Next-generation handgrip trainers

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Date: 22.05.2023

Introduction

Handgrip trainers are tools that can be used to improve handgrip strength, which is an essential component of physical health. As explained by J. Depp[1], grip strength is just as important for everyday life as it is for athleticism. It is additionally reported to be an important predictor of good health, muscular endurance, dexterity and overall strength[2] and has been used in a variety of clinical areas for multiple purposes[3]. As such, it follows that a reliable measurement of grip strength is a necessity, from both a fitness and a rehabilitation point of view. However, even though there are many different handgrip trainers on the current market, none of them are equipped with a measurement system that can provide accurate data on handgrip strength.

Assignment

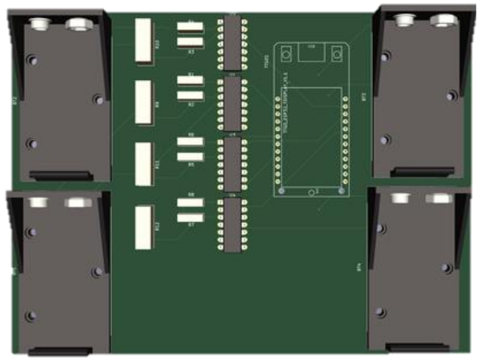
The main focus of this project was:

- Design a handgrip trainer with a measurement system
- Implement a functioning Kalman filter
- Estimation of parameters for describing system dynamics
- Lay down a framework for future development of the device.

This involved designing a device capable of measuring grip strength, logging the data and processing said data. The finished product should be a proof-of-concept device, for possible further development

Theory

The theory which serves as the foundation for this project is the compartmental model developed Ross, Nigam and Wakeling[4] which describes muscle contraction dynamics. This model describes the development of fatigue in a muscle mass based on how much of it has been active at any given time. This modelling principle is formulated through state-space models. This makes the following parts of the project easier to understand and implement. Additionally, this model can be extended further if necessary, by adding cramps as a part of the model.



Mathematical framework

The mathematical framework described in the theory has been implemented in MATLAB as a two-state model.
The measurement model obtains data for the active muscle mass. The fatigued muscle mass is a hidden state.

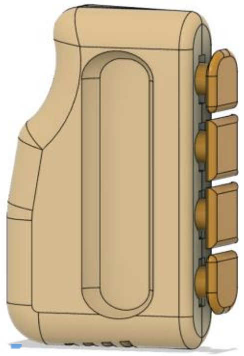
The parameters for this model had to be estimated, and in that regard, a least squares estimator was used to find the parameters that best fit the data.

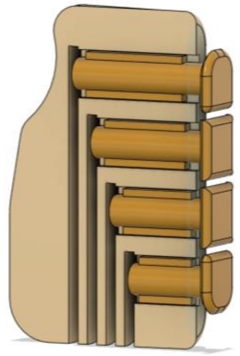
Lastly, a Kalman filter has been implemented in order to generate the hidden state (fatigued muscle mass), in addition to reducing the noise from the measured state. This implementation has been programmed on an ESP32 and it runs in real-time.

Design

The final design measures each individual finger with equal separate circuits. Each circuit consists of one piezoresistive pressure sensor, one OP-amp, a resistor and a 9V battery. There is a linear relationship between the sensor output and pressure, when connecting the sensor to the OP-amp in an inverting OP-amp configuration. The sensor output is read by an ESP32.

The final device design was 3D printed in PLA plastic. It incorporates the sensors inside and utilizes pogo-pins to press the sensors. Rubber foam is placed between the pins and the sensors to spread the pressure across the sensors. This also gives the pins a springlike feeling.



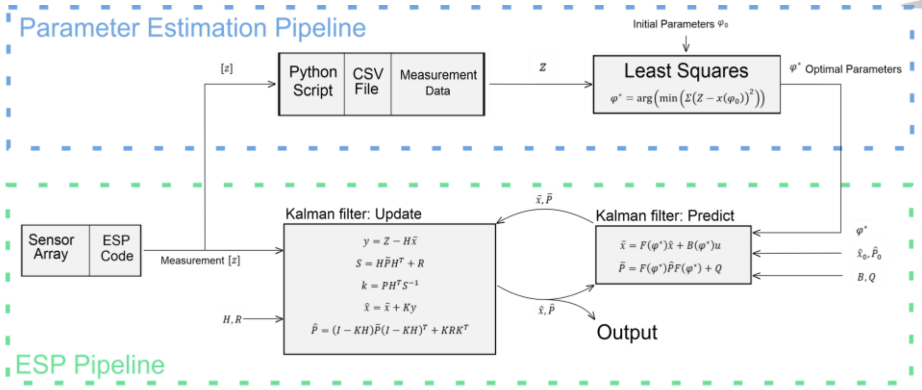


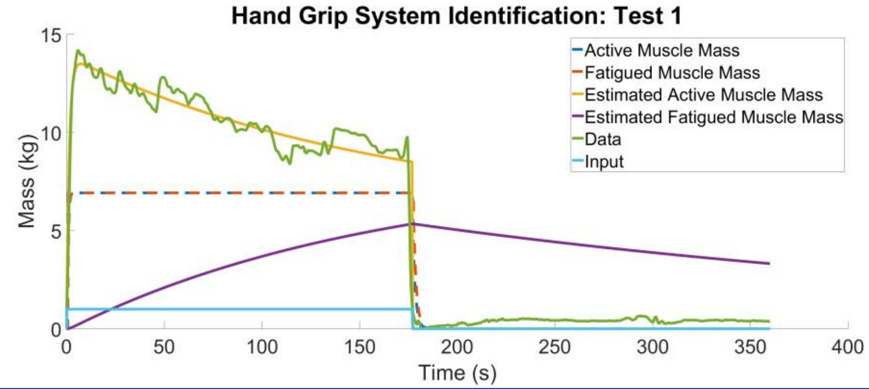
Result

The result produced is a functioning handgrip trainer that can measure the grip strength accurately. The implementation of the Kalman filter counteracts most of the noise produced by the electronics and other sources. The least squares estimator is however not consistent in its resulting outputs.

Conclusion

The project successfully implements a Kalman filter to enhance the stability and accuracy of the measurements.
However, the hidden state estimation is not as desired.
The electronics are quite large, and smaller versions could be further developed.
The 3D printed device achieves an acceptable ergonomic design, but further development could see a better design.
The parameter estimation relies on high signal-to-noise ratio data to accurately produce working parameters.





[1]J. Depp, Why a strong grip is important, and how to strengthen those muscles, (Apr. 2022) https://health.osu.edu/wellness/exercise-and-nutrition/why-a-strong-grip-is-important#:~:text=In%5C%20athletes%5C%2C%5C%20it's%5C%20important%5C%20to,improve%5C%20your%5C%20quality%5C%20of%5C%20life. (visited on 4th May 2023).
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[4]S. A. Ross, N. Nigam and J. M. Wakeling, 'A modelling approach for exploring muscle dynamics during cyclic contractions', PLOS Computational Biology 14, 1–18 (2018).

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