Electrical Overview

Year: \_2023\_ Semester: \_Fall \_ Team: \_16 \_ Project:\_Autonomous Air Hockey Robot \_

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Assignment Evaluation: See Rubric on Brightspace Assignment

1. Electrical Overview

Our project can be broadly divided into 4 categories of electrical subsystems: Image Recognition, External Sensors/UI, microcontroller/PCB elements, and motion devices.

* PCB elements: STM32 microcontroller, 3.3 to 5V level translator IC, 8-bit shift registers, 5 to 3.3V LDO IC, USB to UART translator
* External Sensors/UI: IR LEDs for distance sensing, 7 segment display \*8, speaker \*2.
* Motion Devices: 2 NEMA 23 2 phase Stepper Motors, 2 motor controllers.
* Image recognition: 120 FPS camera, PC/Laptop/Desktop

To illustrate the electrical flow of data we will follow the critical path of functionality, beginning with the image recognition system.

1. At 120 FPS, the camera transmits images to the PC
2. The PC processes these images into puck location and velocity.
3. PC generates path vectors which the gantry system will follow.
4. Path vectors will then be passed to the microcontroller via USB 🡪 UART translator (see interface considerations).
   1. Note that this connection will not be exclusively for path vector communication. Other, general purpose stating of the microcontroller will be done over this interface as well
5. The microcontroller will then determine the number of stepper steps, direction, and velocity required to move along this vector.
   1. Prior to transmission this information is translated into pulse frequency and count
6. PWM signals sent via GPIO pin to the Level Translator IC (3.3 🡪 5V).
   1. Note that there are actually 3 lines of GPIO communication: PWM/Pulse, ENA, DIR. Each will have a dedicated GPIO pin.
7. Level Translator IC (on PCB) connects to motor controller (off PCB) sending relevant control signals.
8. Motor controller connects 24V line to each winding phase and follows control signals to generate mechanical motion in gantry system.
9. In the event that the puck enters the goal, break-beam sensors will detect the score and trigger an interrupt on the micro. This information will then be translated into SPI data which will update the 7-segment displays on the HUD (heads up display) to reflect the new score to the user.
   1. As a stretch goal, scores may also be accompanied by audio controlled by the micro via PWM on speakers also located in the HUD.

2.0 Electrical Considerations

Operating Frequencies

Image Recognition System: The camera will be operating at 120FPS and transmitting data at near the maximum speed of a USB 3.0 device, 600 Mbit/s. This is an unavoidable consequence of many high-quality images.

Microcontroller: Operates at 48 MHz. As the micro will not be doing any computational heavy lifting, this operating frequency should suffice for interfacing and controlling the other external systems.

Motion Devices: The maximum operating frequency of the motors is defined by the motor control box interface speed (200 kHz). See Interface considerations for analysis.

Power Budget and Loading Considerations

There will be two separate power supplies for the system. A 5V supply to power the PCB/Micro/External Sensors/UI, and a 24V supply to run the motors. As the motors will be ramping up current consumption incredibly quickly, loading and brown outs are a serious concern if only a single supply were used. For system stability, these two power systems will be optically isolated from each other.

5V supply power consumption:

* LDO 5 to 3.3V w/ 66% typical efficiency
* Microcontroller 120mA max @ 3.3V = 0.396W
  + Plus 33% for LDO efficiency = 0.53W
* USB->UART Translator 15mA max @ 3.3V = 0.0495W
  + Plus LDO = 0.065W
* 7 Segment Displays 20mA/section = 10mA \* 7 \* 8 = 560mA = 1.848W

Motion Devices:

* Motor Control Box w/ 98% typical efficiency
* Stepper motor Max current 2.8A, winding resistance 1.13 ohm = 8.85W \* 2 windings = 17.7W/motor
  + Ideal = 40W to account for 20% overhead in motor consumption

24V supply must provide at least 1.67A to supply motor system.

Tolerances

Users of 5V Supply:

* Level Translators: 4.5 to 5.5V
* LDO: 4.5 to 5.5V

Users of 3.3V (LDO generated) Supply:

* Micro: -0.3V to 4.0V, max 120mA
* Shift Registers: 2V to 6V, 40uA to 80 uA
* 7 Segment Display: 3V to 4V, 10mA to 20mA

Users of 24V Supply

* Motor Control box: 20V to 50V supply, output min 1A @ 18V output max 4.5A @ 50V
* Stepper Motors: 12V to 48V, 2.8A max

3.0 Interface Considerations

Image Recognition

The camera 🡪 PC interface is notable for the electrical overview (rather than exclusively being software) due to the latency requirements of its interfaces. As the PC will be mounted on the underside of the table and the camera at a ‘birds-eye’ view, the cable connecting the two will need to pass directly adjacent to the gantry motors. As the motors are electrically noisy devices, the cable connecting the camera to the PC must be magnetically isolated. Latency will directly depend on the quality of isolation and length of cable required for this interface.

The PC 🡪 Micro interface is more complex in that it will require a USB (PC side) 🡨🡪 UART (micro side) translation IC. Operating at max speed, USB 2.0 will support 480 Mbit/s and UART will support 6.25 Mbits/s. The translation IC (and therefore the path’s max transfer rate) is limited to the minimum of the two.

External Sensors/UI

There are three subsystems for the user interface/UI: 7 segment HUD, score detectors, and speaker systems.

7 segment HUD: Controlled via two 8 bit shift registers over a SPI connection. This SPI connection will be constantly active to enable persistence-of-vision time multiplexing to drive 64 individual ‘LEDs’. However, the interface must only run at 3.092kHz (490Hz \* 8 individual displays, 490Hz being the accepted standard for POV).

Score Detectors: The score detection LEDs are an analog control circuit which triggers a digital comparator when the distance goes below a certain threshold. This digital comparator is connected off PCB and will be detected using an interrupt-enabled GPIO pin.

Speaker/Audio System: Will be driven by the micro via PWM and an analog amplifier (on PCB). Ports will then connect off PCB to the speakers in the HUD.

Motion Systems

The motion system is interfaced via PWM to the microcontroller. As mentioned in the critical path analysis section, the PWM control signal is level translated from 3.3 to 5V on PCB, from which it connects to the motor control boxes. These motor control boxes then connect to the individual windings on the stepper motors.

The maximum PWM frequency supported by the motor control box is 200 kHz. For our device, this corresponds to a max linear speed of 223 mph. Needless to say, we will be well below this max frequency.

4.0 Sources Cited:

[1] “Digital Stepper driver 1.0-4.5a 18-50VDC for NEMA 17, 23, 24 Stepper Motor,” StepperOnline, https://www.omc-stepperonline.com/digital-stepper-driver-1-0-4-2a-20-50vdc-for-nema-17-23-24-stepper-motor-dm542t (accessed Sep. 16, 2023).

[2] FT232R, https://www.ftdichip.com/old2020/Products/ICs/FT232R.htm (accessed Sep. 16, 2023).

[3] “STM32F0X1,” STMicroelectronics, https://www.st.com/en/microcontrollers-microprocessors/stm32f0x1.html (accessed Sep. 16, 2023).

[4] “LM3940,” LM3940 data sheet, product information and support | TI.com, https://www.ti.com/product/LM3940#:~:text=The%20LM3940%20is%20a%201,from%20a%205%2DV%20bus. (accessed Sep. 16, 2023).

Appendix 1: System Block Diagram

*A computer screen shot of a computer

Description automatically generated*