VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

# DESIGN, DEVELOPMENT, AND FABRICATION OF A 6 DOF HUMANOID WELDING ROBOT MANIPULATOR

Sami Salama Hussen Hajjaj and Meisam Khonbreh
Centre for Advanced Mechatronics and Robotics (CAMARO), College of Engineering, UNITEN Jalan IKRAM-UNITEN, Selangor, Malaysia
E-Mail: ssalama@uniten.edu.my

## ABSTRACT

This work reports on the design, development, and fabrication of humanoid welding robot manipulator with 6 D.O.Fs. By mimicking the movement and motion of the human hand, this robotic welder manipulator could mimic or even surpass the performance of the human welder. This work is a component of a bigger project on Human-Robot Interaction (HRI). The objective of this work mainly is to focus on mechanical design of the manipulator. That includes analyzing the human hand, arm and developing a robotic manipulator to mimic some or most of the motions of the human arm, from the shoulder to the wrist. Kinematics analysis of the human arm, joints, and linkage structure were conducted in Creo, AutoCAD. These were used in the fabrication and development of a working prototype. This project was developed in collaboration with another project; namely the humanoid gripper. As such, upon construction of this manipulator, it was attached to the humanoid gripper and allowed to manipulate it and allow it perform its function of gripping objects, pick and place, and perform a human gesture. Results obtained from this work illustrated the good functionality of the design.

**Keywords**: mechanical design, robotic components, robotic welders, humanoid robotic welders, humanoid manipulators, human robot interaction (HRI).

## INTRODUCTION

In a scientific or a mechanical view, robots are seen as machines so they act and communicate as machines. Robots can complete tasks more accurately and in shorter times compared to humans. This is the main reason that makes robots as an essential part of human life [1-6]. Humanoid robots are special because not only do they function accurately and efficiently, they also mimic human’s motion, speech, and appearance. This makes robots not only more efficient, but also more sociable [1, 7, 8].There are many examples of humanoid robots that exist nowadays, such as the ASIMO, and TAPIO robots. ASIMO for example, is a humanoid robot developed by Honda in 2000, and continues to grow and develop every year since. This robot can walk and move like human [1, 9]. For this work, a 6 DOF humanoid robot arm is to be design, developed, and fabricated. The purpose of this design is to develop such a humanoid robot hand which can perform as close as possible to the human hand. This is in part to help people with disabilities. This is not the first time a humanoid robotic arm has been developed. Uehara *et al.* developed a similar mechanism composed of a mechanical robotic arm, a collection of DC motors, attached to some reduction gears, as well as three-position switches that provide a direct control over each motor, therefore each joint [9]. Another technique builds the gripper out of elastic material and is powered by compressed air. This was developed by Virginia Tech’s Robotics and Mechanisms Laboratory of the College of Engineering. It uses microcontroller commands to control the movement on the fingers. This robot hand is mainly operated by using the compressed air. The material of the robot hand is mainly elastic ligaments. The fingers will hold tight together when the air inside the fingers is being compressed. This robot hand has 1 degree of freedom on each finger. The pressure of the air can be adjusted to manipulate different object, lower pressure is required when the robot hand is holding a soft fragile object while high pressure is used to hold an object tightly [10-14].Kolluru *et al.* [15] discovered that a cockroach leg is very flexible and acts like a spring, which allows the cockroach to walk or run on uneven surface. The robot fingers are made by using plastic springs that could deflect naturally and so are flexible to grasp a wide range of objects. Besides, the material is light in weight and cheap. The main components that operate inside the hand are cables and pulleys which run by motors [15]. Hajjaj *et al.* [16] also tackled the issue of the humanoid gripper. In their work they focused on developing a structurally sound robotic gripper that mimics the human arm, while at the same time is structurally and mechanically sound [16].

## EXPERIMENTAL SETUP

### Simulated design and CAD/CAM

The first step was to create the 3D Creo Model for the robotic manipulator. For simplicity of the design. Figure-1 shows this model.

The tip of the robot was lift as is intentionally; because that would allow for any kind of gripper to be attached to the robot and so add more functionality to it. This is shown in Figure-6. Dimensions were selected according to the ergonomics of the human arm. Dimensions of each link where set to mimic that of human counterpart. Given the payload of the robot be its own weight plus 1 kg, Load analysis, Stress-Strain analysis were all conducted in Creo, and Pro-Engineering programs. After completing software simulations and analysis, models for estimating the Von Misses stresses were developed and values were estimated.

**Figure-1.** Creo model showing the 3D assembly of the manipulator used for this work.

## Control of motion of manipulator

The primary focus of this work is the mechanical design and fabrication. Therefore, control of motion of individual joints and the creation of complex motion was postponed to later work. To control the motion of each individual joint, 6 servo motors were actuated to each joint, each motor is then linked to the PARALLAX control chip, with its accompanying software, PSCI. This software allow user to control and adjust the rotation of each motor separately, record that motion, then playback the motion of all motors (and joints) together, resulting in complex motions achieved. The switches attached to this model provide an alternative, and simpler, mode of control. It allows the user to control selected motors (and their joints) directly. For the purposes of this work, these two modes of motion control are the primary modes used to control the motion of the Manipulator. As it can be seen from the photo, there are a total of 15 channels available to control the motion of the servo motors. A special connection is designed to join the parts together. This design is a combination of motor coupling, shafts and some screws. Since the DC motors are attached with a gearbox on the top, then the rotational shaft needs to be connected to the following part in other to transfer the produced Torque to the following link to make the rotation. To complete this process, motor coupling is attached to the motor shaft and it is fixed there by two screws, other head of coupling is fixed to the following link by screws as well.

## Material selection

The base of the robot is chosen from a material that is heavy, easy to machine, and cost effective. Therefore, wood is ideal and is the material chosen for this part. The remainder of the robot is made of Aluminum. Aluminum was selected because it has the right balance between strength and weight, which makes ideal for components of a robotic assembly, and to reduce overall payload of the robot [10].

## Mechanical analysis and motor selection

This is not the first time a humanoid robotic arm has been developed. Uehara *et al.* [2] developed a similar mechanism composed of a mechanical robotic arm, a collection of DC motors, attached to some reduction gears, as well as three-position switches that provide a direct control over each motor, therefore each joint.

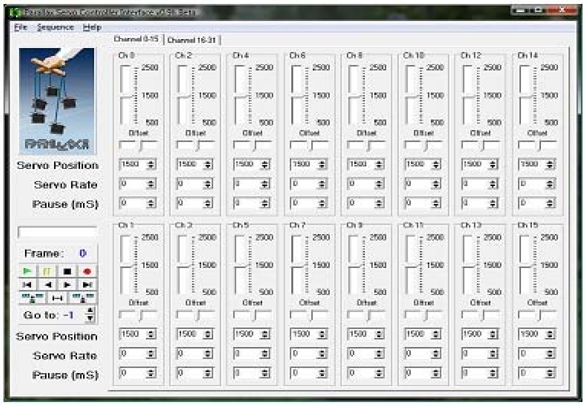
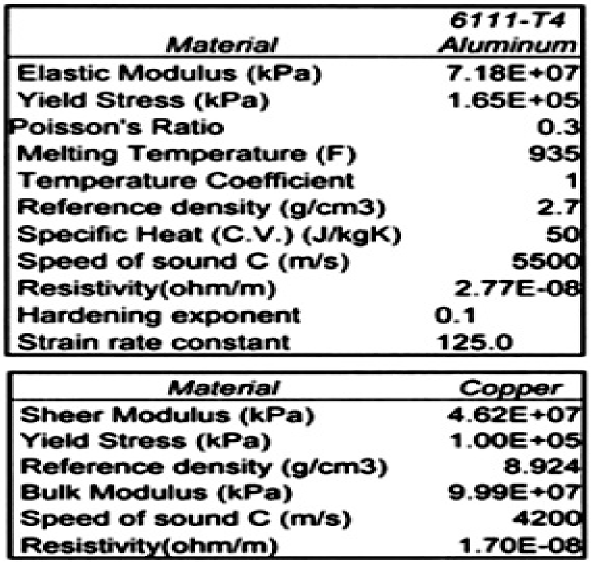


**Figure-2.** The PCSI software package that allows users to program motions of the robotic manipulator.



| Material | 6111-T4 Aluminum |
|---|---|
| Elastic Modulus (kPa) | 7.18E+07 |
| Yield Stress (kPa) | 1.65E+05 |
| Poisson's Ratio | 0.3 |
| Melting Temperature (F) | 935 |
| Temperature Coefficient | 1 |
| Reference density (g/cm3) | 2.7 |
| Specific Heat (C.V.) (J/kgK) | 50 |
| Speed of sound C (m/s) | 5500 |
| Resistivity(ohm/m) | 2.77E-08 |
| Hardening exponent | 0.1 |
| Strain rate constant | 125.0 |

| Material | Copper |
|---|---|
| Sheer Modulus (kPa) | 4.62E+07 |
| Yield Stress (kPa) | 1.00E+05 |
| Reference density (g/cm3) | 8.924 |
| Bulk Modulus (kPa) | 9.99E+07 |
| Speed of sound C (m/s) | 4200 |
| Resistivity(ohm/m) | 1.70E-08 |

**Figure-3.** Mechanical properties of aluminum alloy used in fabrication of this robot.

## Simulated design and CAD/CAM

Every fabricated component of the manipulator was analyzed using Creo and Pro-Engineering. Von Misus stresses applied on each component were found, and design were adjusted accordingly to insure components do not fail under loading. Figure-4 shows selected components and their analysis.

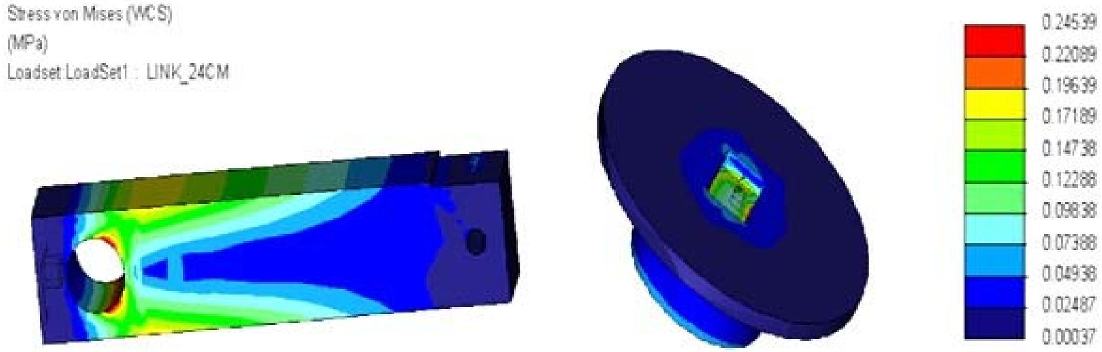


**Figure-4.** Stress analysis of some components.

Once stresses on each link is found, then analysis can proceed to torque analysis and motor selection for each joint, as follows, Figure-5:

$$FS = \frac{Q_{max}}{Q_{allowable}} \text{ Used throughout} \tag{1}$$

$$F = mg = 3kg(9.81) = 29.53N \tag{2}$$

$$FS = \frac{455}{2.296(10^{-2})} = 15361.24 \tag{3}$$

$$Torque\ \ i = Total\ \ weight\ \ i\ \ x\ \ Total\ \ length\ \ i \tag{4}$$

$$Total\ \ weight\ \ i = weights\ \ of\ \ all\ \ links\ \ up\ \ to\ \ link\ \ i$$

where,

Total length i = total equivalent length of all links up till link i
Therefore,

$$\text{Torque } 1 = (3.21\text{kg})(0.3 + 0.24 + 0.2) = 2.3754\text{N.m}$$

$$\text{Torque } 2 = (3.11\text{kg})(0.74\text{m}) = 2.3014\text{N.m}$$

so on,
Torque 3 = 0.4616 Nm
Torque 4 = 0.188 Nm
Torque 5 = 0.5 Nm
Torque 6 = 0.2 Nm

Figure-5 shows the various torques calculated for this work. As expected, the value of the torques gets smaller as we move to the wrist, since the movable weight is reduced.

## Challenges and solutions

Torque analysis underestimated the amount of torques needed for this project, therefore, motors proved to be too powerful to move and carry the robot's payload. While this seems to be a bonus, it proved problematic as rotational speedsof various joints were too high, even with the reduction gears. While amusing, it was far from emulating the performance of the human hand. Since it was too late to change the motors, this problem was solved by adding more weight to the payload and adding more reduction gears to further slowdown the motors.

**Figure-5.** Torque analysis and motor selection.

## Construction and final assembly

Once all challenges tackled and solved, the robotic assembly was completed as follows.

## CONCLUSIONS

As a conclusion, it can be said that the project has been done successfully and all the expectations have been met by the final results. Also it is obvious that there are lots of possibilities to modify, magnify and improve this mechanical arm.Based on the evidences and results, it is proven that a successful prototype of mechanical robot hand is done by end of this project.

**Figure-6.** Construction of the Robotic manipulator, and combining it with the humanoid gripper, which was developed previously by the author.

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