Prior Arts Report Supplement  
Team RollRight

Analysis pipeline

# Data Sources

Our inertial measuring unit (IMU) module contains three sensors which we will use in our analysis pipeline. First, the accelerometer measures acceleration in units of meters per seconds squared. Second, the magnetometer measures the ambient magnetic field in units of milliTesla. Third, the gyroscope measures angular motion or rotation in units of radians per second. All sensors measure along all three Cartesian axes: x, y, and z. The IMU containing the three sensors will be worn on the wrist.

# Initial Data

Our initial accelerometer, gyroscope, and magnetometer data in their raw form can be seen in Sup. Figures 1, 2, and 3. These signals are all analogue electrical signals which will be turned into digital signals via our microcontroller. The sample data used in this section was created with 5 initial seconds of rest for calibration.

For monitoring the motion of wheelchair users’ arms, we are primarily concerned with wrist displacement. We cannot simply obtain displacement by integrating the raw acceleration data because the raw acceleration data contains acceleration due to gravity and large amount of noise. Gravity and noise, if left in the data, cause accelerometer drift and skew our displacement results. Therefore, they must be removed.

# Removing Gravity from Measured Acceleration

We are measuring acceleration in order to integrate and calculate position. Therefore, we only care about acceleration due to wrist motion and gravity should be removed from our acceleration measurements. First, we must measure gravity using our initial 5 seconds of motionless calibration. Gravity is measured in three dimensions by averaging the acceleration values for each axis during the initial calibration rest period. However, we cannot naively subtract this vector from every time point, as the sensor is moving and rotating with the user’s wrist and thus the sensor is oriented differently at every time point after the rest period relative to the rest orientation. Fortunately, the magnetometer provides a measurement of the sensor’s orientation to the planet’s magnetic field. We can use this magnetic orientation to rotate the gravity vector to its proper frame for each time point.

To accomplish this rotation, each time point on the triaxial vector of magnetometry data is first normalized to unit vector length. Then, every time point of magnetometry orientation data is compared to the average of the orientation values during the calibration period. We can use Rodrigues's rotation formula to calculate a rotation matrix relating each time point’s sensor orientation to the initial orientation. We then have a rotation matrix for each time point which can reorient our average gravity vector to the proper direction in each time point’s rotated frame of reference. We do this through multiplying our gravity vector by each time point’s rotation matrix and then subtracting each time point’s rotated gravity vectors from their respective acceleration vectors. The result is shown in Sup. Figure 4. This result was also treated with a 0.3 Hz corner frequency high-pass filter along each axis to remove full-chair linear acceleration and other unwanted signals.

# Calculating Wrist Position

All three axes of acceleration data were numerically integrated twice using cumulative trapezoidal numerical approximation in order to achieve velocity data. To further prevent accelerometer drift, we centered each velocity vector at zero by subtracting the average velocity of each direction component from each direction’s respective velocity vector. This adjusted velocity was then integrated to calculate position. Sup. Figure 5 shows the results of this integration, the displacement over time for each axis of acceleration. Once we have obtained this position data, we can analyze it for clinically relevant parameters for wheelchair users such as push frequency and rotation.

# Calculating Push Cycle Frequency

Push cycle frequency is one clinically relevant wheelchair pushing parameter. We can calculate pushing frequency by dividing each of the three axes of displacement data into push periods of varying length. We can find the periods of each displacement axis through finding relative maxima in the displacement data to use as starting and ending points for cycles of propulsion motion. Maxima below a magnitude threshold of 0.05 meters or within 0.3 seconds of the previous maxima were thrown out, as these were not likely true maxima defining the beginning of a new period. The number of remaining maxima is a good approximation for the number of cycles completed in the considered time. We then took the mean number of periods calculated from the results for each displacement axis as the number of cycles and divided this by the length of the time sample to get a push frequency. The data shown in Sup. Figure 5 resulted in a calculated pushing frequency of 0.6009 cycles per second, which was close to the 0.6 Hz average frequency used to create the sample data.

# Calculating Push Cycle Area

Push cycle area is another clinically relevant wheelchair pushing parameter. We calculate push cycle area by using the cycle delineations found in the previous section to consider the displacements during each cycle individually. For each cycle, the 3-axis displacement vectors for each position in that cycle were averaged to find a mean position over that cycle. This mean position approximates the center of the cycle geometry. Then, we calculate the distance from each time point’s position to that center position, giving us a reliable value of the radius for the swept shape at that point along the shape. Next, we approximate the angle of each position within the cycle by assuming constant velocity within the cycle and an ellipsoid shape. These approximations for radius and angle allow us to conduct numerical polar integration and find the approximate area swept during each motion cycle, measured in m2. Numerical polar integration was conducting by approximating the area swept between two time points the area of a triangle formed between the two theta and r points for those two time point. The average cycle area for our sample data was 0.8367 m2.



**Supplemental Figure 1. Initial accelerometer data** shows sample acceleration data before any processing.



**Supplemental Figure 2. Initial gyroscope data** shows sample gyroscope data before any processing.



**Supplemental Figure 3. Initial magnetometer data** shows sample acceleration data before any processing.



**Supplemental Figure 4. Acceleration data without gravity** shows the sample acceleration data after removing the rotated gravity vector from each time point. Results were also treated with a high-pass filter, edge frequency 0.3 Hz.



**Supplemental Figure 5. Position data** shows the displacement values calculated from ours ample acceleration data after removing the rotated gravity vector from each time point, filtering, and integrating twice. We do not show the initial 5 seconds of rest here.