ECE 445

SENIOR DESIGN LABORATORY

EARLY REPORT

Early proposal for ECE445
Wireless Fast Charging Autonomous Car

Team # 18

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1 Introduction

1.1 Problem

Current automobile vehicle is not completely auto since it can not go charging automatically when uses up electricity. Another problem is the current charger would occupy location so it may cause the waste of space. Our objective is to develop a vehicle that seamlessly integrates automatic wireless charging, autonomous navigation, and obstacle avoidance functionalities, enabling it to navigate its environment effortlessly while ensuring efficient energy replenishment.

Wireless charging cars may face several challenges. Efficiency loss due to electromagnetic interference and distance between coils is common, leading to slower charging and energy wastage. Precise alignment of charging coils is crucial, as misalignment affects charging efficiency. Interference from electronic devices and obstacles can disrupt charging. Heat generation during charging sessions poses risks to battery health. Compatibility issues between different charging standards hinder widespread adoption. Balancing range, efficiency, and battery size is crucial for optimizing wireless charging in electric vehicles.

1.2 Solution

A proposal is put forth for the development of an autonomous vehicle equipped with wireless fast charging capability ($P_{in} \geq 100W$). This vehicle is designed to autonomously detect the location of wireless charging stations and navigate to them swiftly and efficiently. In addition, the proposed autonomous vehicle will incorporate computer vision technology to enable obstacle avoidance, further enhancing its navigational capabilities. To save the space, the charging system is set at the ground of the vehicle instead of standing at the side of the vehicle.

Using supercapacitors instead of lithium-ion batteries at the receiver end of wireless charging coils offers several advantages. Supercapacitors provide rapid charging and discharging capabilities, with precise control over the magnitude of current flow. This allows for quick energy storage and release during short charging sessions while ensuring efficient energy management. Additionally, supercapacitors offer enhanced safety, and durability compared to lithium-ion batteries. Overall, integrating supercapacitors into wireless charging systems improves reliability, safety, and sustainability while enabling precise control over current flow for optimized energy storage.

1.3 Visual Aid

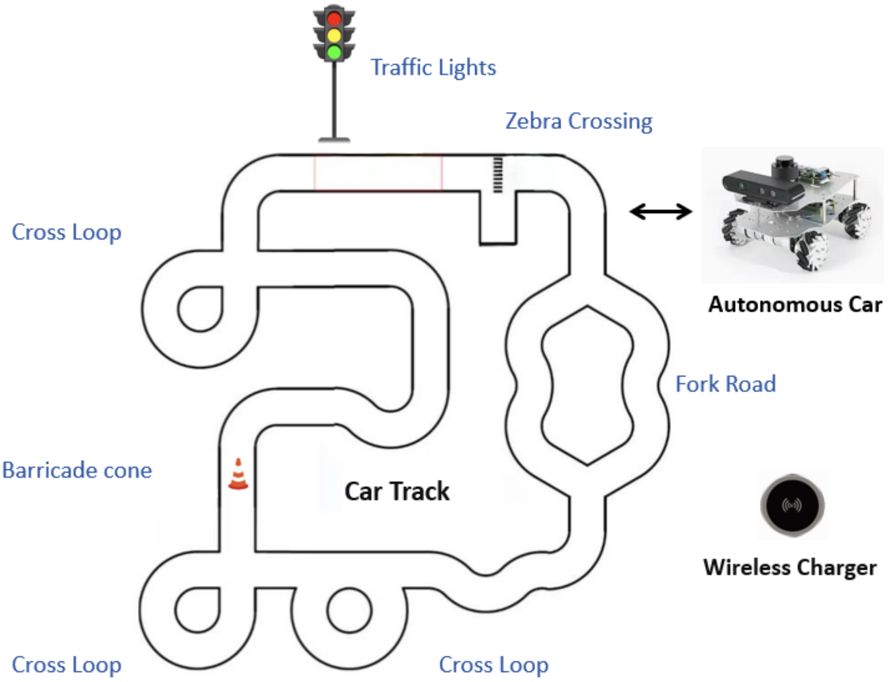

Figure 1: **Visual Aid.** This diagram combines our visual aids, including a driving map, a wireless charger on the ground, and the vehicle.

1.4 External Systems

We require both a ground-based charging station and a detailed map for the vehicle's navigation purposes.

The requirements of the driving map will be stated below. The car should be stopped when recognizing the traffic lights. When recognizing the zebra crossing, it should be slowed down. When passing through the curve or cross loop, you should not touch the wall. Finally, when you recognize the barricade zone, it is determined to reach the target, and automatically go to the charging point for wireless charging.

1.5 High-level Requirements List

- The wireless charging power $P_{in} \geq 100W$.
- Car can automatically align to the charging coils.
- Car can detect the place of wireless charging station.
- The overall size of the car is around 266mm×230mm×202mm.

2 Design

2.1 Block Diagram

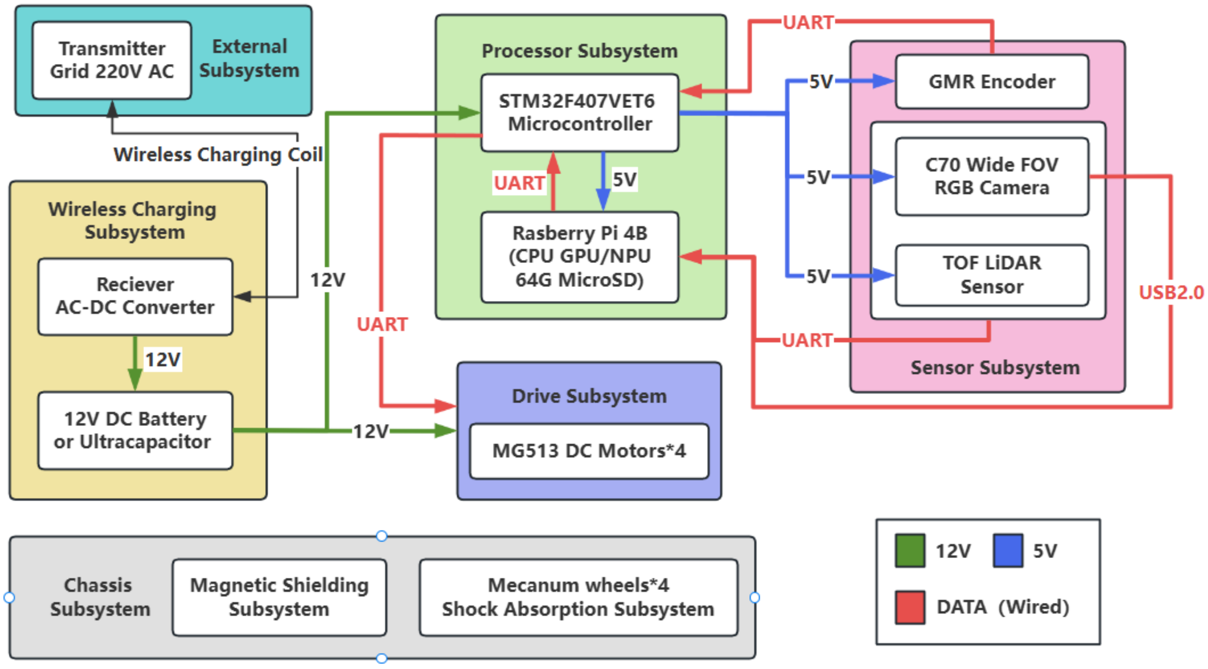

Figure 2: **Block Diagram**

2.2 Subsystem Overview

2.2.1 Wireless Charging Subsystem

To find the maximize the power of charging, the vehicle would first locate the best position for charging using Maximum Power Point Tracking (MPPT) algorithm. The implement of the MPPT algorithm is based on Raspberry Pi. Once the vehicle moves to the expected place, the charging would start.

A rectifier connected to the grid is used to transfer the AC voltage to DC voltage. A converter is used to adjust the DC voltage to meet the requirement of battery. When power is supplied, it creates an alternating electromagnetic field around a ”primary” coil in the base station. The electric vehicle is equipped with a ”secondary” coil that receives this oscillating magnetic field as the vehicle is parked over the base station. The varying magnetic field induces a current in the secondary coil in the vehicle. More detailed parameters are shown in subsystem requirements section.

2.2.2 Drive Subsystem

The drive subsystem of the intelligent car responds rapidly to instructions provided by the processor system and ensures smooth and accurate control over the car’s movement in various directions, including forward, backward, left, right, and even turning in place. The drive subsystem primarily consists of the MG513 metal gear reduction motor, clamping type couplers, motor brackets, and other components. The four motors are mechanically connected to the four Mecanum wheels and mounted on the chassis subsystem, powered by the power subsystem, and controlled by the processor subsystem. Specifically, the car requires four DC reduction motors, consisting of full-metal gear reduction boxes and GMR encoders from the sensor subsystem. The selected motors have a rated voltage of 12V, a rated current of 0.36A, a reduction ratio of 30, and a power of approximately 4W. The rated torque of the motors is 1kg.cm, and the unloaded speed after reduction is 366±26rpm. We estimate that the motors can drive the car at a maximum speed of approximately 1.2m/s and can carry a maximum weight of 3-4kg, which fully meets our requirements.

Figure 3: **MG513P30_12V DC motor**

2.2.3 Sensor Subsystem

The C70 wide field-of-view (FOV) RGB camera will be utilized for computer vision tasks, including detecting target charging points and various road facilities such as pedestrian crossings (zebra crossings), among others. The camera features a resolution of 720P, operating at a frame rate of 25fps, with a field of view (FOV) of H64.5° x V50°. It connects via a USB2.0 interface and supports the UVC (USB Video Class) standard.

We will employ the Leishen N10P radar sensor to facilitate obstacle avoidance functionality, which is a commercial-grade Time-of-Flight (TOF) LiDAR sensor, with a measurement range of 25 meters, a sampling frequency of 5400Hz, and a serial interface for communication. This radar will be employed to detect obstacles on both sides and in front of the vehicle, including roadblocks and walls, allowing for timely adjustments to the vehicle's trajectory as necessary.

For obstacle avoidance function, the GMR (Giant Magnetoresistive) encoder can help the intelligent car accurately identify obstacles and perform obstacle avoidance operations, thereby ensuring safe driving. And it can also help intelligent vehicles achieve path planning and autonomous navigation, enabling them to autonomously travel and complete tasks in complex environments. The rated voltage is about 5V.

2.2.4 Chassis Subsystem

Shock Absorption Subsystem The cart shock system consists of four independently suspended hydraulic shock structures, and each structure is independently attached to the cart chassis, thus enabling the four Mecanum wheels to independently realize the shock function in complex terrain and increase the overall stability of the cart. The four independently suspended shock absorbing structures can better ensure the horizontal state of the trolley chassis, which is conducive to improving the efficiency of wireless charging.

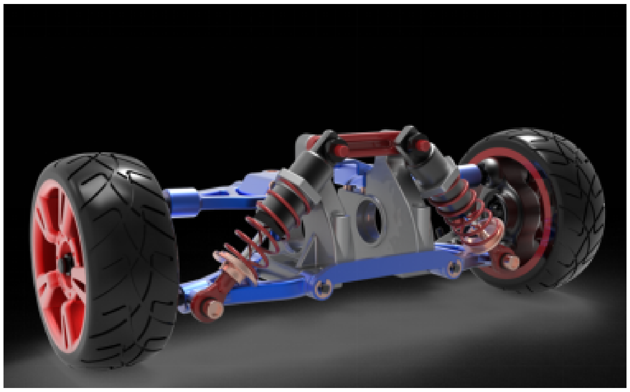

Figure 4: **Shock Absorption Structure**

Magnetic Shielding Subsystem The material to isolate the magnetic field will be placed above the wireless charging structure in the chassis of the cart to protect the control system components of the main body of the cart, preventing the magnetic field during high power wireless charging from having an effect on the circuitry components, which can affect the control of the cart.

2.2.5 Processor Subsystem

Our ROS (Robot Operating System) controller is based on the Raspberry Pi 4B, featuring a quad-core ARM Cortex-A72 processor clocked at 1.5GHz, 4GB of RAM, with a computational power of 0.2 TOPS. It operates on a 5V power supply.

The ROS controller, running on the Raspberry Pi 4B, establishes connections and controls the camera and LiDAR sensor via their respective interfaces. The camera, operating through a USB 2.0 connection and supporting the UVC standard, streams RGB images to the Raspberry Pi. These images are processed using ROS-compliant computer vision algorithms.

Furthermore, we use the STM32 microcontroller to provide supply voltage to the Raspberry Pi 4B and the sensor subsystem and receive data from them. The STM32 microcontroller can also provide control signal to the drive subsystem.

On the other hand, the LiDAR sensor, the Leishen M10P, communicates with the Raspberry Pi via a serial interface. The ROS controller sends commands to the LiDAR sensor to initiate measurements and receives distance data back from the sensor. This data is then processed to detect obstacles and adjust the vehicle's navigation path as required.

In summary, the ROS controller orchestrates the interaction between the Raspberry Pi and the camera/LiDAR sensor, receiving data from these sensors, processing it, and making control decisions for the autonomous vehicle's navigation and charging operations.

2.3 Subsystem Requirements

2.3.1 Wireless Charging Subsystem

- 12V 5000mAh Lithium Battery or Ultracapacitor
- 220V/20V Rectifier
- 20V/12V Converter
- 100W Wireless Charging Coil Transmitter

2.3.2 Drive Subsystem

- MG513P30_12V DC Metal Gear Reduction Motor

2.3.3 Sensor Subsystem

- C70 wide field-of-view (FOV) RGB camera
- Time-of-Flight (TOF) LiDAR sensor
- GMR Encoder

2.3.4 Chassis Subsystem

- All-metal dual-stage spring-loaded hydraulic shock absorbers.
- Ferrite material: Ferrite is a ceramic material with spin magnetic moment, which has high magnetic field permeability, high magnetic permeability, and high magnetic saturation strength, and can effectively isolate high frequency electromagnetic waves and magnetic fields.

2.3.5 Processor Subsystem

- STM32F407VET6 Microcontroller
- Rasberry Pi 4B(CPU GPU/NPU 64G MicroSD)

2.4 Tolerance Analysis

Considering the wireless charging requirements in our project, we identify the wireless charging subsystem as the area most susceptible to risks. We are concerned that the current-voltage ripple in the charging circuit may affect the normal operation of other subsystems, posing a significant demand for debugging the inductor and capacitor in the circuit. Below is the schematic simulation of the wireless charging section conducted in MATLAB Simulink. We have omitted the circuit for rectifying 220V AC into DC. Our simulated circuit includes a high-frequency inverter and a rectifier.

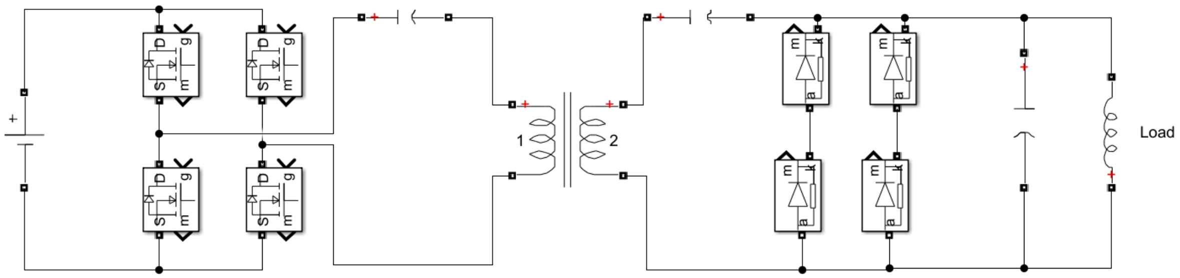

Figure 5: **Schematic simulation circuit of part of the wireless charging subsystem**

For the left-side inverter circuit:

$$V_{out} = \frac{4V_{in}}{\pi} cos\frac{\delta}{2}\, cos(\omega_{out}t - \frac{\delta}{2})$$

where V_{in} is the DC input voltage, V_{out} is the output voltage, ω_{out} is the angular frequency of the high-frequency AC, and δ is the displacement angle.

For the right-side rectifier circuit:

$$\Delta V_{out} \leq \frac{V_O}{2fRC}$$

$$C \approx \frac{V_O}{2fR\Delta V_{out}}$$

where ΔV_{out} is the DC output ripple voltage, V_O is the peak voltage of the AC, f is the frequency of the AC, R and C are the resistor and capacitor on the output side of the circuit, respectively. We adjust the size of the capacitor to minimize the ripple voltage.

We have not provided specific values for the capacitance, resistance, and inductance in the circuit yet because the internal resistance and impedance of coils and other electronic components are unknown. This requires adjustment in our laboratory experiments. We are also concerned about the possibility of damaging the battery due to excessive peak voltage during wireless charging. We plan to use ultracapacitors instead of lithium batteries. However, ultracapacitors have a larger volume and pose a significant risk of short circuits. We plan to design protective circuits and employ MPPT algorithms to align the coils as accurately as possible to minimize the occurrence of such situations.

3 Ethics & Safety

3.1 Ethics Issues

Ethical Issues of High-Power Wireless Charging Autonomous Vehicles:

1. **Privacy Concerns:** The wireless charging system may require communication with the vehicle to better manage the charging process. This communication may involve information such as the vehicle's location and driving habits. Ensuring the privacy of this data, preventing misuse, and unauthorized access raises ethical considerations regarding user privacy [1].
2. **Social Equity:** The widespread adoption of high-power wireless charging technology may face issues of social equity. If the implementation of this technology is predominantly limited to specific regions or socioeconomic groups, it could exacerbate technological divides, leading to ethical concerns related to social fairness.
3. **Emergency Handling:** In emergency situations such as fires or accidents, the ethical responsibility for safely interrupting the charging process and ensuring the safety of the vehicle and the surrounding environment comes into play.

3.2 Safety Issues

Safety Issues of High-Power Wireless Charging Autonomous Vehicles:

1. **Electromagnetic Radiation:** High-power wireless charging systems may generate strong electromagnetic radiation, posing safety risks to individuals, animals, and other electronic devices. Ensuring that the system complies with relevant electromagnetic radiation safety standards is critical to reducing potential health risks.
2. **Charging Speed and Battery Life:** Pursuing excessively fast charging speeds may negatively impact battery life and performance. Safety-wise, it is necessary to balance charging speed and battery health to ensure the safe operation of the vehicle and preserve battery life.
3. **System Failures and Safety Standards:** The design and implementation of high-power charging systems must adhere to strict safety standards [2]. System failures could lead to fires or other safety issues, necessitating measures to ensure the system can operate safely in various conditions, including emergency shutdown and fault-handling mechanisms.
4. **Energy Source and Environmental Safety:** If the charging system primarily relies on non-renewable energy sources, it could have adverse environmental impacts. Ensuring the use of clean, renewable energy sources is a crucial safety issue to reduce the risks of environmental pollution and climate change [3].

References

[1] J. Robinson, J. Smyth, R. Woodman, and V. Donzella, “Ethical considerations and moral implications of autonomous vehicles and unavoidable collisions,” *TheoreTical issues in ergonomics science*, vol. 23, no. 4, pp. 435–452, 2022.

[2] M. Ragheb, “Risk and safety ethics,”

[3] T. Muneer, M. Kolhe, and A. Doyle, “Electric vehicles: Prospects and challenges,” 2017.