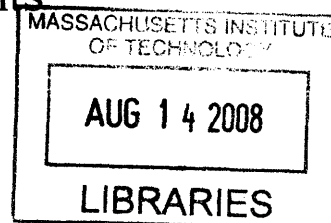


Development of a Robotic Arm to Teach Autistic Children Social Movements

by

Devanie DuFour



SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Submitted to the Department of Mechanical Engineering on December 03, 2007 in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Mechanical Engineering

Abstract:

By controlling a robotic arm, autistic children can learn the movements associated with social interactions. The goals of my invention are that autistic children would safely interact with the robotic arm and mimic the robotic arm to replicate movements associated with social interactions. The results from my Peter J. Eloranta Summer Undergraduate Research Fellowship suggest that all autistic children successfully learned social movements by mimicking a robotic arm. A more effective robotic arm would better replicate human motion than currently available commercial products. Additionally, a protective sleeve that conceals wiring and joints would make this product safer for young children, the main client of the invention.

Thesis Supervisor: David Gordon Wilson

Title: Professor Emeritus of Mechanical Engineering

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Introduction:

Designing a robotic arm to better interact with autistic children could allow social interactions to be effectively taught. The summer after my freshman year, I was the principal investigator for a Peter J. Eloranta Summer Undergraduate Research Fellowship that analyzed the ability of autistic children to learn the movements associated with social interactions by controlling a robotic arm. The concept leading to the fellowship and subsequent robotic arm design were created solely by me and based on my preliminary observation involving autistic children and robotic arms. Autism is a pervasive disorder that impairs several areas of development. Often, a person with autism struggles with reciprocal social interactions. My fellowship focused on five social interactions important for children: waving goodbye, shaking hands, picking up an object, putting down an object, and giving an object to someone else. My goals were that autistic children would interact with the robotic arm to learn movements associated with social interactions. My results were that autistic children were 100% successful in imitating robotic social movement. The fellowship utilized a commercially available robotic arm, the Lynx 6 from Lynxmotion, which had two major flaws for this application. First, the robotic arm did not replicate human movement specifically in the shoulder, elbow, and hand joints. Second, wires and joints were exposed which poses a danger to small children. By designing a more suitable robotic arm for autistic children, social interactions could be taught more effectively and safely.

Background:

The following section describes the preliminary observation that led to both my fellowship and present thesis. The next section details the work I completed during my Peter J. Eloranta Summer Undergraduate Research Fellowship, which is a competitive fellowship award to MIT underclassmen to pursue novel student-initiated research. The fellowship was established in 1969 by Dr. Edwin H. Land to encourage undergraduate creativity and stimulate a broader range of activity than what is possible during the term.¹ The final section includes information on relevant research involving autistic children and robotics.

Preliminary observation:

As a senior in high school, I took a yearlong independent study on robotic programming. My concluding project was to expose elementary students to robotic technology. Kindergarteners had the opportunity to move the robotic arm with arrow keys while third, fourth, and fifth graders had the task of moving inanimate objects. In a kindergarten classroom, a five-year-old child diagnosed with autism was fascinated with the robotic arm. During his turn to move the robotic arm, he placed a toy figurine in the robotic arm's path and practiced moving the robotic arm until he was able to pick up the toy. With the toy figurine dangling in the robotic arm's grip, the boy excitedly moved the robotic arm in complex turns before placing the toy delicately down. Surprising, over the course of ten minutes this autistic child completed the complex task of moving an inanimate object, a task that was difficult for a group of gifted fifth graders. I never expected a five-year old to place the sequence of movements in the correct order so that the robotic arm would complete a task. Immediately I began thinking about the learning process, linking something known with something unknown with the use of repetition.

Fellowship:

The robotic arm had preprogrammed positions, which when clicked, made the robotic arm physically move to a position in space. The positions could be clicked in any order. The robotic arm could complete a specific social interaction if the autistic child put the positions in sequential order, such as the hand up, hand down, hand up for waving. My research focused on five tasks: waving goodbye, shaking hands, picking up an object, putting down an object, and giving an object to someone else.

My fellowship had three distinct goals for the interaction level of the children in my study. The first goal was to quantify the level of interaction autistic children in my study would have with the robotic arm. My hypothesis was that the autistic children in my study would interact with the robotic arm. I tested this hypothesis by noting several responses. First, in the session to play with the robotic arm, I quantitatively measured the time each child was engaged in the program. Second, I noted outward responses to the robotic arm. I collected data on the quantity of both verbal and non-verbal responses. Verbal responses included any conversation concerning the robotic arm. Non-verbal responses included acting out the robotic arm movements. Since autism is a spectrum disorder, I did not judge the amount of responses from one child against the amount of responses from another. Rather, I kept a daily report for each child and compared one day's responses to the next.

The second goal was to quantify the child's interest in the sequencing of the positions so that the robotic arm would complete a task. At the beginning of the session and every five minutes thereafter, I asked the child to complete a task. Then the child was free to move the robotic arm. I did not help the child place the sequence in the correct order or give any negative or positive feedback for changing the sequence. I used this approach because autistic children often have weak social interaction skills. Any interaction I had during the session may have had a negative outcome on the clarity of my results. I quantitatively measured the time it took to place the sequence of positions in the correct order. As before, I did not judge one child's progress against another child's progress. I also made note of the trials predicted by the autistic child. I used this data to scramble the initial sequence of the positions so that the child could complete the same task using the same preprogrammed positions.

The third goal was to quantify the ability of the robotic arm to teach autistic children the movements associated with social interactions. Once the child correctly sequenced the motions of the robotic arm to complete a task, I opened a video clip on the computer. The person in the video clip was asked to complete the same task that the child just completed using the robotic arm. The person in the video acted out the same task that the robot performed. Once the video was over, the child was free to control the robotic arm again. If the child repeated the same task, without further verbal instruction, then I showed the video again. The remaining time in the session was unstructured. I noted if the child mimicked the motion of the person in the video while the video was playing. I noted if the child mimicked the movement while moving the robotic arm. After every session, I discussed tasks that were taught with the child's parents. I asked the child's parents to monitor the use of the movements during social interactions.

Relevant research:

There is a wide variety of current autism research related to my thesis project. The University of Hertfordshire is researching the use of a mobile robot as a therapeutic and educational tool for children with autism.² Named The AuRoRA Project, researchers engage autistic children in human-like social interactions with an autonomous mobile robot. The goals for the research are to create a behavior based control system for a mobile robot that is based on basic behaviors. The robot's repertoire of behaviors and the unpredictability of its actions slowly increase over the course of interactions with an autistic child as it identifies and adapts to play patterns. While this study links robotic technology and social interactions, the premise that autistic children can learn from unpredictable behavior is debatable.

One of the first accounts of using a robotic platform to teach autistic children using robotics is from published research from 1976. Sylvia Weir and Ricky Emanuel used programming language LOGO and a small robot called a turtle, products from the MIT AI LAB, to create a learning environment. They reported positive effects on an autistic boy in initiation of communication while interacting with the robot.³

The Affective Social Quest, completed by two professors at MIT, utilized four stuffed dolls and embedded technology to link emotion with visual cues. Four emotions were targeted: happiness, sadness, surprise and anger. By touching one of the four dolls, an autistic child was encouraged to match the doll's emotion to the emotion of the video clip taken from sources of popular culture. The authors conclude that the technology was interesting and engaging for autistic children.⁴

Many researchers have used robotic technology as a tool for mimicking human movement. Kismet is a robotic head that can imitate a variety of facial expressions while interacting with humans.⁵ Developed by the Social Machines Project at MIT, KISMET is inspired by the social development of infants to engage in natural and intuitive social interactions with a human. The Robota dolls are dolls which demonstrate the ability of humans to teach robots.⁶ Utilizing speech, vision, and body imitation, the dolls can engage in complex interactions with humans. An interesting finding is that autistic children were more likely to interact with a plain featureless doll than a pretty doll with clothing and hair.

Additional research comes from personal accounts of adults with autism. Autistic adults who live independently often do so by learning and applying explicit rules to overcome social barriers.⁷

Methods:

Human modeling

An important component in the design of the robotic arm was to allow the movements to be more human-like. The goal was to match human anatomy as best as possible, while being mindful of the end price point for mass appeal. The structure of the human arm is detailed in figure 1. The scapula, or shoulder blade, is the starting point for analysis. It connects the arm to the torso via the collar bone. From the shoulder joint, the first bone of the upper arm is the humerus. The elbow is a hinge joint between the humerus and the bones of the

lower arm, the ulna and radius. The ulna is on the inner side of the forearm. A point of articulation for the ulna is provided by a depression on the end of the humerus. The radius rotates around the ulna allowing for the rotation of the wrist and hand. The wrist is formed by eight cube-like bones. The metacarpus, or palm, contains five metacarpal bones. Each of the four fingers has three phalangeal bones. The thumb is opposable, which means it can move in directions opposite to the other four digits. Two phalangeal bones compose the thumb.

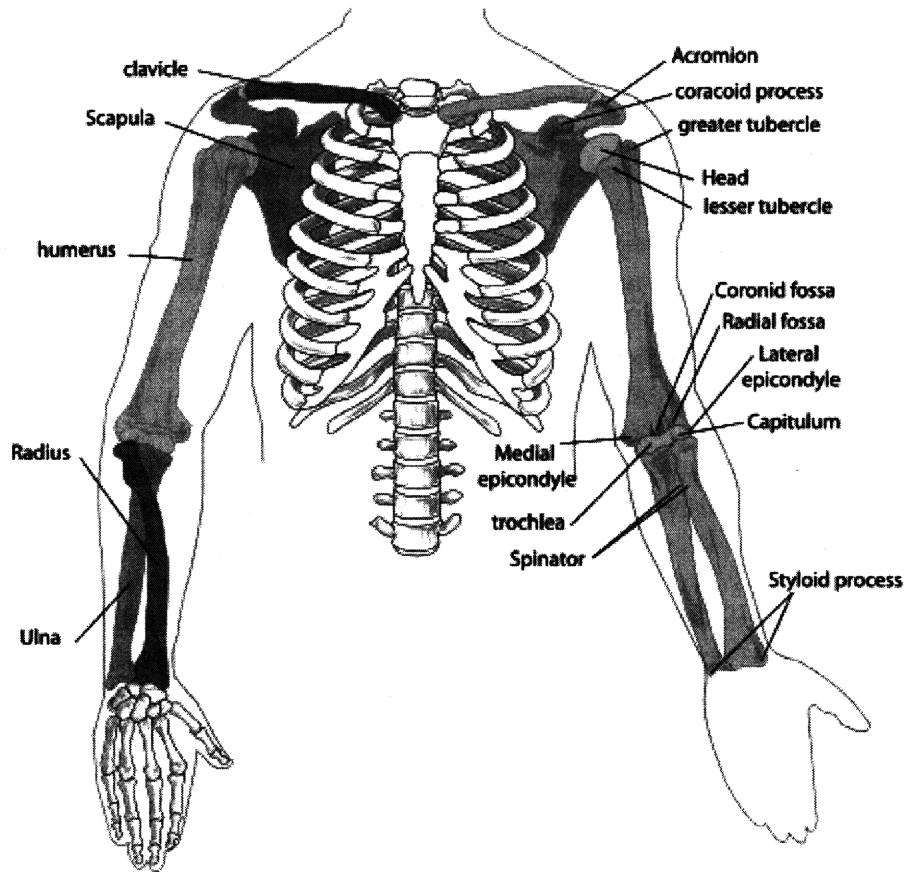


Figure 1. Image depicting the bones of the arm.⁸

I conducted research on the physical structure of the arms of children, specifically the size of the bones. The length and width of the bones was used to better model the bone structure of the robotic arm. The dynamics of the human arm were studied in depth, using both research and observational techniques. Emphasis was placed on the shoulder, elbow, and hand. Based on this research, I began to design a robotic arm that improved upon commercially available robotic arms. For comparison, the robotic arm used for my fellowship is shown below in figure 2.



Figure 2. Lynx 6 created by Lynxmotion⁹ is a commercially available robotic arm that has six degrees of freedom that can each rotate 180°.

Shoulder modeling:

With the robotic arm sitting flat on the table, the base of the robotic arm does not imitate a shoulder joint. My design will mount the robotic arm onto a torso base. This will cause the robotic arm to be outstretched along the side of the torso, a natural position for the human arm. This subtle change allows the robotic arm to have the ability to replicate human motion in all other joints. The commercially available robotic arm allows the base of the arm to spin 180°. This is vital so that the whole arm can rotate to be in a better position to grab and pick up objects. In human anatomy, the shoulder blade moves in a variety of directions to allow for a full range of motions. However, to increase stability of the robotic arm and to allow the child to forcefully interact with the machinery, I decided to fix the shoulder blade to the torso. Movement for the shoulder and upper humerus will be powered by two motors. The motion of the upper arm will be 180° outward, stretching away from the torso. This is the vital motion of the upper arm for social movements. To shake hands, the upper arm should be extended from the torso at approximately 90° depending on the height person with whom the child is interacting.

Elbow modeling:

The elbow joint of commercially available robotic arms has one degree of freedom. This motion is in the same direction as the shoulder motion, allowing the arm to unfold and fully stretch to meet objects. My design will better model human anatomy by having two degrees of motion in the lower arm. At the elbow joint, one motor will control the ability of the elbow to outstretch. For shaking hands, this motor will fully extend the lower arm.

The rotation of the forearm is controlled at the wrist of most commercially available robotics arms. However, the rotation of human anatomy does not allow for the wrist to rotate independently for 180°. Instead, the rotation occurs as the radius rotates around the ulna in the forearm. My design will imitate this motion by utilizing a second motor in the forearm. This second motor will be mounted at the midpoint of the forearm and allow rotation of the wrist and hand. For the motion of shaking hands, this motor will have the ability to rotate the hand.

Hand modeling:

The two-prong pincher found on most commercially available robotic arms is the most visually obvious deviation from human anatomy. The pincher uses a four bar linkage to grasp and move objects in space. While the pincher is very safe due to its low force, the four-bar linkage poses a safety danger for a child's small fingers. The complete motion of the four fingers is impossible to replicate with the pincher. My design will better imitate the motion of the hand. Four distinct fingers will be created. The finger bones will have holes through which pulley cables will be run. As the motor rotates, all four fingers will curl downward at a natural knuckle position. The fingers will be staggered in order to replicate the overall shape of the hand. Rubber rods connected to both joints in each finger will provide tension. If the motor is not constricting the cables, the rubber rods will cause the natural position of the fingers to be outstretched. The flexibility of the rubber rods will produce little resistance to the motor force when the fingers curl. All four fingers will be mounted to a flat base, which will form the palm. The thumb will be controlled independently by a separate motor. The thumb will not be opposable in order to make the design more robust. Instead the thumb will move approximately 60° perpendicular to the palm. For shaking hands, the thumb will move to form a slight J-shape opening in order to accept another person's hand.

Torque capabilities:

A substantial portion of the design study was devoted to the selection of the motors. Complete torque analysis took into account the weight of the motors and material, as well as the distance from the source of rotation. A safety factor of three was determined to be appropriate to allow the hand to grab and move objects. There are a limited range of motors that were best suited for this robotics applications. The following table describes the results.

Table 1. Torque calculations for motor selection

Location	Torque required	Motor selected	Torque provided
Shoulder	2.3	Two HS-475 HB	7.4
Lateral Elbow	0.89	HS-475 HB	3.7
Rotation Elbow	0.21	HS-475 HB	3.7
Thumb	0.058	HS-85	2.6
Hand	0.0054	HS-81	2.2

Control system:

Due to lack of expertise in computer control systems for robotics, a commercially available motherboard and software package were utilized. These two pieces of equipment were used with the robotic arm for the Peter J. Eloranta Summer Undergraduate Fellowship, and should be easily transferred to work on my design.

Solid model:

Based on preliminary sketches, a solid model was created that encompassed the project. The solid model is shown in the following figure. Not shown is the torso, onto which the circular base of the shoulder will mount. From the top, there are two motors that will control the outward motion of the upper arm. The rest position of the upper arm will be against the torso. The upper arm is connected to the lower arm at one motor that represents the elbow joint. The motor will control the outward motion of the lower arm and allow the arm to become outstretched. In the middle of the forearm is another motor, which will allow the hand to rotate. Allowing for rotation of the hand to occur in the forearm better imitates human motion. The hand has four fingers, each of which was fixed to the palm at the innermost joint. The fingers will have a cable looped through the holes, allowing for the fingers to curl downward using the motor. The pulley system controlling the fingers allows all fingers to grasp in a synchronized fashion. The rubber rod connected to each finger provides tension which keeps the fingers outstretched in the natural position. The fingers are robustly designed to allow for greater stability when a child interacts with the robotic arm. The thumb is controlled with an independent motor. The palm of the hand is not connected to the thumb. A separate motor to control the motion of the wrist was deemed unnecessary to imitate human motion. A conscious effort was made to reduce the number of motors to make the system affordable. The combination of motors that were chosen give the robotic arm the greatest degrees of freedom which still correspond to natural movement. After the solid model was completed, each part was converted to a blueprint drawing. Only complex parts were fabricated using the waterjet, due to the cost of running the machine. Complete blueprints of the parts are detailed in the Appendix.

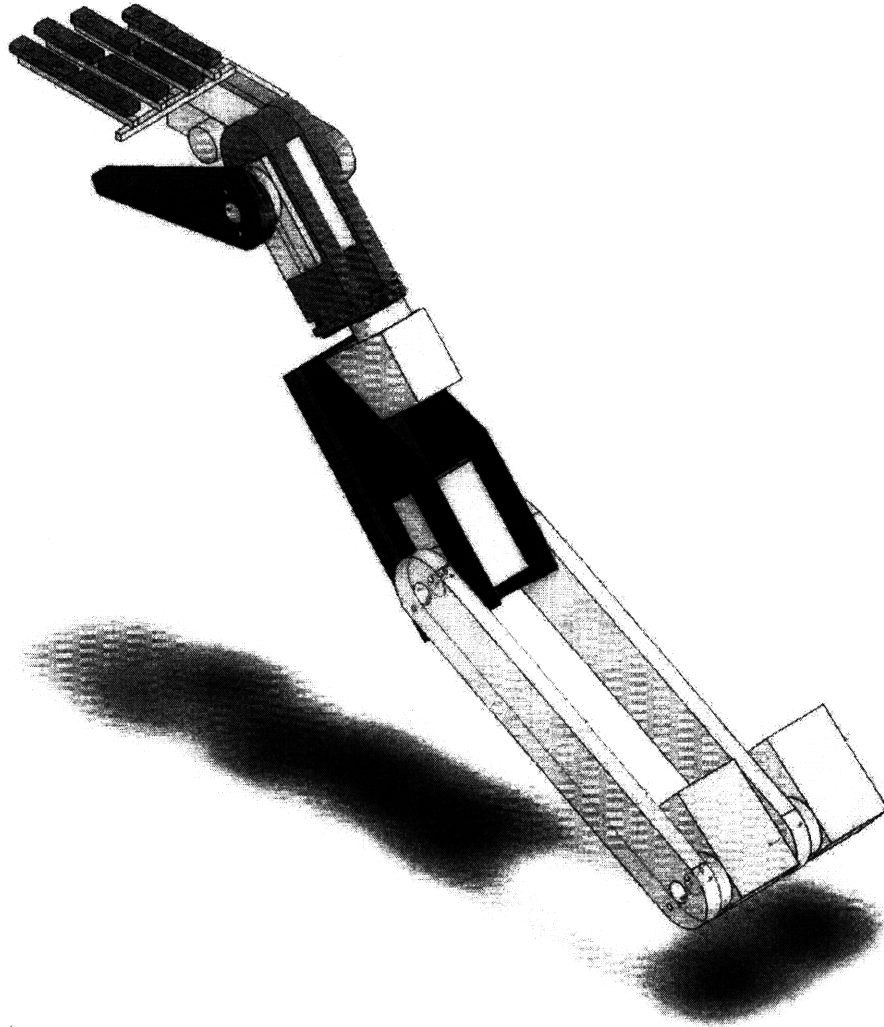


Figure 3. Solid model for thesis, “Development of a Robotic Arm to Teach Autistic Children Social Movements” by Devanie DuFour. The robotic arm more effectively teaches autistic children social movements such as shaking hands compared to conventional methods of imitation, according to research for the Peter J. Eloranta Summer Undergraduate Research Fellowship. The robotic arm design allows for replication of human movement specifically in the shoulder, elbow, and hand joints.

Conclusions:

A simple, relatively inexpensive robotic arm was designed to imitate the movements associated with social interactions. The goal was to match human anatomy as best as possible, while being mindful of the end price point for mass appeal. The bone structure of humans was carefully considered, as was the size of the bones of children. The length and width of the bones were used to better model the bone structure of the robotic arm. The dynamics of the human arm were studied in depth, using both research and observational techniques. Emphasis was placed on the shoulder, elbow, and hand. The shoulder joint is to be mounted onto a torso base. This will cause the robotic arm to be outstretched along the side of the torso, a natural position for the human arm. This subtle change allows the robotic arm to have the ability to replicate human motion in all other joints. To increase stability of the robotic arm and to allow the child to forcefully interact with the machinery, I decided to fix the shoulder blade to the torso. The motion of the upper arm will be 180° outward, stretching away from the torso. The elbow joint will better model human anatomy by having two degrees of motion in the lower arm. At the elbow joint, one motor will control the ability of the elbow to outstretch. The rotation of the forearm is controlled by a second motor in the forearm. This second motor will be mounted at the midpoint of the forearm and allow rotation of the wrist and hand. The hand will have four distinct fingers. As the motor rotates, all four fingers will curl downward at a natural knuckle position via a pulley system. The fingers will be staggered in order to replicate the overall shape of the hand. All four fingers will be mounted to a flat base, which will form the palm. The thumb will be controlled independently by a separate motor. A substantial portion of the design study was devoted to the selection of the motors. Complete torque analysis took into account the weight of the motors and material, as well as the distance from the source of rotation. A safety factor of three was determined to be appropriate to allow the hand to grab and move objects. The motors were selected from a limited range that is best suited for robotics applications.

The robotic arm has been assembled, and successfully mimics the motion of the human arm. During the process of assembly, many parts easily fit together. Minor design alterations occurred after manufacturing. A key oversight in the design was the mounting brackets attached to the motors. The brackets served to support most of the motors after mounting holes were added to the design. The range of motion was programmed into the control system, with minor delays caused by flawed software. Foam was added to the structure to fill out the shape of the arm. While the robotic arm does not fully imitate the human arm in degrees of freedom, the design is a robust and cost effective approach to mimicking the key motions of social movements.

Recommendations:

There is a growing market for this invention as the number of children with autism increases. If this product could be reasonably priced to compete with other robotic arms in the market, then the invention could be marketed to both parents and schools. I have been meeting with the Technology Licensing Office at MIT to protect the intellectual property contained within this thesis.

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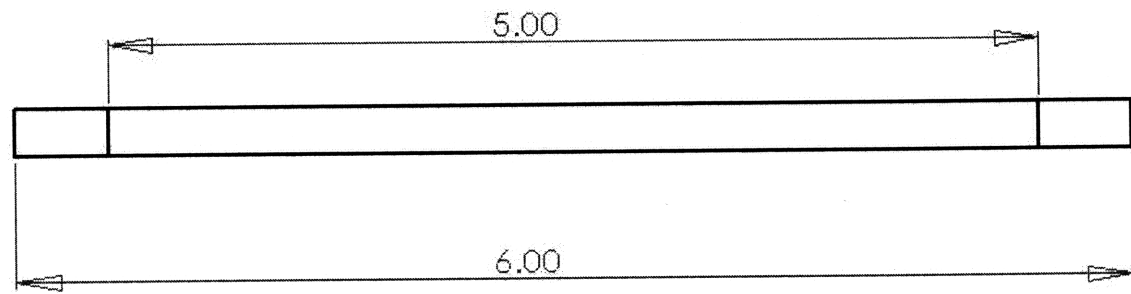
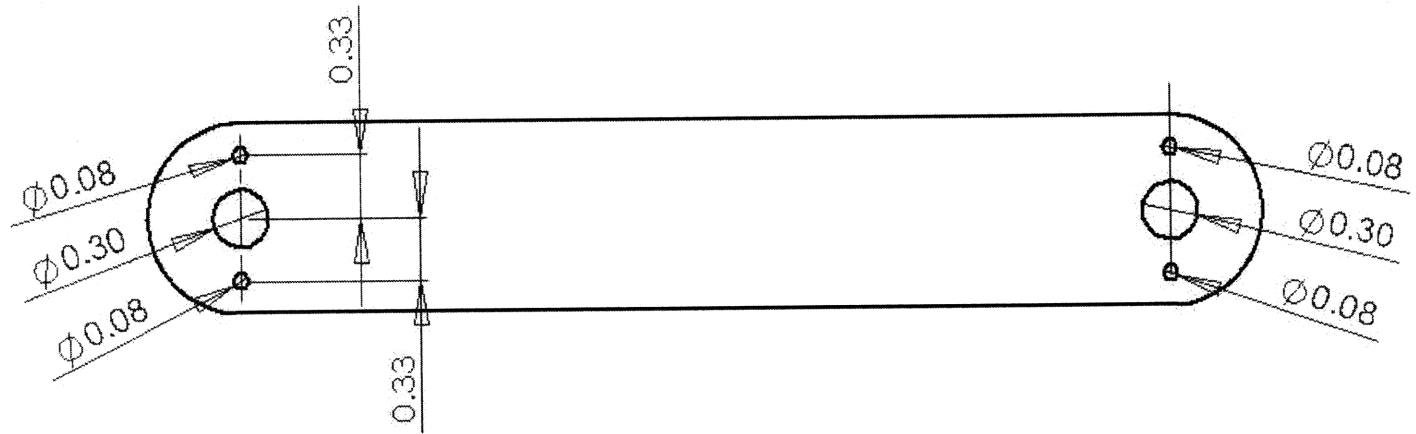
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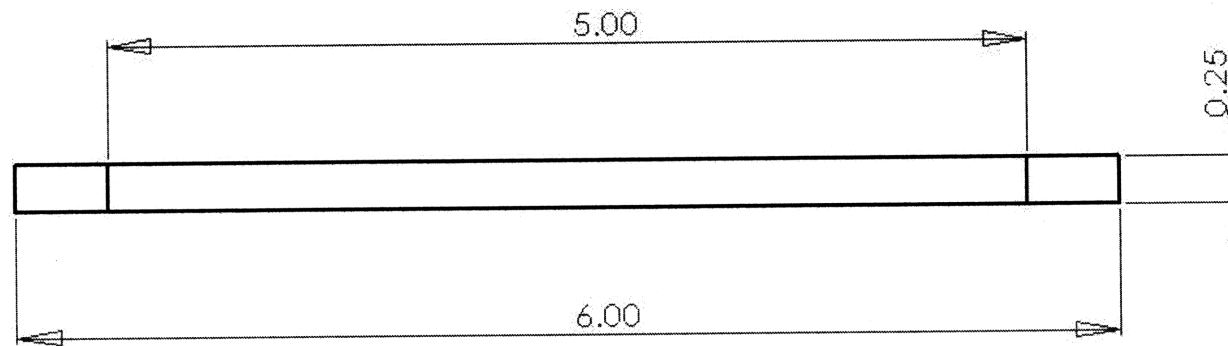
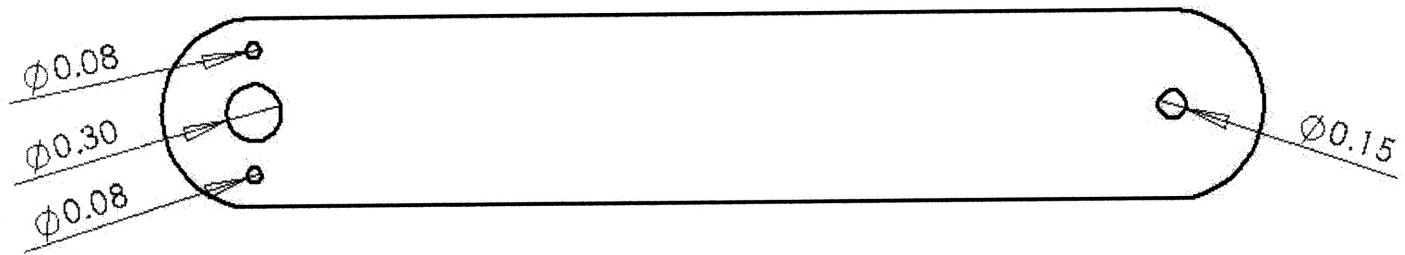
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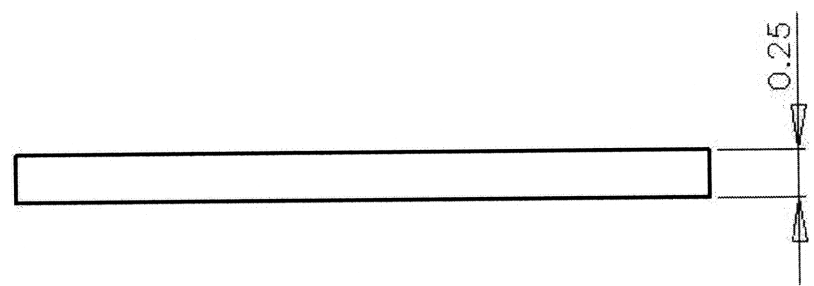
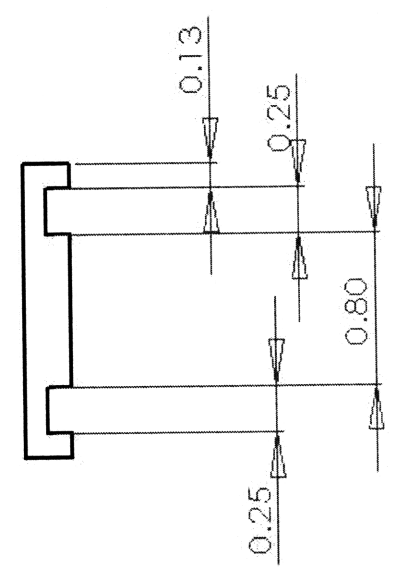
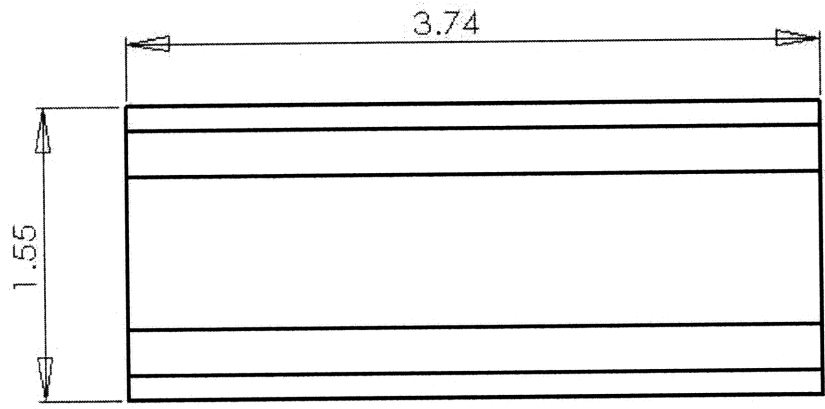
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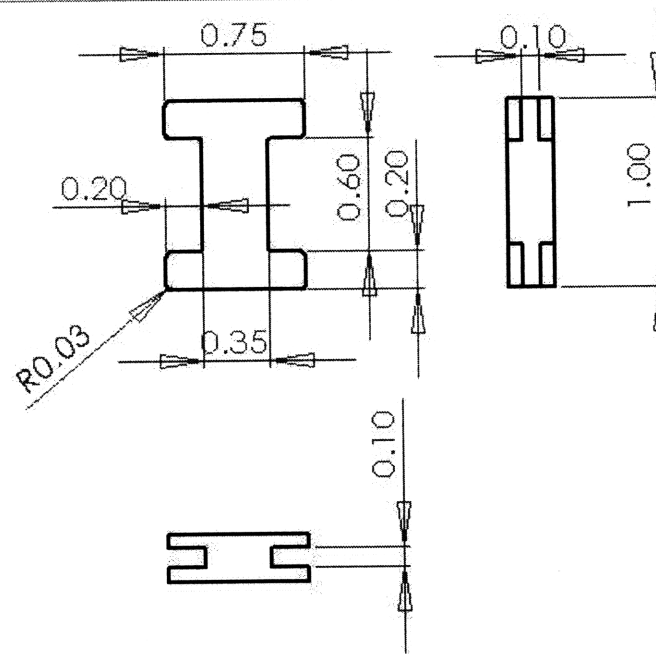
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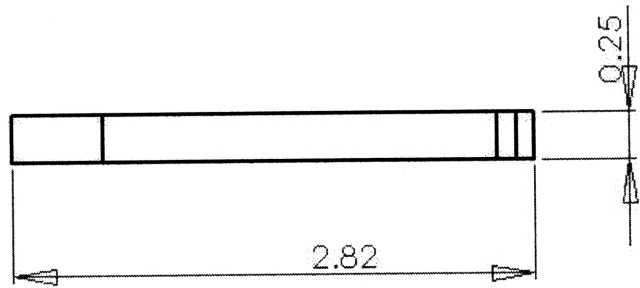
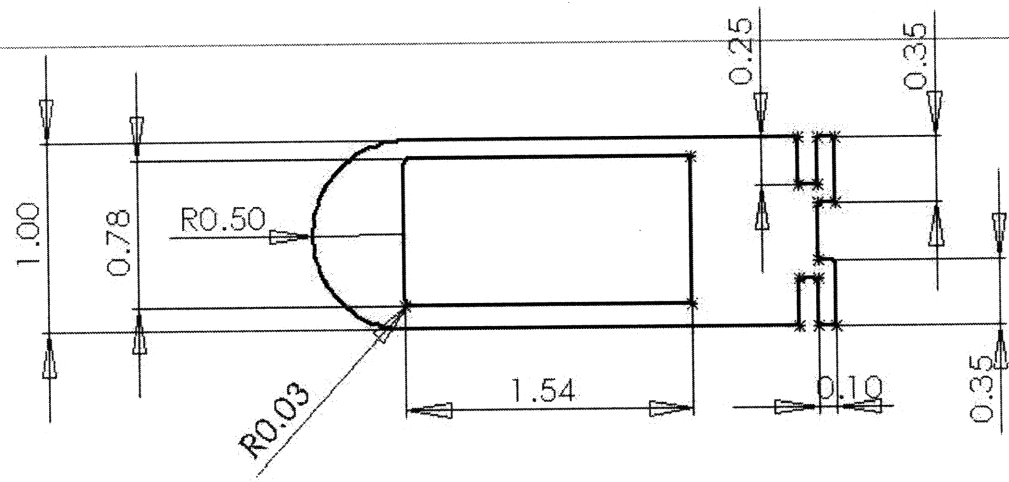
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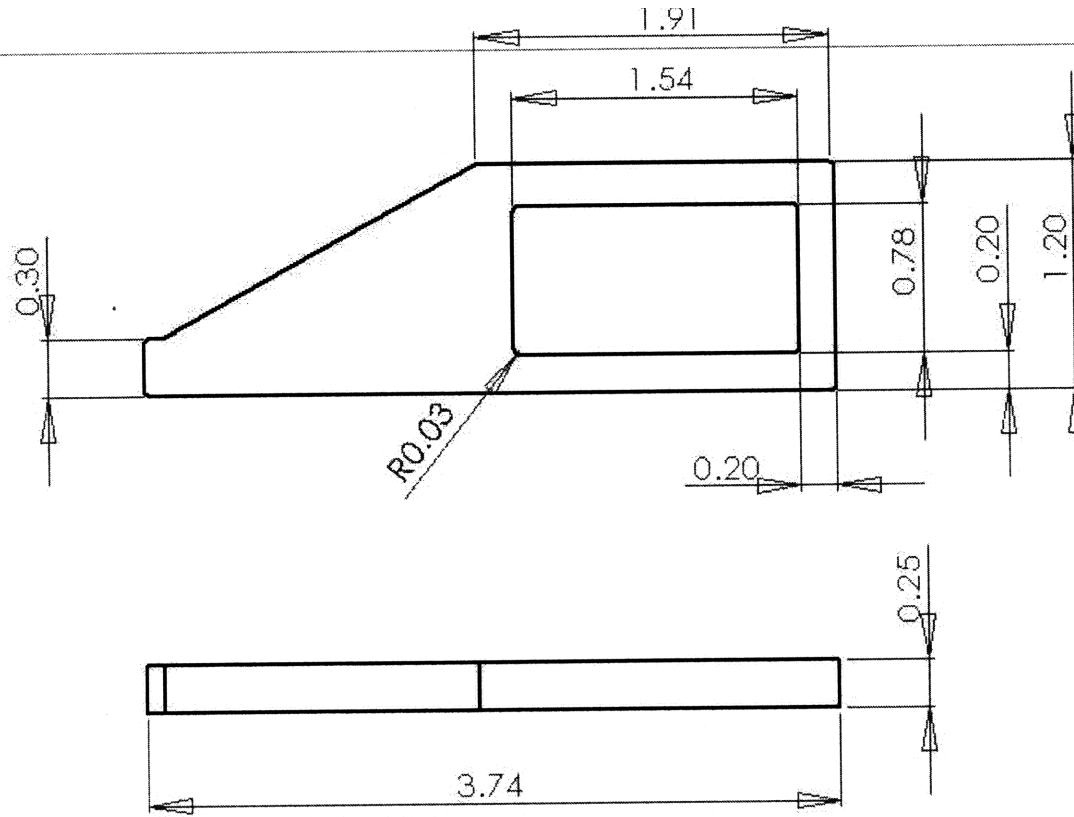
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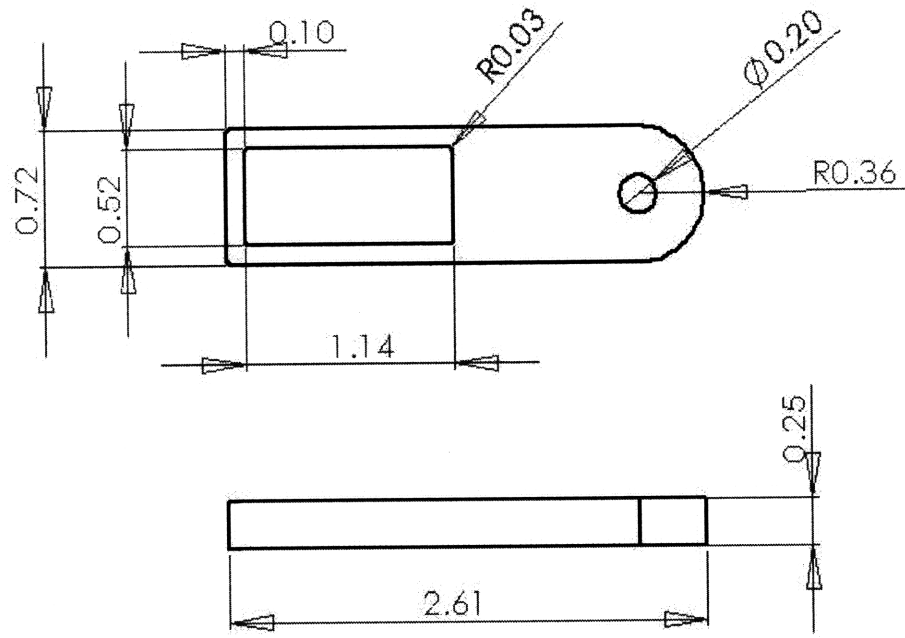
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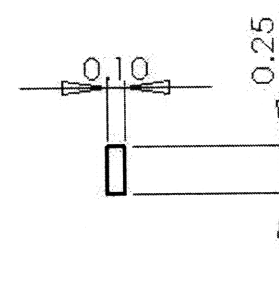
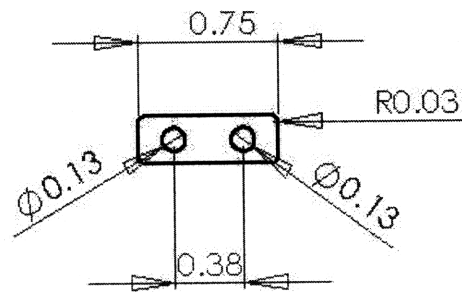
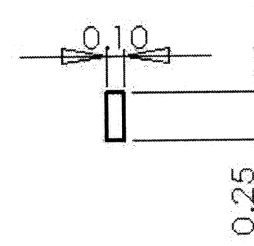
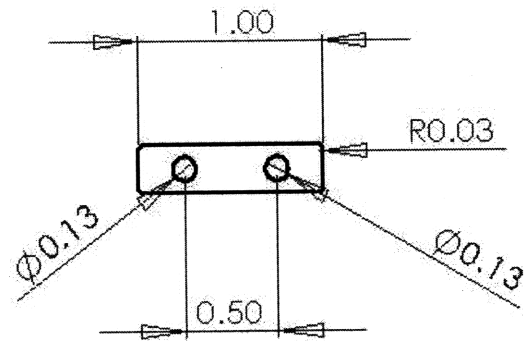
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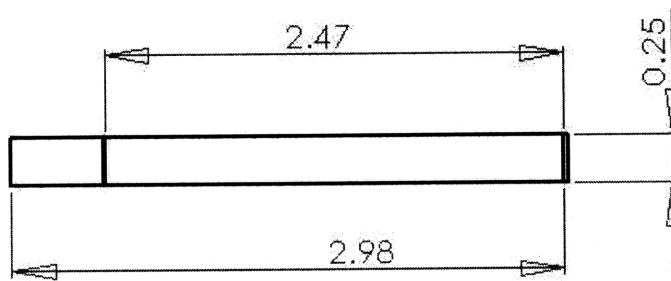
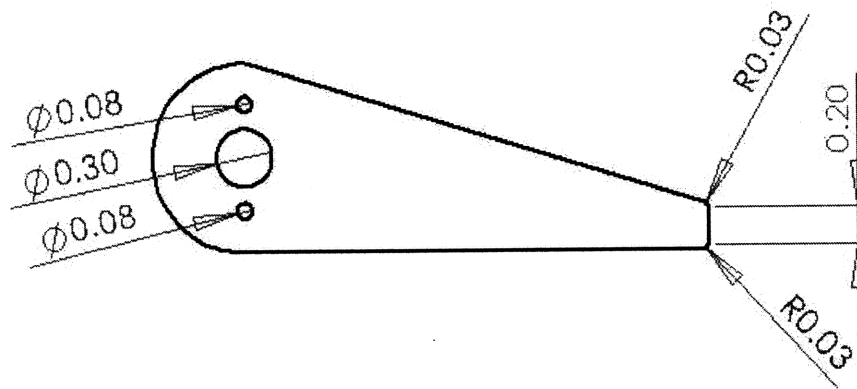
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