Fig. 1. PRT - Morgantown, WV. Adapted From [1]

Improving the PRT through Data Capture and Analysis

PRT Capstone (Group 4)
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1 Project Goals

1.1 Outline

The PRT capstone group will implement data collection technology to address a fundamental lack of ability to gather information about PRT car GPS location, capacity, and power utilization. Implications of this project include increased safety and the ability to analyze collected data to make generalizations about PRT usage and provide new, efficient solutions to common issues.

1.2 System

Collection of PRT usage data will be done via a telematics device that is equipped to a PRT car. This solution is considered a subsystem of the larger PRT System as its operation is separate. The work done by this project group will be done in addition to the typical operation of WVU's PRT System, ensuring the solution does not interfere with the expected daily operation of the PRT.

The PRT data collection system will be implemented on each car, forming a larger network of Raspberry Pi devices. The following report describes the individual Raspberry Pi collection device, but it should be noted that the concept is scalable.

2 Design Requirements and Constraints

2.1 Technical Requirements

2.1.1 Functional Requirements

The PRT data collection project has functional requirements that include PRT location tracking, power usage, and vehicle occupancy. Other requirements include displaying data in a single-page user interface, calculating time to complete a ride as well as various accompanying statistics, and supplying data to PRT officials to increase the efficiency of the PRT system.

1. Analyze location and power data.
2. Display data in a single-page user interface.
3. Track vehicle occupancy
4. Track vehicle location and time to complete a ride
5. Supply data to PRT officials to increase the efficiency of the PRT system

2.1.2 Engineering Requirements

In order to gather data about the PRT cars, it is necessary to equip the PRT cars with a Raspberry Pi 4 Model B as well as additional sensors such as a current clamp and LiDAR to track occupancy. The devices should be non-visible to ensure they are not targeted by passengers and transmit the data wirelessly while at the platforms. The transmission will be encrypted to prevent session hijacking and will be immediately stored in a SQL database. The data collected will then be used to make predictions to better improve the PRT.

1. Equip PRT cars with a Raspberry Pi 4 Model B.
2. Attach additional sensors (GPS, Current Clamp).
3. Devices should be non-visible to the occupants.
4. Data will be transmitted to the database while at PRT platforms.
5. Data will be transmitted wirelessly.
6. Data transmitted with be encrypted.
7. Data will be stored in a SQL database.
8. The database will be kept securely to ensure the confidentiality of data.
9. Use of Infrared or LiDAR to determine vehicle occupancy.
10. Use data collected to make predictions

2.2 Broader Constraints

2.2.1 Public Health, Safety, and Welfare

In order to ensure the Public Health and Safety of the passengers of the PRT, the operation of this project's data collection solution will remain separate from the standard PRT System operation so as to remove the ability for our solution to create new or more frequent issues with PRT operation. In terms of data collection, only necessary information will be collected with human-safe collection methods. For example, the collection of capacity data will be done using LiDAR sensors that use Class 1 lasers. A Class 1 laser is considered safe for human eyesight and poses no risk to eye health and safety The information collected will be used to inform decisions made about future PRT operation and future safety issues.

2.2.2 Global Constrains

Due to the locality of the project, there are no meaningful global constraints to follow. Despite the fact that this project will only be implemented for WVU's PRT System, the solution should be implemented in such a way that it may be applicable to different transportation methods worldwide.

2.2.3 Culture Constrains

As with the Global implications, the locality of our solution does not require extensive cultural considerations. Our implementation will remain unobtrusive. However, a potential cultural conflict may be present in the fact that our information gathering includes tracking PRT car capacity, and thus individuals. To avoid controversy, our solution will use LiDAR cameras to conduct non-identifying imaging.

2.2.4 Social Constrains

The concept of facial tracking is often viewed as intrusive by the public. Therefore, in our implementation of a PRT data gathering system, we will avoid controversy and potential privacy infringements by using LiDAR sensors to conduct imaging in a non-intrusive way. The imaging data collected will be free from identifying information and thus allows the project to avoid privacy issues.

2.2.5 Environmental Impact

The application of our project on the PRT System will not create new environmental hazards. The power consumption of our Raspberry Pi based system is between 2 Watts for idle state and 7 Watts for 400% CPU load [2]. This amount of power is negligible in terms of the scale the PRT system operates on.

The PRT System, which runs completely on electrical power, removes 2.2 tons of CO2 emissions each year [3]. The purpose of tracking statistics related to power consumption of the PRT System is to identify ways in which the environmental savings can be further increased.

Also, in order to reduce energy waste during downtimes, the Raspberry Pi system can be accessed remotely to be shutdown.

2.2.6 Economic Factors

The novelty of our implementation lies in its construction. By leveraging components that are available on the public market, we have been able to create a demonstration of our solution with less than $100 USD. It is necessary for a scalable system to consider the ways in which costs can be reduced in order to present a viable and accessible solution.

Marketing Requirements

1. An automated design for monitoring GPS, AC power, and passenger amount.
2. Low-cost devices compared to dedicated hardware.
3. Reduce congestion at PRT stations.
4. Protect PRT carts from damage due to higher-than-normal voltage.
5. Prevent PRT cars from unintentional shutdowns.

Mapping of Marketing Requirements to Engineering Requirements Most of the requirements for our project's marketing and engineering aspects are directly proportional to each other, as using the hardware and software stated in the engineering requirements will allow us to collect enough data to meet the marketing requirements. Our engineering requirements will not directly cause lower congestion times, protection from combustion, and unintentional shutdowns. We will only collect the data from our project in a non-harmful process and send it to the PRT engineering team, who can then use the data to make decisions to improve the PRT based on the data.

Engineering and Marketing Requirements Trade-off Chart

Table 1: Engineering & Marketing Rade-off Chart w/ Legend

✓: Meets Requirement	- : Low	+ : High

	Speed	Performance	Cost	Security	Real-time Efficiency
Data transport (TCP)	-	+		+	
Data encryption (TLS)	+	+		+	
Data storage (micro SD)	+				
GPS			-		
Wireless Modem					✓
SIM Card (LTE)	-	-	**-/mo**	+	✓
SIM Card (4G)	+	+	**+/mo**	+	✓
Wi-Fi	++		-	-	-
AC power sensing (Current Clamp)					
Raspberry Pi	✓	✓	-		
LiDAR	+	+	+/-		

Note: SIM Card cost is an ongoing cost encurred monthly

2.2.7 Industry Standards

Applicable Constrains and Standards

1. **Legal:** This project will have no negative impact on students riding the PRT, so there will not be any legal constraints for our PRT project.
2. **Privacy:** There isn't going to be any personal information collected on students riding the PRT. Instead, we will use LiDAR to determine car capacity.
3. **Sustainability:** This device can be used for several years to get data from the PRT. The device will also have secure housing to prevent outside forces from damaging it, increasing its sustainability.

3 Project Management

In the development of the project throughout the design semester, our project management approach most closely followed the Agile development lifecycle. While we did not spend too much time laying out our approach, we used previous experiences to create a development process that works best for each member of the group. The features of such process, completed weekly or biweekly, include a weekly group meeting to discuss project progress, individual work time, group testing, and a reevaluation of progress upon each deliverable or goal met. The goals for each cycle of our development were determined on a rolling basis, opting to identify which aspects of the project should be focused on for the week that we met.

We schedule non optional meetings at least once a week, with occasional meetings occurring after class on Wednesdays and Fridays as needed for group work and testing. Our document organization was done through common cloud platforms such as Google Drive, GitHub, and Discord. In the future, a more rigid set of rules for a development lifecycle would lend the group well to meet more deadlines, as spending time each week to decide goals can become inefficient.

4 System Design

4.1 Overall Architecture

4.1.1 Overall

The Raspberry Pi Model 4B collects data from three devices—an imaging sensor, GPS, and a current clamp. The imaging sensor counts the number of people inside the PRT car, the GPS hat tracks the current location of the PRT car, and the current clamp monitors the voltage and current being drawn by the PRT car. These three devices transfer their data to the Raspberry Pi. Once the Pi is stopped for about 5 seconds and has a Wi-Fi connection to WVU Encrypted, the data transfers to a SQL database hosted on a Google Cloud server instance. Next, a web application retrieves the data from the SQL database to visualize it, providing graphs and charts to analyze relationships between the data. The overall architecture is in Figure 1 and Figure 2, which represents the system functionality from top to bottom.

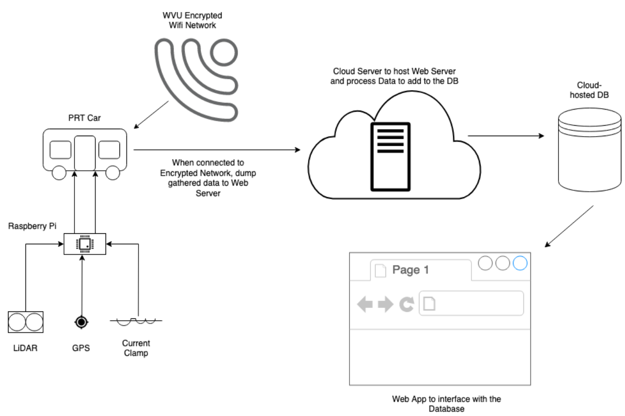

Fig 2. Overall Architecture

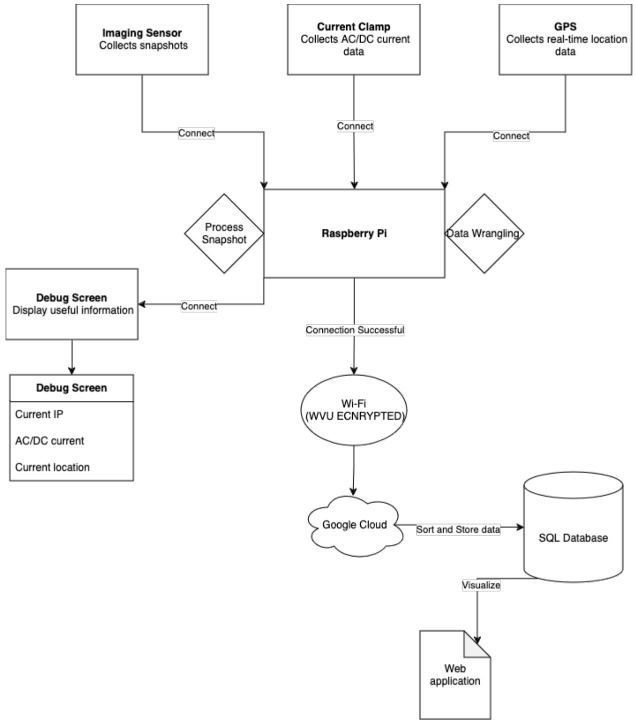

Fig 3. System Functionality

4.1.2 Hardware

Four devices fit onto the Raspberry Pi for the collection of data. The connections are shown below in Figure 4. The Pi communicates with the GPS for real-time location. The antenna plugs into the GPS and realizes the data collection. The current clamp collects voltage levels and current in an AC environment, recording it to the Pi. A debug screen displays the GPS status, IP address, and the current AC reading for debugging purposes. The debug screen displays this information to ensure the hardware components work as intended. Lastly, the imaging sensor collects snapshots of people for detecting the number of people in a PRT car. The snapshots go to the Raspberry Pi, where the Pi will use an algorithm to count the number of people in that snapshot.

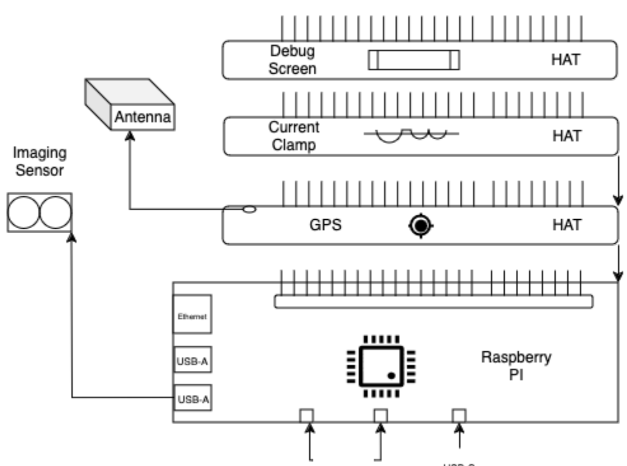

Fig 4. Hardware Architecture

4.1.3 Software

When the Raspberry Pi obtains a Wi-Fi connection through WVU Encrypted and is at a standstill for 5 seconds or more, data goes to Google Cloud. Figure 5 represents the process of data transfer once Wi-Fi connects. The Google Cloud hosts a SQL database that sorts and stores all the metadata from the Pi system. A web application uses this sorted data from the SQL database, providing visualization through charts and graphs to highlight relationships in the data. The web application provides opportunities for identifying potential risks in the system, such as irregular AC currents or voltage on a specific PRT car.

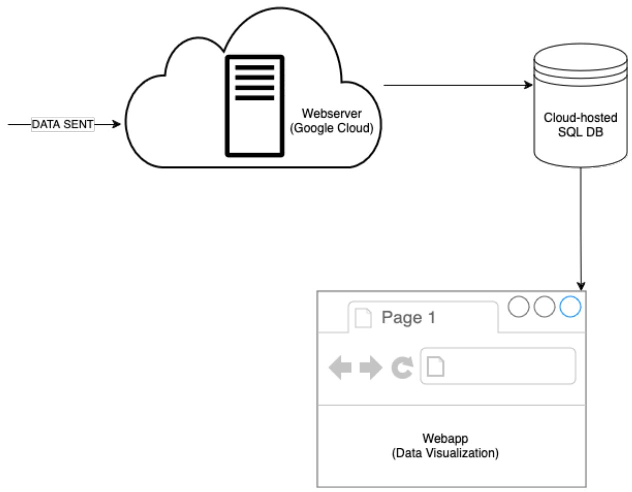

Fig 5. Software Architecture

4.2 System Design

The solution that has been designed is an information system, a combination of hardware and software aimed at collecting and processing data and distributing it to a database over the internet. Further designing is required in collaboration with the PRT engineers to understand the physical implementation restrictions.

4.2.1 Timeline

The PRT Capstone project timeline fits into two semesters. The whole timeline is shown below in Figure 6 as a Gantt chart. The first semester focuses on the hardware portion of the project: connecting the GPS, current clamp, and LiDAR to the Raspberry Pi and testing each for successful integration and creation of a demo. Once the integration is successful, the device will be tested by connecting it to the PRT. Ending the first semester, after successful testing, the Pi is placed into an enclosure. The second semester focuses on the software portion: configuring data to send to the Google Cloud, which hosts a SQL database. Google Cloud will format the data before placing it into the SQL database, where it's sorted and stored. Next, a web application interfaced with Grafana will visualize the sorted data with charts and graphs.

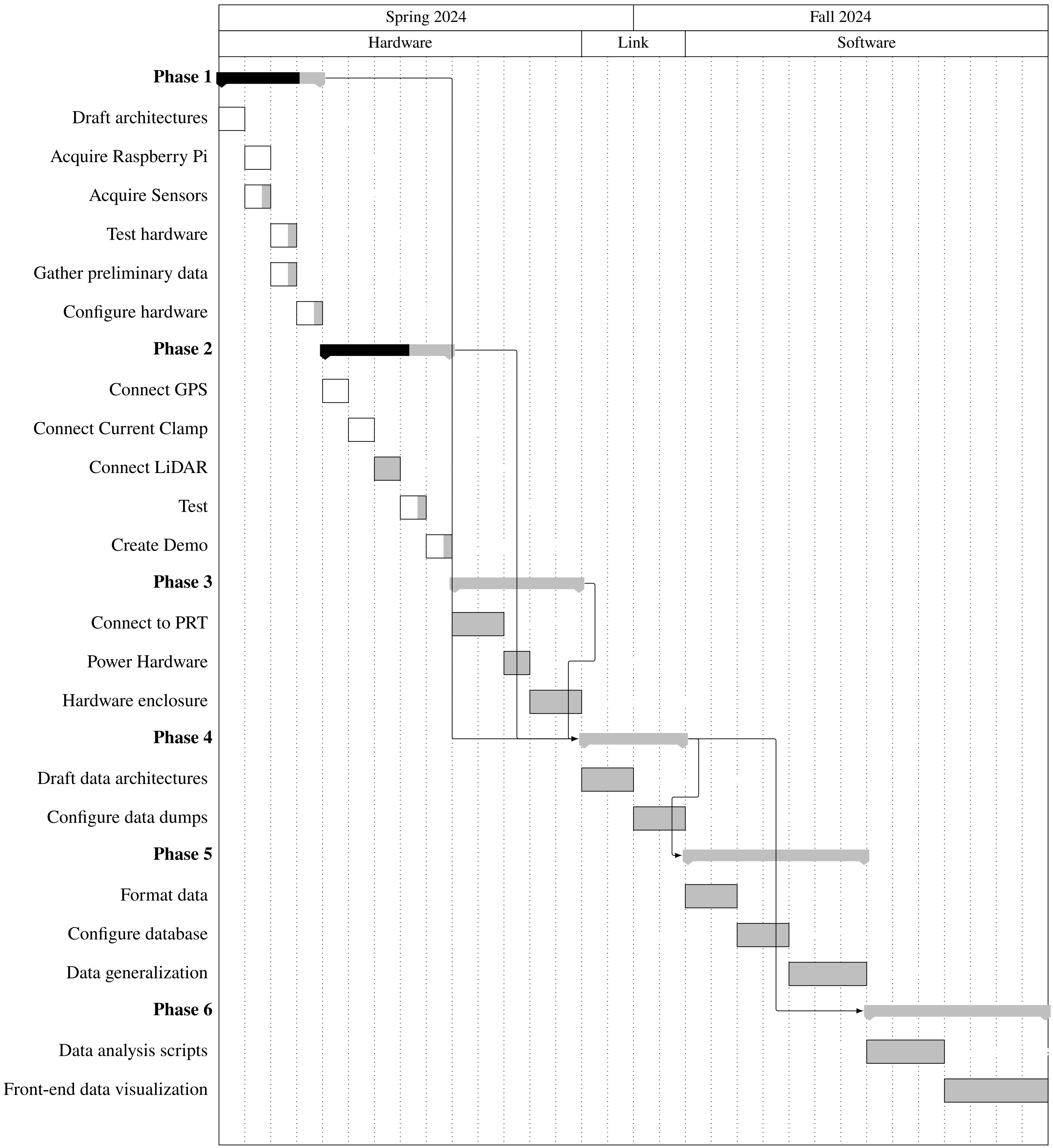
Spring 2024
Fall 2024
Hardware
Link
Software
Phase 1
Draft architectures
Acquire Raspberry Pi
Acquire Sensors
Test hardware
Gather preliminary data
Configure hardware
Phase 2
Connect GPS
Connect Current Clamp
Connect LiDAR
Test
Create Demo
Phase 3
Connect to PRT
Power Hardware
Hardware enclosure
Phase 4
Draft data architectures
Configure data dumps
Phase 5
Format data
Configure database
Data generalization
Phase 6
Data analysis scripts
Front-end data visualization

Fig 6. Timeline as a Gantt Chart

4.2.2 Design Choices

Cost, privacy, safety, and protection are important factors to consider throughout the implementation of this design. With a 200-dollar budget, making inexpensive decisions is crucial. Although, LiDAR can be an expensive device that would consume 200 dollars alone [4]. There are also concerns with eye protection due to the use of lasers [4]. LiDAR using class 1 lasers is considered safe for human eyes and must be necessary for this project [5]. Furthermore, finding the right one that is inexpensive is critical. However, if such cases do not exist, a small camera for a Raspberry Pi would be a good alternative because they are cheap [6].

To mitigate privacy concerns in this project, encryption at rest, in transit, and use is necessary. The camera, if used, will take snapshots of the PRT car at specific intervals to determine the number of people inside. Furthermore, using Wi-Fi with this device instead of having a cellular connection keeps potential hackers from attempting to access the device when the Raspberry Pi is disconnected from Wi-Fi and collecting data.

Increasing the safety of passengers with the device is vital for preventing or detecting harm done by the device itself or the PRT car. As noted earlier, the LiDAR sensor must have class 1 lasers to deter eye damage to passengers. In the event of faulty wires on the PRT car, the current clamp connected to the device will detect potential hazards and display them on the web application. Any irregularities in the current clamp data are identifiable in the graphs and charts created in the web application.

Protecting the Raspberry Pi and its connected components must be a high priority. The device location on the PRT car is essential to prevent any passengers from breaking the device. Placing the device inside the PRT car–under the hood–prevents this destruction from a passenger. Other factors like heat and electricity could also break this device. To counteract these factors, a conformal coating, a type of electronic water-proofing, will shield the device circuitry. To avoid catastrophic power supply issues, the Pi will be battery-powered if the Raspberry Pi system is entirely separate from the inner workings of the PRT car. If the Pi connects to the PRT car's inner wiring, it will use a boost-buck converter to drop the PRT car's voltage down to 5v. This also protects the Pi against low and high voltage scenarios

4.3 Risks

As with any project, there are risks involved in implementation of this project. For the PRT cars, environmental factors like rainy weather conditions or elevated heat or cold temperatures may pose a threat to the data collection system or impact the system performance.

In order for the project to be a convenient solution for the data collection problem, the solution needs to be easily maintainable. Ensuring maintainability is crucial post-installation for system accessibility.

Security is paramount, with data encryption and secure transmission protocols mitigating risks.

Additionally, the choice of LiDAR sensors directly affects passenger eye health, highlighting the importance of careful selection.

4.4 Test Plans

To ensure that our solution meets the requirements specified, multiple stages and techniques of testing will be conducted. As we are currently developing proofs of concept, our testing for this stage involves gathering data and observing that it is accurate and useful. It is during this stage that we must observe the practicality of our initial ideas, noting what works and what doesn't.

Once the proof of concept for the entire design can be established, the next stage of testing will involve implementing a fully functional prototype in an environment that resembles the goal environment. For this project, that environment is the PRT. We must simulate the PRT, to the best of our ability, to create a demonstration of the product. In this environment we will observe how our solution performs, measuring it against our predetermined goals.

Then, the solution must be stress tested to determine how the system will perform under different circumstances, some being situations that are not ideal. By doing this, we can properly communicate the ranges of which the solution works.

Once determined that the implementation is ready for use on the PRT, the data collection will begin on just a single car. Should the system perform to standards, it could then be implemented on all cars in the PRT System.

Overall, the testing process for the PRT data collection system involves several key stages. Initially, proof of concept testing verifies the feasibility and practicality of the system's initial ideas, ensuring accuracy and usefulness of gathered data. Prototype implementation follows, simulating the PRT environment to assess real-world performance against predetermined goals. Stress testing then evaluates system resilience under various conditions, identifying potential weaknesses for improvement. Finally, field testing on a single PRT car validates functionality, usability, and reliability before potential system-wide implementation. Each stage serves as a critical checkpoint, iteratively refining the solution to meet project goals efficiently.

GPS Data Visualization Proof of Concept: *Objective:* Using the GPS on the PRT to visualize a path as proof of concept.

Procedure: We will be attaching the GPS to the PRT vehicle and record its path through the GPS data. We will then use the test run to help us visualize the path traveled by the PRT vehicle.

Outcome to be achieved: We should be able to visualize the route from the GPS data and this will then demonstrate the effectiveness of the data collected by the GPS data during its route.

Current Clamp Testing with Space Heater: *Objective:* Verify the functionality of the current clamp on a space heater to show its effectiveness as a subtitle for the internal PRT

Procedure: We will attach the current clamp to a space heater and record its power usage. We will take and analyze the data received from this and measure the power of consumption.

Outcome to be achieved: We should be able to retrieve data from the space heater that shows the current clamp is accurate and working perfectly.

5 Individual Contributions

5.1 Andrew DeGarmo

Role: I chose to attend every meeting we had with questions, concerns, and ideas about the project goal so we could outline the team's objectives clearly. As a group, we ensured each member was on the same page. I kept track of our budget and the amount we had spent. Although the roles in the team weren't clearly defined, we equally shared responsibilities such as ordering materials, tracking the budget, setting our achievable goals before the next meeting, and brainstorming ideas during meetings.

Tasks Completed: The tasks I completed during this semester were sharing thoughts and ideas contributing to the goals of our project. I attended all meetings and ensured we were all on the same page before dismissing–having a clear understanding of our roles and responsibilities before meeting again was important to clear up confusion among the members. I ordered the parts for the current clamp and designed the hardware architecture, software architecture, and system functionality diagram. I contributed to the overall architecture design at the beginning of the semester. I contributed to the design choices throughout the semester and wrote the design choices section in the Final Report. I also completed the Overall architecture, Hardware architecture, Software architecture, and Timeline sections. The last design I completed was to create the wire for the current clamp. I created a pinout architecture from the GPS and the Raspberry Pi.

Results: The architectures from Figure 4 shown above were modeled to create the Raspberry Pi and its hardware connections necessary to finish the hardware portion of our project. Interfacing the current clamp onto the Raspberry Pi and GPS module correctly required knowledge of the Pi and GPS pinout. Figure 7 represents this pinout configuration and was used to connect the current clamp Pi hat to the Raspberry Pi.

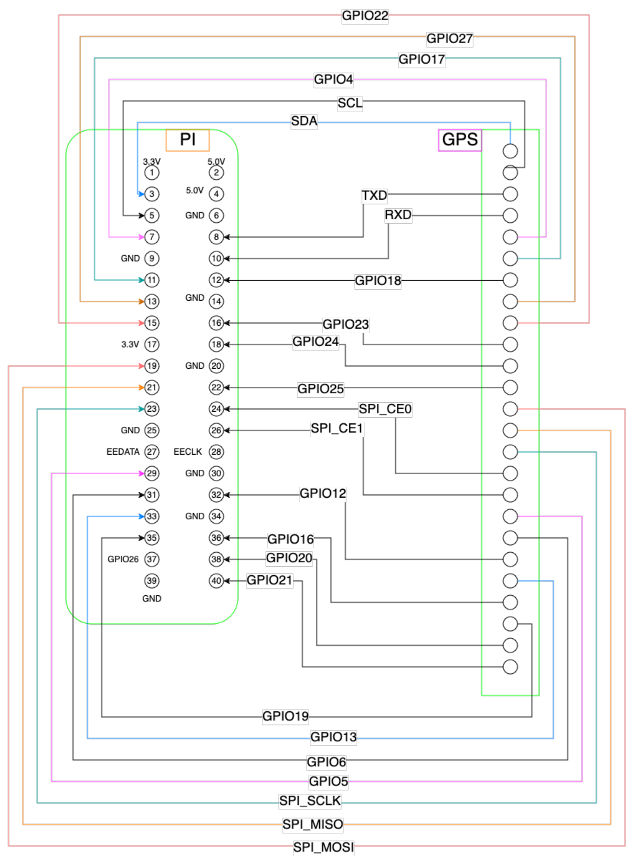

Fig 7. Raspberry Pi to GPS pinout

5.2 Samesh Desai

5.3 Emma Kupec

Role: My role within the team was not consistent. I would consider myself to be one of the organizers, however most often we shared responsibilities. Within the team, I often found myself taking charge of being aware of the goals we needed to achieve and helping to facilitate the completion of such goals. My role as a designer was shared this semester with nearly all of my team members, as we mostly contributed equally to brainstorm sessions and communicated as a group about decisions regarding our proposed design.

Tasks Completed: The following tasks completed this semester were a collaborative effort. At the beginning of the semester I helped facilitate initial contact with our mentor and proposed many ideas for how to get started with the project. Throughout the designing process, I contributed equally to group brainstorming sessions, discussions, build days, and test days. I was available to work on class assignments and made sure I was reviewing group work to ensure an optimal product.

5.4 Kevin Meyers

5.5 Omar Ndiaye

Role: As a team member, my role was versatile, adapting to the needs of the project as they arose. Primarily, I focused on ensuring my tasks were completed efficiently and effectively. This involved actively listening to project requirements and trying to get it done before the due date. Additionally, I contributed to group brainstorming sessions by listening to different ideas and trying to implement them, and I also tried to be very collaborative and have an understanding approach to all project activities.

Tasks Completed: For this assignment I contributed to the tasks in a collaborative effort with the team. As the project progressed, I participated in some group brainstorming sessions, discussions. I ensured to get some of my team members to review my group work to maintain the quality and get fresh ideas on what more to include. For this assignment I completed the risk, and test plans section with the GPS Data Visualization Proof of Concept and Current Clamp Testing with Space Heater.

5.6 Greyson Weimer

Role: My role within the team was primarily technical, leveraging my breadth of knowledge across Electrical Engineering, Computer Engineering, Computer Science, and Cybersecurity. I helped with planning and designing the current clamp measurement system. I have extensive knowledge of Linux, and this came in handy when designing our remote access and remote management system. I have a love for LaTeX and thus converted all of our deliverables into LaTeX formatted PDFs.

Tasks Completed: For this assignment I was not able to contribute as much as I would have liked due to personal issues. I was primarily focused on doing the conversion to LaTeX, as well as helping out with general grammar and technical editing. For the other assignments, I made sure to share equal responsibility. Throughout the project I helped a lot with research for the Pi HATs, determining which ones to get, what libraries and code we could use to use them, as well as soldering the current clamp circuit together.

6 Lessons Learned

6.1 Documentation

To maintain a streamlined workflow over the course of this project, we have utilized GitHub as a public-facing repository and Google Drive as a collaborative workspace to organize our documentation for the PRT module. The git repository stores all the deliverables including assignment 1, a brief project proposal, and the final report. All files can be accessed at: `https://github.com/2024-PRT-Senior-Capstone/CSEE-480-Assignments`

Our group made use of a shared Google Drive to easily collaborate on creating documentation before submitting the final copy to the git repository. Using Google Docs allowed us to easily create an outline, divide work, and leave feedback on others' work using the comments feature to create a quality final product. In addition to documentation, Google Drive stores internal files such as architectures created, attendance, and external technical documentation.

Overall, the group leveraged GitHub and Google Drive collaboration tools to effectively document the PRT System data collection and analysis project.

6.2 Lessons Learned

Throughout the completion of the spring semester's project goals, team members gained experience with new hardware, software applications, and project management skills.

The core of this project is a Raspberry Pi which is attached to the various data gathering tools. As a result, we learned how to install an operating system on a Pi, and how to attach and initialize the sensors. We went with a Linux installation on the Pi since most group members had experience with it. However, we ran into some difficulty remotely accessing the Pi and gained knowledge of SSL, VNC, and installing libraries. Overall, we knew we needed a method of accessing the Pi from our computers, however, we didn't know the best method. After trying a few different options, we decided to use a free software called Tailscale and learned that this was the most reliable method. Essentially, Tailscale connects to the Raspberry Pi and provides a static IP to be used with SSH.

After attaching the GPS sensor and gaining a satellite connection, we were able to read raw data using a simple Python script. Using an existing git repository, we were able to run a different script to translate that raw data into longitude and latitude coordinates. We thought we would need to write a program to then translate that data into something more user-friendly that could be displayed on a map. However, we conducted research and learned that Google Earth Pro accepts raw GPS data and will show the path traveled.

In terms of engineering lessons learned, the group agrees that often times, producing a quality solution requires piecing together pre-existing applications and services. It is often more effective to use prior art in new projects so as to reduce time spent reinventing the wheel, so to speak.

Many aspects of project management were learned during this semester. Since this project had some physical components that needed to be ordered as a team, we researched the correct components to purchase. As with most projects, we had an allotted budget and we needed to use our money wisely by being 100% certain that our purchases wouldn't go to waste. Next, we needed to set and meet deadlines for ourselves. Up until this point, many of us have only had deadlines set for us, however now we learned to break the scope of the project into realistic goals and then set deadlines accordingly. Lastly, we learned what collaboration tools worked best for the group, for example, we chose to communicate via Discord and share files with Git, and Google Drive. Again this was something we got to pick for ourselves rather than just being assigned a specific system. Overall, we learned research skills and independence with project planning.

7 References

7.1 Sources

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7.2 Contribution Table

Team Members	Content	Setup
Andrew DeGarmo	Overall Hardware Software Timeline Design Choices Marketing Requirements Mapping of Marketing Requirements to Engineering Requirements	Assignment Outline Editing
Sam Desai	Lessons Learned Documentation	
Emma Kupec	Overview Public Health Constraints Social Constraints Environmental Impact Economic Factors Project Managemen	Document Layout Editing
Kevin Meyers	Design Requirements Broader Constraints Project Management	
Omar Ndiaye	Risk Test Plans	Editing
Greyson Weimer		Conversion to LaTeX Editing