ELEC 390: Principles and Design and Development

Proposal for the Development of an Autonomous Taxi to Enhance Public Road Safety in Quackston

Team 49

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Statement of Originality

All concepts, drafts, and written content enclosed within this document are the exclusive creations of the designated authors. Any elements not constituting the intellectual property of the authors shall be duly referenced in the bibliography.

The use of Generative AI was used only for spellchecking, proofreading, and clarification.

Table 1: Task delegation for the proposal report.

Name	Task(s)	Time Spent
Saad Rizvi	Introduction, Expected Outcomes, Conclusion, Editing	7 Hours
Saad Kaka	Technical Specifications, Algorithms, Editing	6 Hours
Nigel Radhakrishnan	Executive Summary, Ethical Risks and Considerations, Project Management, editing	8 Hours
Badru Celil	Methodology, Research, References, editing	7 Hours

Table 2: Signatures of group members.

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Executive Summary

This project proposal report written by Team *AutoQuack* provides detailed information on the design and development of an autonomous taxi system in the town of Quackston geared towards performing exceptionally in competition, maximizing cash flow, and maintaining a strong reputation while balancing safety, efficiency, and ethical considerations. The solution is proposed with the ability to navigate dynamic environments with real-time decision-making. It involves advanced technologies such as computer vision, machine learning, and sensor integration coupled with detailed algorithms for object detection, lane following, obstacle avoidance, and brake light activation to create a Level 5 autonomous vehicle optimized for safe and efficient performance in the transportation of ducks in Quackston.

The vehicle is designed to meet the functional and performance requirements within the prescribed constraints of the design competition, focusing on critical tasks such as traffic sign recognition, lane keeping, and maintaining safe operating distances. Performance is measured against strict criteria to maximize cash flow and maintain a strong reputation, including precise stopping accuracy, collision avoidance, and rapid decision-making.

Key technologies include TensorFlow Lite for machine learning inference, YOLO for object detection, and OpenCV for lane detection. The project will integrate hardware components including the Raspberry Pi 4, Coral USB Accelerator, and various sensors including ultrasonic range finders and line trackers to achieve seamless system operation. With regards to software, the full algorithm will be comprised of four integrated object detection, lane following, obstacle avoidance, and brake light activation, and will be trained using detailed datasets to mimic the conditions to be seen in the design competition.

The group has developed an Ethos to perform exceptionally at the design competition while prioritizing ethical considerations and risk assessments to ensure that safety, fairness, and reliability are upheld. The design aims to meet competition standards while providing scalable insights for future autonomous transportation innovations.

A high-level schedule in the form of a Gantt Chart, budget, and resource allocation has been carefully planned to ensure the successful completion of the project. In addition, the report outlines the reasoning behind assigned roles and plans to solve any conflicts that occur within the group. The anticipated outcome is a high-performing autonomous taxi that demonstrates the feasibility of scalable autonomous vehicle systems, accomplishing the prescribed functional and performance requirements for ELEC 390, and paving the way for advancements in safe and efficient autonomous transportation technologies in the future.

Introduction

With the increasing popularity and rapid development of autonomous driving, modes of transportation have been seeing enormous changes. Factors such as traffic congestion, road safety, and environmental concern furthered interest in this sphere of engineering as the populous started understanding how beneficial a full-functional autonomous transportation system would be. Not only would it positively affect the factors mentioned above, but it will also give more personalized access to individuals who are unable to drive due to disabilities, otherwise, it would also cause a decrease in overall transportation time as human-induced error is reduced.

Despite all the innovation currently happening for self-driving vehicles, there are aspects of fully autonomous driving that are still lacking and would need to be fixed for these vehicles to be fully realized and go into production. Real-time decision-making in dynamic settings, object detection, and response underscore the need for the implementation of a system that could operate safely in various scenarios.

The project seeks to address these challenges by designing and developing an autonomous taxi system capable of navigating dynamic terrains while carrying a load. There will be a focus on integrating modern computer vision and machine learning technologies enabling accurate object detection and avoidance, efficient route planning, and a safe passenger experience.

The project scope is designed to align with course requirements and competition guidelines to allow for a realistic outcome. As course requirements do not include broader requirements such as long-distance navigation, the project will exclude implementing those while focusing on object detection, traffic sign recognition, and autonomous driving. This focus would allow the project team to deliver a high-performing prototype within the given time and resource constraints. The resulting system will potentially be able to be used as a scalable model for future innovation in the field of autonomous transportation.

Technical Specifications and Design Overview

Functional Requirements

The autonomous car from Team *AutoQuack* is a Level 5 autonomous vehicle designed to perform all driving functions without human interaction. The vehicle's automation is expected to ensure the safety of its occupants and the surrounding environment. The system is required to detect and respond to traffic signs such as stop, yield, and one-way signs, as well as identify and react to obstacles and pedestrians. Additionally, *AutoQuack* must precisely follow road markings. This is assessed through lane keeping, complying with right hand traffic rules, stopping accurately at stop lines and crosswalk markers, passing at center lines when appropriate and navigating the correct direction on one-way streets. Instances where other vehicles approach intersections at the same time will be handled by arrival time. The vehicle will also stay within safe operating distances of other vehicles and only reverse, when possible, to do so safely. The overall size of the map is 20 x 16 feet, with multiple zones and buildings that mimic a real-life atmosphere and will require safety measures to be taken into consideration to safely navigate around the town of Quackston [1]. Finally, the vehicle will be required to decide on passenger pick up based on a positioning and fare system.

Performance Requirements

The evaluation of the vehicle's performance will be conducted on several quantifiable constraints. The constraints have been designed to closely model the functional requirements. Firstly, the system must maintain lane boundaries with a tolerance of a centimeter. The vehicle's bumper must also stop within two centimeters of the white line at crosswalks and stop signs. Additionally, the vehicle is required to maintain a safe operating distance of ten centimeters and make all decisions within two seconds. Navigation of one-way streets is expected to be one-hundred percent accurate and all other traffic signs must have accurate detection ninety-five percent of the time. The vehicle must be able to identify obstacles in its path up to forty centimeters away and avoid all collisions with pedestrians and obstacles completely. In addition, the Duck Deck must be designed to be able to accommodate a variety of duck sizes, with the provided ducks being 1.4" long, 1.6" wide, and 1.2" tall, and taking into consideration that ducks found around town will be slightly larger, at 2" long, just under 2" wide, and 2" tall [1].

High-Level Design Description

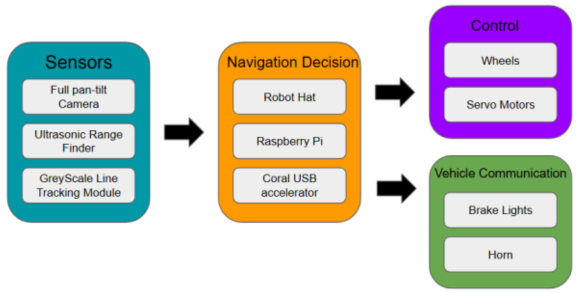

Figure 1: High-level system architecture block diagram.

The system architecture provides the necessary equipment to perform essential functions within the imposed competition dimension restrictions. Size constraints are limited to a height of 300 mm, 120 mm width, and 210 mm length. The hardware includes a pan-tilt camera, an ultrasonic range finder, and a greyscale line tracking module placed at the front of the robot. Servo motors are attached to the camera for horizontal and vertical adjustability and the front wheels enable steering. The software aspects of the vehicle are handled by a Raspberry Pi, Robot Hat, and Coral USB Accelerator placed at the back of the car. Communication with other vehicles is conducted via brake lights and a horn. Finally, an AprilTag is included on the vehicle for identification purposes.

Methodology

Technologies and Tools

The vehicle used in this project will be the *PiCar-X* Robot Car, an AI-driven self-driving robot car [2]. The main control unit of the car is the Raspberry Pi 4 series, containing forty General Purpose Input-Output (GPIO) pins for the interconnection of the Robot Hat. The Raspberry Pi will act as a computer interface which will allow the team to integrate the code for the cameras, sensors, and motor functionality for the car. Mounted on the PiCar-X are the 2-axis camera module, ultrasonic module, and line tracking modules that provide the functions of color, face, traffic-signs detection, automatic obstacle avoidance, and automatic line trafficking. The Robot Hat provides a module that controls the operation of the electric motors such as speed and direction [3] in addition with more analog and digital input/output pins that enable the option of adding a LiDAR sensor, head lights and brake lights, and speakers. The team is still deciding on using additional sensors such as a LiDAR sensor.

The hardware will need to process machine learning (ML) models for object detection, object avoidance, and navigation. To do so, the team will implement the Coral USB Accelerator to accelerate the machine learning inferencing. It does this using an on-board Tensor Processing Unit (TPU) which can execute four trillion operations per second. The Coral USB will connect to the Pi via USB and will have TensorFlow Lite models compiled to run on the Edge TPU.

The software frameworks that will be used to import the key algorithms are as follows:

- TensorFlow Lite: The YOLOv11 algorithm will be used for object detection and will be compiled on the Coral USB accelerator. This will be done by exporting the model to an Edge TPU format.
- OpenCV: Will be used to import Lane detection specific algorithms.

Algorithms

Object Detection

An image can include multiple objects and thus it requires many localized regions of interest [4] – this makes object detection a more complex problem of image classification. The object detection models will need to know what the object being detected is and where the object is. The latter will require a bounding box for all the collected data. That is, for each image, a bounding box with the correct coordinates will be placed around the object in the image. This will be done using open-source annotation tools for the training data we gather from the servo-mounted computer such as Make Sense or LabelImg.

Additionally, since our application requires real-time image processing, the team will opt for a Single-shot object detection model such as YOLO [4]. The YOLO algorithm will classify the entire image in one iteration to detect objects and their locations [5]. The YOLO algorithm, in brief, first divides an input image into a $S \times S$ grid. Each cell in the grid will predict B bounding boxes and assign a confidence for those boxes. Lastly, a probability will be applied to the bounding boxes to determine the likelihood of the bounding boxes containing a class of an object [6].

Lane Following

Lane detection is a specialized case of image classification and object detection that is crucial for autonomous vehicle navigation. To optimize driver safety though lane keeping the team has opted to use a camera-based algorithm known as canny edge detection. Canny edge detection removes many complications relating to light levels, texture, and obstacles that other algorithms may encounter [7].

The lane detection process begins with preprocessing, where the image is converted to grayscale to simplify data and improve processing efficiency [8]. Factors such as brightness, contrast, edges, shape, texture, and contours are maintained [9]. The next step is to reduce noise using a 5x5 Gaussian filter, followed by applying Sobel kernels to compute pixel gradients and their directions for gradient thresholding [10]. Non-maximum suppression and hysteresis thresholding are used to refine edges by removing low gradient pixels. To isolate important edges, a region of interest is applied to form a white triangle mask. Lane edges are produced by performing a bitwise and operation on the mask [9]. Finally, a Hough Transform will be used to create continuous lines. The remaining edges vote on bins in a discretized space to create lines.

Obstacle Avoidance

The team has chosen to implement the Artificial Potential Field (APF) method for obstacle avoidance. The method is widely used in path planning for autonomous vehicle navigation. The technique treats particles as opposing forces: destinations or goals exert an attractive force on the navigation route, while obstacles exert a repulsive force. The potential field is designed such that the goal acts as a global minimum and all obstacles act as local maxima, guiding the target through obstacles without collisions. The APF method is computationally efficient, which is necessary for reacting to unexpected events. However, the algorithm can sometimes suffer from local minima. If the team finds this to be problematic, other techniques may be combined with the artificial potential field to address the issue.

Brake Light Activation

The braking system algorithm for the autonomous automobile is designed to ensure safety and effective communication with surrounding vehicles through three parts. Firstly, the brake lights will flash whenever a full stop is required, this will handle cases such as at intersections or unexpected events that occur. The logic for determining when full stops are required will be done through object detection. Stationary objects in front of the vehicle that are detected will trigger the software to turn on the brake lights. Secondly, the system addresses deceleration due to slower vehicles in its route. The ultrasonic sensor provides the capability to detect vehicle distance in front of it. Once the ultrasonic sensor detects a diminishing distance the brake lights will illuminate, and the car will decelerate. Finally, to handle situations where deceleration is required for safe operating speeds, AutoQuack will turn on its brake lights when the threshold value for deceleration is met.

Data Sources

Quality data is to be collected for the algorithms to work effectively during the competition. The datasets that will be collected for the objects present during the competition will be collected from taking multiple photos using the camera mounted on the car. Key data objects that will be collected include traffic signs (stop signs, yield signs, one-way), road markings (crosswalk, stop lines, road edge lines, passing centerlines, one-way arrows), buildings, and rubber ducks.

Images that will be used for object detection will be manually labeled using open-source annotation tools like Make Sense and LabelImg to add bounding boxes around the objects and provide their coordinates and object classes within the data files. The images will then be exported into the Pascal VOC format for the organization of the data.

For image classification, the images will be labeled using an automated Python script labeled collect_images.py that comes with the AIY Maker Kit. The labeled images will then be stored in separate folders depending on their class.

The datasets that the team collects are intended to be diverse to aid the algorithms in detecting objects of the same class across different textures, lighting, and angles. More specifically, when collecting data for a specific object, we plan to take multiple images of the object within different lighting conditions, environments, and angles. In addition, each object will be captured with various examples to avoid bias. Lastly, we intend to make sure that annotations of images are correct, bounding boxes for objects are maintained close to the object, and the quantity for each dataset will be substantial such that the models’ performance maintains consistent and accurate results.

System Integration

The Raspberry Pi 4 will act as the central processing unit for the vehicle. The Pi will handle the peripheral communication between the sensors, motors, and other components and will run the software stack. To mitigate computational demand on the Pi, the Coral USB will act as an extension of hardware-software integration, specifically for ML inferencing.

The sensors will gather data in real time and will be sent to the Pi. This data is then sent to the Coral USB Accelerator as inputs for the pre-trained ML algorithms stored as TensorFlow Lite models. The Pi receives and processes the control logic, sending instructions to the motors and actuators.

Ethical and Risk Considerations

The group's Ethos is to strive to create an autonomous taxi solution that will perform exceptionally in competition, maximizing cash flow and maintaining a strong reputation while balancing safety, efficiency, and ethical considerations, all the while upholding the key pillars of a strong engineering project as a group.

Ethical Considerations

The creation of autonomous vehicles requires large ethical considerations. As described under the AV Act, the liability for incidents involving AVs is the responsibility of the manufacturers and operators of the autonomous systems [11]. As such, it must be understood that the consequences of failures within the design and development of the autonomous taxi are the responsibility of the group. In the context of the project, the main stakeholder of the solution is the town of Quackston and its duckizens, for which ethical considerations must be considered for.

Ethics and safety are paramount in Quackston. The autonomous taxi solution must be designed to conform to the rules and regulations outlined in the *Quackston Road Safety Act,* a set of rules and penalties designed to ensure the safety of both duckizens and other vehicles. The rules govern everything from avoiding collisions with other ducks to proper signalling at intersections, with financial penalties and reputational impacts for violations. The design must be created to meet these requirements, for example, proper brake light activation to minimize the risk of collisions with other vehicles or ducks [1]. Concerning safety within the group, the electronic devices being used carry implicit risks, which group members must familiarize themselves with to be able to mitigate the associated risks.

Furthermore, to ensure fairness and accessibility for all duckizens, Quackston has implemented the Vehicle Positioning and Fare System (VPFS) standardized system for autonomous taxis. The group must design the autonomous taxi solution with fairness in mind in the sense that the Duck Deck is accessible and ergonomical for ducks of all varying shapes and sizes [1]. Concerning fairness within the team dynamics, the group will ensure that each member has an equal opportunity to contribute to any aspect of the project they choose, and that all members will strive to complete an equal share of work throughout the duration of the project.

To address privacy concerns, the group will collect data only essential for safe operation and performance improvements, and clearly communicate how collected data is used, shared, and stored.

Risk Assessment

There are several potential risks associated with autonomous vehicles, for which measures must be taken to mitigate them.

Hardware risks include sensor failures, power system interruptions, or battery failures. To mitigate these risks, the group can look to implement redundant systems, for example, dual sensors or backup power supplies to ensure continued operation in case of failure. Continuous testing and monitoring of sensor, battery, and all hardware performance will be the most effective measure to mitigate hardware failure risks.

Software failure risks include algorithmic errors leading to incorrect decision-making and bugs or glitches that disrupt operations. To mitigate these risks, the group will use mathematical models to verify the correctness of the crucial algorithms, regularly update software to address bugs and enhance performance, and conduct extensive testing in a variety of settings to prepare for the competition. Additionally, software to transition the vehicle into a safe state during malfunctions can be designed as a proactive measure for this type of failure.

Potential risks with data include inaccurate or outdated maps leading to navigation errors, sensor data misinterpretation, or insufficient training data resulting in unreliable decision-making. To mitigate these risks, the group will use a diverse range of datasets to train machine learning models to improve reliability and fairness and implement robust validation processes for incoming sensor data.

Expected Outcomes

The main goal of this project is to complete the development of an autonomous taxi system capable of navigating complex environments with a high degree of safety, accuracy, and efficiency, to maximize cash flow and maintain a strong reputation in competition. By integrating computer vision, machine learning, and sensor technologies, the anticipated results are to have a functional prototype with results that include:

1. Reliable performance in navigating environments, including object avoidance, traffic sign recognition, and real-time decision-making.
2. Safety mechanisms are designed to prioritize passenger, duckizen, and other road vehicle safety, using detection and response algorithms to minimize the risk of accidents.
3. A final system that is competition-ready, optimized to excel, and exceeds evaluation criteria.

More lucrative outcomes would be to have a design that leaves a meaningful impact on the field of autonomous driving. The project aims to give a concept that is scalable and provides critical information that can be used by others to further improve autonomous transportation technologies. The group strongly believes that this project is valuable to the education of all students in ELEC 390. The field of autonomous vehicles is growing rapidly with exciting prospects for the future, and this project offers an introduction to the field in the form of a very fun and exciting group project with a design competition to look forward to and motivate everyone to create the best product possible. In addition, experience with autonomous vehicles in this small-scale form exposes and educates students about the extremely important ethical and safety implications of autonomous vehicles in real-life operation, and the responsibility that manufacturers hold in their development.

Project Management

Team Roles and Responsibilities

The group contains team members split between two disciplines, Computer and Electrical Engineering. Each member has a unique skill set for which the team has allocated a role to put everyone in the best place to succeed. Members specializing in Electrical Engineering are more comfortable with the hardware aspects of the course, and as such will be more heavily relied upon in these areas, such as designing the Duck Deck. Members studying Computer Engineering are more fluent in coding and programming and hence will carry more responsibility in this part of the project, such as designing the necessary algorithms for the project. Assigned Roles can be seen in Table 3.

Table 3: Project Member Roles

Role	Name (s)
Software Development	Saad Rizvi, Saad Kaka
Hardware Development	Nigel, Badru
System Integration and Testing	All
Report Writing and Engineering Logbook	Tasks for the engineering logbook and within each report to be divided equally amongst all members

While roles were assigned based on the strengths of each member, it is expected that all group members will be willing to aid each other in any area where necessary. Equally as important as completing an individual role is being adaptable as a teammate and willing to contribute to any area of the project. The responsibility of leadership within the group is divided equally amongst all four members; constant communication and collaboration between all four members will be key to fostering team cohesion and motivating all members to achieve shared goals.

Decision and Conflict Management

Most of the important decisions within the project will be made as a team, accepting various opinions from all members, and reaching a final decision collectively. Individual work will be necessary to be able to complete the project in a timely manner, for which each member will be responsible for making their own decisions at times and consulting other group members.

To address possible conflicts within the group, the group will maintain constructive dialogue with each other and aim to follow Robert Maddux's five styles of conflict management; *competing, avoiding, accommodating, compromising, and collaborating,* being understanding of which style is necessary to solve a given conflict. All team members share the common goal of completing the project together to a high degree of quality while maintaining positive relationships with each other; as such, all members will strive to resolve conflicts together in an effective and respectful manner [12].

Timeline

Figure 2: Gantt chart highlighting the timeline and milestones for the autonomous taxi.

displays a high-level Gantt Chart timeline for the project. To generate the timeline, both the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) were used.

The CPM method helps identify the sequence of tasks critical to the completion of a project and understanding the dependencies between tasks, ensuring that the project is completed on time. Specifically, the CPM method was used to identify the four subsystems of the software part of the project, understanding that all four are critical and will be dependent on each other for the successful function of the overall system and hence must be completed in a timely manner [13].

The PERT method was used to guestimate the amount of time required for each task. For example, five weeks were allocated to each subsection of the coding, which was estimated using the following formula: $T_E = \frac{T_O+4T_M+T_P}{6}$, where T_O is the shortest possible time to complete the task (three weeks), T_M is the most likely time to complete the task (5 weeks), and T_P is the longest possible time to complete the task (6 weeks) [14].

$\frac{3+4(5)+6}{6}$ = 4.833 weeks, thus five weeks were allocated for each individual coding task.

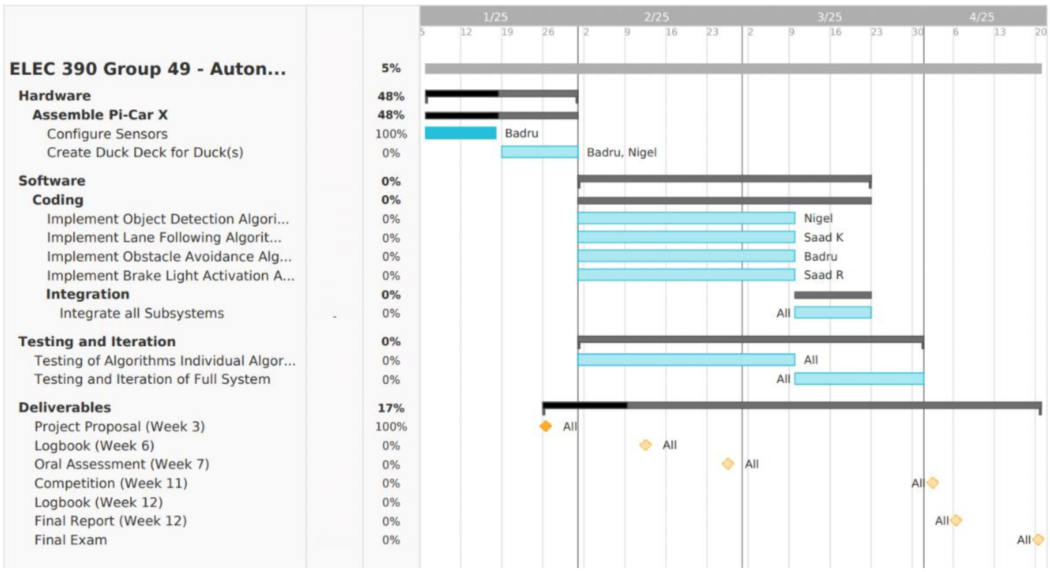

Figure 2: Gantt chart highlighting the timeline and milestones for the autonomous taxi.

Budget

The following items will be purchased for the successful completion of the project.

Table 4: Budget Outline

Item	Cost
Engineering Logbook	$10.95
3D Printed Part(s) for Duck Deck	$30
Backup Camera Sensor	$20
Total	$60.95

Conclusion

The report offers a comprehensive proposal for the design and development of an autonomous taxi system following the design requirements and constraints as defined in ELEC 390 tailored to the town of Quackston. The project addresses critical challenges in autonomous transportation, including safety, efficiency, fairness, and real-time decision-making for obstacle avoidance and duckizen safety with to perform as well as possible at the design competition by maximizing cash flow and maintaining a strong reputation. By integrating advanced technologies such as computer vision, machine learning, and sensor systems with intricate algorithms for object detection, lane following, obstacle avoidance, and brake light activation, the solution aims to excel in the design competition while setting a benchmark for future innovations in the field.

Also detailed in the report is a framework for project management and team dynamics, including assigned roles based on the strengths of each team member, strategies to uphold a healthy team dynamic, and a high-level timeline in the form of a Gantt Chart for the team to follow. The anticipated outcome of the project is a fully functional autonomous taxi that is designed to excel at the design competition while also offering a scalable foundation for advancements in autonomous transportation. This endeavor showcases the potential of engineering innovation in addressing real-world challenges while prioritizing fairness, safety, and reliability.

Citations

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