ME327 Final Project Proposal - Haptic Control Panel Assistance for Autonomous Driving

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I. Team Members and Skills

The project team consists of four master's students in the mechanical engineering department.

Kexu Zhou, a first year master's student in the robotics track. With ME degree in her undergraduate. Her skillset covers data analysis, software development and manufacturing design. She is able to contribute to coding, data analysis and manufacturing.

Yafei Fan, a first year master's student in the robotics track. In her ME undergraduate period, she focus on the robot navigation and simulation. Now she's covering skills of robotics,manufacturing design, programming and data analysis. She is able to contribute robotics analysis and design, coding and manufacturing.

Kexin Weng, a second year master's student in the robotics track. With ME and CS dual degree in her undergraduate and research experience in smart manufacturing, her skillset covers the machine learning and manufacturing design and is able to contribute to the coding and manufacturing of the prototype.

Zhuzhu Wang, a second year master's student in the robotics track. With ME and ECE dual degree in her undergraduate and research experience in acoustics, reinforcement learning, she's able to design and improve the control system with abundant domain knowledge of the learning tools.

II. Topic and Motivation

With the fast iterations of learning tools, autonomous driving as an interdisciplinary field has attracted thousands of talents to compete in the markets over the recent decade. As the definitions of vehicle autonomous and security are enriched, we are obsessed with the idea of embedding haptic control into the autonomous system. Therefore, after getting exposed to the domain knowledge and hand-on experience in previous homework, we became motivated to design a system that simulate the driving environment. We can use a 3D printed stirring wheel attached to our hapkit, where we can manually stir the wheel to give input to the system, and in the meantime, we are able to receive haptic output in formats such as damping force, elasticity force, or vibrations.

The expected outcomes of our system are described as follows:

1) We will 3D print a stirring wheel which got attached to our hapkit, whose magnetic sensor can detect the angle of the wheel angle. We should be able to stir the wheel and drive the virtual car to take turns, and change lanes. We can control the acceleration and deceleration of the driving speed from pressing the key on our computer. (Input to the system).
2) Vehicle Autonomy Level 1 Driver Assistance: To make the driving more stable, we would apply damping force to prevent from stirring the wheel too sharply. If the car is becoming too close to the road shoulder when we make turns, the wheel would vibrates to alarm the danger. (Haptic output from the system)
3) Vehicle Autonomy Level 2 Partial Driving Automation: Meanwhile, our developed algorithm is capable of deciding the optimal angle in driving. For example, the car is aimed to keep centered in a driving lane, and stay away from the road shoulder. If the algorithm-determined desired angle deviates from our current wheel angle, the system would output a force to drive the wheel to the optimal location. The force should be proportional to the difference in desired-angle position and real-angle positions.

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III. Previous Work

1. **Implementation of Bilateral Control System Based on Acceleration Control Using FPGA for Multi-DOF. [1]**
   Link to the publication.
   - **Summary of the publication:** The implementation of haptic endoscopic surgery robot is based on bilateral control system. This kind of system needs to have enough freedom for applying various operation procedures. As the degrees of freedom of the system increase, the amount of control computation increases, and it becomes difficult to shorten the sampling period. However, bilateral control systems require relatively short sampling periods to achieve quick synchronization. It means that it's necessary to make the position and force transmission between master and slave robots as simultaneous as possible. Therefore, using FPGA-based motion system is a good choice. The FPGA is a programmable logic device and it has the advantages of short sampling periods(high-speed computation), parallel processing of control computation, accuracy of the sampling periods, low power consumption and small occupied space. Using FPGA to implement high-speed parallel computing for motion control systems can highly improve synchronization.
   - **Implication for our project:** Our project is intended to implement the bilateral control system on autonomous driving, so the synchronization between the 3D printing device and the virtual car is necessary. For example, when the virtual car detected it's too close to the obstacle, we want the 3D printing device to receive the force, position and acceleration as soon as possible. Meanwhile, when the 3D printing device turned steering wheel, the virtual car should react simultaneously. In order to achieve this goal, we can refer to FPGA-based motion system.

2. **A New Scheme for Haptic Shared Lateral Control in Highway Driving Using Trajectory Planning. [2]**
   Link to the publication.
   - **Summary of the publication:** Collision between the driver and the automatic steering system is an important issue which can affect driver safety and system acceptability. This paper presents a new framework for shared lateral control of highway driving using track planning. The core idea of this work is the driver's steering torque is considered at the trajectory planning level in order to tune the desired trajectory of the system in a way that is more appropriate to the driver's intent. The system uses the desired lateral displacement prediction to plan the route so that help reduce conflicting torques between driver and autonomous system. The main method used in desired lateral displacement prediction is to isolate effects of the driver's torque on the vehicle dynamics to predict vehicle trajectory as if the system were not acting on the steering wheels, and then using constant turn rate and velocity(CTRV) model to predict. With the prediction, integrating the driver's actions in the trajectory plan and robust the integrated plan using Takagi-Sugeno model.
   - **Implication for our project:** Our project is intended to choose the best trajectory plan so that avoid steer causing by obstacles as much as possible. Using high order polynomial path primitives mentioned in the paper can help ensure continuous velocities, accelerations and curvatures. Also, we may want to add the desired displacement prediction as an extension if possible.

3. **Haptic Shared Control: Improving Human-Automation Collaboration in Semiautonomous Driving. [3]**
   Link to the publication.
   - **Summary of the publication:** In order to realize smooth control transition between human manipulation and automation, this paper proposed a Haptic Shared Control (HSC) method in the autonomous driving system, in which the driver remains themselves in the loop with their hands on a motorized wheel and be prepared to apply a steering torque at any time that adds to the automation's torque to produce the total steering action. Similar with the human driver, the automation system applies torque with modest mechanical impedance such that it can be overridden. After detailed test and designed system, the Haptic Shared Control supported smooth transitions and improved the performance of the human-automation process, and more importantly, the haptic feedback benefits a lot while the volunteers are distracted both by visuo-manual task and the driving task.
   - **Implication for our project:** In this haptic project, we are intended to design a system that links the steering wheel and the interface with the virtual car. The topic described in this paper introduce us with a Haptic Shared Control (HSC) method utilized in the autonomous driving system, which helps us to process the problem about the transition between the user's applied torque on the wheel and the automation's torque.

IV. Plan

The project can be divided into four parts - software visualization for user interface, manufacturing of the hardware control module, connection of software and hardware using the bilateral control and dynamic modeling. Last, we should use metrics to evaluate the performance of our product. Detailed designs are discussed in the following.

In the remaining two weeks, we aim to finish coding and manufacturing of the wheel hapkit in the first week, and then in the second week we improve the quality of the control system using the evaluation and validation methods, and prepare for the final presentation, report and demo.

User Interface

We plan to build our user interface via Processing, a flexible software sketchbook. On the interface we show a little town with different types of roads such as the straight lanes, roundabouts, and T-intersections, as well as a vehicle moving at a constant speed.

The direction of the vehicle is controlled by the hapkit and shown on the user interface. The vehicle is restricted to driving on the lanes, so we will prevent it from passing through the buildings or walkways visually. However, the hapkit will penalize the users with a strong force if they carelessly drive the vehicle off the way. A sketch of our user interface can be seen in Fig.1.

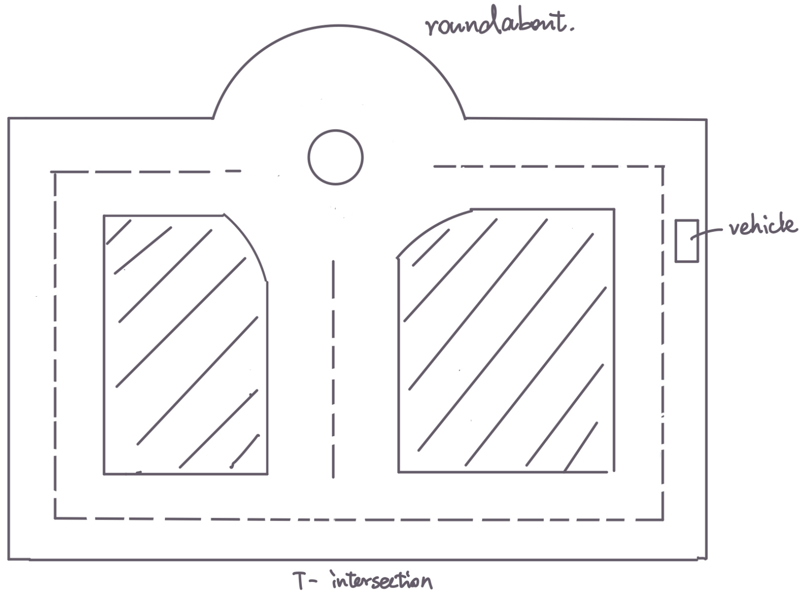

Fig. 1 Sketch of our UI design

Hardware manufacturing & Assembly

A sketch of our design can be seen in Fig.2. Most of our hardware can be reused from the previous projects, including the 3D-printed base, stand, cables, and screws. Additionally, we need to 3D-print a stirring wheel and attach it to the stand via the shoulder screw and the bearing. The stirring wheel can be rotated freely with a cable/ capstan drive system.

We plan to use the KMA221 magnetoresistive sensor to measure the change of the angle of our stirring wheel. The signal is sent to the hapkit board, and processed to get the orientation of our vehicle. The output port of the hapkit board is connected to a motor, which exerts force when the users carelessly drive the vehicle off the road.

Bilateral Control & Dynamics

We should use the mass-spring-damping dynamic model to get the wheel automatically rotate from current angle to optimal angle. The difference of optimal angle with current angle is denoted using θ. I, k, R and b are coefficients of

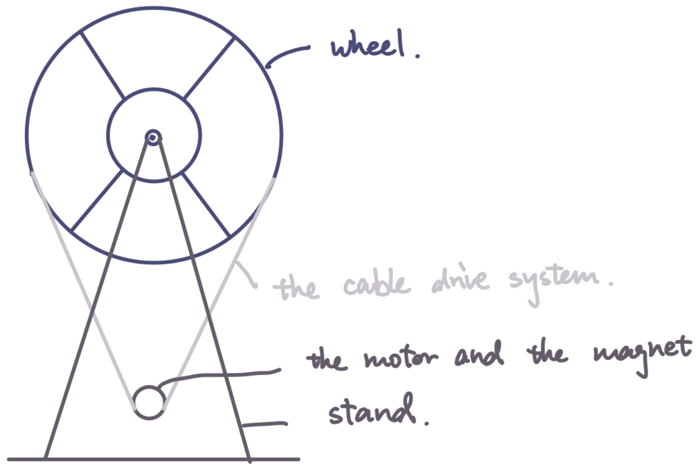

Fig. 2 Sketch of our hardware design

the system (for Moment of inertia, spring stiffness, radius of the wheel and damping coefficient) to be determined and improved by iterative testing.

$$I\ddot{\theta} = -b\dot{\theta}R - k\theta R$$

Intuitively, k should be relatively large, because we want the wheel go back to optimal angle in a fast manner. b should also be relatively large, since we don't want the system to have too much reciprocating motion.

Evaluation & Validation

In software, We would test across different algorithms for decision making of optimal wheel angle, and different force coefficients, etc. to achieve a more stable driving system, which can be observed by the noise the hapkit generated, the quality of the visualization. To indicate a higher level of driving security, we would also check the lag between software and hardware, to make sure that control is reactive with low latency.

Peer evaluation would be useful for hapkit control testing, since developers are biased towards the product they build. We will invite friends to give scale from 1-5 in terms of notice-ability, stability, noise-free, realism, software-hardware connection, etc. so that we can work further on the parts with room for improvement.

References

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[2] Benloucif, M. A., Nguyen, A.-T., Sentouh, C., and Popieul, J.-C., "A new scheme for haptic shared lateral control in highway driving using trajectory planning," *IFAC-PapersOnLine*, Vol. 50, No. 1, 2017, pp. 13834–13840.

[3] Wan, Y., Cutlip, S., Bhardwaj, A., Ghasemi, A., Watts, L., Garber, B., Sarter, N., and Gillespie, B., "Haptic Shared Control: Improving Human-Automation Collaboration in Semiautonomous Driving," , 05 2018.