Gesture-Based/Tactile Music Composition

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ECE 445 Project Proposal - Spring 2017
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Introduction

1. Objective

Musicians face a unique problem as artists. When inspiration strikes, expensive recording equipment is not always readily available, especially on-the-go. It is possible, for example, to use a drum sequencer mobile app to "jot down" an idea for a drum pattern, but users are confined to a small space and an often unintuitive interface. Instead of having a dedicated application for a step sequencer, there needs to be a cost-effective way to capture rhythmic taps and smooth gestures that can control any MIDI-based device wirelessly.

The aim of this project is to build a scalable, wireless glove that can capture motion and tactile data from a musician and generate Musical Instrument Digital Interface (MIDI) signals and sounds on a mobile platform more intuitively than a traditional graphical user interface (GUI) and without the need for more expensive, specific hardware.

2. Background

Many current solutions exist, such as Air Beats[1], a glove that allows musicians to compose music digitally without interacting with a screen. There are simpler alternatives, such as the Xkey[2], but a MIDI keyboard requires a stable surface and ample space for movement in order to be an effective composition tool. Our device needs neither, as the gestures are compact and only need as much space as your hands occupy. There is yet to be a commercially successful gesture-based product as there is a high reliance on either expensive pre-existing technology with questionable reliability (digital paper technique), or a lack of throughput capability due to inexpressive language during pattern recognition. Our solution aims to solve both of these problems with current solutions by using a minimal set of viable hardware and an expressive language that can be used to quickly translate motion into synthesizable sound.

3. High-Level Requirements

- Glove must be able to stay powered with a Li-ion battery for more than 2 hours.
- Glove must be able to process sensor data (taps and gestures) and map it to MIDI data.
- Glove must be able to wirelessly transmit MIDI data over Bluetooth LE.

Design

This design will satisfy our project requirements for the following reasons:
First, our Bluetooth transmitter will be able to transmit MIDI data by leveraging the MIDI over Bluetooth protocol. We will implement this protocol on the Adafruit Trinket microcontroller. Second, our sensors will be able to recognize gestures with the IMUs providing orientation and velocity data. The sensors also recognize taps, thanks to the strain gauges measuring deformation of the glove upon surface contact. Third, our power subsystem will include a voltage regulator to provide a consistent 3.3V well over our 2 hour requirement (we plan on using a Li-ion battery with 2200mAh capacity).

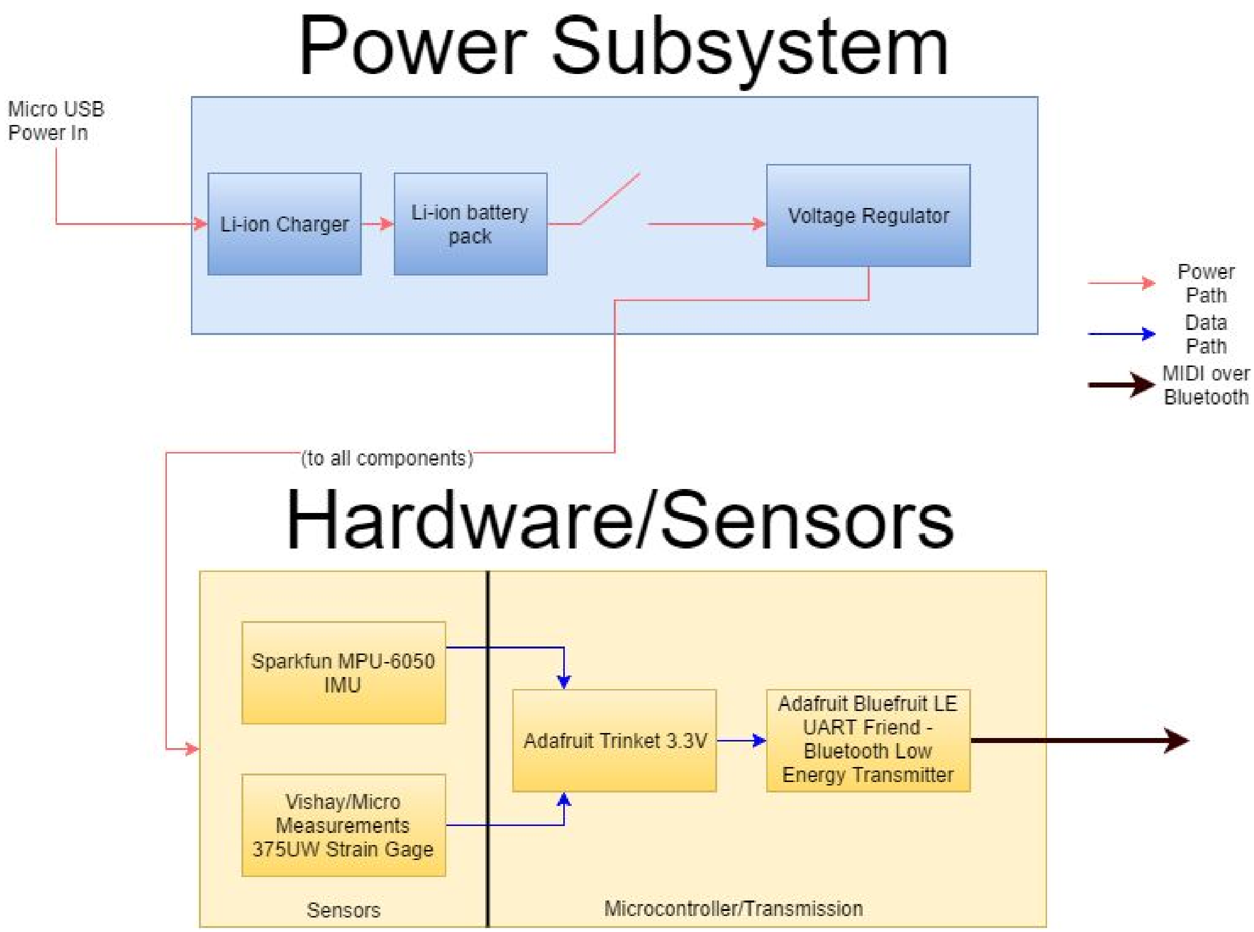

Figure 1. Block Diagram

Our physical design diagram shows the key placements of the devices we will use in our project. Notably we will consolidate most of the crucial elements -- the microcontroller, transmitter, and power supply -- together on the back of the glove. This placement will vastly simplify connecting components and keep the design concise. We opt to use two IMUs -- one on the wrist, and one on the middle finger's first knuckle. This decision gives us the flexibility we need to recognize all of the gestures we require. Finally, the strain gauges will be placed on each fingertip to provide us with the ability to detect taps.

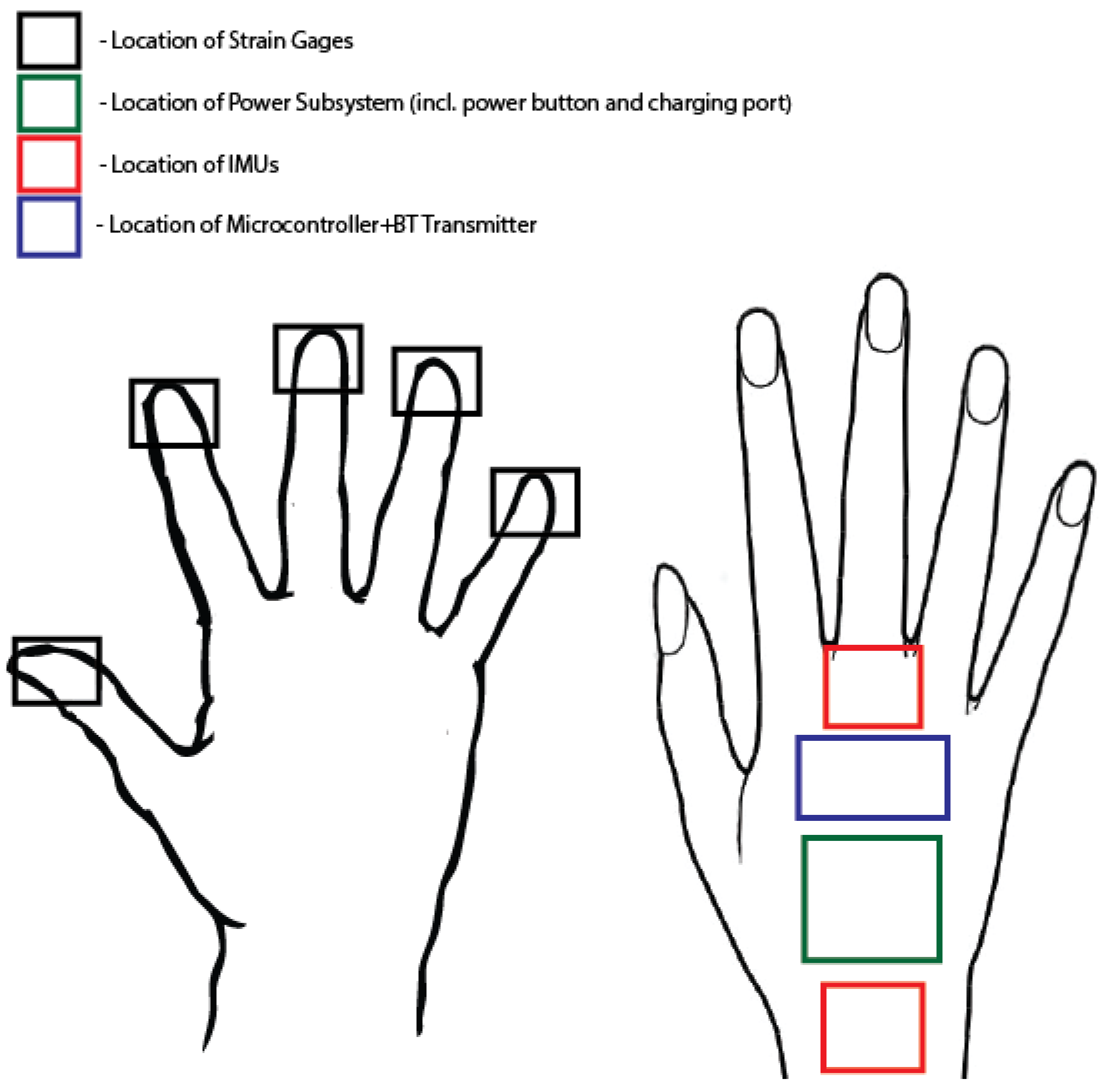

Figure 2. Physical Design

1. Power Subsystem

A power supply is required to safely power all components of the system.

1.1. Li-ion Charger

This is an IC that will allow us to safely charge the Li-ion battery pack. It will act in redundancy to the battery's built-in overvoltage and overcurrent protection to keep the battery in nominal ranges while going through a charge/discharge cycle.

Requirement: The charger will allow the battery pack to be charged to 3.6 - 3.8V within 4 hours while staying below the maximum charging temperature of 45°C[4].

1.2. Li-ion Battery

The battery will be able to power all components of the system through the voltage regulator mechanism. It will have 2200mAh capacity which should be more than sufficient in this application.

Requirement: Must power all components stably for at least 2 hours from a full charge (which we will define as within 50mAh of its 2200mAh listed capacity).

1.3. Voltage Regulator

Transforms the battery's output voltage of 3.7V to the voltage needed by the hardware components of the glove, which is 3.3V. Also acts as a protection mechanism for the strain gauges which do not have built-in voltage regulation, and as a redundancy for all the other components which do have built-in protection circuits.

Requirement: Must provide 3.2-3.4V from the 3.6-3.8V source continuously while glove is on.

2. Sensors

Sensors are required to enable the user to perform gestures and taps, which will be recognized by the glove and converted into a MIDI signal.

2.1. Inertial Measurement Unit (IMU)

An IMU is needed to detect and quantify hand movement and orientation for gesture recognition. We will use two units -- one placed on the glove where the first knuckle of the middle finger is, and one placed at the bottom of the glove, near where the wrist starts.

Having these two IMUs will enable us to recognize both translational gestures and rotational gestures. Specifically, these devices will provide data on angular and linear velocity using a combination of a gyroscope and an accelerometer.

Requirement 1: Gyroscopic functionality can distinguish an angle on all three axes to an accuracy to within +/- 0.1 rad.

Requirement 2: Accelerometer functionality has an accuracy of greater than 95%.

2.2. Strain Gauges

Strain Gauges are needed to detect taps on a surface. These sensors work by measuring the deformation of a physical material[5]. In this application, they will measure glove deformation, and we will determine a threshold of measurement that we will consider a "tap". These sensors will be placed on the fingertips of the glove.

Requirement: Strain gauge can detect a force of up to 50N without malfunctioning.

3. Microcontroller/Transmission

Microcontrollers and Transmission are required to generate the MIDI signal and wirelessly send the signal over Bluetooth to a compatible receiver.

3.1. Microcontroller

We need a Microcontroller to process all sensory input data and convert it into a meaningful MIDI signal. The microcontroller is the heart of this project: all paths go into or out of this device. It will act reliably and consistently to meet our project requirements.

Requirement: Translates gestures and taps into a MIDI signal with greater than 90% accuracy.

3.2. Bluetooth Low Energy (LE) Transmission Unit

We need a Bluetooth LE unit because it will enable us to use our glove with any MIDI controller supporting MIDI over Bluetooth. The unit will receive a MIDI signal from the microcontroller and transmit it wirelessly to any (arbitrary/outside project scope) receiver which we assume will be a MIDI controller that will enable playback.

Requirement: The Bluetooth LE connection allows communication between the glove and a receiver within 0 to 5.5m.

4. Risk Analysis

The part of our project we are most concerned about is the availability of MIDI controllers supporting MIDI over Bluetooth. It's a very new standard with scant adoption, but we are willing to take the risk of supporting it because it will vastly simplify our design. If we were not to use a Bluetooth transmitter on the glove to directly transmit MIDI, we would still have to transmit to a generic Bluetooth receiver which we'd have generate MIDI over USB. This decision is due to the glove being wireless is a key design requirement.

Safety and Ethics

Our design and product will comply with the IEEE Code of Ethics. The following two points from the Code are especially relevant for our design:

1. "*to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment*" [3]

   We considered the safety and health risks of our design and have provided a list of precautions to take when using our hardware. We also designed our hardware to reduce any potential risks to the users.
2. "*seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others*;" [3]

   We will properly cite the contributions from previous research and similar products.

The hardware operates at a low voltage, so there is no prominent risk of electric shock from normal use. However, the sensor unit contains fragile components that can be broken when the hardware is not used properly. For example, the strain gauge can be damaged when too much force is applied, and the IMU can be damaged if the hardware is dropped to the ground from high places.

If the Lithium-ion battery is not charged properly, it can explode. During the build process, we will use a thermometer to monitor the temperature of the power subsystem to make sure the cell temperature does not reach unsafe levels. To make sure the battery does not get overcharged, all of the charging circuitry will be tested thoroughly so the maximum threshold is not exceeded.

List of precautions to take when using the wearable hardware:

- Avoid using the hardware with wet hands or near water.
- Avoid dropping or squeezing the hardware.
- Use the hardware within the safe temperature range: 0°C to 45°C (32°F to 113°F).
- Be cautious for the potential electrostatic discharge.
- Before using, check that there is enough space around you. Also, make sure the hardware cannot slip out of your hand. If the hardware hits a person or object, this may cause accidental injury or damage.
- Be cautious of the hardware overheating. Remove the hardware immediately if it feels too hot.

References

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