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Arthur Connors
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P09029 – AIR MUSCLE
ARTIFICIAL LIMB
Introduction

- Fourth project in artificial limb track
- First three projects focused on hand DOF
Project Goals

- To create a computer simulation of the kinematics of an air muscle-controlled human joint (the elbow)
- Build a prototype joint to compare to and improve the computer model
- Make end product adaptable and useful for future iterations
# Customer Needs

<table>
<thead>
<tr>
<th>Customer Need #</th>
<th>Importance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN01</td>
<td>10</td>
<td>Must create a computer model that predicts the kinematics of an air-muscle controlled robotic arm. The kinematics of the elbow joint must be included in the model.</td>
</tr>
<tr>
<td>CN02</td>
<td>9</td>
<td>The computer model created must predict forces that would be applied to the robotic arm design if air muscles were used as the force actuating mechanism.</td>
</tr>
<tr>
<td>CN03</td>
<td>9</td>
<td>Must validate critical aspects of the design feasibility and the fidelity of the kinematic computer model using appropriate “breadboard level” physical prototype pieces (does NOT need to be complete physical prototype of arm). The breadboard pieces will also be used to develop the computer model.</td>
</tr>
<tr>
<td>CN04</td>
<td>9</td>
<td>Must design elbow mechanism that has the same degrees of freedom as the human arm.</td>
</tr>
<tr>
<td>CN05</td>
<td>8</td>
<td>Must develop controls software that can control both a computer model and a physical prototype. Control software must be capable of receiving displacement feedback from a virtual or physical model.</td>
</tr>
<tr>
<td>CN06</td>
<td>8</td>
<td>Must complete an analysis of the forces generated by the air muscles to integrate with the computer model.</td>
</tr>
<tr>
<td>CN07</td>
<td>6</td>
<td>Motions must resemble human motions.</td>
</tr>
</tbody>
</table>
## Engineering Specs

<table>
<thead>
<tr>
<th>Specification (description)</th>
<th>Unit of Measure</th>
<th>Marginal Value</th>
<th>Ideal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer model needs to be able to predict collisions</td>
<td>Boolean</td>
<td></td>
<td>TRUE</td>
</tr>
<tr>
<td>Computer model needs to be able to predict the forces acting on the arm components</td>
<td>Boolean</td>
<td></td>
<td>TRUE</td>
</tr>
<tr>
<td>Computer model needs to prove the design feasibility</td>
<td>Boolean</td>
<td></td>
<td>TRUE</td>
</tr>
<tr>
<td><strong>Prototype</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow has same number of degrees of freedom as the human hand</td>
<td>degrees of freedom</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Bicep length</td>
<td>Inches</td>
<td>10-15</td>
<td>12</td>
</tr>
<tr>
<td><strong>Test Stand</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large enough to contain arm motion</td>
<td>Inches</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>Withstand catastrophic air muscle failure (safety glasses standard: 1/4” steel ball shot at ft/sec</td>
<td>150</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td><strong>Movement</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow Flexion resembles human motion (Elbow)</td>
<td>Degrees</td>
<td>130</td>
<td>150</td>
</tr>
<tr>
<td>Elbow Movement speed (median)</td>
<td>Degrees/Second</td>
<td>180</td>
<td>215</td>
</tr>
<tr>
<td><strong>Controls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control system able to control both SolidWorks and Prototype</td>
<td>Boolean</td>
<td></td>
<td>TRUE</td>
</tr>
<tr>
<td>Control system able to take feedback from both SolidWorks and Prototype</td>
<td>Boolean</td>
<td></td>
<td>TRUE</td>
</tr>
<tr>
<td>Control system operates fast enough to control prototype (USB, Relay, DAQ, and Calculations)</td>
<td>milliseconds</td>
<td>100-500</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>
Team Roles

- **Casey**
  - Math Theory
  - Pneumatics
  - Arm Design
  - Arm Fabrication
  - EDGE

- **Arthur**
  - Controls System
  - Electronics
  - Simulation
  - Integration

- **Andrew**
  - Test Stand Design
  - Test Stand Fabrication
  - Testing
  - Data Analysis
System Architecture

P09029: System Architecture

- PC (With LabVIEW and SolidWorks)
- LabVIEW Interface (For User Inputs)
- SolidWorks Sub VI (Using NI Mechatronics Toolkit)
- Physical Prototype Sub VI (Feedback Control)
- LabVIEW 8.6
- Relay Boards
- 120 V ac to 12 V dc Transformer
- Solenoids
- Air Muscles
- Potentiometers (Linear and Rotary)
- DAQs
- Wall Air Supply
System Architecture

P09029 – The Proof-of-Concept Tripod
Revision 2 – 2/11/09

Control System

Tests Control System for future use on prototype

Computer Model

LabVIEW → Mechatronics → COSMOSMotion → SolidWorks

Receives Feedback from Potentiometers

Predicts real world physics and Kinematics

Open and closes solenoids to contract muscles

Physical Prototype

Provides Proof of Concept
Physical Prototype
Components

Air Muscle Artificial Limb
Elbow joint moved by pneumatic actuators

Test Stand
Holds arm and sensors in place

Strain Gauge
Produces voltage change with displacement

Solenoid
Controls airflow

Pressure Gauge w/ Flow Restrictor
Measures and/or slows airflow

Relays
Provide power to and control solenoid

Air Tank
2 count: one holds pressurized air, one is vacuumed

Vacuum Pump
Sucks air out of muscles
Calculating Air Pressure

Fill:

\[ P_{\text{muscle}} = (P_0 - P_{\text{Tank}})e^{(\sigma)t} + P_{\text{Tank}} \]

Hold:

\[ P_{\text{muscle}} = P_0 - 0.28t \]

Drain:

\[ P_{\text{muscle}} = P_0 e^{(\sigma)t} \]

1) LabView first calculates what air pressure should be in the air muscle given the amount of time that has passed.

2) LabView calculates the force the air muscles should be exerting based on the pressure in the air muscle given a few characteristics of the air muscle.

Apply Calculation of Force Out of McKibben Air Muscles*

\[ F = \frac{\pi D^2 P_{\text{muscle}}}{4} (3\cos^2 \theta - 1) + \pi P_{\text{muscle}} \left[ D_{t_k} \left( 2\sin \theta - \frac{1}{\sin \theta} \right) - t_k^2 \right] \]

*"Measurement and Modeling of McKibben Pneumatic Artificial Muscles" by Ching-Ping Chou and Blake Hannaford
Testing

- Components
- Pressure Tests
- Elastic Cord/Strain Gauge
Components

- Air muscles – contract the way they should
- Relays and Solenoid – Power works
- Vacuum Pump – Failed to power up; worked after rewiring
Pressure Tests

- Muscles filled with air at different increments (0.05, 0.125, 0.25 seconds)
- Data fitted to function
Test Data

Test Results

- Test 1
- Test 2
- Test 3
Fitted Curve

Case Fill

Pressure (psi) vs Time (sec)

- Fitted Curve
- Theory
Elastic Cord/Strain Gauge

- 6 strings, different sizes
- Weights 50g-2kg added
- Displacement measured
- Linear Regression to find k

Cord tied onto gauge
- Cord displaced set amounts, voltage measured
- LRA to find Constant

Scatterplot of % Deformation vs Weight (lbs)

Elastic Cord
\[ k \approx 0.212 \text{ lbs/in} \]

Strain Gauge
Constant \( \approx 2347 \text{ lbs/Volt} \)
Simulation
Communication is Key!!!

- Mechatronics Toolkit is a linking tool between LabVIEW and COSMOS Motion
- Each program receives, translates, and passes data to the next program
Lessons Learned

• Using a single 3-position, 5-way solenoid is cheaper than four 2-way, 2-position solenoids, and takes half of the relays.

• Find local suppliers:
  • Roessel has many pneumatic parts on hand.
  • Cross Bros has sprockets and chain on hand.

• Don’t rely on non-team members for mission critical parts.

• Start programming earlier.
Future Work/Recommendations

- Expanding to the shoulder
- Refining and generalizing models
- Scaling
- Don’t reinvent the wheel
- Rely on past BOMs
- Use updated version of SolidWorks