I/O System Design for the PSYONIC Advanced Bionic Hand

Team 28 — Byron Hopps and Steven Sun
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TA: Zipeng "Bird" Wang

1 Introduction

1.1 Objective

There 11.4 million hand amputees in the world, and over 80% are in developing nations [1]. Less than 3% of these amputees have access to the rehabilitation necessary to rebuild the functionality they lost by losing a limb [2]. The high cost of existing prosthetics makes them unaffordable to amputees in developing nations. Most low-cost designs for prosthetic hands focus on the mechanical design of the hand, not on the design of an integrated system that is a viable product for amputees [3].

PSYONIC is a startup on campus that is working to fix these issues by developing a low-cost prosthetic hand for use on amputees worldwide, in both developed and developing nations. They are working alongside clinicians and amputees to ensure that the hand will meet the needs of amputees. With features such as control by electromyographic (EMG) pattern recognition and tactile feedback through use of electrotactile stimulation, the PSYONIC Advanced Bionic Hand will be a serious competitor to existing prosthetic hands on the market today [4].

1.2 Background

PSYONIC is a startup on campus that is developing an affordable prosthetic hand for people with upper-limb amputations worldwide. Their prototypes have reached a high level of functionality, and they are now moving the design towards production hardware [5]. While the core functionality of the hand is well-integrated, auxiliary functionality such as battery charging and external I/O are either nonexistent or require specialized hardware to be used.

We plan to design a new system for PSYONIC's prosthetic hand, to be known as the I/O system. This system will integrate all the external I/O necessary for the prosthetic arm. It will contain two external interfaces, namely USB type-C and Bluetooth. USB type-C allows for rapid battery charging and wired data communications. Bluetooth enables the hand to be capable of wireless data transfer. These interfaces will let us build an API that will let us, and more importantly, clinicians perform a variety of remote control and configuration tasks. This includes the ability to query and write values that control various aspects of the hand's operation, such as the finger speed sensitivity or the battery charge level. While there are COTS solutions for individual aspects of this problem, there is no commercially available solution that can perform all the required functionality, let alone in the space constraints the project requires.

1.3 High-Level Requirements List

- The I/O System shall be capable of powering the prosthetic hand from both an external power source and an internal battery
- The I/O System shall be capable of communicating with external devices using Bluetooth or USB
- The I/O System shall be capable of sending commands to the EMG board

2 Design

The I/O System consists of two modules, the I/O Board and a 2.2Ah lithium-ion battery. The I/O Board contains four schematic blocks, a USB-PD controller, a lithium-ion BMS, a USB serial interface, and a Bluetooth SoC. The USB-PD block controls the USB power source that is used to power the hand. The lithium-ion BMS charges the battery and regulates the battery output for use by the rest of the hand. The Bluetooth SoC implements the hand's communication protocol and controls the rest of the I/O Board. Lastly, the USB serial interface enables the microcontroller to communicate with an external USB host. Lastly, an external lithium-ion battery supplies power to the entire hand when external power is not connected.

2.1 Block Diagram

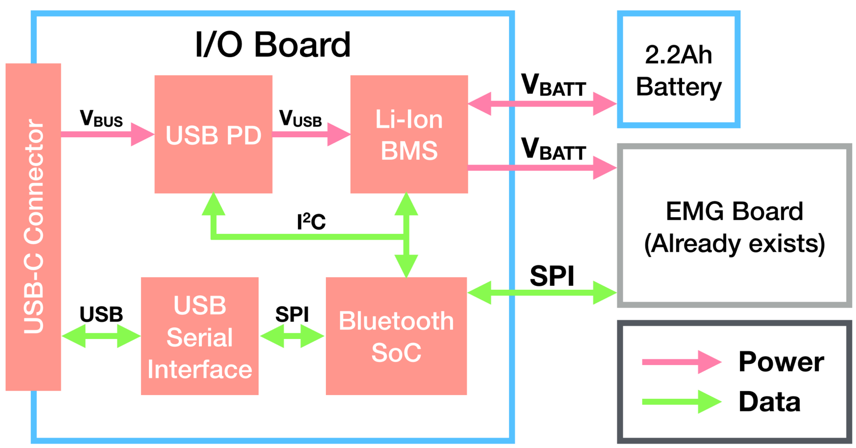

Figure 1: System Block Diagram

2.2 I/O System Functional Overview

2.2.1 USB-PD Controller

The USB Power Deliver (PD) controller implements the majority of the USB-PD specification, allowing the hand to accept more power than the 2.5W available through standard USB from a wide variety of commercially available wall chargers. The FUSB302 was selected for this task since it has an I^2C interface. This provides a simple interface to control the parameters of the power supply, allowing the I/O Board to accept a wide variety of power supplies.

Requirement: The USB-PD Controller shall select the output voltage with the maximum available power

2.2.2 USB Serial Interface

The USB Serial Interface allows the hand to communicate with USB devices. It receives serial data from the microcontroller, as it does not have a USB interface built in. The FT2232H was selected due to its ease of implementation and wide variety of supported protocols.

Requirement: The USB Serial Interface shall support a baud rate of at least 115200

2.2.3 Lithium-Ion Battery

The lithium-ion battery powers the hand during most of the hand's operation. It consists of two lithium-ion cells in series, with a nominal output voltage of 7.4V, and a capacity of 2200mAh.

Requirement: The Lithium-Ion battery shall be able to sustain a continuous discharge current of 1 amp with a voltage drop of at most 100mV

2.2.4 Lithium-Ion Battery Management System

The Lithium-Ion Battery Management System (BMS) charges the battery and regulates its output. It contains a switch-mode constant-current/constant-voltage (CC-CV) voltage regulator, which charges the batteries. The BQ25700 was selected due to our experience implementing it in similar designs, as well as its wide feature set available. It is capable of powering downstream system while charging the battery at the same time. It also monitors the battery voltage, and will not overcharge the battery.

The EMG board has an onboard voltage regulator, and it is capable of handling the full range of battery voltages, making an onboard voltage regulator not necessary for the I/O Board.

Requirement: The BMS shall charge the battery with a maximum charge current of at least 750mA, with a preferred value of 1.1A

Requirement: The BMS shall not charge the battery when any cell voltage is greater than 4.2V or less than 2.7V

2.2.5 Bluetooth System-on-a-Chip

The Bluetooth System-on-a-Chip (SoC) controls all the other blocks on the I/O Board. It communicates with external Bluetooth or USB devices and sends commands to the EMG Board over an external SPI bus and monitors the state of the battery charger and USB-PD controller through an internal 400kHz I^2C bus. The NRF51822 was selected for its strong support resources and its wide variety of I/O peripherals.

Requirement: The Bluetooth SoC shall support Bluetooth Low Energy (BLE) 4.0 with a 5kbps transfer rate

Requirement: The Bluetooth-Enabled Microcontroller shall be capable of communicating with the EMG Board at speeds of at least 1Mbps

2.3 Risk Analysis

The software for this project poses the greatest risk to its successful completion. There is a wide variety of software that needs to be written, doing everything from battery management to Bluetooth communications, to USB-PD configuration. All the software will be running on the Bluetooth-enabled microcontroller, so designing a software architecture which allows for low-level management functions to be performed regardless of the state of the communications software will be important. There are limited resources available on the microcontroller, requiring that the software have a lightweight resource footprint.

Risk will be mitigated by a combination of good hardware and software design practices. For safety-critical systems such as the BMS, hardware failsafes will be used, preventing a software error from overcharging the battery, for example. When writing software, we will follow proper documentation and testing procedures. We will also keep a test log to document all tests performed. Additionally, tests on safety-critical systems such as the BMS will initially use dummy loads to verify expected performance before moving on testing with actual batteries.

3 Ethics and Safety

The main safety hazard with our project is the lithium-ion battery used to power the hand. If not properly managed, it has the potential to outgas and catch fire. The only way to put out a lithium-ion battery fire is to wait until it burns out. Battery fires can be avoided by keeping the battery within the safe operating area, as defined by the manufacturer. This generally entails keeping the battery voltage above 2.7V and below 4.2V, as well as keeping the cell temperature between -40ºC and 60ºC [6]. To prevent battery fires, care will be taken to ensure that the battery is not overly charged or discharged. This follow #1 and #9 from the IEEE code of ethics [7], as an improperly designed battery management system has the potential to cause serious harm.

Another aspect of our project is that it is intended for use as part of a medical device. This gives our project a greater potential to do harm to people. As a medical device, our project will be regulated by the Food and Drug Administration (FDA), which means that our project will need to meet strict testing requirements. We will be documenting all the tests we do on the I/O System to support the FDA approval process to help PSYONIC gain FDA approval for the PSYONIC Advanced Prosthetic Hand. Of course, we will follow #3 from the IEEE code of ethics when documenting the tests that we perform, as falsifying test data is a serious ethical violation [7].

Our project will add the capability to configure the hand remotely. This raises the possibility of an unauthorized individual gaining access and doing things against the wishes of the user. This possibility is mitigated by the encryption of the Bluetooth protocol and the access model of the Bluetooth pairing process. Even then, we will be careful to only implement features that will not result in sudden and unexpected changes to the hand's behavior.

Lastly, our project will include an intentional emitter of electromagnetic radiation in the form of a Bluetooth radio module. It will also contain moderately high-speed digital busses and multiple switch-mode circuits. All of these circuits have the potential to cause unintentional emissions. The electromagnetic spectrum is a shared resource by all of humanity, and the noise floor has been steadily increasing due to the proliferation of circuitry which have not been designed with EMI concerns in mind. In the USA, the Federal Communications Commission (FCC) requires that all products sold in the USA pass unintentional emissions testing. We will keep EMI considerations throughout the design process, especially during PCB layout, to ensure that our design meets FCC regulations.

4 References

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