ECE 445

Spring 2021

Project Proposal

Head-Motion Controlled Wheelchair

Team Members: Dev Manaktala, Arnav Jain, and Jiayuan Liu

Section: H

TA: Yichi Zhang

Date: 2/17/2021

1. Introduction

1.1 Objective

Classical wheelchairs are designed to be operated by people who have the ability to maneuver them with a functioning arm. There are people, such as amputees and those suffering from paralysis, that cannot operate such wheelchairs.

We propose a head-motion controlled wheelchair that would allow people with such disabilities to be able to travel. The wheelchair would have a mounted camera facing the user and use computer vision to detect head motion to move and turn the wheelchair. The wheelchair would also have a vibration module allowing users with compromised vision to maneuver. This would be done through IR/ultrasonic sensors on the wheelchair detecting obstacles in the path and giving vibrational feedback to the user.

1.2 Background

Existing prototypes of such wheelchairs either use eye movement as user input or require the user to wear some sort of device on their head. We believe that our design could provide a much simpler and more viable solution compared to these since head motion is a more natural way to provide input. Furthermore, one of the features that distinguishes us from current alternative options is the object detection system as this would add another layer of safety to the wheelchair.

1.3 High Level Requirement

- Wheelchair should be able to move instantaneously with head motion with minimal lag (less than 1 sec)
- Wheelchair motors should have a good enough torque to move any person upto 250 lbs between speeds of 4.5 and 8 mph
- Wheel-chair should not have false-positive inputs, i.e, the wheelchair should not move if the user did not intend it to.

2. Design

The design consists of four major subsystems and a microcontroller. The power supply subsystem consisting of both high and low voltage batteries provides power to the microcontroller, the Raspberry Pi, and the motor controller circuits. The motion detection subsystem involves the camera and the Raspberry Pi. Frames are sent from the camera to the Raspberry Pi [1]. The Raspberry Pi processes the data and sends output to the microcontroller. The microcontroller gives instructions to the motor controller circuits and thus drives both traction motors. The object detection subsystem measures objects close to the surface by ultrasonic sensors and gives vibration feedback to the users through the vibration motors. The Raspberry Pi, the microcontroller, and two sets of motor control circuits will be on a single board to avoid external wiring and extra power distribution.

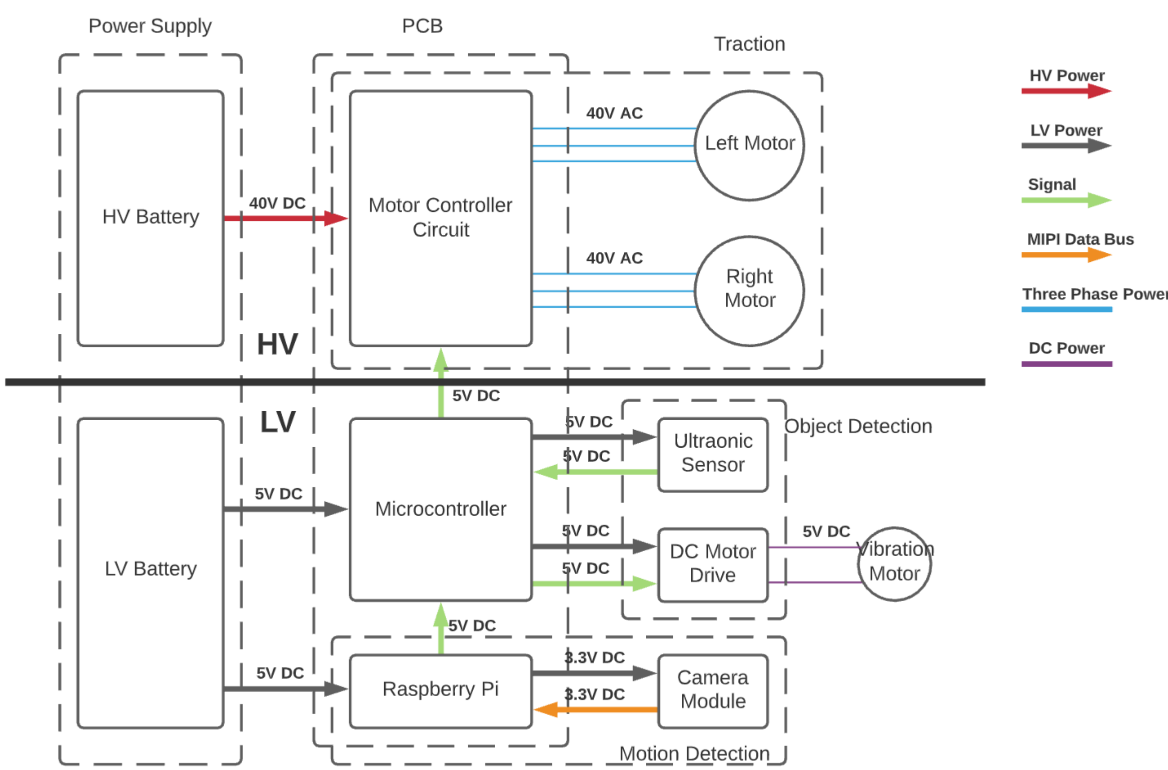

Figure 1. Block Diagram

3. Subsystems

3.1 Power Supply

3.1.1 Functional Overview

The power supply consists of one high voltage battery at 40V and one low voltage battery at 5V. The high voltage battery powers a pair of motor control circuits and thus powers two traction motors. The low voltage battery powers both the microcontroller and the Raspberry Pi. It also directly powers the vibration motor because the current required by the vibration motor may exceed the current limit of the microcontroller.

3.1.2 High Voltage Battery

Requirement 1: The battery should be able to provide at least 300W at 40V to power both traction motors.
Requirement 2: Should be rechargeable because batteries at this voltage are expensive and switching high voltage batteries is not safe for users. Users need to be able to recharge their wheelchair without changing the high voltage battery.

3.1.3 Low Voltage Battery

Requirement 1: The low voltage battery should continuously provide steady voltage at 5V to protect the microprocessors in both the microcontroller and the Raspberry Pi. The voltage difference cannot exceed 5% which is 250mV.

3.2 Motion Detection

3.2.1 Functional Overview

The motion detection subsystem involves the camera and the Raspberry Pi. The camera will be mounted on the wheelchair facing the user and send each frame to the Raspberry Pi. We will then be running HaarCascade face detection [2] algorithm on startup. We will then extract features and calculate deviation of eyes from the center, compare it to a threshold value and predict desired input by the user. Furthermore we will be testing the need for facial detection and tolerance for the number of frames that do not require face detection.

3.2.2 Raspberry Pi

Requirement 1: The Raspberry Pi needs to be powered by a 5V DC power supply.

Requirement 2: Output from the Raspberry Pi should be sent with minimal latency (~1 sec)

3.2.3 Camera Module

Requirement 1: The camera module must have a frame rate above 40 fps.

Requirement 2: The camera module must have a resolution of 480p or above.

3.3 Traction System

3.3.1 Functional Overview

The traction system is powered by the high voltage battery at 40V. It allows the wheelchair to both move straight and turn left or right by adjusting the speeds of two motors according to the signals received from the Raspberry Pi. When receiving a moving forward signal from the microcontroller, the motor controller controls two motors to operate at the same speed. On the other hand, when receiving a turning signal, the motor controller moves the two motors in opposite directions to turn the wheelchair.

3.3.2 Motor Controller Circuit

Requirement 1: The motor controller should be able to supply the required current and voltage of both traction motors.

Requirement 2: The circuit should be controlled by 5V signals from the microcontroller.

Requirement 3: The motor controller should be able to drive both motors separately. This includes making both motors operate at the same speed and driving each motor both forward and backward.

Requirement 4: Both the gate drivers and the MOSFET/IGBT gates should afford 40V of voltage and 10A of current.

Requirement 5: The traces of the three phase output current on the PCB should be at least 150mil in width [3]. The traces of the DC power input should be at least 300mil in width.

3.3.3 Traction Motors

Requirement 1: The working voltage should be under 5V, which is the voltage of the low voltage battery.
Requirement 2: The total output power should be no less than 300W to drive the wheelchair. The power of each motor should be at least 150W to generate a total power of 300W.
Requirement 3: The diameter of each motor should not exceed 25cm to be successfully mounted on the wheelchair.

3.3.4 Wiring

Requirement 1: The wires that deliver three phase power to traction motors should be at least 16 gauge to handle 10A of current [4].
Requirement 2: The wires that deliver power from the high voltage battery to the motor controller should be at least 14 gauge to handle 20A of current [5].

3.4 Printed Circuit Board

3.4.1 Functional Overview

The printed circuit board will integrate one Raspberry Pi, one microcontroller, and two sets of motor control circuits. All three modules are on a single board so that no external wiring and no extra power distribution is required.

3.4.2 Microcontroller

Requirement 1: The microcontroller should be able to continuously provide at least 8mA at 5V on its output pins to power the ultrasonic sensor [6].
Requirement 2: The microcontroller should strictly avoid any input above 5V to protect the integrated circuit.

3.4.3 Layout

Requirement 1: There should be a one inch margin between the high voltage components at 40V and the low voltage components at 5V.

Requirement 2. The number of traces between the high voltage side and the low voltage side should be minimized. Any of these traces should be perpendicular to the margin lines to minimize the length inside the margin.

3.5 Object Detection

3.5.1 Functional Overview

The object detection subsystem measures objects close to the surface and gives vibration feedback to the users. When an object is detected by the ultrasonic sensors, a signal is transmitted to the microcontroller. The microcontroller toggles a signal to make the DC motor drive to operate the vibration motor. Users should be alerted by the vibration.

3.5.2 Ultrasonic Sensors

Requirement 1: The ultrasonic sensors need to have a front-facing 120 degree field of detection.
Requirement 2: The sensor would need to accurately detect objects upto a distance of 3 meters.
Requirement 3: There needs to be minimal latency between the ultrasonic sensor and vibration motor (less than 0.5 sec).

3.5.3 Vibration Motor

Requirement 1: The working voltage should be under 5V, which is the voltage of the low voltage battery.
Requirement 2: The vibration magnitude should be large enough to alert the user.

3.5.4 DC Motor Drive

Requirement 1: Should be able to supply the required current and voltage of the vibration motor.
Requirement 2: Should be controlled by a 5V signal from the microcontroller.

4. Risk Analysis

One of the most important things we need to ensure is that the ultrasonic sensors we use are sensitive and wide-ranged enough so that users would know if there are objects they might collide with. Besides, we also need to ensure that there are no false-positives with the head motion detection. This could lead to the wheelchair moving forward or backward without notice and lead to potential injury. Moreover, we need to make sure that the motors on the wheel chair have a sufficient torque so that it does not move too slowly. The difficulty of the attachment of two motors to the wheelchair is a potential risk to the successful completion of this project. The position of both the motors and the wheels needs to be accurate enough so that the wheels can gain enough torque from the ground. On the other hand, receiving data from the Raspberry Pi by the microcontroller and giving instructions to the motor controller circuit is another potential risk of this project. The microprocessors inside the motor controller circuit have specific requirements for the input signal. It may be difficult to generate the required signals from our microcontroller directly. Another risk factor is achieving fast face detection run-time along with low latency between the raspberry pi and the motor controller since instantaneous movement of the wheelchair is a very important aspect of the project concerning the safety of the user.

5. Ethics

Since we will be using facial detection, a big ethical concern for the users of the product would be that none of their data is stored. We will not be storing any frames captured by the camera on an external server. We will also not be performing any facial recognition.

6. Safety

Since the wheelchair will be operated on head-motion as input, causing the wheelchair to move, safety is a priority for the product. The biggest safety concern is false positive input, that is, the wheelchair moving without the user intending it to. To ensure this does not happen, we will be designing the forward movement command to be something that cannot be provided in an unexpected way such as a specific facial expression. Another concern is the instantaneous halting of the wheelchair when required. To achieve this we must ensure that the facial detection is fast and that there is low latency between the detection subsystem and motor controller. Besides, the head-motion controlled wheelchair is a project consisting of both high voltage and low voltage electrical systems. Generally, 30 volts is considered as a conservative threshold value for dangerous voltage [7], which means any system above 30V could be dangerous to humans. To avoid any hazard brought by high voltage, we first need to refuse any exposed high voltage anodes and cathodes. This includes the high voltage battery output and the three phase power output of the motor controllers. Second, we need to set apart the high voltage and low voltage circuits on the PCB. Since both systems are existing on a single board, we need to avoid the low voltage system to be shorted with anything above 5V, especially the high voltage system which may go over 30V.

References

[1] ArduCam, 'Raspberry Pi MIPI CSI Camera Pinout', 2014. [Online]. Available: https://www.arducam.com/raspberry-pi-camera-pinout/. [Accessed: 18-Feb-2021].

[2] G. Behera. "Face Detection with Haar Cascade", 2020. [Online]. Available: https://towardsdatascience.com/face-detection-with-haar-cascade-727f68dafd08. [Accessed 18-Feb-2021].

[3] Bittele Electronics, 'PCB Trace Width Calculator', 2021. [Online]. Available: https://www.7pcb.com/trace-width-calculator.php. [Accessed: 18-Feb-2021].

[4] JST, 'Wire Size & Current Rating (A) Guide', 2021. [Online]. Available: https://www.jst.fr/doc/jst/pdf/current_rating.pdf. [Accessed: 18-Feb-2021].

[5] JST, 'Wire Size & Current Rating (A) Guide', 2021. [Online]. Available: https://www.jst.fr/doc/jst/pdf/current_rating.pdf. [Accessed: 18-Feb-2021].

[6] Murata, 'Ultrasonic Sensors FAQ', 2021. [Online]. Available: https://www.murata.com/en-us/support/faqs/products/sensor/ultrasonic/char/0002. [Accessed: 18-Feb-2021].

[7] All About Circuit, 'Ohm's Law', 2020. [Online]. Available: https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/ohms-law-again/. [Accessed: 18-Feb-2021].