Virtual Design Review #3

T102

Andrew Baumert

Nick Cadavid

Arianna Escalona

Kyle Giddes

Aaron Gonzalez

Joseph Liberato

Department of Mechanical Engineering, FSU

Department of Chemical & Biomedical Engineering, FSU

EML 4551C

EML 4801

Dr. Shayne McConomy

Dr. Stephen Hugo Arce

December 3, 2024

Current State of Work

Mechanical Design

The objective of the device is to strengthen the quadriceps muscles in patients who have undergone a total knee replacement. After consulting with physical therapists and other subject matter experts, we have determined that quadriceps strength is a limiting factor in recovery from a successful surgery. Following Dr. Higgins' advice, we have modeled the knee as a simple hinge joint. The device's current iteration will be strapped to the thigh and lower leg using Velcro and consists of three printed parts held together using M4 screws, dependent on an AK80-8 48V Joint & AGV Motor to produce torque. The motor is rated for 10 Nm of torque which will act a distance of 20 cm from the axis of rotation at the knee. This will simulate 5 kg of force in a similar manner to a leg extension machine as seen in commercial gyms. This resistance will be sufficient for the target market as they are primarily elderly. If the design proves feasible, it can be scaled. We currently have a 3d printed prototype that does not fully function as we were waiting for the motor to arrive, to supplement this we have created a digital twin. The next iteration of prints will integrate the motor as we refine our design.

Electrical Stimulation (E-Stim)

The electrical stimulation aspect of the device will also enhance quad growth and aid in muscle activation for post total knee replacement patients. The specific type of electrical stimulation we are currently focused on developing is neuromuscular electrical simulation (NMES). This type of stimulation will supply a current (up to 100 mA) to create muscle contractions which will override the brains inhibitory signals, enabling direct activation of the muscles to restore functional movement in addition to the muscular strengthening benefits.

The e-stim device will be produced in-house and built using a microcontroller. The microcontroller will be a Teensy due to its satisfactory capabilities and minimal size. The device will also consist of transistors, resistors, and other common electrical components to achieve the desired outcome and safety measures. The desired outcome is a biphasic pulse signal with a max current of 100 mA. This current represents the intensity of the signal and can be lowered, using a potentiometer controlled by the patient. The current will travel into and out of the patient's quad muscle via two 3x5in (7.62x12.7cm) electrode pads. The device will be mounted to the external exoskeleton and will be battery-powered. Currently, a prototype has been developed, and a schematic has been drawn. A PCB is being developed, and tests will be conducted to ensure it meets our safety and performance standards. The prototype lacks additional safety measures beyond basic theoretical considerations at this time. Future work will be to discover common industry safety techniques (such as the use of inductors/transformers) and implement them into our design.

Control System

Modeling the knee joint as a simple hinge allows us to get this equation:

:. Using this equation, we can derive the proper transfer functions to create a control system that will receive an input of the desired angle and apply the proper force desired by the user.

Forecast of Future Work

Outline of Testing

Force Testing is required to determine appropriate control system parameters for safe operation. Durability testing will be conducted to finalize the final selection of materials for the final design. Currently, everything has been created in PLA plastic, which has been shown to be far too weak to support the current torques in the system. Once preliminary testing is finalized, we can test the output resistance and range of motion to ensure the design inputs are met.

Testing the electrical stimulation components on oscilloscopes is also required to prove that outputs are safe for humans (ideally between 0-20V and 0-100mA). Testing the built-in safety features as well as the control system is also vital to the success of this project. Testing the synergy of the E-Stim with the mechanical motion of the motor is also required to ensure safe operation.

Synergy of Components

Designing the control system to allow for E-Stim to be used in conjunction with the motor function will be a challenge that we plan on tackling in the next semester. Our goal is to have the E-Stim “force” a patient to resist the applied torque of the motor thus simulating a leg extension machine. This is the purpose of the synergy of the E-Stim and Mechanical Motion. An initial approach to designing an appropriate control system is to have set ‘modes’ that will use subsets of the overarching controller. For example, when the patient is told to ‘isometrically’ extend their leg against the hard brace, we want the motor to resist that motion up to 25 Nm, so having a set position and set torque is that is desired during that motion. During that isometric motion we want the E-Stim to occur during that duration which will allow for better outcomes based on the literature.

User Interface

Concurrently with making the components synergize we will be designing an appropriate UI to allow users to easily interact with the device. We currently have a touch screen LCD that we plan to use as an interface, and we will be creating a simple design that allows users to interact with the device with minimal complications.

Collect Data

We plan to collect data using software and the PID control in the motor. Using this, we will be able to determine the user's progress over time. We will calculate the force applied by the motor using torque data and the fixed lever arm length of 20 cm. This lets us estimate resistance without adding extra sensors. The motor's built-in system will record torque during exercises to ensure the right amount of resistance is applied and to track user progress. We'll use the motor's encoder to measure knee joint angles in real-time. This helps track the range of motion and any improvements over time.

Problem Areas

Motor Control system modeling

E-stim safety and integration

additionally, who can we talk to about our safety option?

Measuring success of design without clinical testing due to time constraints

Material selection and fabrication/ordering

EOM based on discussion with Dr. Arce:

$$\Sigma F_x = 0 = F_{Ax} - F_{Mx}$$

$$\Sigma F_y = 0 = F_{My} - F_{Ay}$$

$$\Sigma M = 0 = F_A * d_A - F_M * d_m$$

Still unconvinced these will help the project in any meaningful way.

P = Problem; S = Solution

P1: estim; Wacky magnetic issues on the breadboard

S1: Will hopefully be less problematic on a PCB Since there are no wires and everything is flat (no crossing wires or resistors. Also connectivity will be much better)

P2: estim; Low voltage batteries. (Need a range of 10 V for ideal use but we only have 9V battery)

S2: either add another battery, or decrease the input signal

(update: if we use Teensy it will use 3.3V as the input signal. Some resistors will change but a 9V battery will allow for +4.5 Vcc and -4.5 Vcc (our range will need to be -3 to +3 so this should actually be fine)