DYNAMIC ADJUSTING PROSTHETIC SOCKET

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Co-Advisors: Michael Delph, Christopher Nycz

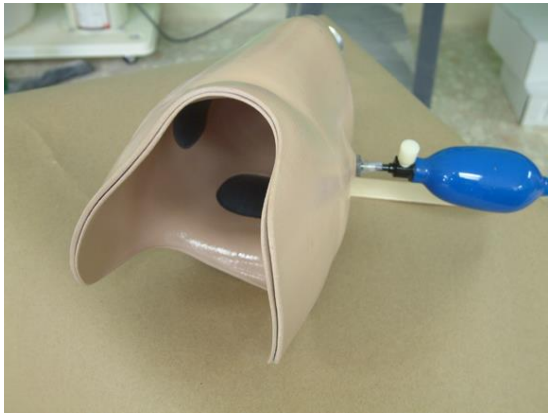
Project significance

- 1.6 million Americans with limb loss (2005)[1]
- Importance of Prostheses
  - Return to activities
  - Increased mobility
- Many challenges with prosthetic use
  - Unnatural forces → injury[2]
  - Poor fit → prosthesis misuse[2]
  - Increased energy from user[3]

Acute erthyema and edema[4]

Current Prosthesis

- Adjustable
  - Mechanical
  - Inflatable Inserts
- Daily Fit
  - Vacuum
  - Suction
- Static Fit
  - Compression Release Stabilized (CRS) Socket
  - Conventional Sockets



Socket with Pump [6]

SmartPuck [7]

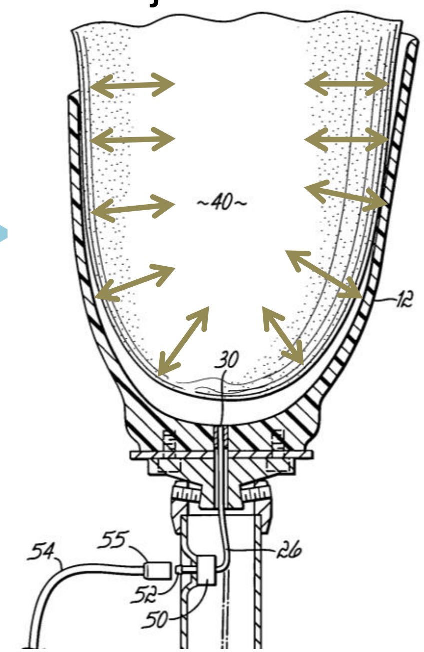
Purpose

- Controllable smart variable geometry socket
- Utilize compression/release stabilized (CRS) socket ideas[9]

Prosthetic Socket[7]

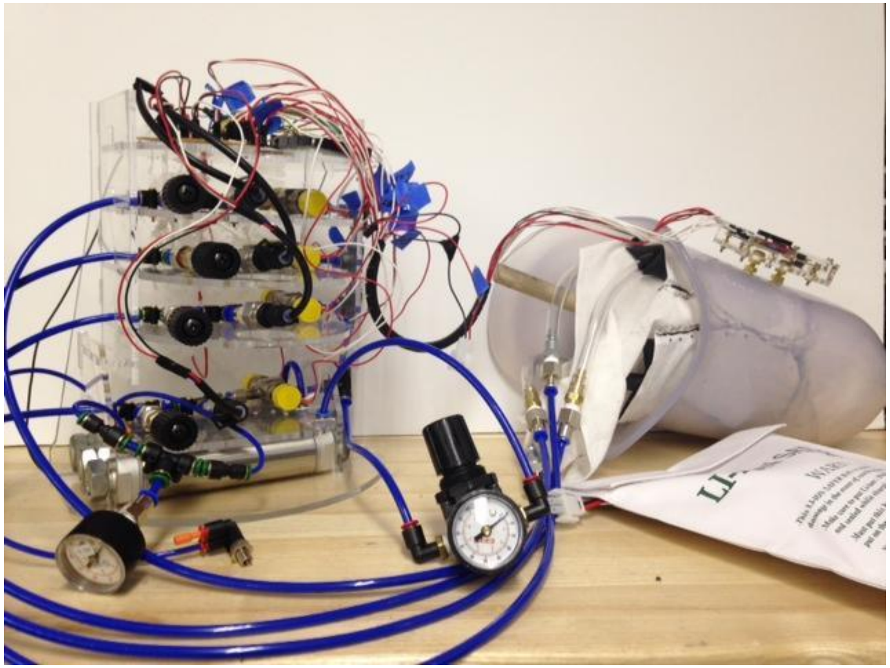
Sense User Activity

Adjust in fit[8]



Improvements

- Bladder system
  - Pneumatic vs. hydraulic
- Custom electrical system
- Advanced sensor systems
- Lighter weight/increase portability
- Safety Regulations



Previous MQP Project [10]

Project Objectives

Safe	• Must not cause more harm than current socket technologies • Meet FDA device requirements[11]
Reliable	• Must fail in predictable ways which shall not harm user
Comfortable	• Be comparable in comfort to current technologies
Minimal user-input	• No need for adjustments throughout the day after initial donning
Long-lasting (daily use)	• No need to recharge or adjust for minimum of average shopping trip length (58 minutes)[12]
Compact	• Able to be mounted on the socket • Able to be worn under clothing
Lightweight	• Within 25% of the current heaviest socket on market

RESEARCH ANALYSIS

FDA/CDRH Certification

- 3 Categories
- Based upon regulatory control required for safety
- Detailed testing data recorded for future certification

Class I

- External limb components
- Socket components
- Foot drop orthosis
- Other limb braces

[13]

Class II

- Most hearing aids
- C-leg microprocessor knee
- Powered wheelchair

[14]

Class III

- Stair climbing wheelchair

[11]

[15]

Types of Socket Solutions

- Mechanically adjusting
- Vacuum Suspension
- Inflatable Inserts/Bladders
- Compression Release Stabilized (CRS) Socket




Mechanically Adjusting

- Examples:
  - LIM[16]
  - Revolimb[17]
- Pros:
  - Fully adjustable
- Cons:
  - Potential to over-tighten and occlude circulation

Vacuum Suspension

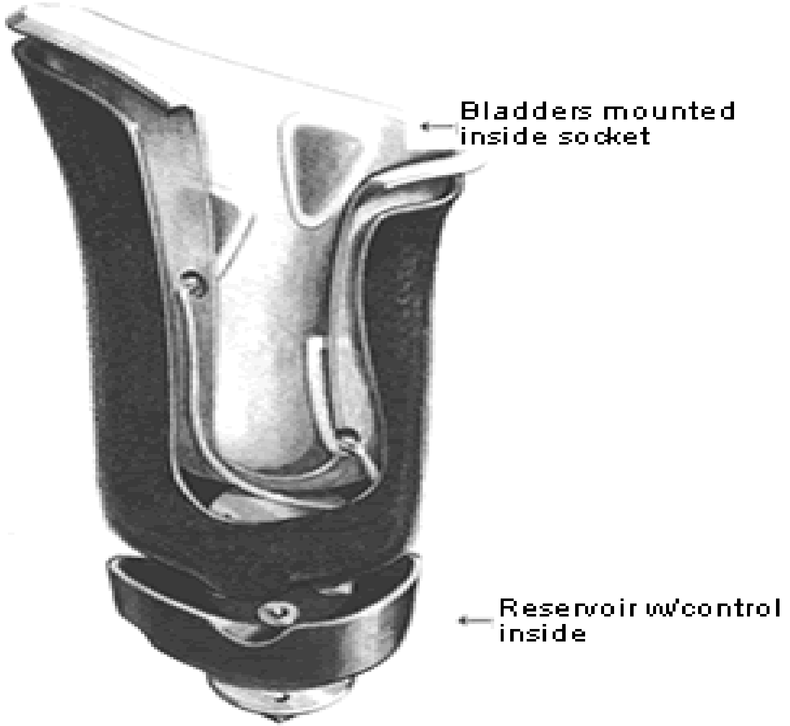
- Examples:
  - Vacuum Assisted Suspension System (VASS) [18]
- Pros:
  - Better adhesion to socket
- Cons:
  - Possibility of soft tissue damage if donned incorrectly

Inflatable Air Inserts

- Examples:
  - Pump it up! [19]
  - Pneu-fit[20]
- Pros:
  - Easy to use and inflate
- Cons:
  - Do not work over wide volume range

Inflatable Liquid Bladder

- Example:
  - Smart Variable Geometry Socket[21]
- Pros:
  - Wider volume management range
- Cons:
  - Requires pumping or hydraulic system

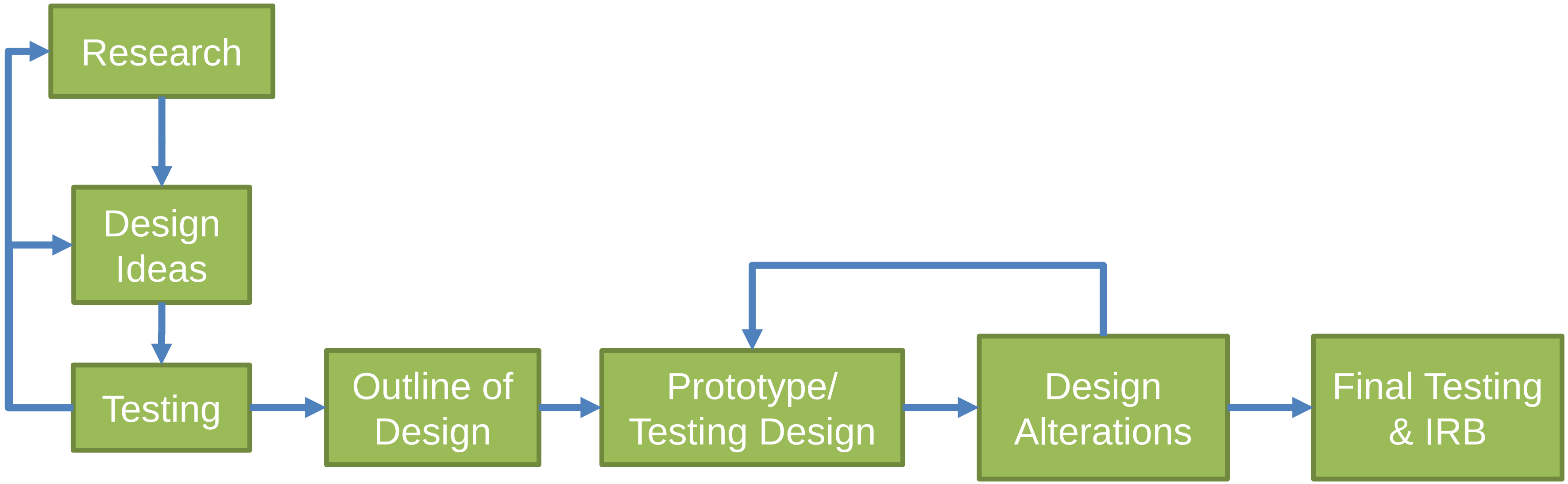


Compression Release Stabilized

- Currently in development
- Pros:
  - Better torque transfer from limb to socket
- Cons:
  - Static system

Dynamic Adjusting Prosthetic Socket (DAPS)

- Our Project Approach



Bladder Types

- Variation in shape[22-24]
  - Rectangular
  - Cuff
  - Cylindrical (tubing)
  - Custom
- Materials
  - Silicon
  - Canvas
  - Kevlar
  - Neoprene
  - Polyurethanes
  - Nylon
  - Etc.

Electromyograms (EMG)

- Research Tool[25]
- Upper limb prosthesis[26]

Signal Noise

- Electrode inherent noise[27]
- Movement artifact
- Electromagnetic noise
- Internal noise
- Inherent noise

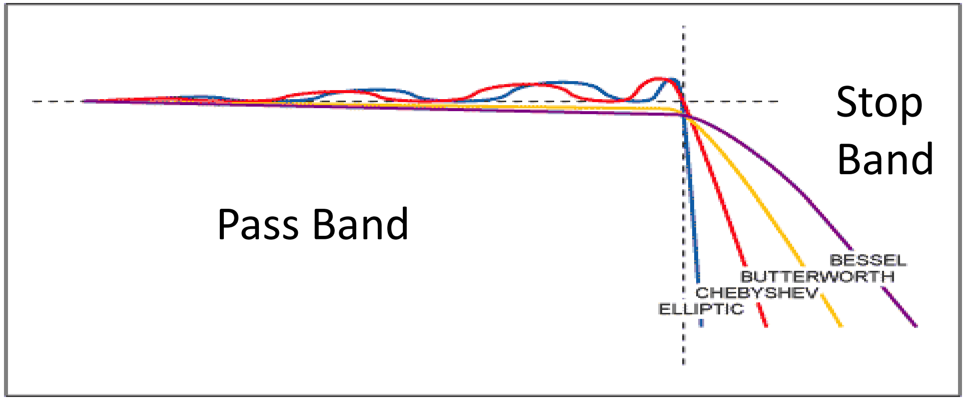
Noise Removal

- Design techniques[27,28]
  - Pre-amplifications
- Electrical Filtering[29,34]
  - Why we need it?
  - 10-20Hz Min.
  - 400-450Hz Max.

Noise Removal

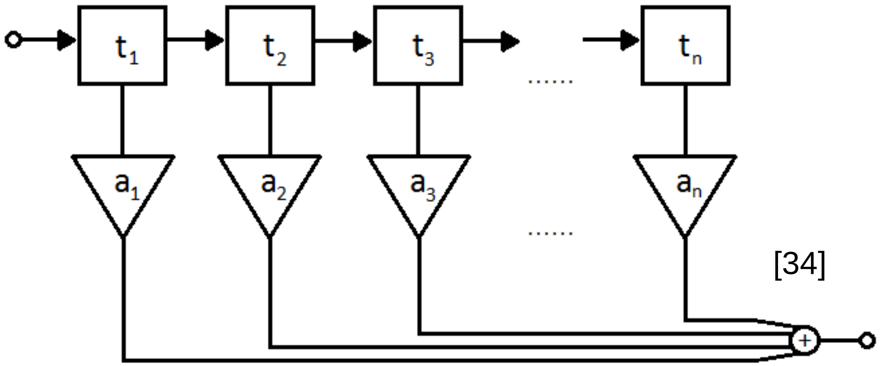
- Electrical filtering
  - Butterworth filter[29.30]
  - Chebyshev filter[30]
  - Elliptical filter[30]
  - Bessel filter[30,31]

[30]



Noise Removal

- Electrical filtering
  - Butterworth filter[29.30]
  - Chebyshev filter[30]
  - Elliptical filter[30]
  - Bessel filter[30,31]
  - Laguerre filter[32,33]
    - All Pass



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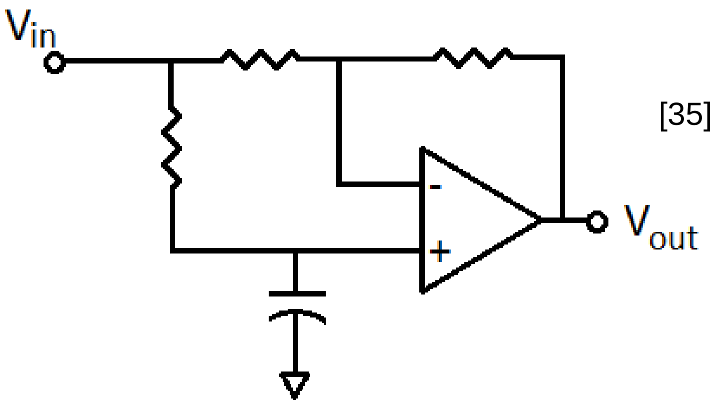

[35]

Noise Removal

- Electrical filtering
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  - Chebyshev filter[30]
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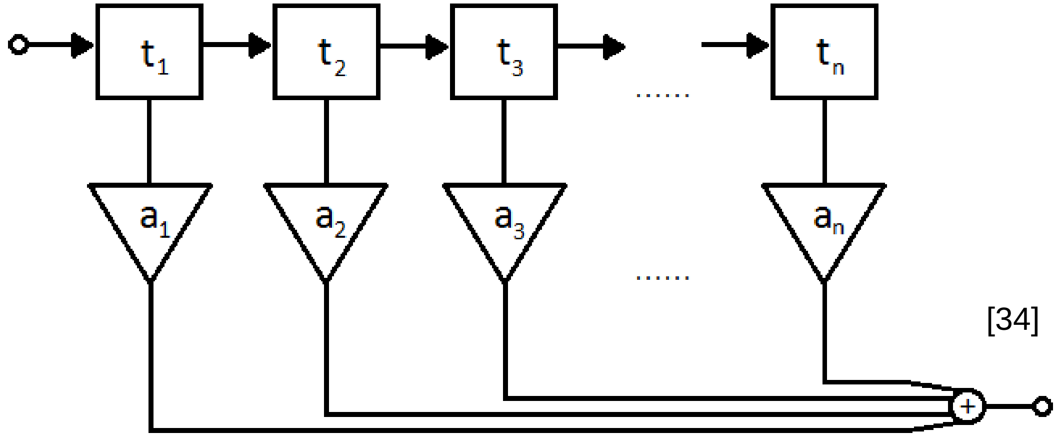
  - Bessel filter[30,31]
  - Laguerre filter[32,33]
    - All Pass



[34]

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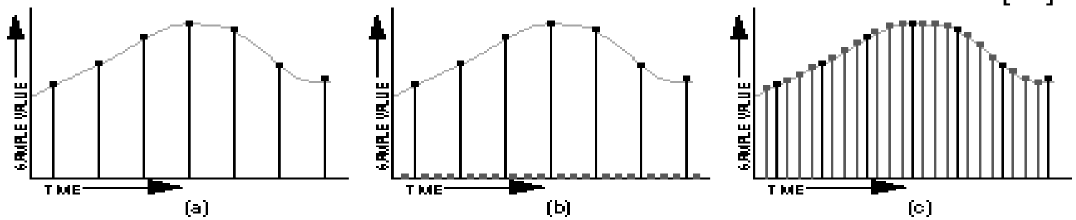

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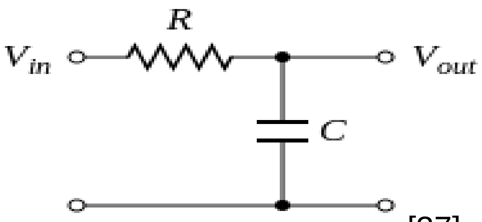
  - Laguerre filter[32,33]
    - All Pass
  - High/low pass[34]
  - Rectifiers[34]



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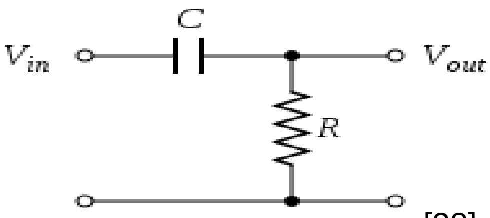

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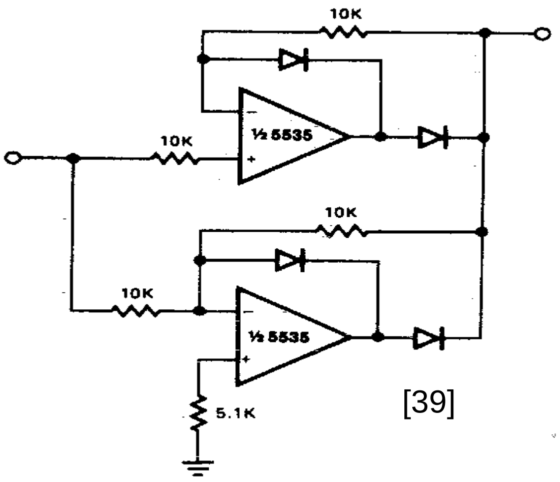
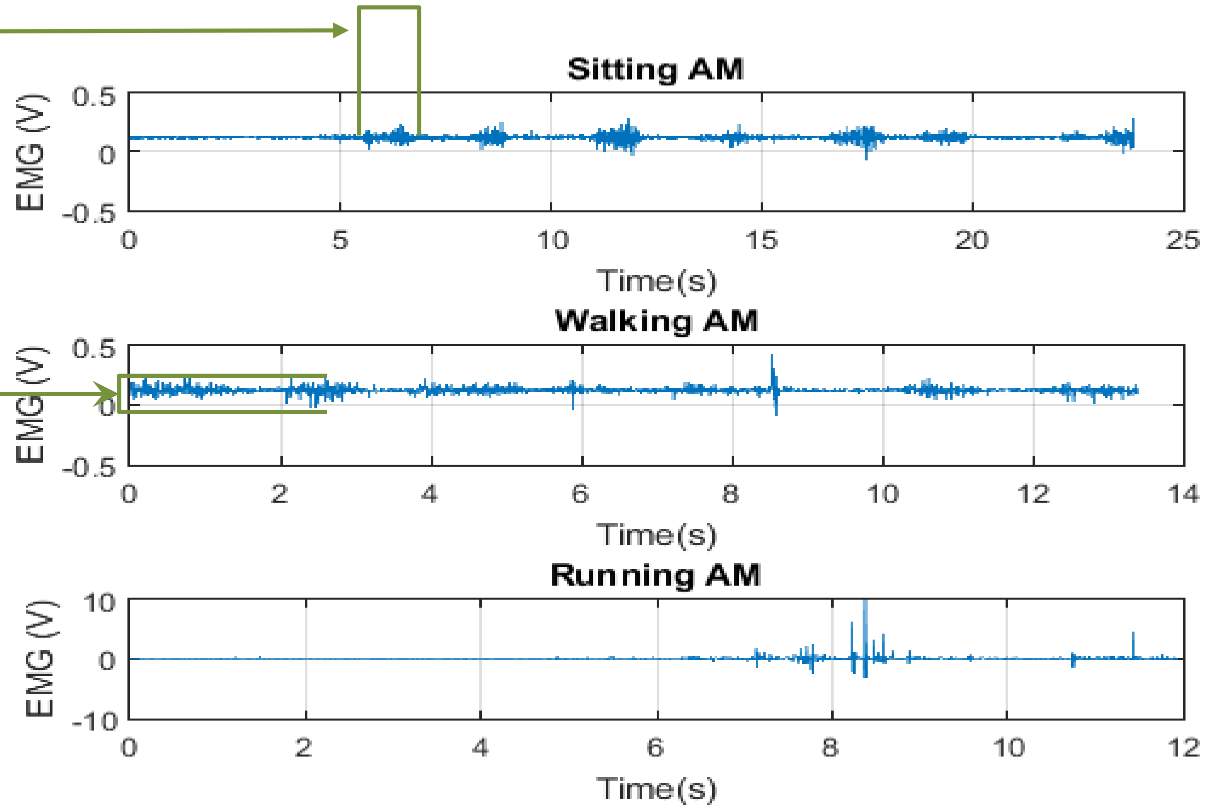


[39]

Signal Analysis

- Intervals
- Amplitude



DESIGN REVIEW

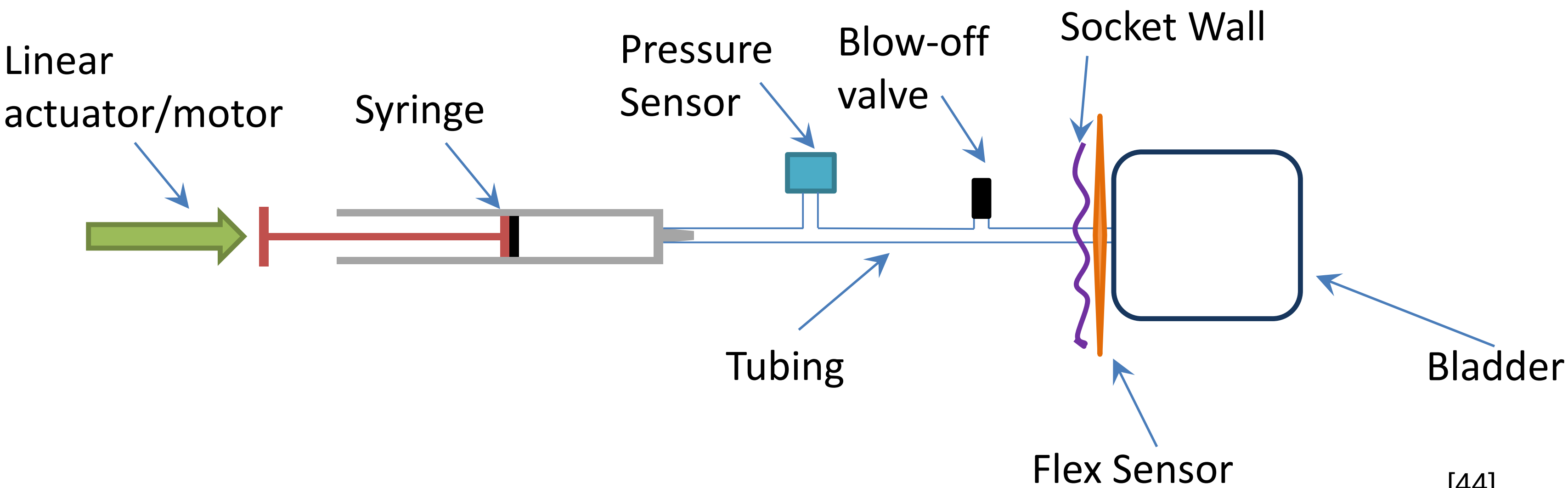
Bladder Actuation Design

- Why hydraulics?[42]
  - Wider volume range than air
  - More precise fluid control
  - More independent control of bladder
  - Easier to implement than pump-reservoir system
  - Can create a “dynamic” CRS control

Bladder Actuation Design

- Considerations[43]
  - Actuation of syringes
  - Type of fluid
  - Waterproofing electronics/leak prevention
  - Syringe/bladder volumes
  - Sensors
  - System weight

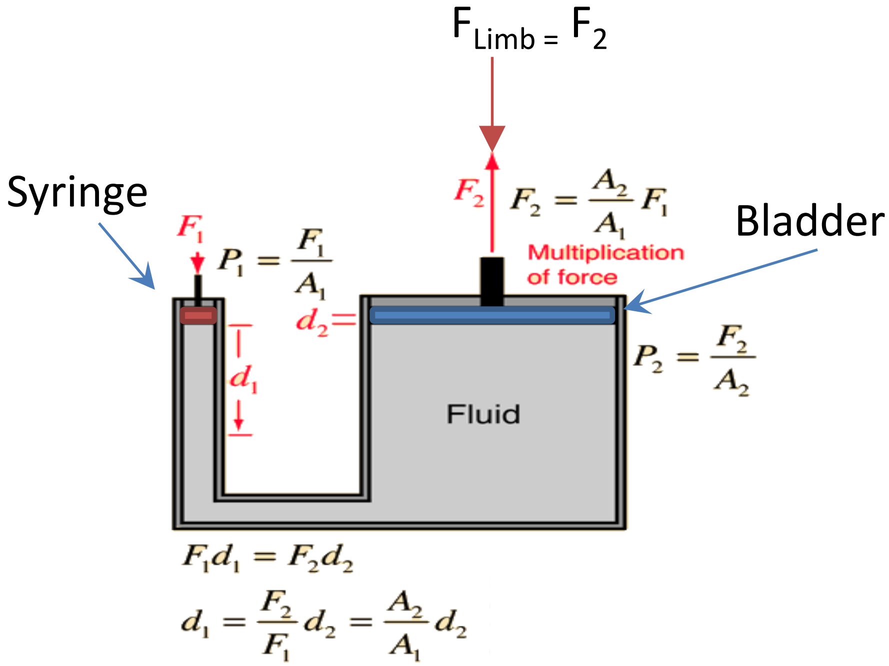
Hydraulics Diagram



[44]

Hydraulics Calculations

- Force Plate Testing
- Motor criteria[44]
  - Meet F_1 value: ~40.86N
  - Stroke length d_1: ~15.4cm
  - Adequate speed
- Further testing
  - Syringe-bladder test rig



Bladders Prototypes

- Blood pressure cuffs
- Fabric
- Silicone rubber mold
- Surgical tubing

[46]

Bladders Prototypes

- Blood pressure cuffs
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[47]

Bladders Prototypes

- Blood pressure cuffs
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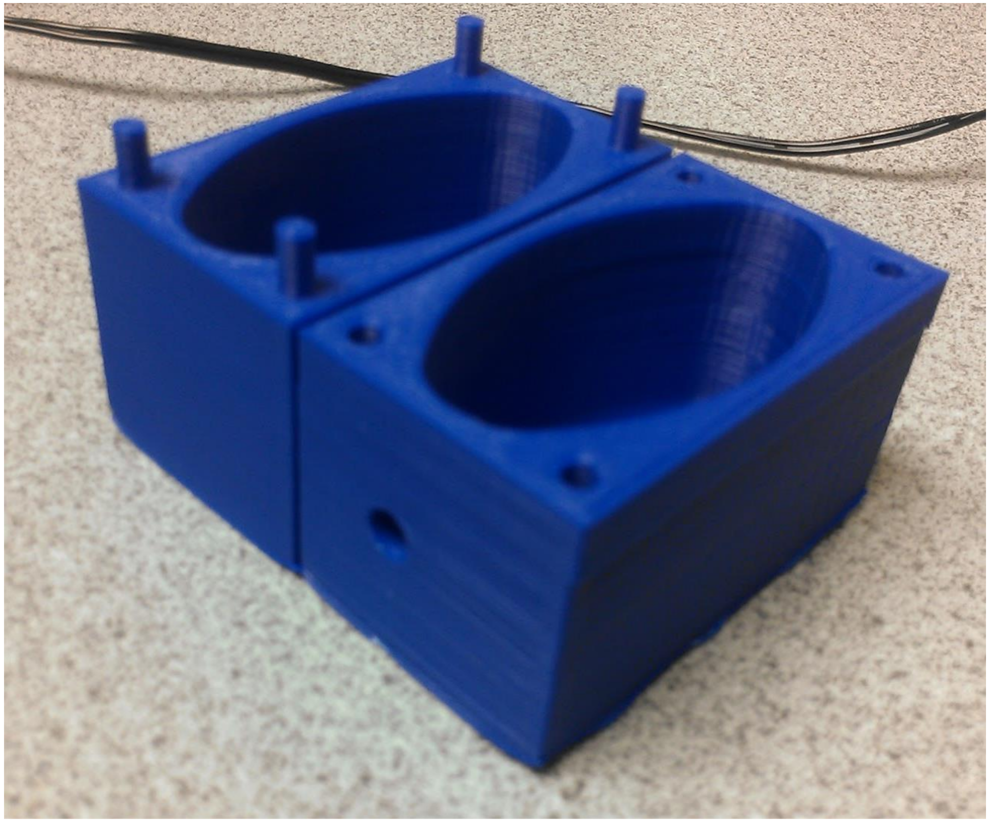


[48]

Bladders Prototypes

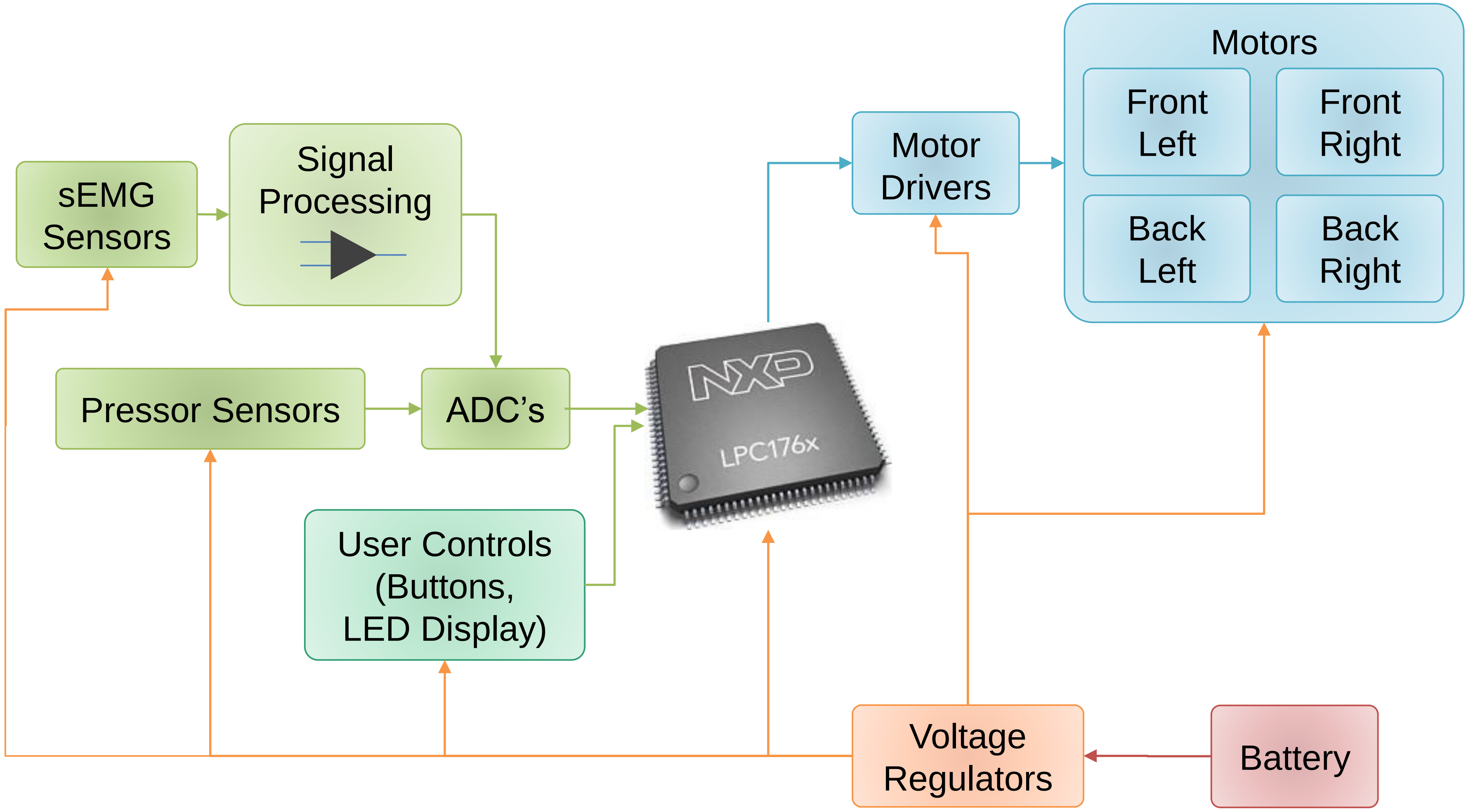
- Blood pressure cuffs
- Fabric
- Silicone rubber mold
- Surgical tubing

[49]

Design Matrix

Quality	Weight
Force (N)	33%
Cost ($)	12%
Durability	12%
Effectiveness (x minutes)	11%
Manufacturability	10%
Customization	10%
Weight (g)	7%
Volume (mL)	5%

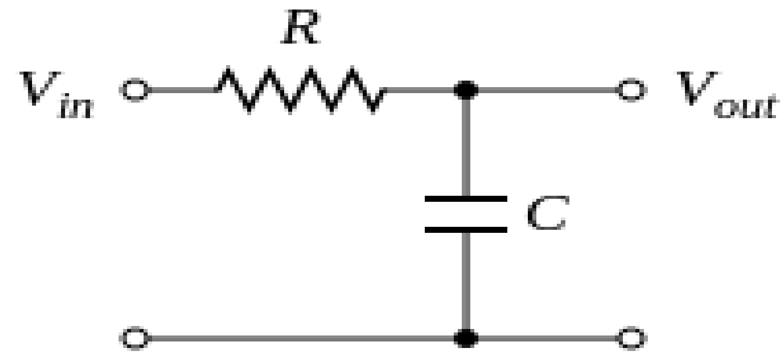
Sensing & Control



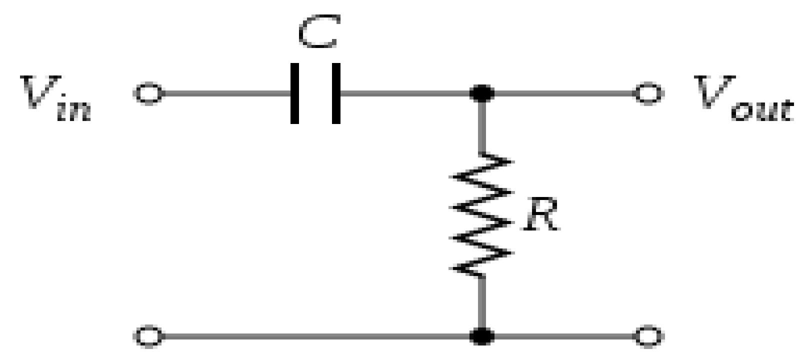
[50]

Filtering Circuit

- High and low pass filters
- Full wave rectifiers



Low Pass Filter

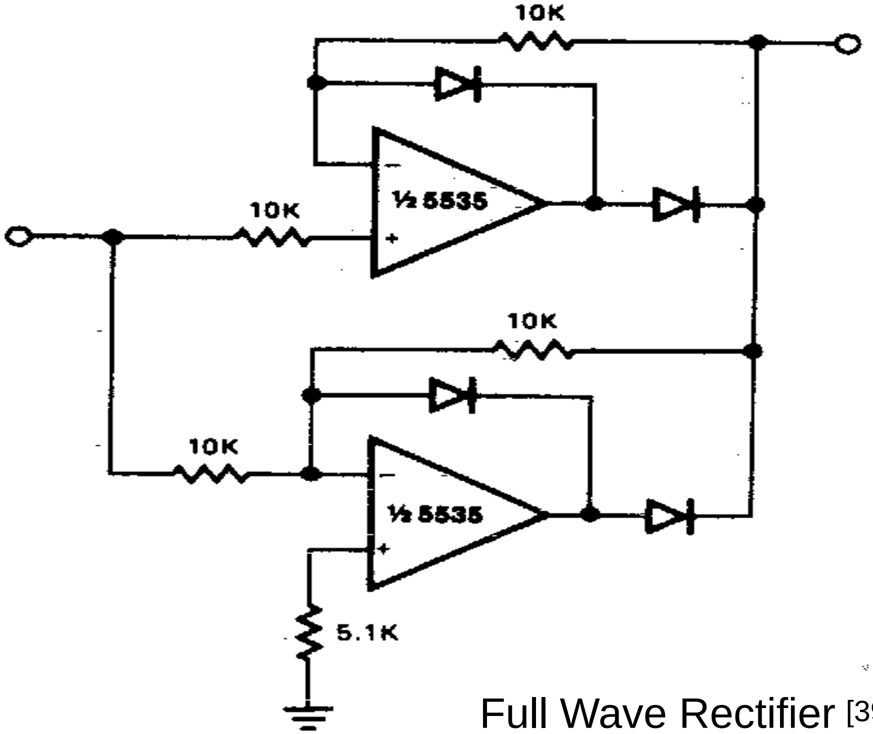


High Pass Filter

[37-38]

Filtering Circuit

- High and low pass filters
- Full wave rectifiers



Full Wave Rectifier [39]

System Control

- Microcontroller (NXP1764FBD100)
  - I/O Pins
  - 32-bits
  - High clock speed
  - USART to USB

[51]

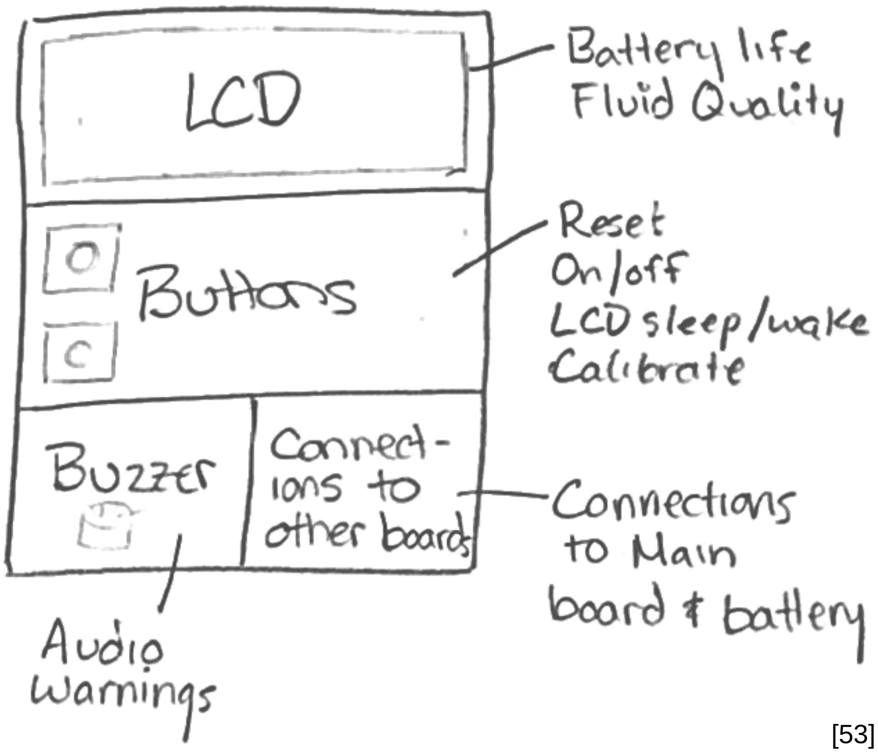
System Control

- Motor Control
  - Drivers
  - Battery requirements
  - Voltage regulators

[52]

System Control

- User Interface
  - Warnings – visual and audible
  - Reset
  - LCD
    - Sleep/wake
    - Battery life
  - On/off button
  - Load/unload
  - Debug/calibrate



[53]

EMG Wiring

- Flex wires with coating
- Fitting sock with EMGs

[54]

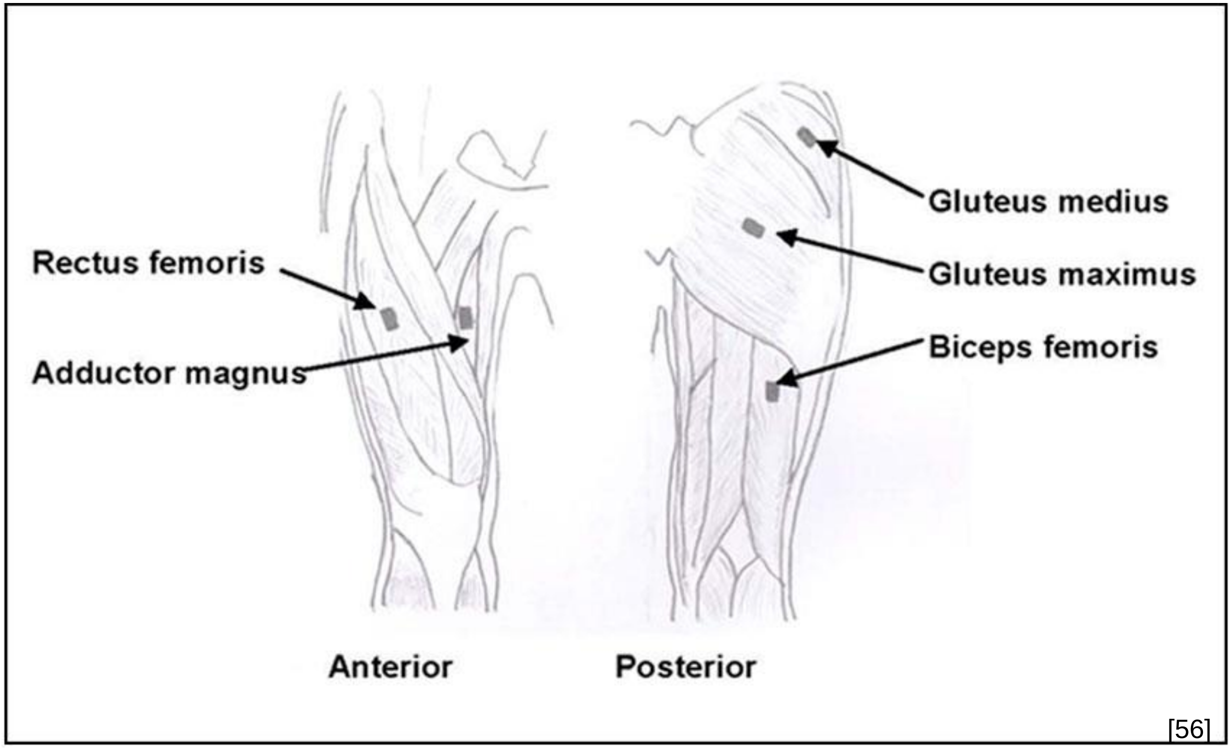
EMG Wiring

- Flex wires with coating
- Fitting sock with EMGs

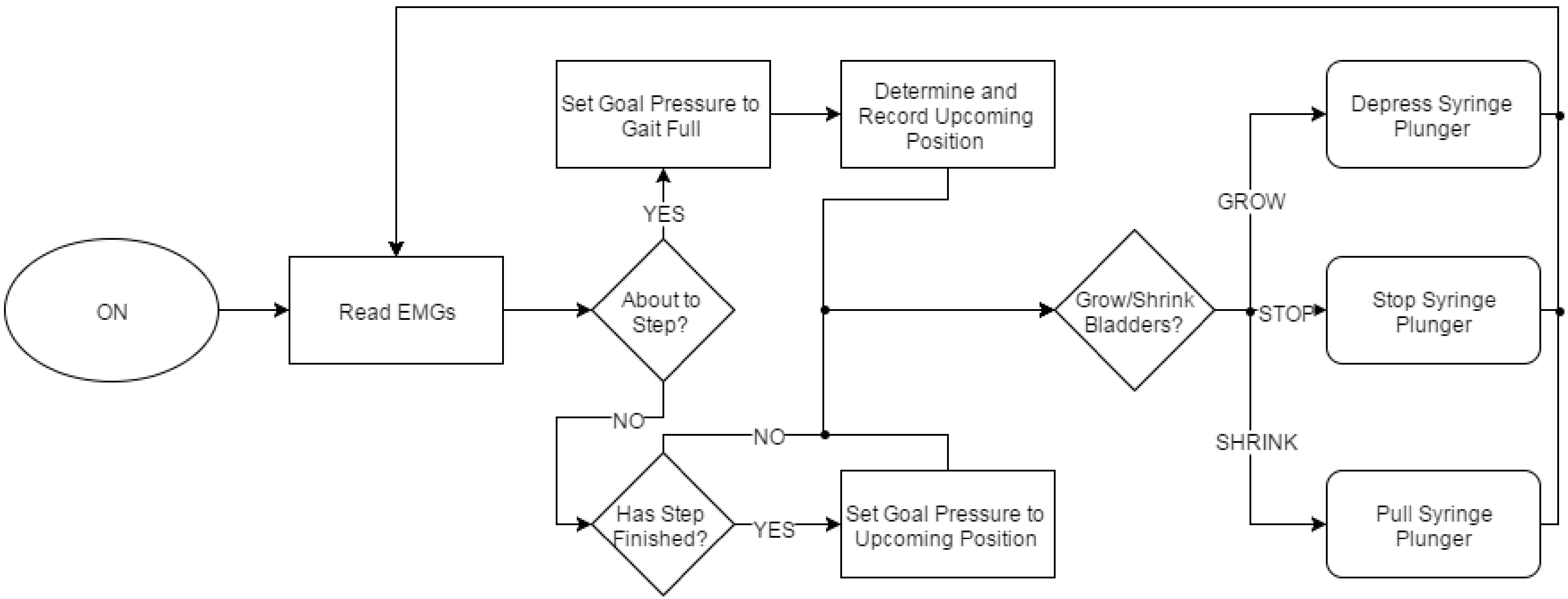
[55]

EMG Placement

- Muscles to control leg extension/flexion
  - Abduction and adduction
- Superficial muscles

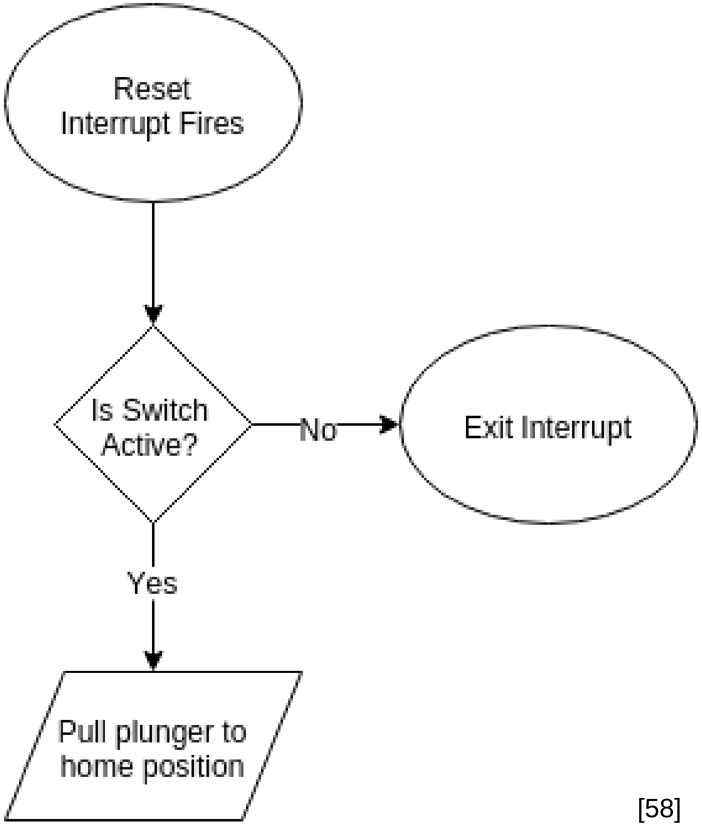


Control Algorithms



[57]

Control Algorithms



[58]

Safety

Bladders are too pressurized → Sensor information informs system to retract syringes

Safety

Bladders are too pressurized → Sensor information informs system to retract syringes

Bladders are too pressurized & sensors have failed → User triggers the reset switch, syringes retract

Safety

Bladders are too pressurized	→ Sensor information informs system to retract syringes
Bladders are too pressurized & sensors have failed	→ User triggers the reset switch, syringes retract
Unforeseen emergency	→ Blow off valve releases pressure

PROJECT TIMELINE

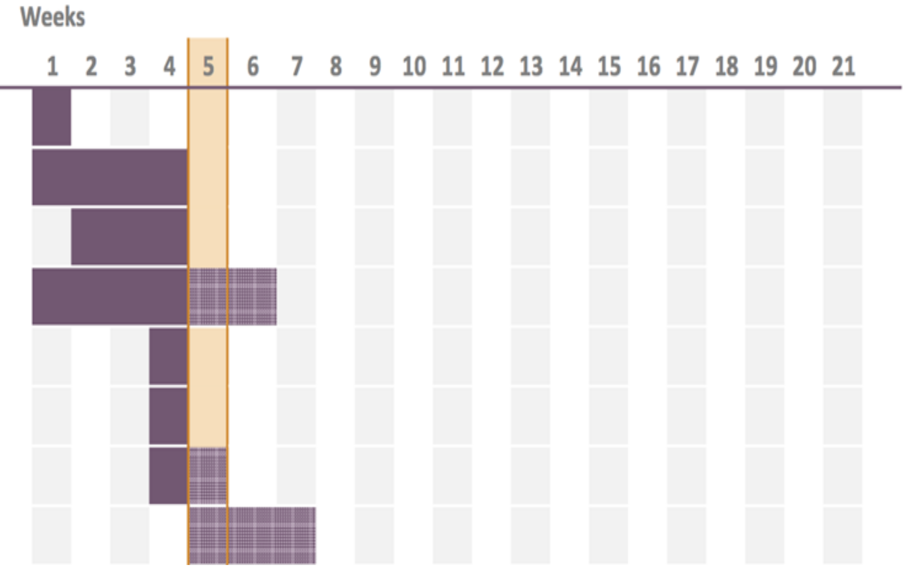
A-Term Schedule

Robo Knee Gantt Chart

Week Highlight: 5

Planned | % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project Proposal	1	1	1	1	100%
Literature Review	1	4	1	4	100%
Hydraulics Design	2	3	2	3	100%
Bladder Design	1	6	1	6	80%
Electrical Design	4	1	4	1	100%
General Code Design	4	1	4	1	100%
PCB Design	4	2	4	2	30%
Obtain Components	5	3	5	3	0%

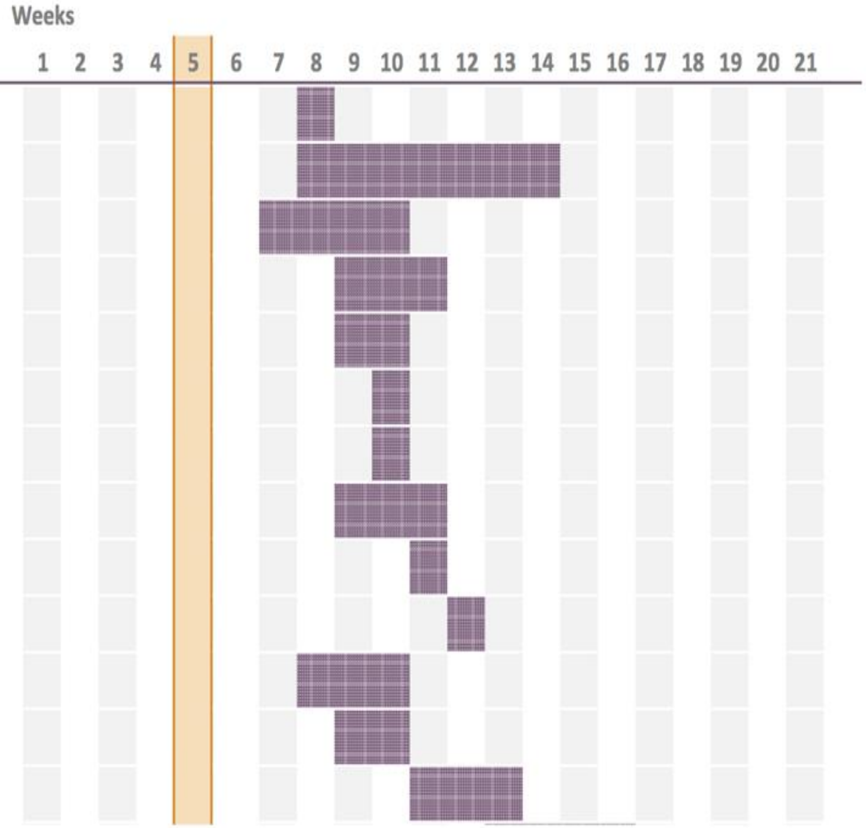


B-Term Schedule

Robo Knee Gantt Chart

Week Highlight: 5 | Planned | % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Prioritize Code Functions	8	1	8	1	0%
Write Code	8	7	8	7	0%
Design Final Testing	7	4	7	4	0%
Build Bladders	9	3	9	3	0%
Build Hydrolics	9	2	9	2	0%
Test Sensors	10	1	10	1	0%
Test Pressure Systems	10	1	10	1	0%
Make Electrical Board	9	3	9	3	0%
Assemble Enclosure	11	1	11	1	0%
Test Enclosure	12	1	12	1	0%
Write Up Project Structure	8	3	8	3	0%
Write Up Alternitive Design	9	2	9	2	0%
Write Up Design Verificatioı	11	3	11	3	0%



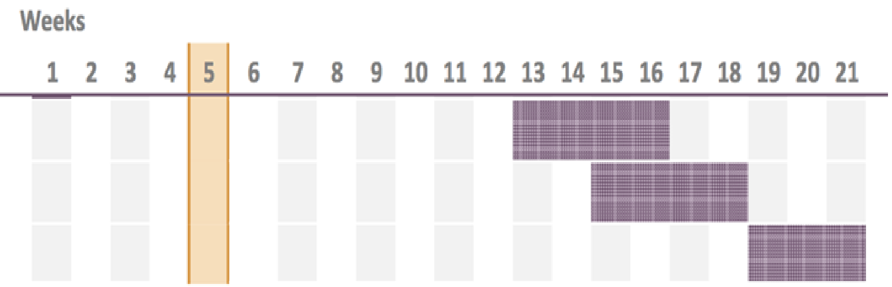
C- Term Schedule

Robo Knee Gantt Chart

Week Highlight: 5

Planned % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Final Testing	13	4	13	4	0%
Complete Write-Up	15	4	15	4	0%
Edit Report	19	3	19	3	0%



THANK YOU!

Questions?

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45. Filter drawn by Meagan H.
46. Photo taken by Jake Z. of plastic mold
47. SURGICAL TUBING | Brownells
48. Outline of Circuit drawn by Meagan H. Photo of NXP LCP176x from http://www.nxp.com/
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