AC 2012-4628: FABRICATION AND TESTING OF A SIMPLE "BIONIC ARM" DEMONSTRATOR WITH AN ARTIFICIAL TENDON

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Bringing Biomechanics and Engineering into the Classroom with a Legacy Cycle

Abstract

This paper reports on a research experience for a teacher in the fabrication of "Bionic" or human-like arms. These have inspired many movies and science fiction books, but have many possible purposes, including active prosthetics, robotic arms, and exoskeletons to aid the movement of heavy objects. Previously, students and faculty at Texas A&M University-Kingsville fabricated two simple Bionic Arms that used Rubber Muscle Actuators (RMA). The current work develops an improved RMA that replicates human like range of movement through the use of integrated artificial "tendons." The tendons made of a flexible elastomer and braided carbon fiber do not stretch but bend relative to their attached "bone structure." Previous "Kingsville Arms One & Two" utilized actuators that transferred loads through rigid attachments to "bones." The rigid attach points allowed good load transfer but restricted range of movement. The current Kingsville Arm 3 (KA3) utilizes a 3D printed mold of rigid and flexible elastomeric composites to make artificial "tendons" that are placed between the rigid closure of a RMA and rigid attach points to the "bone." Two KA3 actuators were completed. The first used a fiber-filled brittle resin for the rigid components on each side of the tendon. The tendon performed well, but an adjoining rigid section failed under load. A second KA3 actuator used a carbon-fiber filled semi-rigid polyurethane for the rigid sections, and performed well in flexure and load transfer.

A learning module based on a legacy cycle is developed that challenges the students to position the actuators to allow for maximum range of movement and to find the relationship on how the output force varies with the configurations. The learning modules will be introduced in basic algebra classes in schools with majority Hispanic students in the fall semester. Assessment of the students' performance will be carried out and reported.

Overview of Research Experience

During the summer of 2011, a high school Algebra teacher was granted the opportunity to participate in the Research Experience for Teachers program at Texas A&M University-Kingsville (TAMUK). The teacher spent six weeks working on a mechanical engineering project with a mechanical engineering professor and a graduate student. The research focused on fabricating and testing part of a simple "bionic" or human-like arm similar to those in Figure 1.

The objectives of the summer research were to:

1) Fabricate an actuator that could produce high forces while utilizing the new flexible tendons,
2) Improve the range of motion (rotation) for the third generation bionic arm, and
3) Have a more human like muscle placement.

Previously, students and faculty[1] at TAMUK fabricated two simple bionic arms that used Rubber Muscle Actuators (RMAs), as shown in Figure 1. KA1, the left-hand arm was completed in only 2 weeks, and proved quite powerful, but the RMAs used in it were attached to the "bones" by bonded carbon fibers. This allowed the muscles to rotate relative to the bone, but they frayed and "tore a ligament" quickly. The second or KA2 arm had RMAs that were also very powerful, and that lasted much longer, but their rigid molded ends did not allow rotation between the muscle and bone. A better RMA end attachment was desired. A unique feature of the current research is that the new design incorporated artificial tendons at the rigid attach points where the RMAs connect to the artificial bone structure.

Figure 1: Kingsville Arm 1 and Kingsville Arm 2 [1].

As seen in Figure 1, previous "Kingsville Arms One & Two" utilized actuators that transferred loads through rigid attachments to "bones." The rigid attach points allowed good load transfer but restricted range of movement. A new attach method, involving ligaments, was developed, based on suggestions from a previous work[1]. Figure 2 shows previous RMA attach methods, and a suggestion for a new attachment.

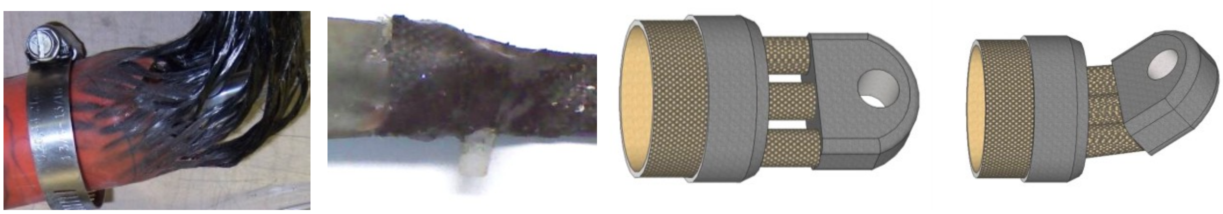

Figure 2: KA1 and KA2 ends, and suggested KA3 RMA end attachment.

The summer Research Experience for Teacher (RET) work focused primarily on the design, fabrication of molds for the RMA ends/tendons and the complete RMA assembly. New Rubber Muscle Actuators with integrated tendons were fabricated using molds made with a 3D printer as shown in Figure 3. The new RMAs as shown in Figure 3 were tested for range of rotation and tensile force.

The new integrated tendons allowed the RMAs and thus the KA3 Bionic Arm to have a much greater range of rotation, however the new tendons were too thick, and the polyurethane used for the rigid parts of the actuators were too brittle and failed prematurely. More tests using tougher (more compliant) polyurethane for the end attachments and a thinner tendon are needed to make a working bionic arm, however. Through this experience the teacher was introduced to both the demands and frustrations associated with designing, fabricating, and testing RMAs.

Figure 3: 3D printed molds, KA3 RMA being tested, new RMA showing bending.

Learning Module

In parallel with the research experience, the development of a learning module that builds on the research was required. The learning module will be introduced to students in Algebra I classes in Alice High School. It was developed based on a methodology known as the legacy cycle [2]. It is a proven model based on the research findings of the VaNTH project group. The Legacy Cycle lesson format consists of six stages:

1) a challenge question,
2) generate ideas,
3) multiple perspectives,
4) research and revise,
5) test your mettle, and
6) go public.

The cycle is based on current learning theory presented in How People Learn: Mind, Brain, Experience, and School[3]. During the summer research institute, a two-day Legacy Cycle workshop was presented to the teachers. The workshop provided the framework for the teachers to develop their instructional materials and is delivered early enough in the summer to allow for brief checks of progress during the summer institute.

It is planned that the teacher will beta test components of their modules during the spring semesters following the summer research experience. Using feedback from the Evaluation of the legacy cycle, the teacher participant will present a final Legacy Cycle Module at the scheduled Legacy Cycle Module Conference in June, a calendar year after the summer research institute.

Learning Environment

Alice High School is located in Jim Wells County in South Texas. It is the only high school in the Alice Independent School District and serves a largely rural population. Enrollment for the 2011-2012 school year is 1,354 with a 91.6% Hispanic population and a 7.5% white population, while the city population is 83.7% Hispanic and 14% White. 63% of the students are economically disadvantaged, and 56.9% percent are labeled as "At-Risk" for dropping out. The median household income in Alice is $32,481, while the state average is $48,259 (Census 2000). A total of 61 students will be instructed using the legacy cycle. All students are enrolled in a freshman Algebra course (Algebra I) which is the precursor for all other secondary level math courses. Fourteen (14) students are enrolled in a Pre-AP (Advanced Placement) Algebra course which offers a more rigorous pace for the purpose of promoting college readiness. Of the 61 students who participated, 37 are males and 24 are females. All students are classified as freshman.

During the Spring semester of 2012, students will participate in a Legacy Cycle called Bionic Muscles in Motion. Students will be faced with the challenge of designing a simple "bionic" arm that both resembles human-like movement and allows for a maximum range of motion. Throughout this unit of instruction, students will learn about the fundamentals of biomechanics, utilizing force diagrams, and recording and analyzing test data. Additionally, the embedded engineering, technology and mathematics standards will be addressed. This unit should help prepare students for their End of Course (EOC) exam for Algebra I, a new exam being introduced by the Texas Education Agency (TEA). By providing a real world application of mathematics, students will begin considering the impact of their choices on design, and how mathematics and mechanical engineering are tied together. The results from the implementation of the Legacy Cycle on three classes with one instructor will be presented along with the analysis of how the project influenced student learning.

Details of Learning Module

The Legacy Cycle design consists of six parts: Challenge Question, Generate Ideas, Multiple Perspectives, Research, Test Your Mettle, and Go Public. Below is the outline the six element of the Legacy Cycle as it will be applied in this unit.

1. ***Challenge Question:***

Robotics that resemble human-like movement are no longer mere science fiction or special effects. Artificial arms are now incorporated in active prosthetics, specialized robots, and exoskeletons which aid in the movement of heavy objects. The National Association for Science and Spacecraft (NASS) has recognized the importance of maximizing the mobility of robotic components used in space. By offering larger ranges of motion for robots, scientists can take samples from more remote areas, and fix hard to reach areas of spacecraft. You have been charged with designing the bionic arm of a new robot prototype. The materials given to you will be used on the single bionic arm of the prototype during its fabrication. You are responsible for researching and designing a "human-like" bionic arm that replicates the biomechanics of a human arm. You must therefore determine the placement of muscle joints and the orientation of two arm muscles to allow for a maximum range of motion. You will have to model various muscle orientations and produce tabulated and graphical data that will be compared with actual test data from testing the bionic arm. This data will be used justify how closely your bionic arm resembles a human arm with respect to muscle placement and range of motion.

2. *Generate Ideas:*

Students will Think-Pair-Share and exchange ideas in teams. They will analyze what they already know, what they must determine, and generate ideas on how human muscles work, and answer various questions like: What materials do you have with you? How do muscles provide movement for human limbs? What are forces and how do they interact with each other? Can you produce a force diagram for a human arm? How do muscles provide movement for human limbs? How does muscle placement on a bone structure affect the range of motion for an artificial arm? The teacher may keep a record of these ideas for later use.

3. *Multiple Perspectives:*

Students will look at the project from multiple perspectives and address the concerns of various people when creating a design. From a mechanical engineers' perspective, the students will consider if muscles will interfere with each other and restrict the range of movement of the arm. Design of the elbow joint as well as the placement of RMA muscles will affect how far the arm will flex, but the goal is to make the arm as "human-like" as possible without losing any range of motion. They also will consider if their design is cost effective based on the materials used, or if they are using available resources efficiently. From a physicists' perspective they will also consider if contraction force is lost by certain orientations, and if the tests results are consistent with their mathematical models.

4. *Research and Revise:*

The research and revise phase will include researching several concepts including:

Mechanics of the human arm
Students will research the positioning of muscles on the human arm muscles and how they are attached to bones. They will also research the movement of human muscles and how contracting muscles cause arm movement. Understanding the mechanics of the human arm will help students generate ideas on how to replicate human arm movement ad achieve a similar range of motion with a simple bionic arm.

Force Diagrams
Students will create a force diagram to model the mechanics of the bionic arm in order to analyze how existing forces interact with each other to achieve arm movement and specific ranges of motion. Students must research how force vectors work and how they are used to model a maximum range of motion when muscles have fully contracted. Sample diagrams are shown in Figure 2 [1].

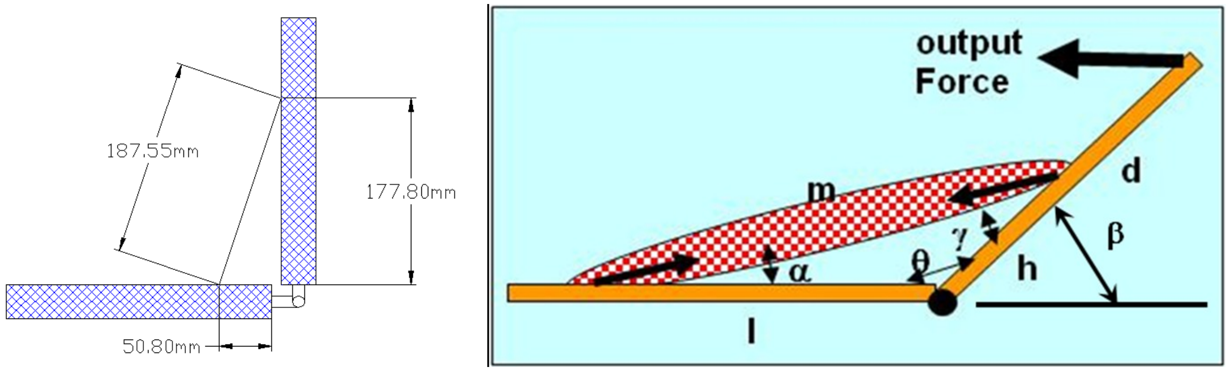

Figure 2: Force Diagrams will be introduced to the students to understand mechanics of bionic arms.

Lessons Covered by Legacy Cycle

Force Diagrams
Students will be introduced to force vectors as they pertain to the physics behind the motion of the arm. They will also see how specific forces in the arm are derived from the axial forces generated from the contracting muscles.

Modeling arm mechanics using formulas
Students will be introduced to simple trigonometric formulas and use those formulas to generate different outputs when given different input information. This will reinforce the concepts of relations, functions, domain and range, and real world data collection.

Data tabulation and graphing using spreadsheets
Students will be given some insight on the importance of record keeping when working with experimental data, and will analyze and compare experimental data with theoretical data developed from mathematical models. Students will show multiple representations of their data and use these representations to support their conclusions.

Analysis of domain and range
Domain and range are frequently misunderstood concepts for high school students. By collecting data and having to tabulate varying ranges of motions and varying pressures exerted by the artificial muscles, students will have a more intuitive model about how these concepts are related. Students will be expected to determine reasonable domain and range values for the given situation and analyze data, both continuous and discrete.

Systems of equations
By comparing the data developed by the different groups, students will observe that the same ranges of motion can be achieved at varying internal pressures for the muscle. They will then be able to calculate when the same motion ranges are achieved by two different groups by analyzing their data as a system of equations, a concept covered in Algebra I.

Comparing theoretical data with experimental data
Students will be given more insight into the scientific method, analysis of experimental data, and other cross disciplinary concepts. Students will gain hands-on experience with engineering design, and will understand the value of collecting data to support conclusions.

5. ***Test your mettle:***

What are the “passing” criteria? What is the range of motion for a human arm? What can be predicted using mathematical models? How do the predictions compare to the experimental results? What conclusions can be drawn from the data? What improvements could be made?

Laboratory work associated with test your mettle includes the following:

a. *Construction of the bionic arm*
Students will bolt muscles to large wooden dowels that will serve as the bone structure for the bionic arms. The dowel rods will be connected using a clovis hinge which will serve as the elbow joint for each arm, similar to that shown in Figure 3. The orientations will be modified up to three times per group and students will record data for each orientation. Students will be given hands-on experience working with materials used in creating robotic arms used for replicating dexterous movement.

Figure 3: Completed KA2 bone and pivot, similar to what students will use[1].

b. *Testing the range of motion at a constant level of contraction (psi)*
Algebra students will be required to measure the range of motion for their arm at different internal muscle pressures and draw conclusions about their muscle placements and account for the differences in their measurements.

c. *Tabulate and graph results*
Students will tabulate both their theoretical and experimental data and compare both sets as a system of equations. Students will be required to offer multiple representations of their data including data tables, graphs, function rules, and a verbal explanation of what the data shows.

6. Go public:

The final phase of the legacy cycle will focus on the students describing to the public the work that they have done. Examples of activities that will be used are:

a. Create a poster describing steps

Students will create posters and offer an introduction of their work, a description of their design process, multiple representations of their data (tables, functions, and graphs), and conclusions supported by their collected data.

b. Run a story in the local newspaper, The Alice-Echo News

The local newspaper will be contacted with information regarding the Research Experience for Teachers in Manufacturing for Competitiveness in the United States (RETainUS) project. The students may be interviewed by the local paper where they can explain their projects, their results, and describe their experience on the project. They may also be asked about their perceptions of engineering before and after the project, and if their experience influenced their plans for college.

Conclusions and Summary

The development of this Legacy Cycle was based on a Research Experience for Teachers site funded by the National Science Foundation (EEC-1106529), Research Experiences for Teachers in Manufacturing for Competitiveness in the United States (RETainUS). The underlying research question focused on creating a human-like McKibben bionic arm utilizing newly designed and fabricated Rubber Muscle Actuators to provide more human-like arm movement. The new integrated tendons allowed the RMAs and thus the KA3 Bionic Arm to have a much greater range of rotation, however the new tendons were too thick, and the polyurethane used for the rigid parts of the actuators were too brittle and failed prematurely. Through this experience the teacher was introduced to both the demands and frustrations associated with university research.

By utilizing the resources and the Legacy Cycle furnished by the program, The teacher will bring university research into a high school classroom and expose students to some experiences they may encounter in higher education. This experience will provide them with a new outlook on engineering, reinforce Algebra standards set by the state of Texas, and better prepare them for pursuing engineering and research after high school. Data will be collected about the implementation of the project and the effect it had on the students for research purposes.

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