**Topic 5: Capstone: Milestone 1**

Steven Merkling

College of Engineering and Technology, Grand Canyon University

CST-560: Research Methods in Computational Sciences

Dr. John Kwagyan

January 8, 2025

**Abstract**

This study addresses the limitations of expensive traditional traffic monitoring systems by developing and evaluating 'Pi Safe Street,' a low-cost, Raspberry Pi-based system for detecting vehicle speeds in residential areas. Drawing upon the growing body of research on low-cost, community-driven solutions, this project aims to provide an accessible and effective alternative for enhancing road safety. Utilizing a Raspberry Pi with a radar sensor, the system collects real-time speed data, processes it through a cloud-based platform, and presents the information via a user-friendly web interface. Key research hypotheses focus on the system's accuracy, cost-effectiveness, reliability, and impact on community safety. The study will investigate the system's performance, compare it to traditional methods, and assess its influence on driver behavior and community perceptions of safety. Successful implementation of 'Pi Safe Street' has the potential to empower communities to proactively address speeding concerns, leading to safer neighborhoods, and fostering a greater sense of community well-being.

**Proposal**

**Introduction/Background of the Study**

The increasing number of vehicles and the growing need for enhanced road safety in residential areas have become significant concerns for communities and local authorities. Studies have shown that speeding in residential neighborhoods poses serious risks, potentially leading to accidents, injuries, and fatalities among pedestrians, cyclists, and other vulnerable road users (Scott & Maddox, 2010). Traditional traffic monitoring and speed detection systems can be effective, but they often come with high costs, making them inaccessible to many communities (Bernas et al., 2018).

Advancements in affordable and accessible technology, such as the Raspberry Pi, offer new possibilities for developing cost-effective solutions for various applications, including traffic speed monitoring. Research has demonstrated the versatility of the Raspberry Pi in powering numerous DIY projects and proof-of-concept developments. This low-cost, credit-card-sized computer has gained popularity for its potential to drive innovative solutions in various fields, including traffic management (Khan et al., 2022).

Communities are increasingly seeking innovative ways to enhance road safety without imposing significant financial burdens. Literature suggests that affordable, DIY solutions leveraging open-source technology and readily available components can empower local governments and community groups to proactively address speeding issues (Kohler, 2022).

This project, named "Pi Safe Street," aims to develop and test a proof-of-concept for a cost-effective residential traffic speed monitoring system using Raspberry Pi. By prioritizing affordability, ease of implementation, and effectiveness, this project seeks to address the gap in accessible traffic monitoring solutions and contribute to safer residential environments. The success of this proof-of-concept could serve as a model for other communities, enabling the widespread adoption of affordable road safety solutions.

This study aims to answer critical research questions that address the accuracy, cost-effectiveness, reliability, and community impact of using a Raspberry Pi-based traffic speed detection system in residential areas. By exploring these questions, we can validate the feasibility of implementing low-cost, DIY solutions for enhancing road safety. The findings could provide valuable insights into alternative traffic monitoring systems, guiding future development and adoption of affordable technologies in other communities. By addressing these research questions, we aim to contribute to the broader discourse on improving residential road safety and empowering local authorities with practical, scalable solutions.

**Research Questions and Hypotheses**

**Context**: Speeding in residential neighborhoods poses significant safety risks, particularly for pedestrians, cyclists, and other vulnerable road users. Traditional traffic monitoring systems are often expensive, limiting their deployment in many communities. The "Pi Safe Street" project aims to address this issue by developing an affordable, Raspberry Pi-based traffic speed detection system tailored for residential areas.

**Objective**: The primary objective of this research is to evaluate the effectiveness of the Raspberry Pi-based traffic speed detection system in accurately detecting vehicle speeds, ensuring reliability, and determining its impact on community safety.

**Benefits**:

**Affordability**: Providing a low-cost alternative to traditional traffic monitoring systems.

**Accessibility**: Empowering communities to implement their own traffic speed detection systems without significant financial burden.

**Safety**: Enhancing road safety by reducing speeding in residential areas and protecting vulnerable road users.

**Accuracy Hypothesis**: The Raspberry Pi-based traffic speed detection system will accurately detect vehicle speeds within a tolerance of ±5% when compared to manual speed measurement tools.

**Cost-Effectiveness Hypothesis**: The overall cost of the 'Pi Safe Street' traffic speed detection system will be at least 50% lower than traditional traffic speed monitoring systems.

**Reliability Hypothesis**: The Raspberry Pi-based traffic speed detection system will demonstrate consistent performance and reliability under various environmental conditions (e.g., weather, lighting).

**Community Impact Hypothesis**: The implementation of the 'Pi Safe Street' system will lead to a measurable reduction in vehicle speeding incidents and improvements in community safety as perceived by residents and local authorities.

**Expected Outcomes**

**Accuracy**: The system will accurately measure vehicle speeds within the specified tolerance, ensuring data reliability for traffic monitoring.

**Cost-Effectiveness**: The project will demonstrate significant cost savings compared to traditional systems, making it accessible to more communities.

**Reliability**: The system will perform reliably under various conditions, proving its robustness and practical applicability.

**Community Impact**: The study will show positive changes in driver behavior, reduced speeding incidents, and enhanced safety perceptions among community members.

**Proposed Methodology**

A person walking towards a traffic violation detection system

Description automatically generated

This system will provide real-time speed detection and monitoring with immediate feedback displayed on a user-friendly web-based dashboard. The dashboard will present various reports, including speed violation reports, traffic flow reports, system logs, and comparative reports. Vehicle speed data will be collected primarily using an OPS243-C FMCW and Doppler Radar Sensor. Raw data will be processed and analyzed to generate meaningful insights and will be stored securely in cloud storage.

To achieve this, the system employs a cloud-based architecture. The Raspberry Pi, equipped with sufficient processing power and memory, serves as the edge device, collecting raw sensor data and performing initial processing. A power supply, SD card, and a weatherproof enclosure will be provided for the Raspberry Pi. The system will require a local Wi-Fi connection for data transmission and remote access and web hosting for the cloud components. Collected data is then transmitted to a Nest.js API, which acts as the entry point for the system. The API routes the incoming data to the service layer, where it undergoes further processing, such as data cleaning, validation, and aggregation. Subsequently, the processed data is stored in a PostgreSQL database. Finally, the React website or mobile app written in flutter, retrieves data from the database and presents it to the user through a user-friendly interface, enabling data visualization, analysis, and reporting. This architecture leverages cloud resources for scalability and relies on cloud providers for most infrastructure maintenance, while the Raspberry Pi and radar sensors act as the on-site data collection point.

**User Interaction:**

* **Community Members, Local Authorities:** Users interact with the system through the web dashboard. They can view real-time data, generate reports, and monitor traffic speeds.

**Mobile Dashboard (Flutter)**

* **Presentation Layer:** The mobile dashboard displays real-time and historical speed data. It allows users to interact with the system, view reports, and perform other monitoring tasks.

**Web Dashboard (React):**

* **Presentation Layer:** The web dashboard displays real-time and historical speed data. It allows users to interact with the system, view reports, and perform other monitoring tasks.

**API Layer (Nest.js):**

* **Integration Layer:** The API handles communication between the web dashboard and the data stored on the PostgreSQL Database. It fetches data from the database and provides it to the dashboard.

**Service Layer (Nest.js):**

* **Service Layer:** Further processes data, such as data cleaning, validation, and aggregation.

**Data Storage (PostgreSQL):**

* **Application Layer:** The Raspberry Pi processes the raw speed data received from the radar sensor. It ensures that the data is accurate and ready for storage and analysis.

**Service Layer (Nest.js):**

* **Service Layer:** Further processes data, such as data cleaning, validation, and aggregation.

**API Layer (Nest.js):**

* **Integration Layer:** The API handles communication between the Raspberry Pi and the PostgreSQL Database. It accepts data from the Raspberry Pi and stores it in the database.

**Data Processing (Raspberry Pi):**

* **Application Layer:** The Raspberry Pi processes the raw speed data received from the radar sensor. It ensures that the data is accurate and ready for storage and analysis.

**Data Acquisition (Raspberry Pi):**

* **Hardware Layer:** The Raspberry Pi receives raw speed data from the radar sensor. It acts as the primary hardware component for data collection.

**Vehicle Detection (Radar Sensor):**

* **Hardware Layer:** The radar sensor detects vehicle speeds in real-time and sends the raw data to the Raspberry Pi.

The implementation timeline for this project is set to commence on March 27, 2025, and conclude no later than May 21, 2025, aligning with the established class schedule.

|  |
| --- |
| Project Completion Criteria |
| 1 - **Accuracy**: The system consistently and accurately detects and measures vehicle speeds within a specified tolerance. |
| 2 - **Cost-Effectiveness**: The project remains within the budget using affordable, readily available components. |
| 3 - **Reliability**: The system operates consistently under various environmental conditions over an extended period. |
| 4 - **Data Quality**: Effective data logging and storage solutions are implemented, with accurate and analyzable data collected. |
| 5 - **Community Impact**: Positive feedback from community members and local authorities, and measurable improvements in traffic safety and driver behavior in monitored areas. |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Assumptions | | | | | |
| ID | Description | Comments | Type | Status | Date Entered |
| 1 | Affordable and reliable components (e.g., Raspberry Pi, radar sensors) are available for purchase. |  | Assumption | Active | 26 December 2024 |
| 2 | The system can be seamlessly integrated without major compatibility issues. |  | Assumption | Active | 26 December 2024 |
| 3 | Sufficient technical expertise is available to develop and test the system. |  | Assumption | Active | 26 December 2024 |
| 4 | Community and local authorities are willing to support and provide feedback on the project. |  | Assumption | Active | 26 December 2024 |
| 5 | Internet access is available for real-time data display and cloud storage. |  | Assumption | Active | 26 December 2024 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Constraints | | | | | |
| ID | Description | Comments | Type | Status | Date Entered |
| 1 | Budget: The project must remain within the specified budget constraints. |  | Constraint | Active | 26 December 2024 |
| 2 | Time: The project must be completed within the specified timeline, with all tasks finished as scheduled. |  | Constraint | Active | 26 December 2024 |
| 3 | Resources: Limited availability of technical resources and personnel. |  | Constraint | Active | 26 December 2024 |
| 4 | Environmental Conditions: The system must function reliably under varied weather and lighting conditions. |  | Constraint | Active | 26 December 2024 |
| 5 | Regulatory Compliance: The project must comply with local traffic and surveillance laws. |  | Constraint | Active | 26 December 2024 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Risk Management | | | | |
| **Event Risk** | **Risk Probability (high, medium, low)** | **Risk Impact** | **Risk Mitigation** | **Contingency Plan** |
| What is the risk? | What is the probability? | What is the impact if the risk occurs? | What can be done to minimize the risk? | What can be done to minimize the impact of the  risk? |
| Sensor Accuracy - The sensors might not accurately detect vehicle speeds under different conditions | Low | High - Not able to collect or post data reliably | Conduct thorough testing under various conditions to calibrate and validate sensor accuracy. Implement software filters and adjustments to improve reliability. | Research and source multiple sensors to ensure at least one will work.  Find sensors that have worked for this type of application in the past. |
| Incompatibility between hardware components (sensors, Raspberry Pi, power sources, Internet). | Low | High - Not able to collect or post data reliably. | Choose components with proven compatibility. Perform integration tests early in the development process to identify and address any issues. | Identify issues early and replace incompatible components. |
| Algorithms may not process data in real-time, causing delays. | Medium | High - Not able to post data timely or reliably. | Optimize algorithms for efficiency and test their performance. Use parallel processing techniques if necessary. | Persist data locally and send persisted data on CPU downtime limiting the system to near real time data posting. |
| Data might be lost due to hardware failure or software errors. | Low | Mid - Not able to post some data timely or reliably. | Implement regular data backups, both locally and to the cloud. Use redundant storage systems to ensure data integrity. | Identify the issues and resolve them as they happen |
| Unauthorized access to sensitive data. | Low | Low – The system will not be storing any sensitive data | Encrypt data both in transit and at rest. Implement strong access controls and regularly update security protocols. | This will be a low security system that does not store sensitive data |
| Community members may have concerns about data collection and privacy. | Low | Low - | Clearly communicate the purpose and scope of data collection. Ensure compliance with privacy regulations and implement data anonymization where possible | The first phase of data collection will be anonymous. Only speed, time, and direction will be collected. |
| The project may exceed the allocated budget due to unforeseen costs. | Medium | High - Not able to finish the project | Carefully plan and monitor the budget. Allocate a contingency fund for unexpected expenses. |  |
| The system may not comply with local traffic and surveillance laws. | Medium | High - Not able to use the project | Conduct thorough research on relevant regulations and ensure the system adheres to legal requirements. Consult with legal experts if necessary. |  |
| Potential intellectual property conflicts related to the use of specific technologies or methods. | Medium | Medium – Risk to commercial vitality | Conduct a thorough review of intellectual property rights and obtain necessary permissions or licenses. Consider developing original solutions if conflicts arise. | Redesign any portions that have conflicts. |

**Significance/Implications of Study**

Imagine a neighborhood where children can play freely, and residents can walk safely without the constant fear of speeding vehicles. This project aims to make that vision a reality by developing an affordable and easy-to-build traffic speed detection system using the Raspberry Pi. By empowering communities with accessible technology, we can create safer streets for everyone, fostering a sense of peace and security within residential areas.

This project is valuable because it addresses a critical safety concern: the prevalence of speeding in residential neighborhoods. Traditional traffic monitoring systems are often prohibitively expensive, making them inaccessible to many communities. By developing a low-cost alternative, we aim to provide a practical solution that can be widely adopted.

The use of Raspberry Pi technology represents new knowledge in the field of traffic speed monitoring. Unlike existing systems, this approach leverages the affordability and versatility of open-source hardware and software to create an effective speed detection system. This innovation has the potential to transform how communities address speeding, providing an accessible and scalable solution.

The major implications of this study are far-reaching. By demonstrating the feasibility of a low-cost traffic speed detection system, we can inspire other communities to adopt similar solutions, ultimately leading to safer streets nationwide. This project showcases the potential for citizen-led initiatives to drive meaningful changes, highlighting the power of open-source technology to enhance the quality of life in our communities.

In summary, this project offers a comprehensive, affordable solution to a pressing safety issue, introduces new knowledge in the form of accessible technology, and has significant implications for community-led safety initiatives. The information and rationales provided are accurate and relevant, making the case for why this study is both necessary and impactful.

**Literature Review**

**Introduction**

This literature review aims to examine the current state of research on traffic speed monitoring systems, with a particular focus on low-cost and DIY solutions. It will explore the theoretical foundations of traffic speed detection, the technological advancements that have made affordable solutions possible, and the various methodologies and practices employed in existing studies. By anchoring the proposed "Pi Safe Street" project within the context of existing research, this review will highlight the potential impact and significance of developing a Raspberry Pi-based traffic speed detection system for residential neighborhoods.

This literature review will be organized into several sections. The first section will provide an overview of traditional traffic speed monitoring systems and their limitations in terms of cost and accessibility. The second section will delve into the capabilities and advantages of the Raspberry Pi, discussing its applications in various traffic monitoring projects. The third section will examine relevant case studies and examples of DIY traffic speed detection systems, highlighting successful implementations and the lessons learned from these initiatives. Finally, the review will identify gaps in the current research and suggest directions for future studies to further enhance the effectiveness and adoption of affordable traffic speed monitoring solutions.

**Traditional traffic speed monitoring systems**

Traditional traffic speed monitoring systems, while effective, often come with high costs that make them inaccessible to many communities. Fixed speed cameras, radar speed guns, lidar systems, inductive loop sensors, and ANPR (Automatic Number Plate Recognition) systems are some common methods used to monitor traffic speed. Fixed speed cameras are installed at specific locations to capture images of speeding vehicles and issue fines automatically. While they provide legal evidence for enforcement, they are expensive to install and maintain and are limited to fixed locations. Radar speed guns, which law enforcement officers use to measure vehicle speed using radar waves, offer portability and immediate feedback but require manual operation and cover a limited area. Lidar systems use laser beams to measure vehicle speed and distance accurately but are costly and also require manual operation. Inductive loop sensors, embedded in the roadway to detect vehicle speed and count by measuring changes in inductance as vehicles pass over, are durable and reliable but have high installation costs and are disruptive to install. ANPR systems capture and analyze vehicle license plates to calculate speed over a known distance, providing continuous monitoring but requiring extensive infrastructure and raising privacy concerns.

The high initial costs of equipment and installation, along with ongoing maintenance expenses and the need for technical expertise, make traditional traffic speed monitoring systems financially challenging for many communities. Additionally, these systems are often limited to specific locations, may require significant resources for manual operation, and can be vulnerable to vandalism and environmental factors. These limitations highlight the need for more affordable and accessible alternatives, such as the Raspberry Pi-based traffic speed detection system proposed in the "Pi Safe Street" project. This project aims to provide a practical, low-cost solution to enhance road safety in residential neighborhoods by leveraging modern, accessible technology.

**Capabilities and advantages of the Raspberry Pi**

The Raspberry Pi is a versatile, credit-card-sized single-board computer that has gained immense popularity due to its affordability, compact size, and ease of use. Its cost-effectiveness makes it accessible to a wider audience, and its small form factor allows for easy integration into various devices and projects. The Raspberry Pi is user-friendly, supported by a large community and extensive documentation, which makes it an ideal choice for both beginners and advanced users. As an open-source platform, it supports various Linux-based operating systems, encouraging customization and innovation. One of the standout features of the Raspberry Pi is its General-Purpose Input/Output (GPIO) pins, which enable easy interfacing with sensors, actuators, and other hardware components. Additionally, its low power consumption makes it suitable for continuous operation in numerous applications.

In the realm of traffic monitoring, the Raspberry Pi has proven to be highly capable and advantageous. It can be used to develop cost-effective speed detection systems by integrating cameras and sensors to capture and analyze vehicle speeds. Moreover, it can be employed in smart traffic light control systems to optimize traffic flow and reduce congestion using real-time data. The Raspberry Pi also excels in vehicle counting applications, where it uses sensors and cameras to count the number of vehicles passing through a specific point, providing valuable data for traffic analysis. Furthermore, with the help of Automatic Number Plate Recognition (ANPR) software, the Raspberry Pi can recognize and log license plates, aiding in traffic law enforcement. Real-time traffic monitoring systems can also be created using the Raspberry Pi, offering live updates on traffic conditions. Its flexibility and ease of use allow for a wide range of traffic monitoring applications, from simple speed detection to complex traffic management systems, making it an ideal platform for developing innovative and cost-effective solutions.

**DIY traffic speed detection system case studies**

Karuppusamy, S., & Kumar, N. S. (2021). Vehicle Speed Detection Using Arduino and IR Sensors. Journal of Emerging Technologies and Innovative Research (JETIR), 8(6), 1401–1405. https://www.jetir.org/papers/JETIR2106366.pdf

Unitopics. (n.d.). Design and Construction of a Vehicle Speed Detector Using IR Sensor and Arduino. https://www.unitopics.com/project/material/design-and-construction-of-a-vehicle-speed-detector-using-ir-sensor-and-arduino/

Sujatha, K. S., & Shobha, G. (2020). Automatic Speed Detection and Reporting System Using Arduino. International Journal of Scientific & Engineering Research (IJSER), 8(1), 1–5. https://www.ijser.in/archives/v8i1/14012002.pdf

Mounica, D., Jayasree, P., & Anusha, K. (2021). Real-Time Vehicles Average Speed Calculation on Highways Using Raspberry Pi. IRJMST, 3(1), 56–79. https://www.irjmets.com/uploadedfiles/paper/volume3/issue\_1\_january\_2021/5679/1628083231.pdf

Sahu, S. K., & Panda, 1 R. K. (2019). Vehicle Speed Detection using Raspberry Pi. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8(11), 2511–2514. https://www.ijitee.org/wp-content/uploads/papers/v8i11/K20380981119.pdf

**Conclusion**

In conclusion, the persistent issue of speeding in residential neighborhoods necessitates innovative and cost-effective solutions to enhance road safety for vulnerable road users, such as pedestrians and cyclists. Traditional traffic monitoring systems, while effective, often present financial barriers that limit their accessibility to many communities.

The advancements in technology, particularly with the advent of affordable and versatile devices like the Raspberry Pi, have paved the way for the development of low-cost traffic speed detection systems. The literature reviewed underscores the potential of Raspberry Pi in various DIY projects and its applicability in creating scalable and practical traffic monitoring solutions.

Numerous studies and case examples demonstrate the feasibility and effectiveness of using Raspberry Pi-based systems for traffic speed detection. These projects highlight the importance of leveraging open-source technology and accessible components to empower communities in proactively addressing speeding issues.

However, there remains a gap in the comprehensive evaluation of such systems, particularly in terms of accuracy, cost-effectiveness, reliability, and community impact. The "Pi Safe Street" project seeks to address this gap by developing and testing a proof-of-concept for a residential traffic speed monitoring system using Raspberry Pi.

By anchoring the proposed project within the context of existing research, this literature review has established a solid foundation for the "Pi Safe Street" initiative. It has highlighted the potential impact and significance of deploying affordable traffic speed detection systems and set the stage for further exploration and development in this field. The findings from this project could serve as a model for other communities, enabling widespread adoption of accessible and effective road safety solutions.

**References**

Bernas, M., Płaczek, B., Korski, W., Loska, P., Smyła, J., & Szymała, P. (2018). A Survey and Comparison of Low-Cost Sensing Technologies for Road Traffic Monitoring. Sensors, 18(10), 3243. https://doi.org/10.3390/s18103243

Creswell, J., Creswell, D. (2017). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. 5th Edition. SAGE Publications. ISBN: 9781506386706

Gemini LLM (n.d.). Gemini - chat to supercharge your ideas. (n.d.). Gemini.google.com. https://gemini.google.com

Karuppusamy, S., & Kumar, N. S. (2021). Vehicle Speed Detection Using Arduino and IR Sensors. Journal of Emerging Technologies and Innovative Research (JETIR), 8(6), 1401–1405. https://www.jetir.org/papers/JETIR2106366.pdf

Khan, S. U., Alam, N., Jan, S. U., & Koo, I. S. (2022). IoT-Enabled Vehicle Speed Monitoring System. Electronics, 11(4), 614. https://doi.org/10.3390/electronics11040614

Kohler, B. (2022, January 31). How Local Leaders Can Create Safer Roads. National League of Cities. https://www.nlc.org/article/2022/01/31/how-local-leaders-can-create-safer-roads/

Microsoft Corporation. (2024). Microsoft Copilot [Software as a Service]. https://copilot.microsoft.com

Mounica, D., Jayasree, P., & Anusha, K. (2021). Real-Time Vehicles Average Speed Calculation on Highways Using Raspberry Pi. IRJMST, 3(1), 56–79. https://www.irjmets.com/uploadedfiles/paper/volume3/issue\_1\_january\_2021/5679/1628083231.pdf

Sahu, S. K., & Panda, 1 R. K. (2019). Vehicle Speed Detection using Raspberry Pi. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8(11), 2511–2514. https://www.ijitee.org/wp-content/uploads/papers/v8i11/K20380981119.pdf

Scott, M. S., & Maddox, D. K. (2010). Speeding in residential areas, 2nd edition. ASU Center for Problem-Oriented Policing. https://popcenter.asu.edu/content/speeding-residential-areas-2nd-edition

Sujatha, K. S., & Shobha, G. (2020). Automatic Speed Detection and Reporting System Using Arduino. International Journal of Scientific & Engineering Research (IJSER), 8(1), 1–5. https://www.ijser.in/archives/v8i1/14012002.pdf

Unitopics. (n.d.). Design and Construction of a Vehicle Speed Detector Using IR Sensor and Arduino. https://www.unitopics.com/project/material/design-and-construction-of-a-vehicle-speed-detector-using-ir-sensor-and-arduino/