hygiene.

These small sensors are attached to small Raspberry Pi Zero Ws which collect the data from the sensors. The data will be sent over Wifi to a Raspberry Pi 3, which functions as in-home local server for the tenant's data. The data is then sent from the local server to our cloud server, where analytics will be performed using our platform's analytics services. The analyzed data for the tenant will be available to the user on the mobile app.

We chose to use passive sensors as our method of collecting data because other methods were to invasive and compromised the subjects privacy. The sensors that we chose will be able to collect data intended to monitor trends in daily habits. We spent the first several weeks of the project researching sensors, and another few weeks will be spent testing the sensors and getting them calibrated. A major weakness of this approach is that we will not be able to collect some important health information that would be helpful in identifying health risks such as the current heart rate.

We chose to use Raspberry Pis in this prototype because they were the easiest and cheapest option for small local controllers and servers. Part of testing the sensors will involve getting the Raspberry Pi Zero Ws hooked up to the sensors and receiving data from them. An important weakness of this approach is that the product won't look as nice as if we used an embedded system for this functionality. This is unavoidable because designing an embedded system would be too costly and difficult for this project.

Totaling the cost of our hardware components for our project gave a net total of $206.09, see section 3.4 for a detailed breakdown.

Azure was initially chosen as our cloud server because it gave us access to a lot of useful services. Additionally, some of the other frameworks work well with the Microsoft ecosystem including Xamarin and our IDE of choice Visual Studio. One weakness of this approach is that many of us had never used Visual Studio before and Azure was new to all of us.

Our team chose to use Xamarin development software because we were impressed by its ability to use mostly shared code for the development of IOS, Android, and windows apps. Initially we want to focus on making an android app, but in the future it will make expansion easier. A clear weakness of Xamarin is that it can make IOS apps but only from a mac computer.

We chose to use a mobile app to display the data to user's because it is more convenient to use at any time and receive notifications.

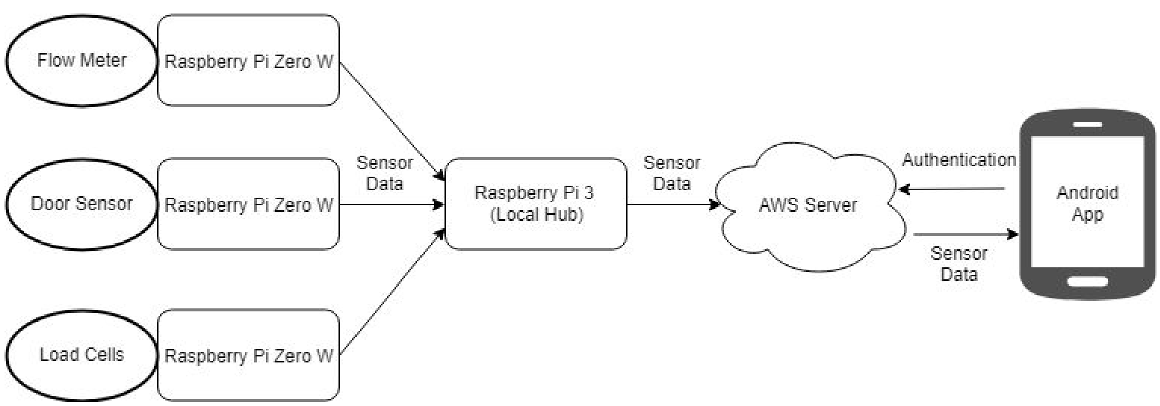

Figure 1

2.11 Standards

We will be building a simulated testing environment for each of the sensors described further in section 2.8. Initial testing of the sensors this environment poses no ethical dilemmas. However, our client has discussed testing our product in an assisted living home on residents for an extended period of time.

One ethical concern with our project is that collecting this health data will be a gateway into other forms of monitoring. Our sensors are only capable of collecting data on what they are currently designed to, so there is not a possibility of sensors becoming more invasive as time goes on. As the company grows and expands it is likely that there will be more sensors added to the platform to monitor more things, but tenants or their caretaker will always have the option to opt out of sensors that they are uncomfortable with.

Another ethical concern is that the sensors are an invasion of the tenants privacy, but our team argues that the sensors actually give the tenants more privacy. People in assisted living homes have more personal freedom and are granted considerably more privacy than those in retirement homes. Our solution allows tenants in assisted living homes to prove to their family that they are staying healthy and capable of living on their own. In many cases the alternative that these tenants would have is to go into a retirement home which, as mentioned above, is much more invasive and restrictive.

2.12 Testing

Our simulated test environment will be structured as follows:

Door sensors:
Attach two sensors to cabinets to insure they can function in parallel. Success includes not disrupting the use of the cabinet and sensor collecting accurate data for each sensor independently. The door sensor will be left installed and then data will be collected over the course of a day.

Load Cell:
Initial testing will involve putting objects of various sizes and weights on top of the cell (between 5-50lbs) and checking that the weight data is correct. After we have determined that the load cell is accurate and can handle the preliminary weight without fault we will test with human subjects.
The load cell will be put under or within a toilet seat, then a test subject (various team members) will sit on the toilet seat. For success the load cell must collect accurate data and allow the toilet seat to lie flat.

Flow Meter:
Construct an apparatus consisting of a bucket and a valve attached to a flow meter with an additional bucket to collect the water. First check that the sensor picks up the time that the water is going through. Next check that the amount of water can be collected accurately. Let water flow through at different rates and see if the metrics received in various combinations are accurate.

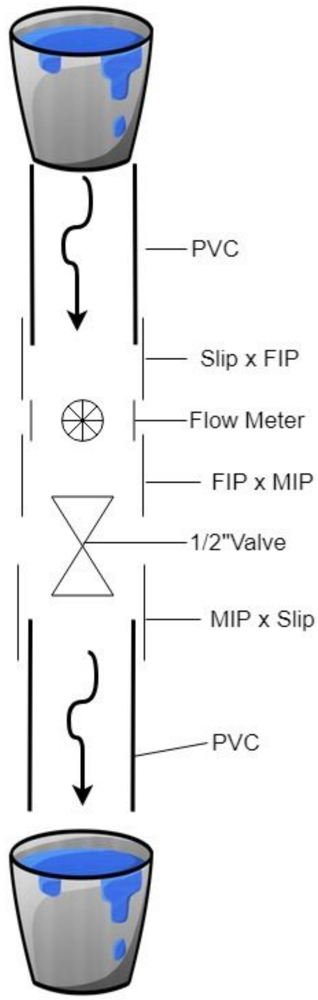

Figure 2. Flowmeter testing apparatus

Application:

Ensure that the application can display the data stored in the database.

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

High level timeline:

January	February	March	April
-Brainstorm various sensor use cases -Determine what data will be useful to health monitoring -Generate and justify list of sensors to collect data	-Work on hardware and software flowcharts -Research cloud/ local server solutions -Brainstorm ways to bypass selected sensors -Begin work on data visualization solution	-Present and finalize sensors and use cases -Design and build tests for sensors -Implement interface between sensors and storage -Work on storage system (cloud and local)	-Refine storage solution -Begin collecting test data -Finish MVP of app prototype -Prep for in depth testing over the summer (done by Client)

September	October	November	December
-Will be determined at the end of August	-Will be determined at the end of August	-Will be determined at the end of August	-Will be determined at the end of August

Detailed timeline:
*See Section 4.3 for Gantt Chart

For the second semester we will begin implementing analytics to find health risk factors in the collected data. This analysis will then become the focus of the mobile app. We may also begin using additional sensors to collect a wider range of data, for example, sleep is an important factor for health but we will not be using a sleep sensor in the first semester.

Deliverables:

1. Server
    1.1. Research into upscalable cloud platforms capable of storing and performing data analysis
    1.2. Implementation of a cloud server based on research
2. Data collection
    2.1. Research into passive, non-invasive sensors to monitor sleep, eating/drinking, and bathroom habits
    2.2. Create a simulated testing environment to demonstrate data collection functionality
    2.3. Research into and implementation of a data transmission solution
    2.4. Establish a local server to handle communication with the sensors and the cloud platform for scalability and simplicity.
        2.4.1. The local server solution is a tentative plan. Further work and research may deem it necessary to use something else as a relay between the sensors and the cloud server.
3. App
    3.1. Research data visualization techniques and libraries
        3.1.1. Initially, a simple textual display of available data will be implemented.
        3.1.2. Time permitting, more research into graphical visualization of usage history will be performed. An implementation will be provided, should research prove sufficient.
    3.2. Provide a prototype implementation of data visualization based on research

3.2 Personnel Effort Requirements

Task	Amount of Personal Effort
Compile and Finalize List of Sensors	High
Hardware Flowchart	low
Project Plan	low
Design Document	low
Design and Implement Sensor Testing	High
Implement Data Storage System	Moderate
Implement Data Visualization	Moderate

The three tasks that will take the least amount of effort are the hardware flowchart, project plan, and design document, but this is not to understate the importance of these documents in the least. These are tasks that we have been directly or indirectly working on since the beginning of the project as we have been meeting as a team, with our client, or with our advisor. Once the content is discussed as a team we each completed each of our assigned parts of the Project plan with relative ease. The same will go for the hardware flowchart and the design document, although these we be created together as a team to an even greater degree.

Implementing a data storage system and implementing data visualization will require a moderate amount of effort. While these are serious roles for the project they will take a smaller amount of effort than other tasks because there are pre-existing systems for both areas that we can learn from and model our designs after.

Finally, compiling and finalizing sensor list and designing and implementing useful sensor tests will most likely be our greatest challenges. The reason for this is because these are new areas that we will be able to find little to no information for our specific project. We may have to go through several rounds of debate and reasoning to come up with the best solutions that we are able to implement for these tasks.

3.3 Other Resource Requirements

There are several things that we will need to acquire to implement our project and the first are the sensors. This is the heart of our project and because of that it is the first thing on our agenda. This sensor list will be scrutinized over and over again that the sensors being bought are in fact the best sensors that we will be able to afford for our application.

Another important resource we will need is a Raspberry Pi. As it stands now the Raspberry Pi will be our device that will have our data from the sensors funneled into. This will be our point in between the sensors and our storage device.

Lastly, we will need to have testing environments for our sensors. There will be two different directions that testing can go. 1.) We attached sensors to existing infrastructure that would be identical or similar enough to our use cases that we could accurately test the sensors. 2.) We create our own test environment for our sensors(e.g. Have water flow through a pipe that a flow meter could then measure).

3.4 Financial Requirements

Resource	Cost
Sensors	Displayed in table below
Cloud server subscription	Initially free
Building materials for simulation environment	Unknown

Sensor Type	**Part/Model Number**	**Quantity**	**Price per Unit**
Flowmeter	YF-S201	2	$8.20
Load Cell	SEN-10245	4	$9.95
Load Cell Combinator	BOB-13878	1	$1.95
Load Cell Amp	SEN-13879	1	$9.95
Door Sensor	375	2	$3.95
BCG (Postponed)	*SCA-11H*	*1*	*$154.00*
		Total	$76.00
Pis			
Type	**Part/Model Number**	**Quantity**	**Price per Unit**
Pi 3	RASPBERRYPI3-MODB-1GB	1	$35.64
Pi Zero W	Product ID: 3708	2	$14.00
		Total	$63.64
Misc.			
Item	**Part/Model Number**	**Quantity**	**Price per Unit**
SD Card	x2 16gb /SDSDB2-016G-AFFP	2	$12.99
SD Card	8gb/ SDSDUN-008G-G46	3	$5.99
Power Supply	Product ID: 1995	3	$7.50
		Total	$66.45
		Net Total	**$206.09**

4 Closure Materials

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 consists of non-invasive sensors passively collecting health habit data and sending it to a cloud server. The data stored on the cloud server is analyzed to find health risk factors and the data as well as risk notifications will be displayed to users on a mobile app. 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

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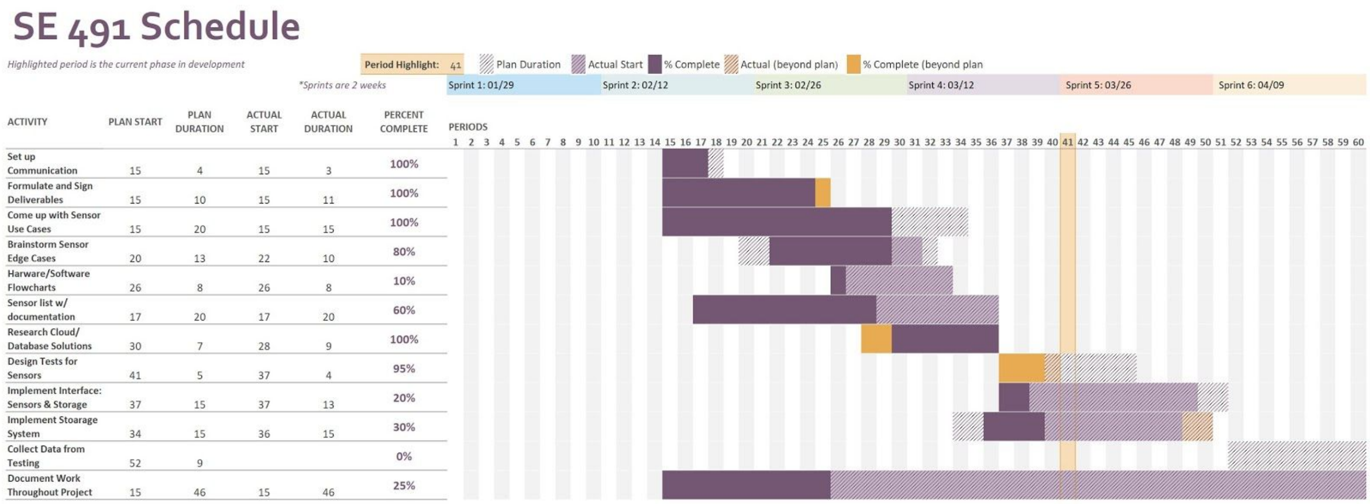
Torres, Roberto L. Shinmoto, et al. “A Battery-Less and Wireless Wearable Sensor System for Identifying Bed and Chair Exits in a Pilot Trial in Hospitalized Older People.” *PLOS ONE*, Public Library of Science, journals.plos.org/plosone/article?id=10.1371/journal.pone.0185670.

4.3 Appendices

Gantt Chart



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Set up Communication	15	4	15	3	100%
Formulate and Sign Deliverables	15	10	15	11	100%
Come up with Sensor Use Cases	15	20	15	15	100%
Brainstorm Sensor Edge Cases	20	13	22	10	80%
Harware/Software Flowcharts	26	8	26	8	10%
Sensor list w/ documentation	17	20	17	20	60%
Research Cloud/ Database Solutions	30	7	28	9	100%
Design Tests for Sensors	41	5	37	4	95%
Implement Interface: Sensors & Storage	37	15	37	13	20%
Implement Stoarage System	34	15	36	15	30%
Collect Data from Testing	52	9			0%
Document Work Throughout Project	15	46	15	46	25%

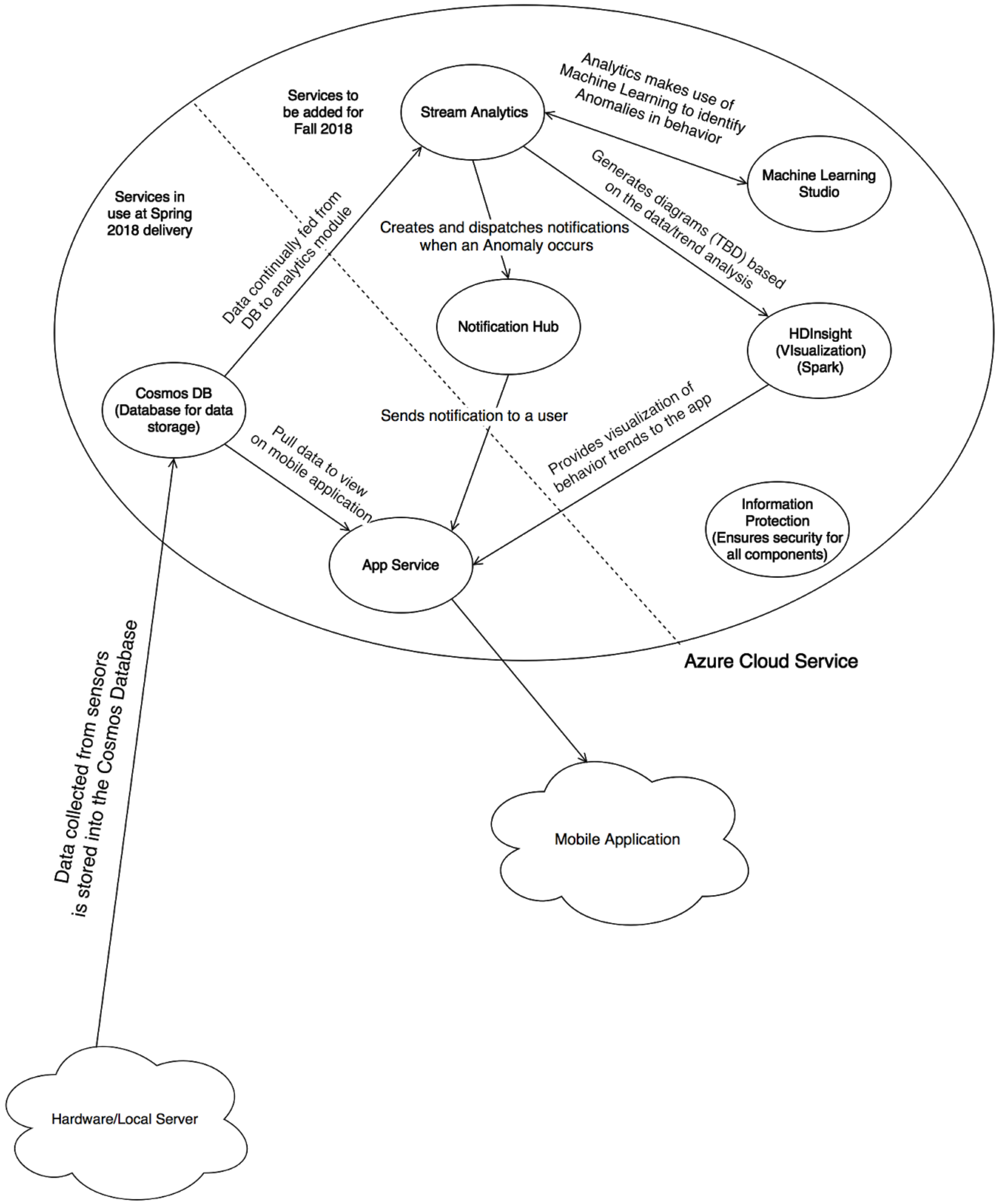


Fig 3. Azure Services and Interaction.