Pneu-MC Gaylord-McKibben Actuated Robotic Arm

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Introduction

The goal of this project was to build a platform to test the fine-grained control feasibility of Gaylord-McKibben actuators. Gaylord-McKibben actuators are interesting because they are lightweight and inexpensive, and offer a lot of potential applications in prosthetics, biomimicry research and human safe robotics.

We decided that a 3 degree of freedom robotic arm was a useful test case, providing an interesting control problem, with the ability to write legibly as an obvious proof of dexterity. The project involved several major milestones:

- First, a several viable driver options for the actuators were investigated and prototyped.
- Secondly, the actuators were tested in attempt of finding a basic model and linear operating region.
- A single actuated link prototype was then designed and assembled as a proof of concept showing joint orientation control using paired sets of actuators.
- Finally, the 3 degree of freedom arm assembled with an upgraded PID controller and computer control interface to attempt to reach our control goals.

Methods

Actuator Drivers

Two potential driver options were investigated for the actuators:

- High Pressure Driver: The high pressure driver is composed of two solenoid valves per actuator with a high-pressure air supply,. This method provides a quick, powerful response, and is easily constructed from off-the-shelf components.
- Hydraulic Piston Driver: This driver option consisted of a hydraulic piston attached to a driving servo. This method was theoretically more promising, as it could have provided more fine grained control response. However, our prototype was incapable of driving our actuators due to mechanical problems. Due to time constraints, we chose the high pressure driver option for our project.

Actuator testing

Testing was carried out with a pressure gauge and a measuring stick to establish a relationship between inflation pressure and displacement length.

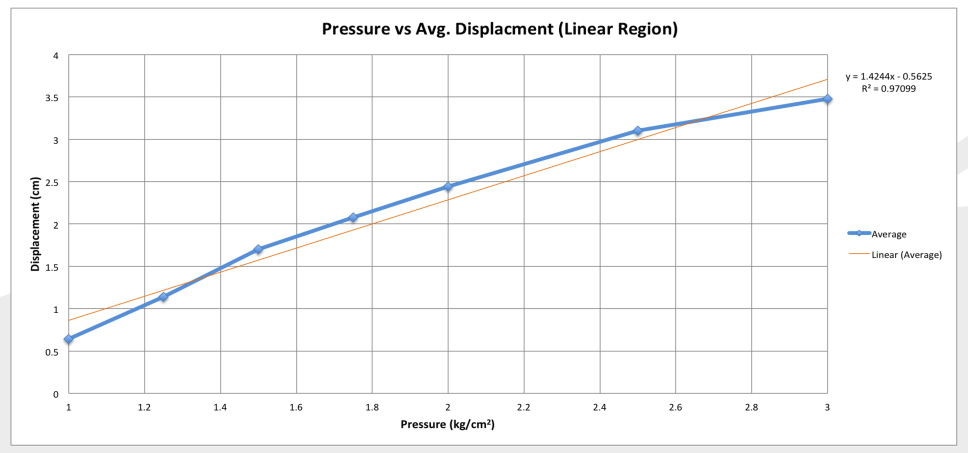
Construction techniques

Construction of both the single-link actuator and the 3 degree of freedom arm was carried out using laser cut fabrication for cut parts, and off-the-shelf components to attach them together. This allowed for a very rapid prototyping and testing schedule, needing only 3 days lead time for cut parts and 5 days for hardware orders.

Control System Implementation

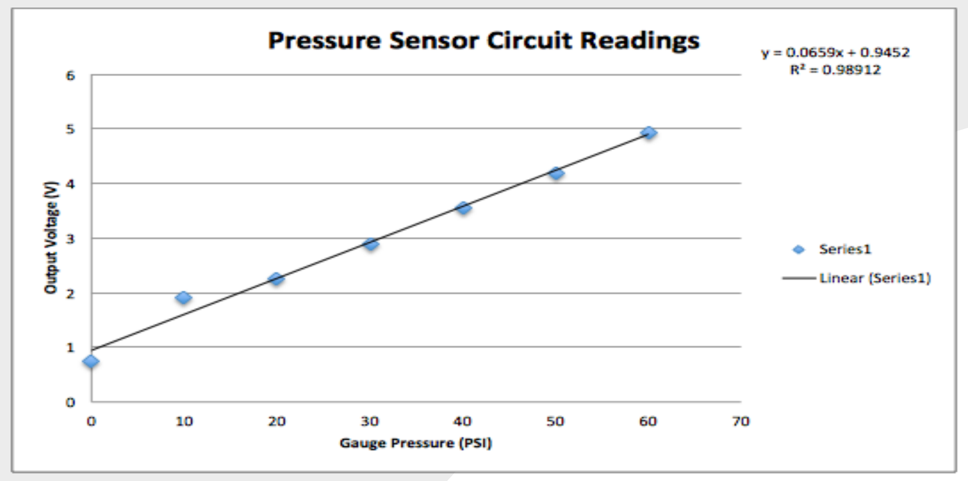
Our control system was implemented using an Arduino Mega ADK microcontroller, with several custom-built daughter boards for solenoid activation and pressure gauge feedback. Position control for the actuated links was provided by PID control using feedback potentiometers.

Results

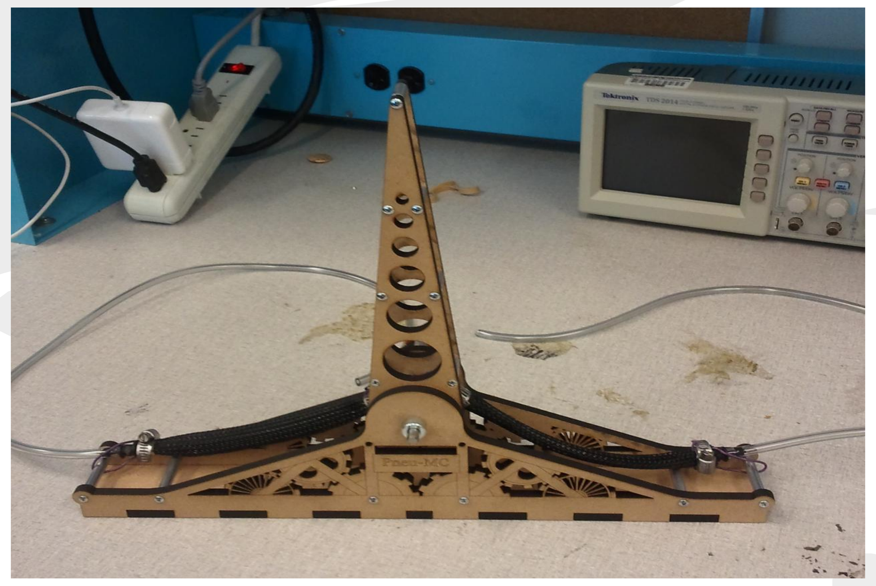


Actuator Testing Results

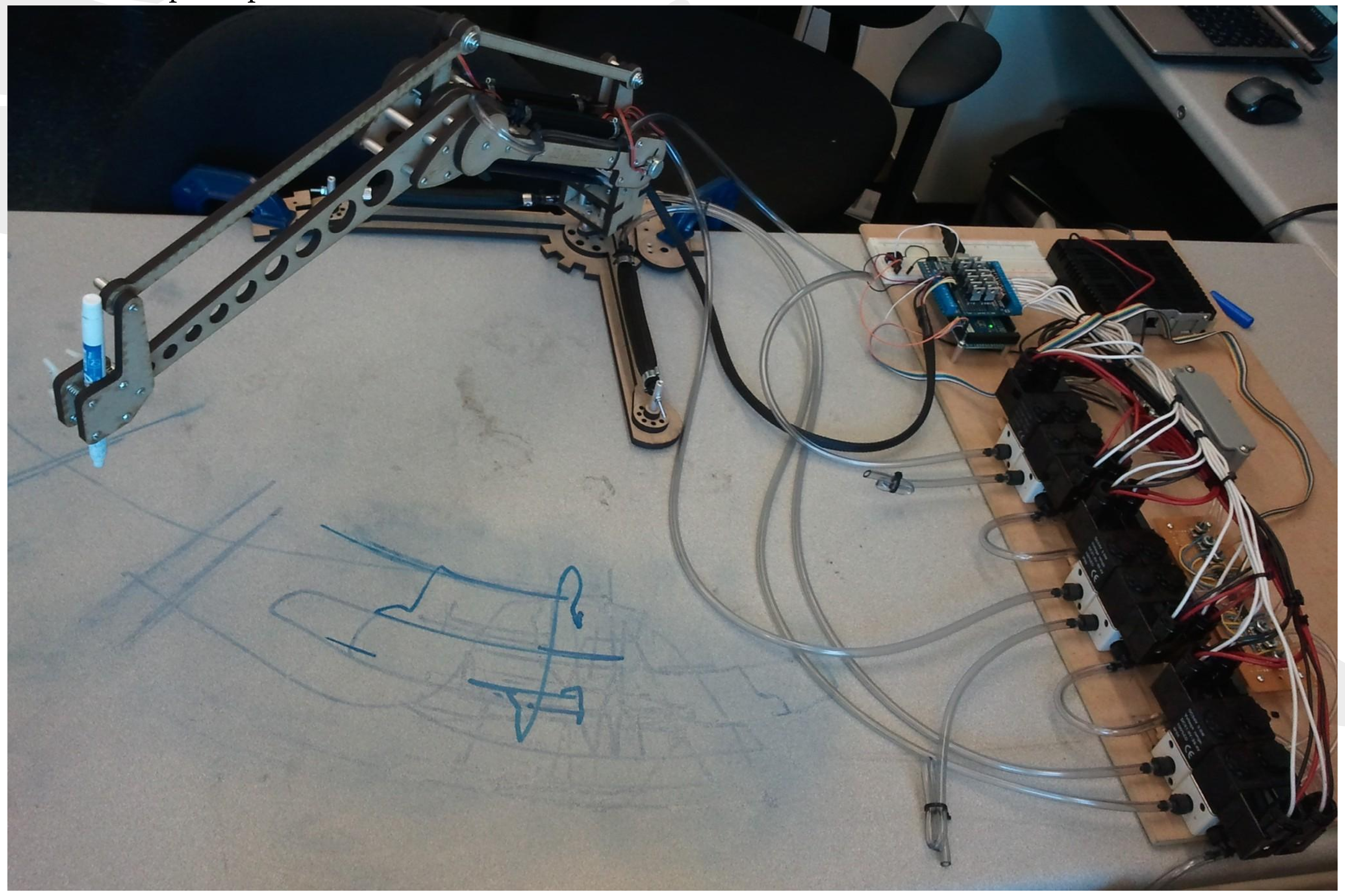
A Gaylord-Mckibben Pneumatic Linear Actuator



Output of pressure feedback circuit



Single Link Arm (proof of concept)



3 Degree of Freedom Robotic Arm (showing driver board and resulting scribble)

Discussion

When testing our McKibben actuators we was found that the actuators have a near-linear operating region for displacement relative to pressure of about for air pressures between 1 kg/cm² and 3 kg/cm². Our joint position systems were designed with this region in mind. Testing of the actuators was carried out using a 1.5kg mass, however it was also found that varying the load had very little effect on their displacement characteristics.

In our robotic arm design, each actuator was attached such that it could fully rotate a joint through a 90° range and remain in its linear region of operation

Once the 3 DoF arm was fully constructed control of each independent joint was achieved with an accuracy of +/- 5 °. However, the limited PWM resolution of the pneumatic valves used did not allow for the fine grained control necessary to reach our goal of +/- 1°. Thus our position control was not fine enough to write legibly with our given drivers. In addition, some kinematic inelegance of our design added to our difficulties, providing an oddly shaped workspace for the task, and poor angular resolution in the workspace. Additional hardware revisions and more PID tuning could fix these issues, However, we believe that proper fine-grained control would require a better actuator driver solution.

Conclusions

Results

Although the desired position accuracy of +- 1% was not achieved, the McKibben actuators proved to be very robust, powerful, and inexpensive actuator for our robotic arm. The driver options we chose proved inadequate to provide the control we desired, but future work and improvements could realize our goals.

Potential for Future Work

- Spend more time tuning PID parameters.
- Solve control resolution issues.
  - Examine using flow restrictors or proportional valves.
  - Mechanical redesign to reduce slop and improve kinematics.
- Re-investigate hydraulic driver option
  - Use worm-drive motors or custom fabricated piston hardware.
- Implement stiffness control.
- Develop better actuator modeling and drivers.
- Implement better incorporation of pressure feedback
  - MIMO control components
  - Adaptive control systems
- Incorporate other robot control improvements
  - Use robot dynamics calculations, inertial tensors and gravity calculations
  - Jacobian analysis, velocity control and better trajectory generation.

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