**Methodology**

Development of the tug toy was motivated to represent natural sea kelp. Thus, the first and only iteration of the toy stood at 5’ by 7.5” with a thick, brown, canvas base (Figure 1). Canvas was utilized given its puncture-resistant properties. Moreover, the toy contains two pockets, each 5.5” by 7.5” at 8.5” from each end of the toy, to enclose the IMUs that will measure handler and otter interaction (Figure 2). The spacing was intended to provide both subjects with ample handling space.

The IMUs which were housed in the kelp toy were built with ESP32 MCU which had Wi-Fi and Bluetooth capabilities in conjunction with an MPU6050 (Figures 7-8) which provided three axis accelerometer and gyroscope measurements. After the system was constructed, we were able to load a simple program that relayed measurements in real-time over a web server. Electronics were placed within a 3-D printed enclosure each 3.5” by 3” by .5” (Figure 8) before being screwed into place for protection from thrashing and biting and then information was collected. A battery was also placed within the enclosures to provide voltage to all electronics. Two such systems were created for the toy – one to be inserted into the handler and one into the otter end.

Since we were unable to arrange a session to test the toy with otters at the aquarium, we tested the toy with a highly trained dog with our project mentor as the handler. Before starting the actual experimentation, we had the dog play with the toy without having the sensors inside to familiarize the dog with the toy and to observe any preferred bite locations and any other behaviors like thrashing (Figures 3-4). After the dog learned that the object was a playable toy, we placed the sensors that measure acceleration and gyroscopic data in the pockets of the toy and conducted five one-minute trials with the handler holding one side of the toy and the dog tugging on the other end (Figures 5-6).

After the experiment we were able to perform data analysis on the collected data. The first pre-processing we conducted was applying a low pass filter to the data – we started with a low-pass moving average filter but gravitated towards a Kalman filter due to its prior application in this field. The data from there that we captured included the average jerk force, asymmetry in play behavior (utilizing the gyroscopic measurements), playtime, and finally using the Kalman filter [12] we could present an overview of the interaction over time in terms of pitch and roll.

**Results**

All five noted trials exhibited regripping, thrashing, and pulling behaviors. The second trial and onward elicited a kill behavior by the dog on more than one occasion. The third trial showed the dog having an issue with situating a good, powerful bite, which we later learned was the animal oriented IMU falling through its stitching into the biting end of the toy (Figure 5). This instance left both the dog and IMU undamaged because of the dog’s wit and the IMU’s 3D-printed encasing. At the end of all trials, there were several bite marks imprinted on the material, but there was only a single, small puncture of significance (Figure 5). The method of wireless data transfer worked albeit minor permutations in the sampling rate. However, this component needs to be further examined for aqueous and longer timeframe trials.

After running the collected data through the data analysis pipeline the results created were intuitive. First, the sensor measurements didn’t report much activity on the z-dimension which was to be expected, furthermore the pattern of pitch and roll oscillated which could be validated with the canine experimentation where we observed a swaying pattern of play, finally the average jerk force exerted waned with time which was also expected. The results proved significant in the context of modelling world behavior but additionally the methodology of data analysis proved abstract and robust enough to translate to sea otter interaction.

We can now take the opportunity to look at the theoretical data analysis pipeline that derives our results. First, starting with two streams of input data – the handler and animal IMUs. In order to isolate the noise resulting from handler movement a very simple corrective protocol was done.

**Equation 1**

Where A represents the vectorized accelerometer measurements (x, y, and z axes). This process was then repeated for the gyroscope data. Afterwards with this data there were some results that we could create from the raw data itself. Namely the average jerk strength. This was done with a simple derivative calculation.

**Equation 2**

Here *dt* is related to our sampling rate and *n* is related to the time of observation. For further results we utilized the Kalman filter. After processing the data through this low pass filter some further results, we could garner involved asymmetric play direction. Using the filter’s position function, we can detect which direction the animal preferred and gravitated towards.