Hydraulically Driven Mechanical Representation of a Biological System

California Polytechnic State University, San Luis Obispo

A Senior Project submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Biomedical and General Engineering

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ACKNOWLEDGMENTS

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ABSTRACT

Cal Poly Rose Float has a long-standing track record for obtaining awards based on animation and creativity. To assist in upholding this tradition, we have eliminated visible gaps due to animation, or the mechanical movement of an element by replicating a human arm and improving the elbow and shoulder joint movements. In addition, we have increased the complexity of float motion potential by incorporating basic human biomechanics of bones and muscles. This was accomplished by designing a steel skeleton frame fitted with hand bent pencil steel which could accommodate the required movements and exhibit a robust structure. Once the mechanical system was constructed, it was statically analyzed and fitted with hydraulic pistons to mimic arm abduction, and elbow flexion. Arm motility was controlled using a microcontroller, monitored by LabView, and induced by a hydraulic system composed of a fluid reservoir, pump, and valve assembly. Fluid motion was accomplished without apparent gaps using a steel construct and a hydraulic driving force. The difficulty of this project was translating the deformable and elastic nature of a biological system to the rigid nature of a steel mechanical model. This was overcome by controlling the location of residual displacements created by deformation from movement. While the goal of gap elimination was met, certain limitations must be accounted for when deciding if this is an effective medium for the Rose Float Project. The time and detail required reproducing this construct may be ineffective with respect to the demands of the rose float construction team due to limitations in time and complexity of designs.

INTRODUCTION

The California Polytechnic State Universities (Cal Poly), both in San Luis Obispo and Pomona, have been participating in the annual Tournament of Roses Parade in Pasadena since 1949 [8]. The parade is known as “America’s New Year Celebration” which features energetic marching bands, beautiful equestrian units, and 100% floral and organic decorated floats [17]. Following the parade is the Rose Bowl Game, an exciting football game between two competing universities. The 2010 Rose Parade was broadcast to 127 countries around the world, including China. This cherished tradition was viewed by about 900,000 people on the parade route and an additional 40 million people on their televisions at home [15]. With all of the parade’s publicity, it is a great opportunity for Cal Poly and its float to be known worldwide.

Fifty students from both universities unite to create the Cal Poly Rose Float (CPRF) team and remains as one of the few connections between the two campuses. CPRF is the only student-built float, which is an extraordinary accomplishment as they compete with large corporations such as Honda, Kaiser Permanente, and Trader Joe's [10]. Producing a float of this magnitude involves a year-round effort and the unwavering dedication of these students which is a true reflection of Cal Poly's motto of *Learn by Doing*. Figure 1 below displays the CPRF 63rd float entry for 2011 that won both the Fantasy Trophy and the Viewer's Choice award.

Figure 1 Cal Poly Rose Float Galactic Expedition: Cal Poly took home the Fantasy Trophy and the Viewer's Choice Award [Photo by Terry Miller].

The Ins and Outs of Building a Float

A month after the Rose Parade, conceptualization for next year's float begins and is inspired by the parade's overall theme. Cal Poly students and other members of the community and are welcomed to submit a concept to CPRF, followed by a democratic approach to selecting the top concepts by the committee members. Once a final concept is selected, the design of the float can begin. This includes what objects, or elements, will be included on the float, orientation, scaling, style, and color. Almost every concept that CPRF has chosen has incorporated human characters or various types of animals.

Construction of the float follows after the details about how it will look are finalized. The majority of the elements is constructed out of steel and is supported by welds. The structural foundation, or skeleton, of

each element is constructed first, followed by its shaping. Shaping involves bending pencil steel into numerous circular shapes and welding it around the skeleton to create the external shape of the element. To create the surface of the element, the pencil steel is then covered with a thin aluminum screen and can be applied with a type of floral glue. After the screening process, an acetone and glue mixture is sprayed over the screen to harden the surface called cocooning. Finally, the element can be decorated with colorful floral material such as dried marigold. Figure 2 below displays a progressive timeline for completing the float.

Figure 2 Progressive Timeline: Completing a float is a yearlong process, from concept to reality.

The Animation Trophy

After 64 floats, CPRF has been awarded 47 trophies, eight of which for the best display of animation and motion. The creation of this award started as a general award that was given based on any merit that the judges saw fit. Consistently, CPRF would win this award for their innovation in float animation and this eventually lead to the Tournament of Roses dedicating a new trophy solely on animation excellence. As noted before, common elements include various animals and human characters that both have great potential for animation. Unfortunately, CPRF has not won the Animation Trophy in 28 years for most of the movement pertaining to these elements are limited in motion and contain structural flaws that decrease its overall aesthetics.

Current Rose Float Design of an Arm and its Flaws

A human character from the 2011 float was examined and its arm served as the baseline model for the project. The elbow joint is simply two, one inch square steel pieces connected by a pin. This design creates a problem because the forces acting at the pin are not balanced by the actual material. This leads to an unstable and unpredictable model, which leads to the destruction of decorative coverings by jarring, unpredictable movement. The hydraulic piston cylinder that drives this joint is currently placed at a set angle the pulls the forearm towards the bicep; this positioning of this driving force creates a short and limited throw length of the cylinder, creating abrupt and turbulent motions. The overall skeleton of the arm also greatly limits the range of motion in the arm, usually to only one direction. Another evident problem is the structure's shaping. It is comprised of welded pencil steel to the entire skeleton which creates a rigid model of an organic and flexible one. This ultimately leads to inherent gaps within the arm to allow of elbow flexion. Currently, gaps of this nature would be concealed by draping a bed sheet over it, but this is an ineffective approach because it causes the bed sheet to bunch up during animation. Furthermore, joint gaps that are smaller are left uncovered and can expose the skeleton underneath which decreases the overall aesthetic of the element. Other joint areas with the similar problem include the shoulder and the axilla. The elbow gap can be seen below in Figure 3.

Figure 3 Visible Elbow Joint Gap: The gap decreases aesthetic appeal to the overall appearance.

Elbow and Shoulder Mechanics

The shoulder, also known as the glenohumeral joint, has multiple degrees of motion due to the many components that make up the shoulder. It works mainly with its rotator cuff muscles which provide stability to the joint [16]. Static stabilizers for the shoulder include the bone anatomy, the negative intra-articular pressure, the glenoid labrum, the glenohumeral ligaments, and the joint capsules [20]. Dynamic stabilizers include the rotator cuff muscles and other muscles surrounding the shoulder joint as seen in Figure 4 below.

Figure 4 Shoulder Joint: The rotator cuff muscles support the movement of the shoulder [12].

The range of motion (ROM) of the shoulder is limited to known angles with respect to the anatomical position. As seen in Figure 5 below, maximum shoulder flexion is 180 degrees, maximum shoulder extension is 60 degrees, shoulder abduction is up to 180 degrees, and shoulder adduction is up 50 degrees.

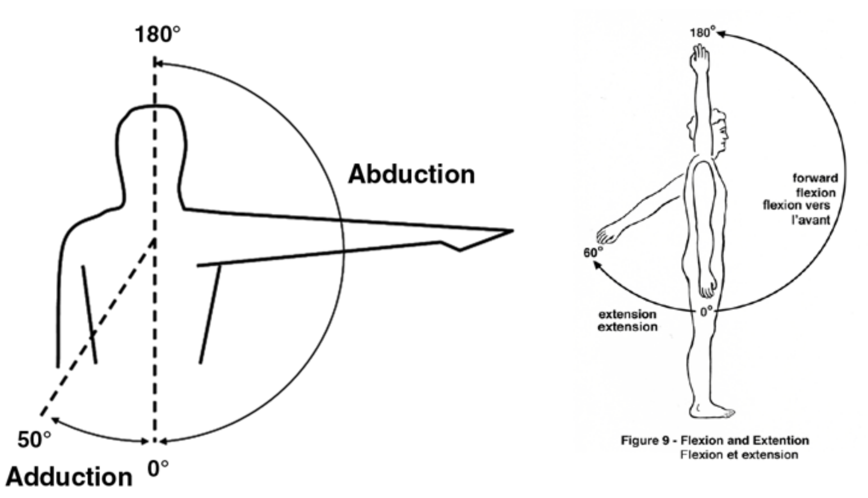

Figure 5 Shoulder ROM: The shoulder has limitations on shoulder extension, flexion, abduction, and adduction

The elbow works with a complex network of ligaments, bones, and a hinge joint which interact to give the hinging motion of the human arm [13]. Static constraints include the ulnohumeral articulation, the lateral collateral ligament, and the anterior bundle of the medial collateral ligament [7]. Dynamic stabilizers include muscles that cross the elbow joint. This is shown in Figure 6 below.

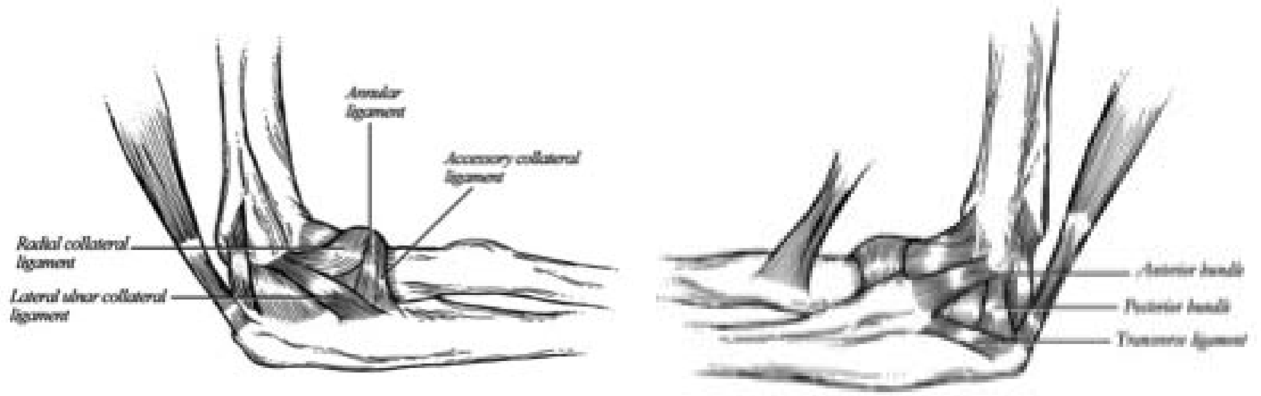

Figure 6 Lateral Collateral Ligament Complex (left) & Medial Collateral Ligament Complex (right): These are the static constraints of the elbow joint [7].

The maximum flexion for the elbow is 135 degrees and based on anthropometric data, elbow flexion for the 50th percentile of males is 150 degrees [4]. ROM for the elbow can be seen in Figure 7 below.

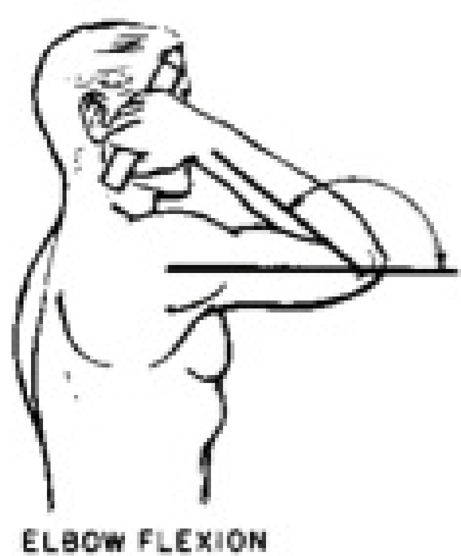

Figure 7 Elbow Flexion: The maximum flexion of the elbow is 150 degrees [7].

Project Goals and Deliverables

The goals and expected deliverables for this project are listed below:

- Mechanical and realistic representation of a human arm due to its variability in motion
- Arm structure utilizing an optimal design for allowing motion in three directions in order to assist CPRF to become strong competitor for the Animation Trophy
- Arm animation simulating a hand wave to show no signs of visual gaps in the elbow, shoulder, and axilla joints in order to increase aesthetic appeal

MANAGEMENT PLAN

Table I below is the proposed timeline for the completion of the project.

Table I: Proposed Timeline for Project with Proposed and Actual Completion Dates

Task	Proposed Completion Date	Actual Completion Date
Construct frame for prototype 1	October 28, 2011	October 28, 2011
Construct frame for prototype 2	November 5, 2011	November 5, 2011
Completed Introduction and Methods	December 2, 2011	December 2, 2011
Order parts	December 17, 2011	January 23, 2012
Design for final model	January 1, 2012	January 1, 2012
Completed CAD model	January 3, 2012	May 20, 2012
Construct frame for final design	January 20, 2012	January 14, 2012
Mount pistons and motors	February 10, 2012	April 7, 2012
Shape for final model	February 20, 2012	February 29, 2012
Set up for motion control	March 9, 2012	April 20, 2012
Screening	March 13, 2012	April 19, 2012
Mount model	March 20, 2012	April 7, 2012

Table II below is a list of the materials purchased, donated and used for the purposes of the project along with their respective cost and the vendor which supplied them.

Table II: Material List, Budget, and Vendor

Item	Quantity	Estimated Cost	Vendor
¼” Pencil Steel	50 ft	$0	CPRF
Piston Cylinders	2	$0	Custom Actuator Products
1” Square Steel	50 ft	$0	Provided by CPRF
5/16” Pin Shafts	15	$3/ea	Ace Hardware
Bolts, Washers, and Nuts	50	$54.04	Home Depot
4” Angle grinder	1	$29.96	Home Depot
Aluminum Screen	1 roll	$6.98	Home Depot
1” Steel Rod	1	$5.99	Home Depot
Zip Ties	1 pk	$3.99	Home Depot
14” Cutoff Wheel	1	$6.97	Home Depot

METHODS

The construction of the arm included creating the skeletal frame, shaping individual cages for the shape of the arm, and screening it to create a skin-like surface to allow it to be decorated. This timeline progression can be seen in Figure 2 above. In addition to the physical construction, pistons were mounted on the arm to generate the desired movement which were connected to a computer controlled hydraulic pump and reservoir.

Design: Proportions and the Skeleton

The average head length is nine inches from anthropometric data from the National Aeronautics and Space Association [2]. This length determined the corresponding lengths for the skeleton of the arm. As seen in Figure 8 below, the entire span of the arm is equivalent to three and half head lengths long [5]. The lower arm and hand is equivalent to two head lengths and the upper arm is equal to one and a half head lengths. The proportions for the design were doubled because CPRF traditionally constructs human characters on a larger scale for visibility on the parade route. Enlarging the scale will also help accommodate the size of the piston cylinders within the arm's shaping.

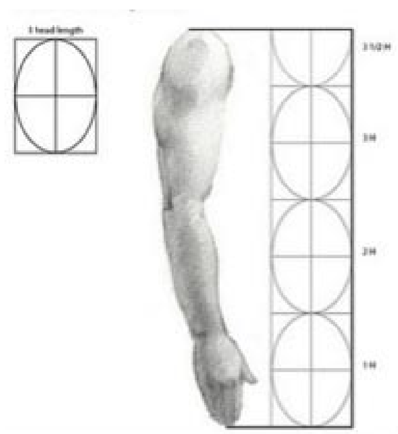

Figure 8 Arm Proportions: Corresponding length of an arm with respect to head length.

The skeleton of the arm was similar to the bones present in the human arm. The forearm was comprised of two steel pieces reflecting both the ulna and radius, while two steel pieces for the upper arm was equivalent to the humerus for additional support of the shaping. Finally, the shoulder was comprised of a fork in order to gain enough torque for the hand wave simulation.

Design: Shaping

A majority of the design for the shaping aspect of the project was based on an iterative process that incorporated the build and rebuild of structures that allowed the desired movement and appearance. Shaping included the creation of individual cages for above and below the forearm and upper arm in order to reallocate displacement due to movement, to the posterior of the arm. The cages were comprised of semicircular pieces of pencil steel that were attached to the skeleton by interior welds or slotted hinges. Cages on the posterior of the arm were connected, and underwent coordinated movement by sliding together as one unit as the arm flexed. Hinges were placed at the shoulder, elbow and wrist joints, to allow the posterior of the arm to slide up and down during elbow flexion. Anterior arm shaping sections including the bicep and tricep were welded directly to the arm and remained static with respect to the skeleton opposed to its moving counterparts on the arms posterior side. The shaping of the shoulder was constructed to absorb and hide the displacement induced by the sliding cages upon the posterior of the arm, while mechanically limiting their respective range of motion. The shoulder also served as a mechanism to cover the gap when the arm was at rest. Overall, the replication of a constant fluid model eliminated the problematic joint gaps. Further shaping construction techniques are discussed in the construction section below.

Design: Mechanical Movement

The goal of the overall animation of the arm was to produce a handwave:

1. Arm at rest, as if it's parallel with the body and the palms facing inward
2. Arm abduction of 90 degrees
3. Arm rotation of 90 degrees
4. Elbow flexion of 75 degrees and extension, repeated multiple times
5. Arm return to rest in reverse order

Arm abduction and elbow flexion were simulated using custom built piston cylinders from Custom Actuator Products because of their lightweight and compact design [9] as well as the digital accuracy and opportunity for future development desired by the Rose Float. This was to combat the size limitation within the shaping of the arm. The piston cylinder for elbow flexion had male ports, a bore size of 1 inch, a stroke length of 2.5 inches, rear pivot mounts with clevis attachment, and standard wet rod size with male ends. As mentioned above, the stroke lengths were determined by the geometric constraints of the shaping. The piston cylinder was the same except with a stroke length of 5 inches. The piston cylinders were hydraulic and contained a linear resistance transducer (LRT) to record its position, as seen in Figure 9 below.

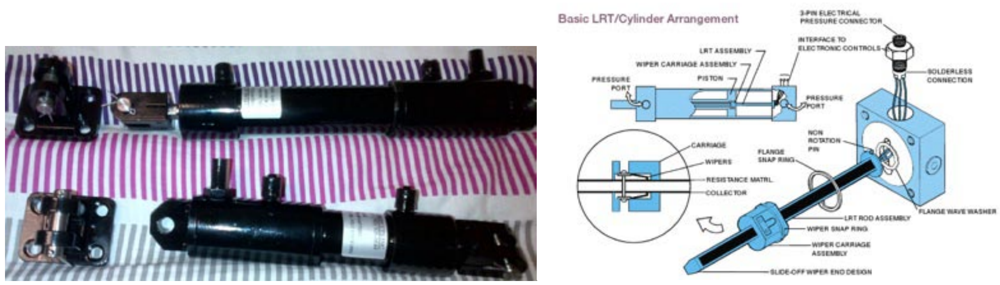

Figure 9 Piston Cylinders: Two cylinders by Custom Actuator Products were used for arm abduction and elbow flexion [9].

The LRTs were able to relay the position of the piston to the master controller and could be controlled through the LabView program that was used on the 2012 float. The LabView schematic is shown below in Figure 10.

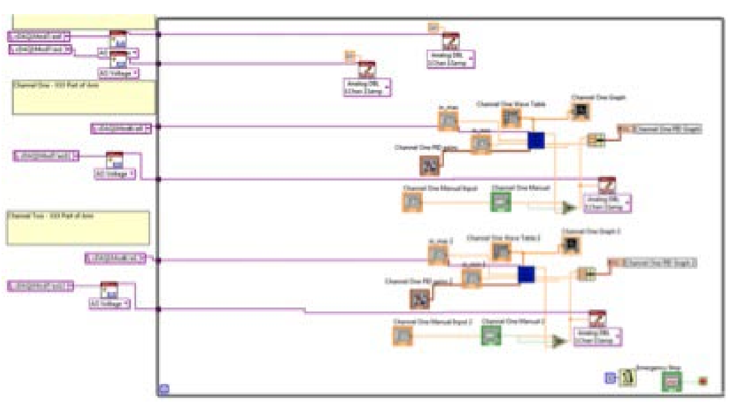

Figure 10 LabView: LabView schematic for the LRTs of the piston cylinders.

Proof of Concept and Prototype Evolution

In the preliminary design of the first prototype, problems occurred in construction that could not be foreseen by the designed model. The steel was cut at skewed angles that did not make a flush contact which produced additional issues for welding. A lack of cohesion between parts caused the stability of the welds to decrease and was further weakened by the high heat output of the welder. In addition, the black paint on the steel made it more difficult to weld. The poor welds of prototype 1 can be seen in Figure 11 below.

Figure 11 Prototype 1: Weak welds were created from non-flushed pieces and black paint

Due to these complications, the prototype 2 was designed to utilize nuts and bolts instead of welds to hold together the individual steel pieces. Overall, this ensured that the pieces were held together well during the design phase and allowed the prototype to be easily taken apart for additional adjustments. It was determined though that final product would be welded to replace the nuts and bolts. Prototype 2 can be seen in Figure 12 below.

Figure 12 Prototype 2: Arm skeleton held together with nuts and bolts.

Although the second prototype was found to be more functional and possessed the necessary flexibility needed for animation, the overall look of the design seemed too robust and not as aesthetically pleasing as first thought. Therefore, the width of prototype 3 was decreased and the secondary fork was eliminated. Instead, a carriage bolt long enough to run through the span of the steel bar was used to hold it in place. Eliminating the fork increased the arm's realistic aesthetic and decreased the amount of construction time. Prototype 3 can be seen in Figure 13 below with the elbow flexed.

Figure 13 Prototype 3: A slimmer skeleton with only one fork during elbow flexion.

Shaping was a challenge because of the numerous prototypes created which was continuously evolving and being fine tuned to eliminate the joint gaps. Figure 14 displays the proof of concept for the elbow joint shaping with pipe cleaners being juxtaposed to the initial shaping attempt.

Figure 14 Proof of Concept and Shaping Prototype: Initial shaping of forearm using pencil steel instead of pipe cleaner

The final prototype design of the arm can be seen in the CAD model below in Figure 15.

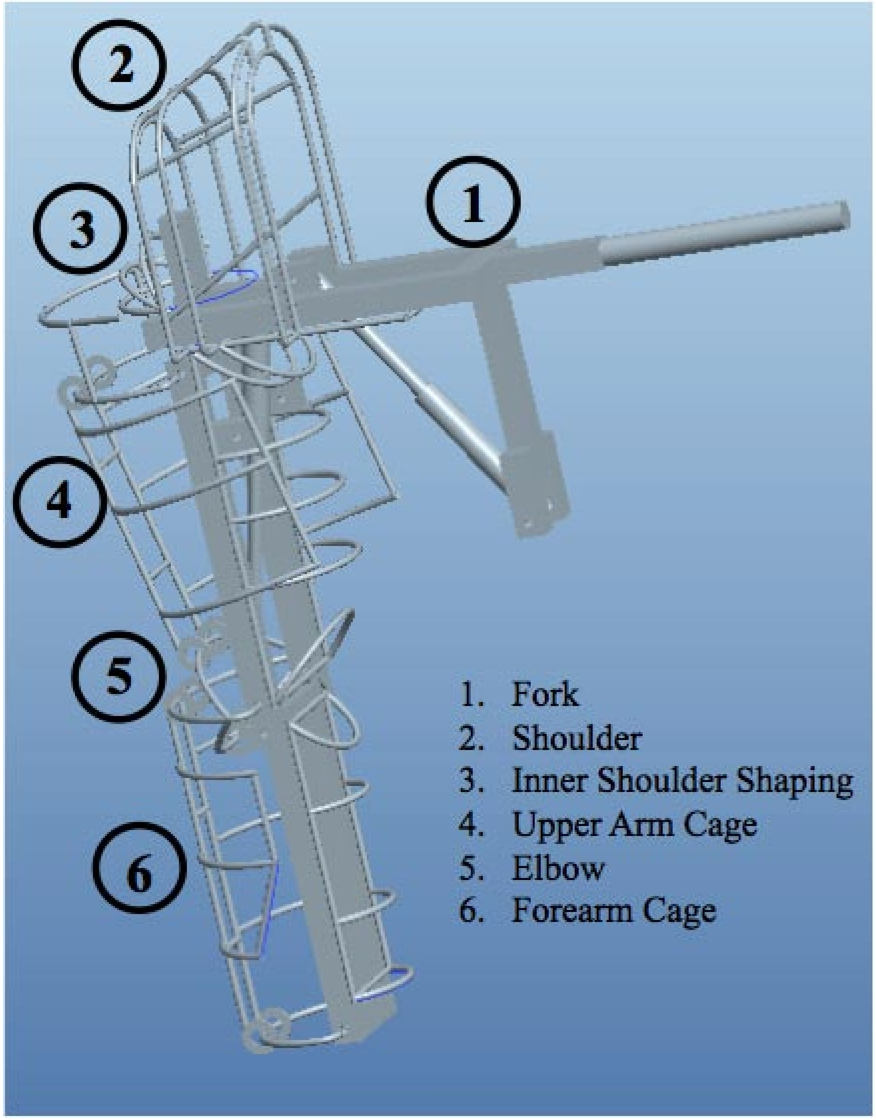

Figure 15 CAD Model: This model reflects the final design of the arm which includes the skeleton, shaping, and two cylinders

Skeletal Construction

One inch square steel was cut to the desired length using a chop saw. Angle cuts were also made by using a chop saw to several pieces in order to prevent friction between the components. To smooth the edges, each piece was ground down using a grinder. Following this, the necessary holes were drilled into the pieces using a drill press and a 5/16” drill bit to allow for movement in the shaping. Construction tools are shown in Figure 16 below.

Figure 16 Construction Protocol: From left to right, steel pieces were cut by the chop saw, edges were grinded down, and then the drill press was used.

Finally, the skeleton frame was assembled using shaft pins and nuts between the fork and the upper arm and between the upper arm and the forearm. The rest of the arm was welded together to create the desired skeletal frame and can be seen in Figure 17 below.

Figure 17 Skeleton Frame: From left to right; end shaft, fork, upper arm, elbow, and forearm.

Shaping

Pencil steel was used for shaping to form the skin surface of the skeleton. Pieces of ¼" pencil steel were cut into predetermined lengths and bent into desired shapes using a variety of bending methods. These methods included bending via pole, via a multi-diameter bending station, and free hand bending using a vice. Figure 18 below shows the standing vise that was used for a majority of the shaping.

Figure 18 Vise: The vise was used for the shaping the pencil steel into the desired shapes.

Half circle pieces were welded on the top of rectangular pencil steel piece, which was then attached to the top of the arm as seen in Figure 19 below. The interactions between the two cages were taken into account by decreasing the angle of the pencil steel to avoid clashing during elbow flexion and to decrease the gap created by movement.

Figure 19 Cage for the Top of the Arm: The arm cage is made out of pencil steel bent in semicircles.

A similar approach was taken in respect to the pencil steel cage that surrounds the arm, except it is larger and is not affixed to the base frame. In order to allow for movement and its control, the two straight pencil steel rods were welded to washers and they were then slipped through the semicircles of the elbow and shoulder. This allowed for restricted rotation about the shoulder and elbow axes. This method was replicated for the forearm, attaching the washer to the semicircles of the elbow and the wrists. The straight pencil steel rods were then connected by a small piece of pencil steel welded across them. Side cages were also welded on the hooks and connected by a flush bar on the skeleton. In order to construct these pieces, pencil steel was first bent into a semicircle and then it was cut in half using bolt cutters. This was done on both sides of the upper arm and the forearm. The shaping for the bottom of the arm and welded washers are shown below in Figure 20.

Figure 20 . Welded Washers and Cages of the Arm's Underside: Pencil steel was shaped to replicate the curvature of the arm (BOTTOM) while still allowing the arm to move all together with the use of welded washers (TOP).

The elbow was generated by using three pieces of pencil steel that were bent into semicircles. The middle piece was designed to be able to be inserted into a drilled hole in the arm's skeleton and the two additional pieces were welded to it as well. This formed a ball like structure that can be seen in Figure 21 below.

Figure 21 Elbow Joint: Three semicircles forming the elbow joint, top view on the right and lateral view on the left.

The shoulder joint was constructed similarly to the elbow. Pencil steel was bent into semicircles which were also used with the same form of attachment and insertion as the elbow. The internal cage was built so it is exposed during rest, and so that during arm abduction it slips into the upper arm cage. Two straight pencil steel rods were welded on washers and attached to the first semicircle of the upper arm shaping as seen below in Figure 22. On the opposite end of the upper arm shaping, washers were slipped through a mushroom-shaped pencil steel frame in order to be able to follow its curvature during arm abduction. A set of short bent pencil steel was welded on the top of the mushroom to the last semicircle ring of the top of the shoulder in order to create a linear frame. Side cages were then welded on similarly to the side cage of the upper arm.

Figure 22 Shoulder Cage: The shoulder includes a slip cage, a set of washers to allow for movement, and a side cage.

Mounting the cylinders

The clevis mount was attached to the end of the elbow cylinder and a secondary mount was constructed from two 1” box steel pieces that were angled cut on both ends at 45 degrees. These two pieces were also welded together. The drill press was used to drill four holes to match up with the clevis mount. Finally, four ¼” hex screws and bolts were used to secure the clevis mount to the secondary mount. The secondary mount was welded onto the underside of the elbow bar. To mount the piston’s clevis, two 1” box steel pieces were angled cut on side end at 45 degrees and each was drilled with a 5/16” hole. These components were welded on either side of the inner upper arm frame. A 4” long bolt then connected the piston’s clevis between the two box steel pieces. This configuration can be seen in Figure 22 below.

The second clevis mount was attached to the end of the shoulder cylinder and a similar mount to the elbow was constructed. A ½” by ½” square was cut out of one end of both pieces by using a vertical band saw. The two pieces were welded together, making a 1” gap in the center to fit around the end stem of the upper arm. The clevis mount was attached the same as in the elbow clevis mount. The mount for the piston’s clevis was constructed using box steel in order to affix the piston to the arm. The original fork was extended to make clearance for the shoulder cylinder, also seen in Figure 23 below.

Figure 23 Piston Mounting: The elbow piston was mounted within the cage of the upper arm and the shoulder piston was mounted across the fork.

Screening

Screening consisted of covering the shaping of the arm with an aluminum window screen adhered with C137 floral glue. Individual pieces were sized and cut to cover each individual shaping cage. With a paintbrush, the glue was applied on the pencil steel and left to become tacky. The screening piece was then placed over the section and glue was also applied to the edges and corners of the screen and was held in place until the glue dried. Screening sections were strategically placed to allow the movement of the shaping during the hand wave. The process can be seen in Figure 24 below.

Figure 24 Screening the Forearm: Window screen was pulled tightly over the shaping cages.

Mounting the Arm and Animation

The arm was mounted on a fixed two bearing axis to gain free rotation. A 1” diameter steel rod was attached to the arm via weld and was turned using a lathe in order to minimize the diameter to fit within the two bearings. Because of the age of the lathe and lack of documentation the part was not cut at the correct RPM which resulted in slight ridges that followed the circumference of the rod. The steel rod was then attached to the top of the arm and inserted through the bearing as shown in Figure 25 below.

Figure 25 Mounted Arm: The arm was mounted through two bearings that remained stationary during animation.

A crank was fabricated by using 1” and 1.5” box steel in order to turn the arm during its rotation. 3/8” holes were drilled in the steel rod and the crank in order to create cohesion between the two parts. The crank created can be seen in Figure 26 below. After all the parts were put together the arm was able to rotate about its shoulder axis.

Figure 26 Manual Crank: Manual crank was used for arm rotation.

A Labview program adapted from the 2012 CPRF was used in order to program the movement that the arm would take. Essentially, this program works by taking feedback from the linear digital transducers and transcribing their resistance values into corresponding positions. Since the cylinders stroke length were predetermined and custom made, only the maximum and minimum values were necessary when simulating motion, denoting full extension and full compression of the piston stoke. The program provides the hydraulic valve system which pumps hydraulic fluid with a signal that denotes how much fluid to pressurize and at what rate it should provide hydraulic power to each individual piston in order to generate the desired movement. By controlling the force and flow of the hydraulic system the simulated motion can be controlled for fluidity which was a problem with previous Rose Float animated models. The completion and refinement of this program created the basis of the animation file used during the filming of the project which can be modified or incorporated into future hand wave simulations that Rose Float may use. A screenshot of the Labview output corresponding to the resistivity and position values as seen by both cylinders can be seen below in Figure 27.

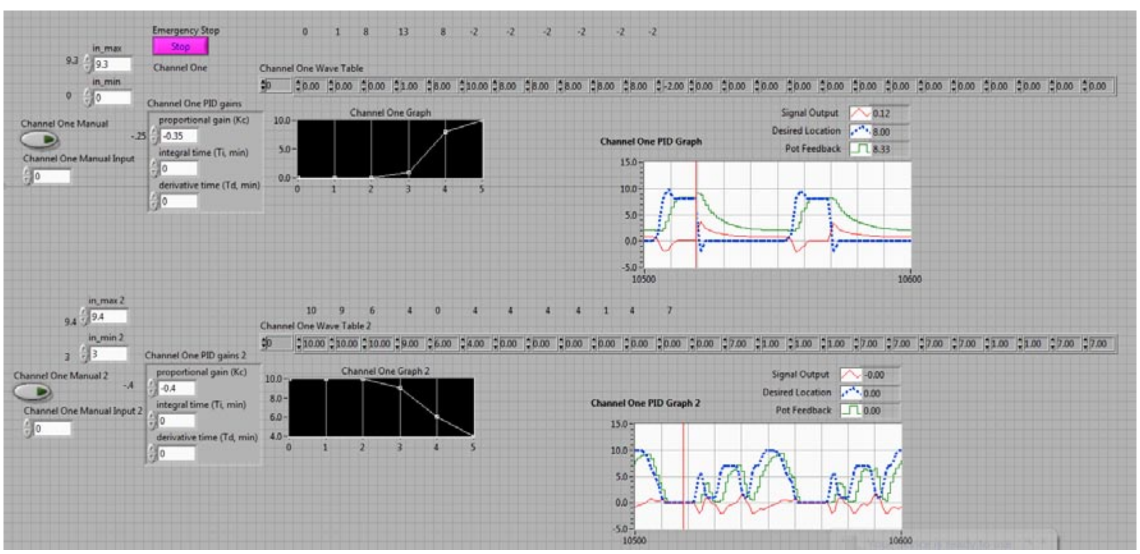

Figure 27 Labview Program: The output screen displays the resistor values from the LRTs

Figure 28, found below displays an overall schematic of the integration of mechanical, hydraulic and electrical components used to interface the cylinders within the arm, the hydraulic system that drives the cylinders, and the electrical feedback controlling them.

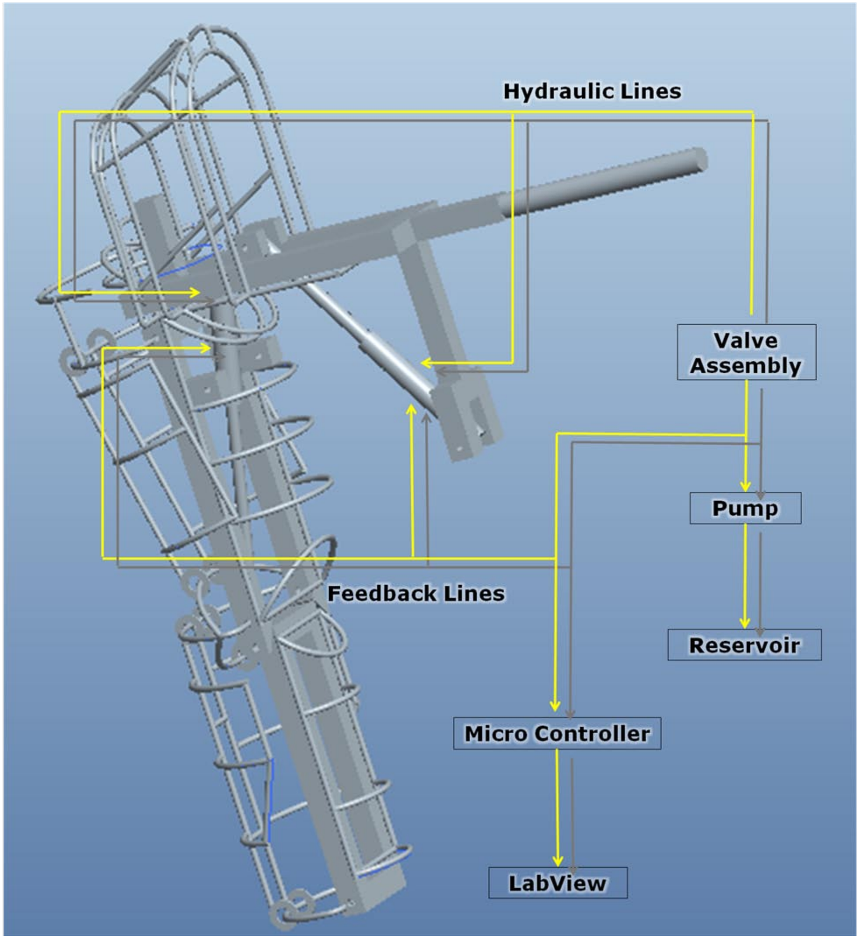

Figure 28 Assembly for Animation: The cylinders were connected to both feedback and hydraulic lines.

RESULTS

The following results pertain to the ability of the arm to perform the handwave and the elimination of joint gaps during the simulation. A video recording of the arm animation can be viewed at http://www.youtube.com/watch?v=nMle3YuAQuw

Handwave Simulation

Joint gaps were minimized and engineered to be concealable, and resulted in an aesthetically pleasing arm. Gaps are inherent within the system because displacement of shaping must be accounted for within a rigid moving model. A more accurate depiction of human movement and appearance would require advanced materials, machining and programming so the basic design generated from this project is feasible for the application at hand.

Figure 28 below, displays screenshots of the arm being animated. Screenshot A is the arm at rest and right before the arm abducted to 90 degrees by the 5 inch stroke piston cylinder. Screenshot B and C depict arm rotation through the manual hand crank, and finally screenshot D exhibits elbow flexion.

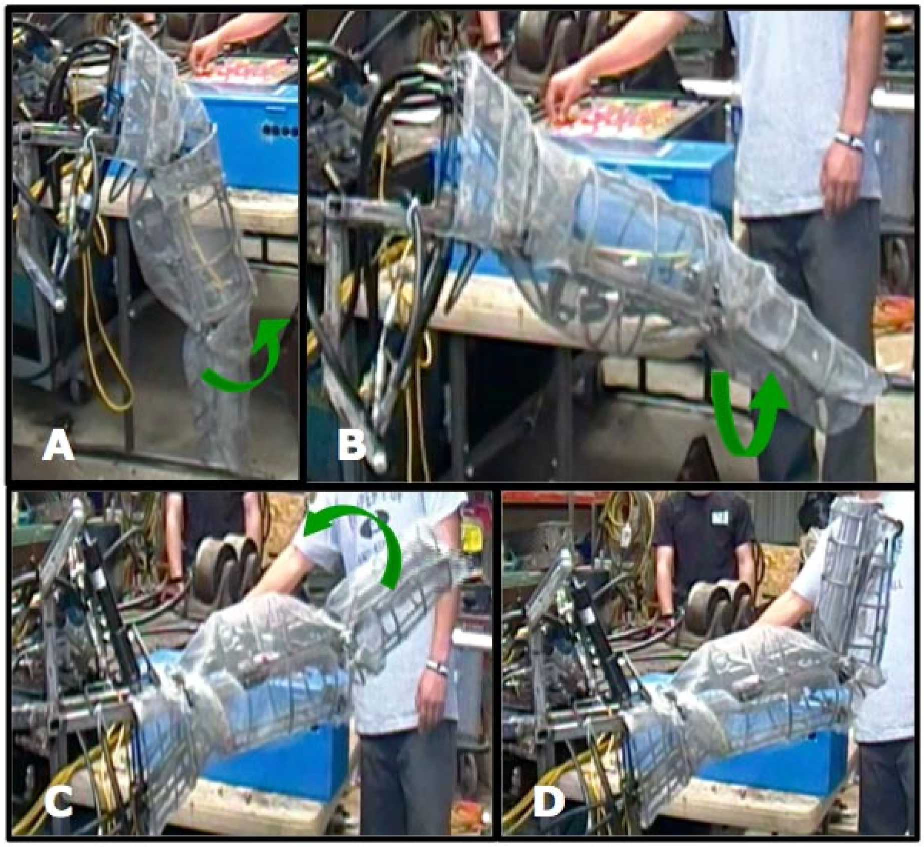

Figure 29 Handwave Animation: The arm underwent abduction, rotation, and elbow flexion and extension.

Gap Elimination

Figures 29 through 31 exemplify the minimization of joint gaps during arm animation, including the elbow gap, inner elbow gap, and the shoulder gap.

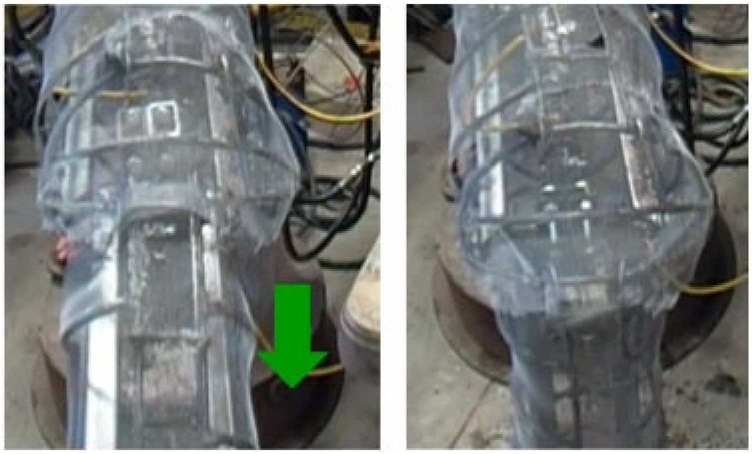

Figure 30 Elbow Flexion Gap: The left shows the elbow at rest and the right shows the elbow flexed

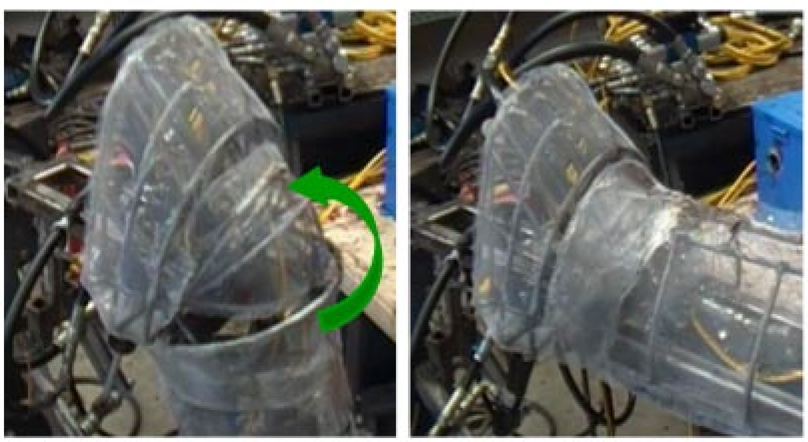

Figure 31 Arm Abduction Gap: The left shows the shoulder at rest and the right shows the shoulder after arm abduction

Figure 32 Inner Elbow Gap: The left shows the inner elbow at rest and the right shows the inner elbow flexed

DISCUSSION

Visible gaps in float elements are created by the inability of materials used, predominately steel, to allow for strain that is induced by motion. Human bodies compensate for this with skin, it constantly covers our bones, and muscle, while stretching and compressing with movement. Inspiration for the design was drawn from experimentation based on: physically feeling the stretching of skin while moving, holding clothing tightly over areas while moving and watching the fabrics behavior, and a reiterative trial and error representative steel design.

Elbow

Original designs for the arm were two steel bars mated with a single bolt at the elbow and shaped with circular pencil steel. The design did not only have a large gap at the elbow but was flimsy, unreliable, and did not resemble realistic anatomy. To combat this, a more robust arm was produced that possessed realistic aesthetics. A steel skeleton was constructed that resembled the bone structure found in humans; this gave a strong frame to build off of and allowed for a larger weight load and more complex shaping. Due to the large amount of strain produced in the skin of the elbow during movement, the underneath of the arm was one continuous piece that would move to compliment motion of the entire arm. This design would fully eliminate the gap and allow large amounts of area within the arm for moving parts such as pistons and motors of different sizes. The elbow was modeled as a hinged steel quarter sphere that was connected to the wrist and shoulder which were also hinged; this allowed for easy removal of the entire shaping so components within the arm could be easily accessed and maintained. The only drawback of this design is that the shoulder would have to absorb the large amount of displacement produced by the elbow reacting to the bending of the arm as seen in Figure 32 below. When the arm is straight the hinged quarter sphere at the elbow is in a neutral position and the wrist protrudes forward, by the time the bend is complete the elbow position has changed and the wrist has moved inward; this motion produces a linear deflection of about 4 inches and must be accounted for by the shoulder.

Figure 33 Wrist Deflection: A 4 inch deflection can be seen in the wrist during elbow flexion.

Axilla

When moving the axilla, minimal amounts of stretching in the skin were found; most of the bunching, stretching and contracting of skin during arm motion was found to occur at the elbow and shoulder. For this reason the axilla was modeled as two adjacent semicircular surfaces, one side connected to the abdomen and the other side to the side of the bicep. These surfaces are mated when the arm is at rest as seen below in Figure 33 on the left and produced an open angle when opened as seen in figure on the right. Since this design induces a "covered gap" during abduction of the arm this design relies heavily on the shaping of the shoulder to compensate for this loss of area. To allow for this open area when the arm is lifted we allowed for a larger shoulder height to give a more physiologically natural look when at rest and in motion.

Figure 34 . Axilla: The gap is eliminated by two semicircles.

Shoulder

The shoulder is the most complex gap resolution because the longitudinal displacement caused by the continuous shaping of the elbow must be converted to a transverse motion. In order to accomplish this, moving parts that are highlighted in Figure 34 were introduced, which can hold up the shoulder when the arm is at rest, and transpose the displacement caused by raising the arm.

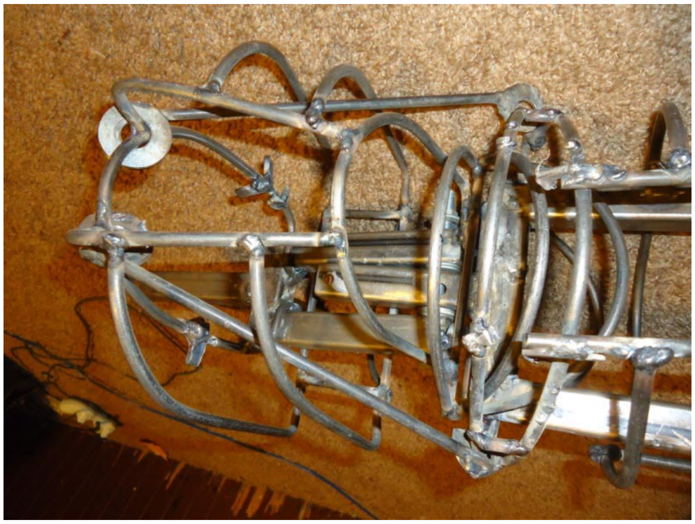

Figure 35 Shoulder: Displacement from the arm abduction is transposed into the sliding bars with washers.

This solution increased manufacturing difficulty and design complexity, but could not be simplified and accomplish the same objective. However, moving parts cannot act as the most outward form of shaping because the outside of float elements are cocooned and decorated. Therefore, caged housings were built over these parts to protect them from dislodgement, to keep their fluid motion uninterrupted and created an exterior that was as close to physiologically accurate as possible. To finish the gap resolution of the shoulder, a dual slip plane design was composed or commonly referred to as a suit of armor because rigid plates slip by each other through motion. The design works like an eyelid, the top lid is represented by a cage located above the shoulder joint, the eye ball is represented as a stationary quarter sphere located at the corner of the shoulder, and the bottom lid is represented by a cage located on the upper region of what would be the triceps.

When the arm is at rest, the figurative eye is open, the top lid is at the shoulder, the quarter sphere is exposed and the bottom lid hangs down with the arm as seen above in Figure 35. When the arm is raised, the top lid remains stationary and the bottom lid slips over the stationary quarter sphere as seen below as well. Small open seams are created in the location of the slip planes, but are too small to be noticed from a distance, and have been defined as “necessary” by Rose Float and not considered gaps.

Figure 36 Dual Slip Plane of the Shoulder: This was implemented to eliminate the gap shoulder.

CONCLUSION

The goals of this project included manufacturing a mechanical arm that moved fluidly and with increased capabilities of motions and replicating a hand wave that showed no visible joint gaps. Statics, dynamics and basic biomechanics of bones, muscles and skin served as the foundation for producing a coordinated design for skeletal and shaping constructs capable of moving in the desired ranges of motion while eliminating gaps. This allowed the induction of two independent planes of motion and rotation of moving elements in comparison to Rose Float's traditional design of single planar movement. Motion capabilities and fluidity were accomplished by incorporating cylinders that possessed internal linear digital transducers that provided real time positional feedback and control of cylinder stroke speed. The aspects of the produced design are summarized below.

- Joint gaps were minimized and engineered to be concealable by eliminating those found in the elbow and reallocating them to the shoulder where they could more effectively be hidden by shaping.
- Gaps are inherent within the system because the displacement of the shaping with respect to motion must be accounted for and dealt with within the system.
- A more accurate depiction of human movement and appearance would require advanced materials, machining, and programming.
    - The use of these extra resources may be ineffective with respect to the demand and time requirements of CPRF construction.

Applying this method of minimizing the visual gaps of an arm or any similar elements will lead to a more overall aesthetically pleasing float as it comes down the parade route on New Year's Day. Accomplishing three dimensional movements through simulating a handwave can be adapted to various combinations and applied to several elements on the float as well. These two goals together will expand the scope of animation for CPRF and make them once again a fierce competitor for the Animation Trophy. In conclusion, this will represent Cal Poly as a school of engineering innovation through the initiative of *Learn by Doing*.

RECOMMENDATIONS

Although the project goals were accomplished, there are still advancements that could be made to the project. The current prototype could be improved by replacing the manual crank with a hydraulic motor, optimizing the hydraulic components for functionality, programming automated LabView protocol for more fluid motion, and implementing mimetic camera relative motion technology.

Replacing the manual crank with a hydraulic motor was the original concept for initial design, but was not implemented due to project time constraints. The motor could be positioned either directly in line with the arm shaft or driven by a gear chain from the arm. Both options would require evaluating gear ratios and implementing a more advanced hydraulic system which would need precise programming to tightly control angle deflection.

Hydraulic components of the system could be optimized to improve the functionality of the prototype. Optimization of the hydraulic cylinders would include more static and dynamic analysis of placement and mounting to create a more fluid and accurate depiction of motion. Once a hydraulic motor is incorporated and all hydraulic components are optimized, a LabView protocol can be created to automate the desired series of movements. An automated protocol would require reiterative troubleshooting of movements with respect to coding to ensure proper rates of movement and time allotments for each motion. Furthermore, the float can incorporate series of complex movements without needing an attendant.

The final recommendation would be to implement mimetic camera relative motion technology. Theoretically this would allow a mechanical model to automatically mimic human movement via camera. The cylinders used in this design possess digital transducers that track position with respect to stroke length. Advanced coding would be necessary to relate angles and distances of reflective markers worn by the moving subject to the position of cylinders and the rate at which they move. This would create the potential for great spectacle on the Cal Poly Rose Float; for someone dancing or waving and a group of mechanical elements replicating their movement.

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