P09029 Air Muscle Artificial Limb

Test Plan & Results

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1. PRELIMINARY TEST PLAN

1.1. Introduction; Overview; Summary; Purpose; History

1.1.1. The long-term goal of this project is to design a robotic arm with full-range of motion capability. Prior phases of the project focused on finger motions. This iteration will focus on wrist, forearm and elbow motion. A software package will be developed that will include a controls system that can output to a 3D computer model for simulation as well as a physical prototype. The primary focus of this project is to create this computer simulation of joints used in making air muscle based robotic arms that can interface with the controls system and predict the forces. To ensure the accuracy of this simulation, joints will be made and compared to the computer model..

1.2. Project Description; Sub-Systems/ Critical Components Being Tested

1.2.1. Prototype joint.

1.2.2. Computer simulation of joint.

1.2.3. Controls system.

1.3. Approval; Guide, Sponsor

Approved by:
- Team Members – Casey Dill.
- Guide – Professor Lamkin-Kennard
- Sponsor – Professor Lamkin-Kennard

1.4. Test Strategy

1.4.1. Product Specifications, Block Diagram, and Pass/ Fail Criteria

Eng. Spec. #	Source	Specification (description)	Unit of Measure	Marginal Value	Ideal Value
Simulation					
ES02	CN02	Computer model needs to be able to predict the forces acting on the arm components	Boolean		TRUE
ES03	CN03	Computer model needs to prove the design feasibility	Boolean		TRUE
Prototype					
ES04	CN04	Wrist has same number of degrees of freedom as the human hand	degrees of freedom		2
ES05	CN04	Forearm has same number of degrees of freedom as the human hand degrees of freedom	degrees of freedom		1
ES06	CN04	Elbow has same number of degrees of freedom as the human hand	degrees of freedom		1
ES07	CN04	Hand length, wrist to fingertips	Inches	5-15	7
ES08	CN04	Bicep length	Inches	10-15	12
ES09	CN04	Forearm length	Inches	9-17	12
Test Stand					
ES10	CN03	Large enough to contain arm motion	Inches	24	36
ES11	CN03	Withstand catastrophic air muscle failure (safety glasses standard: 1/4" steel ball shot at su	ft/sec	150	250
Movement					
ES24	CN07	Elbow Flexion resembles human motion (Elbow)	Degrees	130	150
ES27	CN07	Elbow Movement speed (median)	Degrees/Second	180	215
Controls					
ES28	CN05	Control system able to control both SolidWorks and Prototype	Boolean		TRUE
ES29	CN05	Control system able to take feedback from both SolidWorks and Prototype	Boolean		TRUE

1.4.2. Functions (hardware) and Features (software, customer needs)

Test Number	Trace	Test Name	Description	Reason
TN01	ES02	Force Prediction	The forces predicted by the simultion need to be similar to those found by the prototype.	Predicting the forces using the simulation will help future teams understand the forces they need to drive future systems.
TN02	ES03	Feasablity	The simulation needs to accuratle predict the motions of the prototypes.	Finding feasability issues before prototypign starts will save time and money for future teams.
TN03	ES04	Compatiability	The documentation needs to be such that future teams can read and understand and use the computer simulation.	
TN04	ES06, ES07, ES08	Degrees of Freedom	The design of the arm needs to have 4 degrees of freedom simlar to a human arm.	
TN05	ES09	Lifiting Stength	The arms (all joints) need to be able to support their own weight and that of attatched parts.	
TN06	ES14	Test Stand Safety	The test stand needs to withstand impacts without failing.	
TN07	ES27	Elbow Flex	Elbow Flexion resembles human motion (Elbow)	
TN08	ES30	Elbow Speed	Elbow Movement speed (median)	
TN09	ES31	Controls System Comands	The controls systems need to be able to output to botht the computer simulation and the physical prototypes.	
TN10	ES32	Feedback Comunication	The controls system needs to take in input from both the computer model and the physical prototypes.	

1.4.1. Test Equipment available

1.4.1.1. Test air muscles

1.4.1.2. Computers to run simulations

1.4.1.3. Force gauge

1.4.2. Phases of Testing

1.4.2.1. Relays

Relays will be activated, and should power on.

1.4.2.2. Solenoid

Same test as Relay.

1.4.2.3. Vacuum Pump

Same test as Solenoid.

1.4.2.4. Software

Set relays to the on position and run program. Relays should power on for specified time.

1.4.2.5. Air Muscles

Muscles will be filled with air and rated for leaking. Any leaks should be fixed or the muscle replaced.

1.4.2.6. Strain Gauge

Because there is not a spring available which was suitable for the purpose of this project, an elastic cord will be used. The displacement of the cord will be measured against the force pulling it. A linear regression model will be found to estimate the spring constant of the cord, k.

Once the spring constant is known, the cord will be tied to the strain gauge. The cord will be pulled to set displacements and the voltage measured. The force will be calculated from the spring constant and the force-voltage relationship will be estimated.

1.4.2.7. System

Use software to open solenoid, moving arm.

1.4.2.8. Math Model

The muscles will be filled with air for set time increments (0.05, 0.125, and 0.25 seconds). The pressure will be measured. The trends in the data will be compared to the actual curve.

1.4.2.9. Integration

1.4.2.9.1. Commands sent to and received by Solidworks

1.4.2.9.2. Feedback sent from Solidworks, received by LabView

1.4.2.9.3. Commands sent to and received by relay board

1.4.2.10. Reliability

1.4.2.10.1. Air muscle have already been tested for stress, just not at lengths needed for arm control.

1.4.2.11. Customer Acceptance

2. FINAL TEST PLAN

2.1. Accuracy Testing

2.1.1. Sampling Techniques

The elbow will be moved to different positions and data will be recorded for actual position, force, pressure, and homing angle.

Test Date:________________ Test Start Time:____________ Page __ of __

Test No.	Expected Position	Actual Position	Force	Pressure	Homing Angle

The homing angle will be determined by the homing operation, which consists of moving the elbow to the limits of its range of motion (0 or 150). Then data will be recorded for position, type of homing (normal, hard, or soft), force, and pressure. The data is separate for homing because generally there will be no error in position when homing, since the arm will reach the hard limit; those two positions are known.

Test Date:________________ Test Start Time:____________ Page __ of __

		00=normal, 10=soft, 01=hard, 11=failed			
Test No.	Position	Cat. 1	Cat. 2	Force	Pressure

2.1.2. Sample Size

An initial sample of 10 points will be taken and the standard deviation and half width of the 95% confidence interval will be calculated. These numbers will be plugged in to the equation:

$$n = \left[\frac{Z_{1-\alpha/2} * s}{h}\right]^2 \cong n_0 \left[\frac{h_0}{h}\right]^2$$

to determine the minimum sample size needed to achieve the desired accuracy[1].

The data will be collected in sets; due to the homing states, there will be 8 positions x 4 states(non-homing, homing to 0, non-homing, homing to 150) = 32 data points per set. The suggested sample size found from the equation above will help determine the number of sets needed.

2.1.3. Reporting Problems; Corrective Action

If the above testing cannot be performed, that will indicate a problem with one or more components in the system. Which system it is will become apparent because each failure will show different symptoms.

If during the collection of the initial sample the elastic cord stretches too much so that the force gauge reads zero, then the distance of deformation will be recorded instead and the force calculated from there. Conversely, if the force gauge reads the expected force even with the cord's interference, then the force on the cord will be considered negligible.

2.2. Test Procedure

Thursday, May 14, 2009: Whole Team

2.2.1. Order of Positions

The order in which the different positions will be tested will start as sequentially for the first trial then will be randomized for subsequent trials. The first trial will move through the positions in order without homing. Trials after the first will alternate between homing and non homing.

2.3. Assumptions

All data taken is from a normal distribution – almost all human data is sampled from a normal distribution. Because the elbow is designed to resemble human motion, then the data taken from it should resemble human data, i.e. be taken from a normal distribution.

3. TEST VERIFICATION

3.1. Preliminary Test Results

3.1.1. Relays

Pass – Powered on

3.1.2. Solenoid

Pass – Powered on

3.1.3. Vacuum Pump

Failed first time – needed rewiring

Passed after rewiring – Powered on

3.1.4. Software

Relay was set to turn on at 20 psi for 90 seconds. Relay did not turn on at first, but the problem was found and the relay worked.

3.1.5. Air Muscles

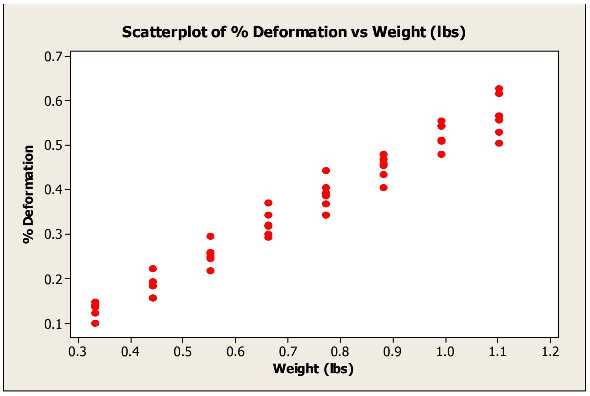
The quality of the muscles, on an arbitrary scale from 0 to 5, is listed below. After the initial test, each muscle was grometed and tested again.

Muscle	Initial Test (out of 5)	Grometed
A	5	5
B	0	N/A
C	4	4.5
D	4.75	4.5

Muscle B was replaced with muscle E, which was rated at 4.75.

3.1.6. Strain Gauge

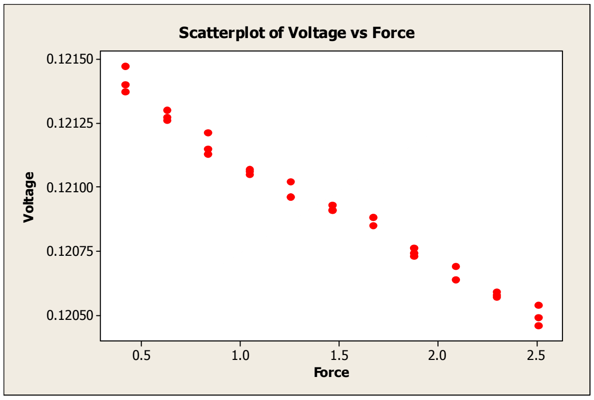
The data looked to be linear between the third and eleventh data points for each cord, so the data was plotted again for just those points.



Linear Elastic Cord data

A linear regression analysis was done on the data to estimate the slope, k. The slope was estimated at around k=0.212 lbs/in.

The same technique was used on the data gathered from the strain gauge. The plotted data are shown below.



Linear Strain Gauge data

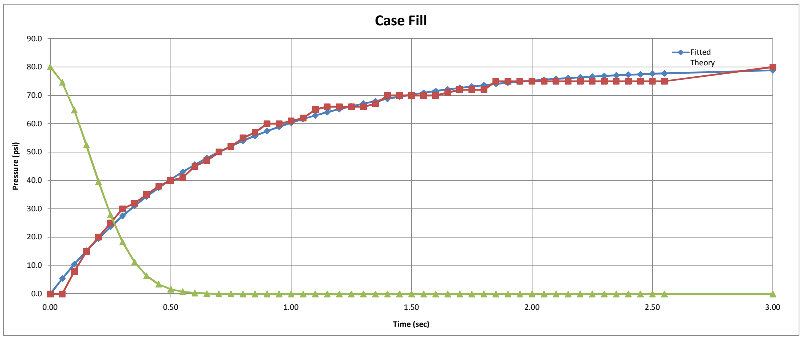
The slope found from the linear regression model was -2347 lbs/volt.

3.1.7. System

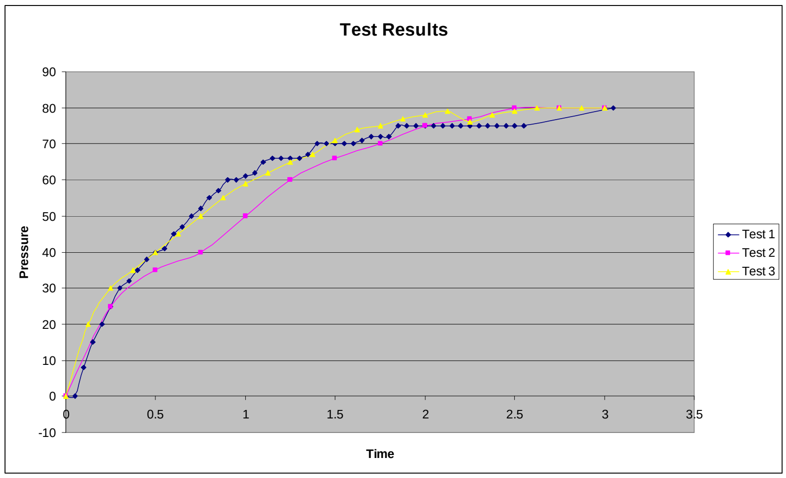
Solenoid opened as planned, but the muscles' movement was quick and through the entire range of motion.

3.1.8. Math Model

The data collected were consistent with the model. The plots of the Function and the test data are shown below.



Plot for Fitted Function



Plot for Data

3.1.9. Integration

3.1.9.1. Commands sent to and received by Solidworks

Pass – Solidworks receives commands. The model moves, but not always as desired.

3.1.9.2. Feedback sent from Solidworks, received by LabView

Fail – SolidWorks will not send feedback to LabVIEW.

3.1.9.3. Commands sent to and received by relay board

Pass – Relay board receives commands and executes.

3.2. Logistics and Documentation

Test results are originally recorded on the Test Forms pictured in section 2.1.2. The data will then be transferred into MINITAB for analysis.

3.3. Definition of a Successful Test, Pass / Fail Criteria

A successful test is a test that is finished with minimal error in movement as measured during testing. If sufficient error exists in the arm's motion, then a problem persists.

3.4. Contingencies/ Mitigation for Preliminary or Insufficient Results

Because the tests being conducted are to test for accuracy of the model, there will be no insufficient results, only passing or failing. If, however, the accuracy tests cannot be performed, then a separate force test should be carried out.

Results of the initial sample will be treated as a separate case, or "warm-up period", and will be compared to the rest of the data.

3.5. Analysis of Data – Accuracy Testing

3.5.1. Plots

3.5.1.1. Force vs. Pressure

This plot will help to verify the math model.

3.5.1.2. Error vs. Expected Position

The error should appear random and hover around zero. Any heteroskedasticity (in the homing cases) or trends will suggest an underlying variable not being accounted for. Heteroskedasticity is expected in the non homing case; experimental error will likely increase over time.

3.5.1.3. Homing Category (histogram)

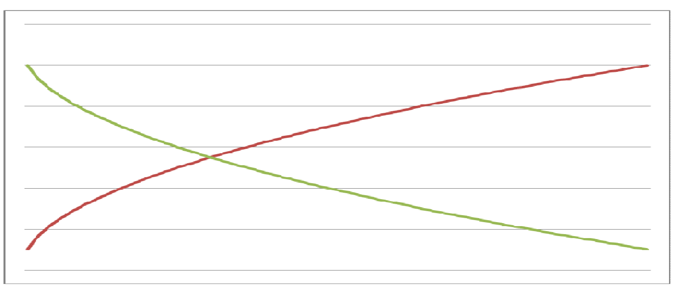
$$Cat.1 + 2 * Cat.2$$

This plot will give an idea of whether the system overshoots or undershoots more, as well as for damage done to the arm by forceful contact with the hard limits.

3.5.1.4. Pressure vs. Expected Position

3.5.1.5. Pressure vs. Actual Position

These plots will verify the relationship of pressure for the two sets of air muscles. As one muscle fills with air, the other empties. The relationship should look similar to this:



3.5.2. Comparisons (t-tests)

All t-test will be performed with an α of .05.

3.5.2.1. Error for simulation model vs. 0

H_0: Error=0

H_a: Error≠0

This test will determine if the simulation is accurate.

3.5.2.2. Error for physical prototype vs. 0

H_0: Error=0

H_a: Error≠0

This test will determine if the prototype is accurate.

3.5.2.3. Difference in error between model and prototype vs. 0

H_0: Difference in Error=0

H_a: Difference in Error≠0

This test will determine if the simulation accurately portrays the prototype. If there is significant error but it is the same for both, then this test will pass and the other two will fail. This will suggest that the model mimics the real system well but there might be an error in the math model.

3.5.2.4. Error when not homing vs.0

H_0: Error=0

H_a: Error≠0

This test will determine if the arm can move accurately without homing.

3.5.2.5. Error when homing to 0 vs. 0

H_0: Error=0

H_a: Error≠0

3.5.2.6. Error when homing to 150 vs. 0

H_0: Error=0

H_a: Error≠0

3.5.2.7. Difference in error between not homing and homing to 0 vs. 0

H_0: Difference in Error=0

H_a: Difference in Error≠0

3.5.2.8. Difference in error between not homing and homing to 150 vs. 0

H_0: Difference in Error=0

H_a: Difference in Error≠0

3.5.2.9. Difference in error between homing to 0 and homing to 150 vs. 0

H_0: Difference in Error=0

H_a: Difference in Error≠0

3.5.2.10. Errors for each position

3.5.2.11. Difference in force between model and prototype vs. 0

H_0: Difference in Error=0

H_a: Difference in Error≠0

3.5.2.12. Difference in pressure between model and prototype vs. 0

H_0: Difference in Error=0

H_a: Difference in Error≠0

These two tests will also be used to verify the math model; the model should accurately predict the behavior of the prototype.

3.5.3. Distribution Testing

These plots will test the assumption of normality in the data.

3.5.3.1. Normal Probability Plots

3.5.3.2. Random Data Comparisons

If the data are not normal, then random data will be created from other distributions to find one more similar.

3.6. Test Results

3.7. Conclusion or Design Summary

Can you explain why a particular function doesn't work? Add here or remove how the conclusions are to be reported or summarized (i.e. significance with confidence, pass/fail, etc.) as applicable.

3.8. Function/ Performance Reviews

3.8.1. Debriefing your Guide and Faculty Consultants

Share test results, conclusions, any follow-on recommendations, design summary.

3.8.2. Lab Demo with your Guide and Faculty Consultants

Perform each of the specifications and features.

3.8.3. Meeting with Sponsor

See Customer Acceptance above. Field Demonstration. Deliver the project. Demonstrate to the Sponsor. Customer needs met / not met.

3.9. References

3.9.1. [1] Kelton, W. David; Sadowski, Randall P.; Sturdock, David T. Simulation with Arena. 4th edition. McGraw Hill, Boston. 2007