Improving the Security of Autonomous Vehicles
Using Model Predictive Control

Valentine Geze¹, Brook Abegaz¹
1. Department of Engineering Science; Loyola University Chicago

Abstract
The security of autonomous vehicles refers to the tasks of safeguarding the transportation system from attacks, risks, and vulnerabilities. Autonomous vehicles include self-driving vehicles and semi-automated vehicles. Although there is a very interesting concept, the operation of autonomous vehicles opens doors to various security attacks that require in-depth research and experimental evaluation.

The various entities that are related to the control of autonomous vehicles include automotive manufacturers and traffic controllers that operate the transport system and control its real-time flow and operation. The important role of vehicle security while the vehicle is running autonomously or semi-automatically has been identified recently, where accidents are being reported in various parts of the country due to a failure of a part or an error in the software triggered by other events.

The research problem addressed in this project comprises the risks and vulnerabilities that are involved with the operation of autonomous vehicles. Autonomous and semi-automated vehicles could be targeted by military or terrorist activity. In addition, the public may not feel safe about their operation on the road if their security issues are not addressed properly.

Introduction
The main objective of the research is to explore ways to identify security threats related to autonomous vehicles and categorize them based on the types of risks and their levels of intensity. Using real-time communication with sensors, operators, and controllers could understand the presence of risks and vulnerabilities. The research will also explore ways of making autonomous vehicles secure and protected by designing new learning-based algorithms using MATLAB-Simulink.

The project would make use of a model predictive control (MPC) approach to predict the occurrence of attacks based on a correlation between the inputs and outputs of the autonomous vehicle. MPC is used to control a system while operating under a set of constraints. MPC has been recently introduced to the field of power electronics, and the approach has been used effectively for industrial control of oil refineries and chemical plants. The implementation of MPC for autonomous vehicles is a hot research area, and it requires the use of dynamic models of a system, and an autonomous vehicle has the right types of system equations that could be formulated and designed to communicate with an MPC. One advantage of MPC over other types of controllers is that it allows optimizing future time slots based on the outputs of the current time steps, and this research project would utilize that advantage for the security enhancement of autonomous vehicles.

In this project, a model predictive controller would be used to anticipate future security risks such as attacks, irregularities, and vulnerabilities and take control actions. The predictive controller could provide faster response time (lower rise time, lower fall time, and lower final stable value) and thus, it could safeguard the secure response of the autonomous vehicle to external attacks.

Materials and Methods

Arduino Car
- UNO Arduino Application and Notepad++
- Car kit assembly
- Using pre-existing code for autonomous vehicle to allow car to have such features as auto-avoidance and line tracking
- Bluetooth and Wi-Fi capabilities

Fig. 1. Arduino car.

Raspberry Pi Car
- Coding in C++
- Raspberry Pi board attaches to car, can be removed to modify code and replaced for testing
- Wi-Fi capabilities

Fig. 2. Sensor for obstacle avoidance.

Fig. 3. Raspberry Pi car.

Fig. 4. Raspberry Pi Microprocessor

Fig. 5. Light sensor for line tracking.

Objectives
- Program the car so that it can be programmed to move from point A to point B
- Potential to try using a mapping program to do this using a Raspberry Pi car
- Auto-avoidance
- Line tracking
- Implement MATLAB-Simulink Model Predictive Control into the car to process the data from car trials and this improve the model
- Compare Raspberry Pi Car to Arduino Car and understand their unique capabilities to determine which is a better option

Results

Autonomous Driving
- First steps: Moving from app-controlled driving to autonomous driving.
- Changes were made to the code dependent on an Android App for motion of the car so that an On/Off button could be toggled and cause the car to begin driving autonomously.

Auto-Avoidance
- Need car to avoid obstacle and return to original path.
- Sensors on front of car detect obstacle, car needs to move left or right based on other surrounding obstacles.
- Considerations taken in code: driving speed, speed and angle of avoidance turn.

Line-Tracking
- Car programmed with ability to follow a darkened line.

Coding Implementations
- Success in avoiding an object in the path and returning to path, but angles found to be slightly off.
- Continued to add more obstacles in a row, car was able to avoid but angles being off kept car from continuing in straight line
- Success in line tracking using light sensors
- Line must be darker than ground (high contrast necessary for sensors to detect line)
- Integrated line tracking and auto-avoidance together, so that auto-avoidance overcomes line tracking when faced with an obstacle but line tracking resumes once obstacle heads back towards original path.

Model Predictive Control
- Uses a model of the system to make predictions about the system’s future behavior
- Optimization algorithm to find the optimal control action that drives the predicted output to the reference
- Multi-input multi-output systems
- May have interactions between their inputs and outputs
- Can incorporate future reference information into the control problem to improve controller performance
- Model Predictive Control Toolbox
- Has functions, an app, and Simulink blocks for designing and simulating MPCs
- Specify plant and disturbance models, horizons, constraints, and weights
- Evaluate controller performance

Fig. 6. Auto-Avoidance

Fig. 7. MPC Simulink Model.

Fig. 8. Sensor Data.

Conclusion
Autonomous vehicles continue to grow in relevance in today’s culture. As technologies develop, safety should be at the utmost concern before they can become commonplace developments in the modern world. With the excitement of autonomous vehicles comes numerous safety concerns that accompany putting people’s lives in the hands of machines.

This research focused on automatic obstacle avoidance and line tracking developments in autonomous cars. The obstacle avoidance is possible through ultrasonic sensors, and line tracking is made possible through light sensors.

The MATLAB Simulink Model Predictive Control Data was used to take data from the sensors to be able to predict future obstacles, risks, and movements from the car in order to improve future decisions made by the car. The output of the scope of the Simulink model includes a scope showing the input data as well as the output data of the sensor having gone through the model. Autonomous vehicles have numerous obstacles and hazards to consider, such as other cars, pedestrians, and objects in the built environment.

The purpose of this study was to identify security issues and risks associated with the development of autonomous vehicles. The research conducted shows the ability of ultrasonic and light sensors to be used to improve the security of autonomous vehicles. This research could be developed by increasing the number of sensors on the car to the sides, back, and front so that the car may have heightened spatial awareness and will drive safely on the roads.

Acknowledgements
I would like to thank Dr. Brook Abegaz for his guidance and expertise throughout the project. I would also like to thank my fellow Provost Fellows, Navi Shah and Sophia Sikar, for their collective collaboration on the ideas that made this project possible.

Resources
[2] UCTRONICS WiFi Smart Robot Car Kit for Arduino with Real Time Video Camera, Ultrasonic Sensor, Line Tracking, WIFI Module Remote Controlled by Android App
[3] UCTRONICS Smart Bluetooth Robot Car Kit K0072