Vibration Rejection and Stabilisation of a Smart Eating Device

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Coláiste na hOllscoile Corcaigh

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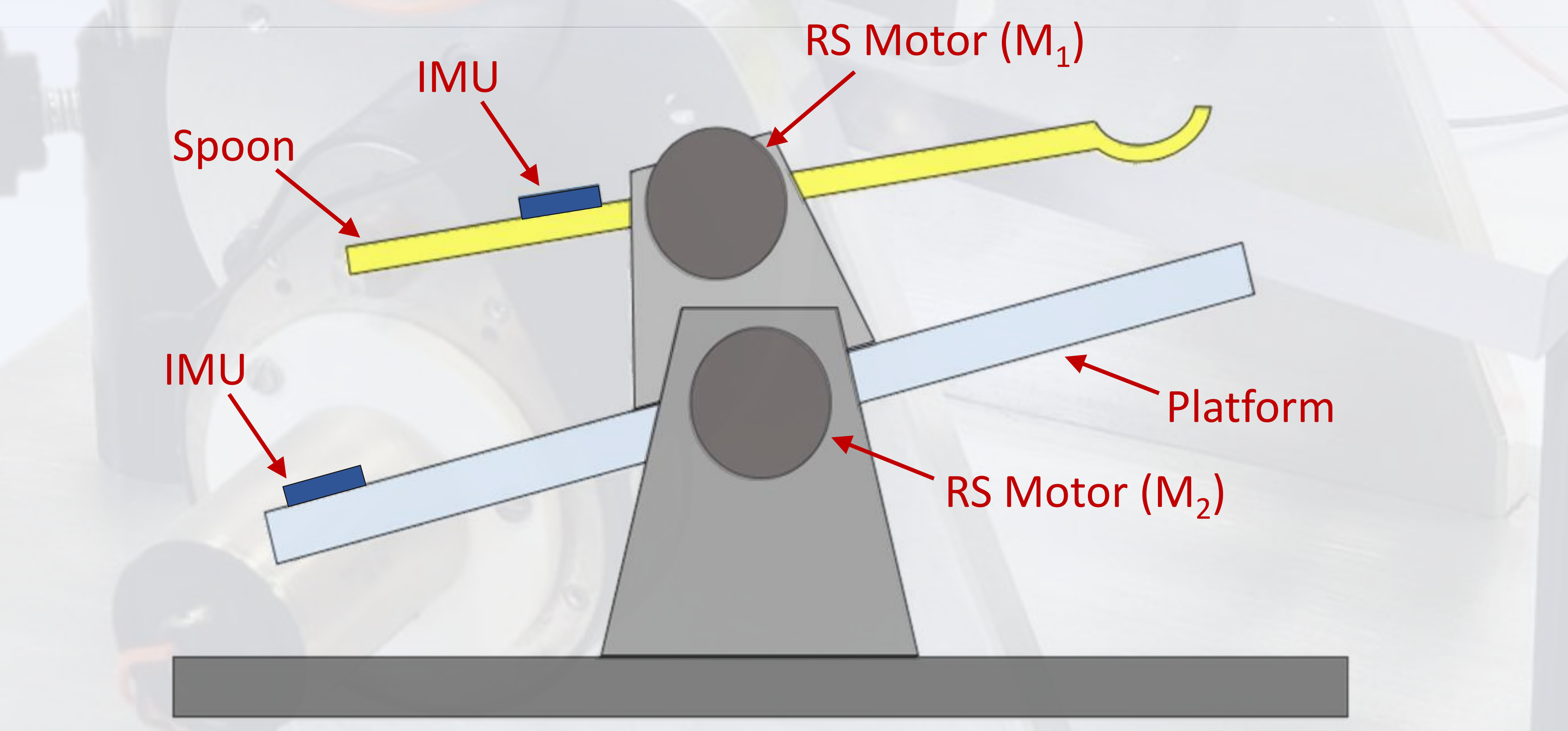
Brief

This project focused on designing a Smart Eating device to compensate for debilitating hand tremors associated with Parkinson's disease. At present no cure has been found that can halt or stop this neurodegenerative conditions that occurs in 0.2% of the general population. The project incorporated developing a feeding implement capable of actively compensating for the tremor, achieved by controlling open source hardware.

Physical Test Apparatus

A proof of concept was developed on a test rig, containing a spoon and platform rotating in a single plane of motion. Both components were servo controlled by a motor and formed a coupled system, where the platform was driven in a sinusoidal motion to mimic the movement of the hand. IMU sensors were used for position tracking and control.



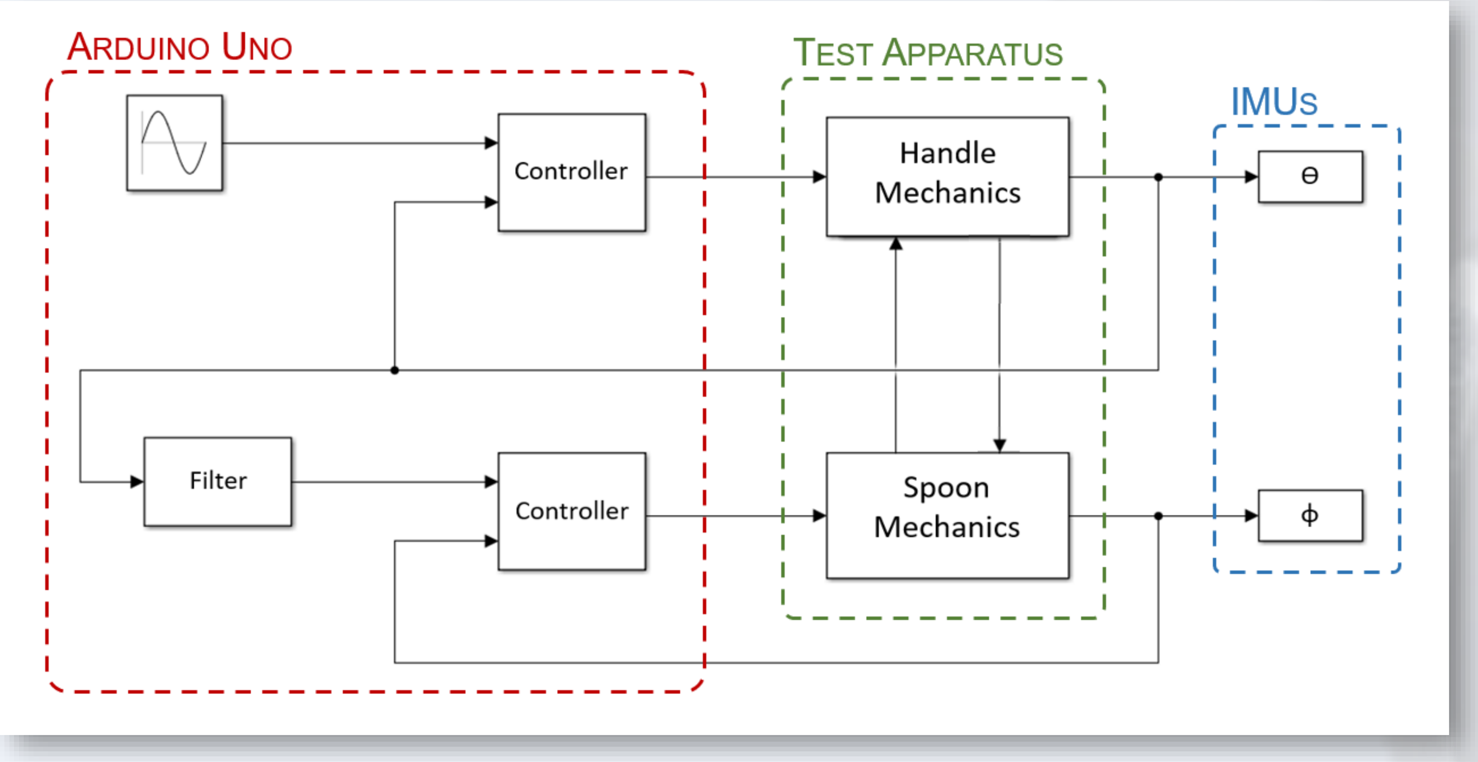
System Modelling

The following equations were used to model the system mechanics. The first equation represents the torque seen by the hand (platform) and the second represents the torque seen by the spoon.

$$J_h\ddot{\theta} = \left(\frac{NK_m}{R}\right)(u_h - u_s) - 2\frac{(NK_m)^2}{R}\dot{\theta} + \frac{(NK_m)^2}{R}\dot{\varphi} - Mgdsin\theta$$

$$J_s\ddot{\varphi} = \left(\frac{NK_m}{R}\right)u_s + \left(\frac{NK_m}{R}\right)^2(\dot{\theta} - \dot{\varphi}) - mglcos\varphi$$

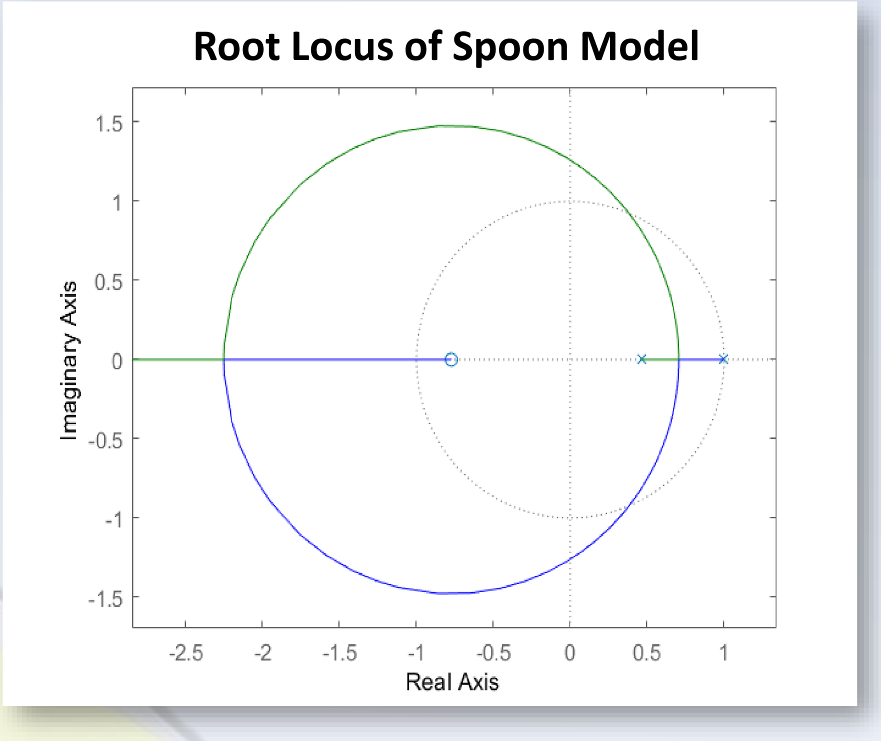
These were then used to construct a Simulink model used for simulating the system dynamics. A simplified schematic of the entire system is shown below.

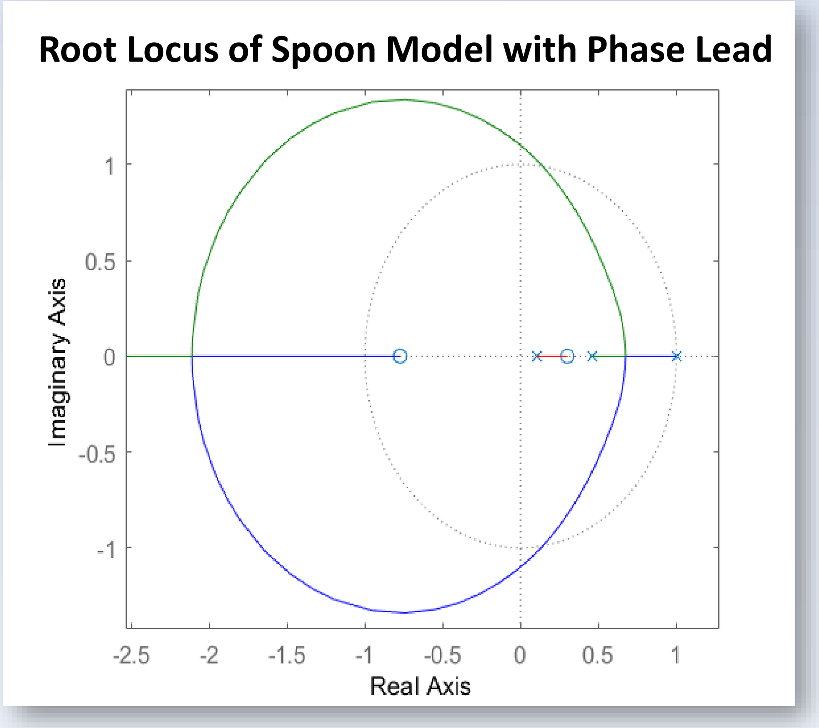


Controller Design

Active vibration cancellation on the device was carried out using a phase-lead compensator. This controller was chosen as it gave a fast system response and an improved settling time than that of a PID. The transfer function below illustrates that a phase-lead adds a pole and zero to the system. When they're adjusted correctly it has the effect of pulling the asymptotes and closed-loop poles further left, adding stability to the system. The compensator for the spoon was adjusted from Matlab, to give an optimal performance exemplified in the root locus plots. A transfer function was formed using the pole, zero and gain of the compensator, which was digitized and coded onto the Arduino.

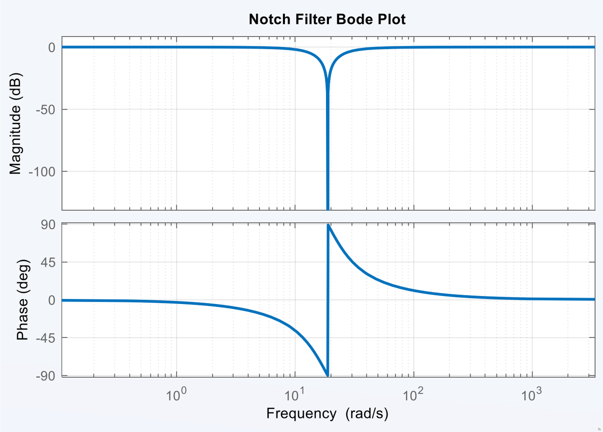
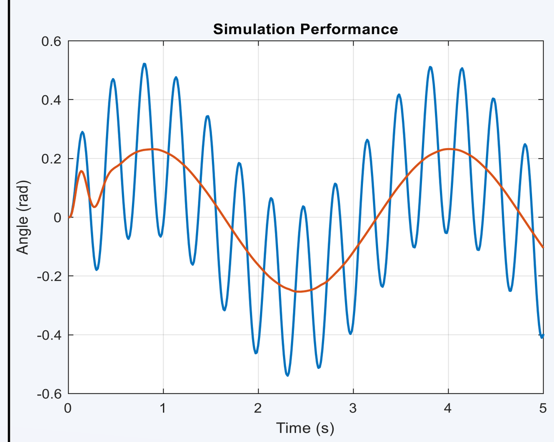
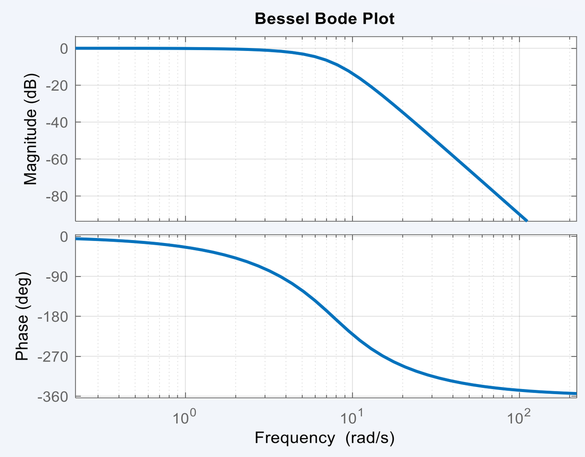
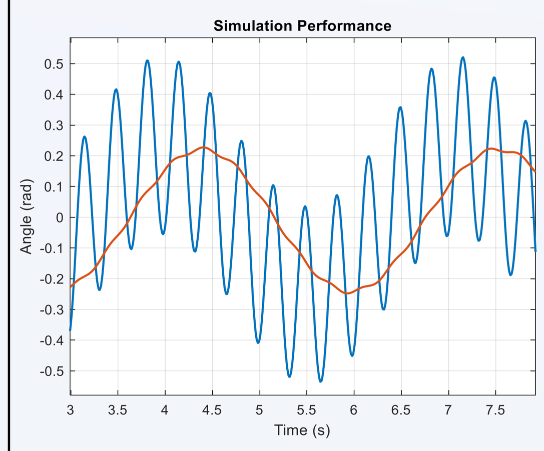
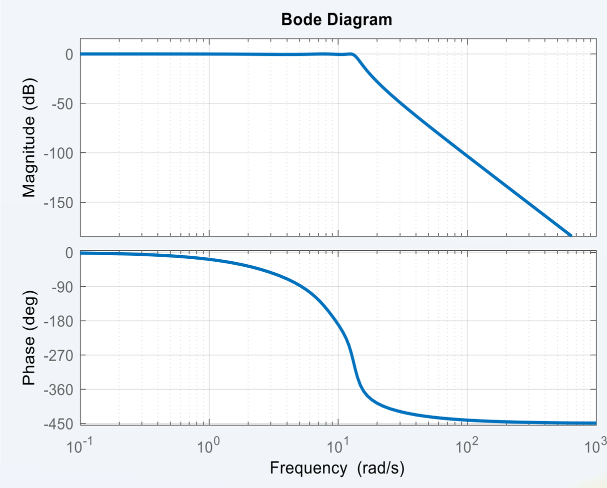
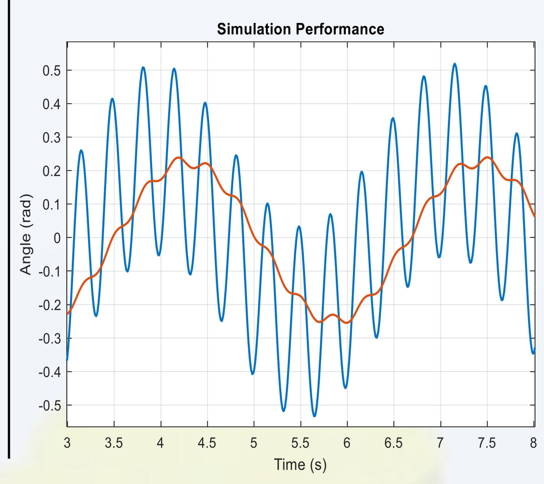
$$C(s) = k\frac{s - z}{s - p}$$





Filtering

The filter used for the design proved to be a critical aspect to a working prototype. To ensure correct performance, the filter had to remove any high frequency components, while allowing the low frequency component to pass through. A notch filter was initially used as it would provide ideal removal of the chosen high frequency. This does not suffice for varying hand tremors so a number of alternatives were investigated. These are summarised below. In each case, the filter transfer function is given along with a bode plot and the performance observed in simulations. Each filter was designed to give 0.5 dB and 40 dB attenuations at 2 rad/s and 18.8 rad/s respectively.

Filter	Bode plot	Performance
Notch Filter: $H(s) = \frac{s^2 + {\omega_m}^2}{s^2 + Bs + \omega_m}$		
4^{th} Order LP Bessel: $H(s) = \frac{5.1{\omega_c}^4}{(s^2+2.72\omega_c s + 2.01{\omega_c}^2)} \cdots \frac{\cdots}{(s^2+1.975\omega_c s + 2.532{\omega_c}^2)}$		
5^{th} Order LP Chebyshev: $H(s) = \frac{}{(s + 0.36\omega_c)} \cdots \frac{0.179{\omega_c}^5}{(s^2+0.22\omega_c s + 1.036{\omega_c}^2)} \cdots \frac{}{(s^2+0.586\omega_c s + 0.477{\omega_c}^2)}$		

Results and Conclusions

Each of the controllers and filters proposed here were converted to digital form using the matched pole zero method and were implemented on the Arduino Uno Controller. Due to unforeseen circumstances, the prototype was not fully completed. The graph below gives an estimate as to what was expected in the real world simulations. Here it can be seen that the hand angle is comprised of low and high frequency components. The high frequencies are removed by the filter meaning the spoon only follows the path of the low frequency signal, with a slight jitter due to the system mechanics.