velocity control (see Challenges). The trajectories were:

$$
\begin{aligned}
x_d[0] &= x_{\text{init}}[0] \\
x_d[1] &= x_{\text{init}}[1] + v_\alpha \cdot \text{sgn}[\alpha > \alpha_{\text{thresh}}](t - t_{\text{toggle},1}) + x_{d,\text{toggle},1} \\
x_d[2] &= x_{\text{init}}[2] + a \cdot (t - t_{\text{toggle},2}) + x_{d,\text{toggle},2}
\end{aligned}
$$

where $t_{\text{toggle},i}$ represents the last toggling time for control on dimension i and a represents a factor proportional to the magnitude of the gyroscope acceleration value (reported by the board in units of mm/s^2). We specified limits for the robot based on positions on our demonstration board.

3 Challenges

3.1 EEG Protocol

Our initial system for detecting brain waves used an Emotiv headset, which is essentially a brain wearable for consumer EEG measurements. The Emotiv system is designed for research and advanced BCI applications and has high spatial and temporal resolution. While we were able to detect alpha waves with this system, we ran into several obstacles that eventually prevented us from using this system in our final implementation. We had trouble using the provided Emotiv libraries to work properly with our system and also ran into coding errors such as a floating point exception. We reached out to employees of Emotiv through GitHub to understand how to overcome these issues. However, it was difficult for them to understand the problems we were encountering with their software specifically for our project application. In addition, because their software is proprietary, Emotiv could not release their implementation to us so that we could further understand the issues. We also considered using a clinical-grade EEG cap to gather our data. While this would have provided significant improvements in signal quality, it would have been necessary to implement software to interpret the signals by hand. However, we collectively decided that we wanted to focus on other aspects of the project instead, and decided that this implementation would be outside of the scope of our project.

We decided to switch to the OpenBCI system, an open source biosensing microcontroller that can be used to gather EEG data. This enables us to have much more control over the system because the accompanying software was open-source. One drawback of using this system as compared with Emotiv is the protocol for lead attachment. While Emotiv consists of an easy-to-use headset that can be configured on a test subject in a matter of seconds, the OpenBCI system relies on manual attachment of electrodes onto the subject's head using attachment glue. Despite some sacrifices in signal quality and system convenience, the OpenBCI system proves to be fairly robust for our application.

3.2 End Effector Design

One of the big challenges for the end-effector design is to get the correct dimensions to connect the designed products to the robot arm. Moreover, for more advanced end-effector designs to fulfill more functions, how to build-up good electrical connections and implementation to robot control system is really critical and challenging. Due to time issues, we only consider the simple end-effector design without any electrical components. The fabrication of end-effector is also challenging. 3D printing is a good way for quick prototype making but is not suitable for the designs require a large amount of materials and complex structures.