Design and Fabrication of Humanoid Robot to Attain Human-Like Movements

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Abstract

This thesis paper analyze the flexibility of humanoid robot structure design based on design parameters of degree of freedoms and joint angle range characteristic. As a result it helps to identify elements that provide flexibility for humanoid robots to attain human-like motion. Description and correlation of physical structure flexibility between human and humanoid robot to perform motion is presented to clarify the elements.

This analysis utilized the joint structure design, configuration of degree of freedoms and joint rotation range of a 17-dof humanoid robot. Experiments utilizing this robot were conducted, with results indicates effective design parameters to attain flexibility in human-like motion.

After the emergence of Wabot from Waseda University in 1973, few full-sized humanoid robots have been developed around the world that can walk, and run. Even though various humanoids have successfully demonstrated their capabilities, bipedal walking methods are still one of the main technical challenges that robotics researchers are trying to solve.

Constructing a full sized humanoid robot is still challenging because most bipedal walking methods, including ZMP (Zero Moment Point) require fast sensor feedback and also fast and precise control of actuators. For this reason, only a small number of research groups have the ability to create full-sized humanoid robots that can walk and run.

Acknowledgement

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We give my true and sincere gratitude to Lt Cdr KMR Sadi (E, BN), GSO-II, Department of Mechanical Engineering, for his encouragement during the thesis.

Finally, we would like to thank our course mates for their appreciable assistance, patience and suggestions during the course of our thesis.

Declaration by Candidate

This is to certify that the work presented in this thesis paper is the outcome of the investigation and research carried out by the following students under the supervision of Dr. Engr. Md. Alamgir Hossain, Associate Professor, MIST, Dhaka, Bangladesh.

It is also declared that neither this thesis paper nor any part thereof has been submitted anywhere for the award of any degree, diploma or other qualifications.

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Supervisor Certificate

This is to certify that, Md. Mizanur Rahman Mizan, Student ID: 201018023; Raihan Masud Saquib, Student ID: 201018051; Fardan Abdullah, Student ID: 200918061 have completed their undergraduate project and thesis entitled "Design and Fabrication of Humanoid Robot to Attain Human-Like Movements". This paper embodies original work done under my supervision.

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CHAPTER

1

INTRODUCTION

1.1 Robot

Chapter 1 – Introduction

1.1 Robot

A robot is a mechanical or virtual agent, usually an electro-mechanical machine that is guided by a computer program or electronic circuitry. Robots can be autonomous or semi-autonomous and range from humanoids such as Honda's Advanced Step in Innovative Mobility (ASIMO) and TOSY's TOSY Ping Pong Playing Robot (TOPIO) to industrial robots, collectively programmed 'swarm' robots, and even microscopic nano robots. By mimicking a lifelike appearance or automating movements, a robot may convey a sense of intelligence or thought of its own.

Robotics is the branch of technology that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing. These technologies deal with automated machines that can take the place of humans in dangerous environments or manufacturing processes, or resemble humans in appearance, behavior, and/or cognition. Many of today's robots are inspired by nature contributing to the field of bio-inspired robotics. These robots have also created a newer branch of robotics: Soft robotics.

As mechanical techniques developed through the Industrial age, more practical applications were proposed by Nikola Tesla, who in 1898 designed a radio-controlled boat. Electronics evolved into the driving force of development with the advent of the first electronic autonomous robots created by William Grey Walter in Bristol, England in 1948. The first digital and programmable robot was invented by George Devol in 1954 and was named the Unimate. It was sold to General Motors in 1961 where it was used to lift pieces of hot metal from die casting machines at the Inland Fisher Guide Plantin the West Trenton section of Ewing Township, New Jersey.

Robots have replaced humans in the assistance of performing those repetitive and dangerous tasks which humans prefer not to do, or are unable to do due to size limitations, or even those such as in outer space or at the bottom of the sea where humans could not survive the extreme environments.

There are concerns about the increasing use of robots and their role in society. Robots are blamed for rising unemployment as they replace workers in some functions. The use of robots in military combat raises ethical concerns. The possibility of robot autonomy and potential repercussions has been addressed in fiction and may be a realistic concern in the future.

The word robot can refer to both physical robots and virtual software agents, but the latter are usually referred to as bots. There is no consensus on which machines qualify as robots but there is general agreement among experts, and the public, that robots tend to do some or all of the following: move around, operate a mechanical limb, sense and manipulate their environment, and exhibit intelligent behavior — especially behavior which mimics humans or other animals.

There is no one definition of robot that satisfies everyone and many people have their own. For example Joseph Engelberger, a pioneer in industrial robotics, once remarked: "I can't define a robot, but I know one when I see one." According to the Encyclopedia Britannica a robot is "any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner." Merriam-Webster describes a robot as a "machine that looks like a human being and performs various complex acts (as walking or talking) of a human being", or a "device that automatically performs complicated often repetitive tasks", or a "mechanism guided by automatic controls". In practical terms, "robot" usually refers to a machine which can be electronically programmed to carry out a variety of physical tasks or actions.

1.1.1 Classification

- Modern robots
    - Mobile robot
    - Industrial robots (manipulating)
    - Service robot
    - Modular robot

    - Collaborative robots
- Robots in society
    - Regional perspectives
    - Military robots
    - Relationship to unemployment
- Contemporary uses
    - General-purpose autonomous robots
    - Factory robots
    - Military robots
    - Mining robots
    - Schools
    - Healthcare
    - Research robots
    - Entertainment

1.1.2 Function

Mobile Robots

Mobile robots have the capability to move around in their environment and are not fixed to one physical location. An example of a mobile robot that is in common use today is the automated guided vehicle or automatic guided vehicle (AGV). An AGV is a mobile robot that follows markers or wires in the floor, or uses vision or lasers.

Mobile robots are also found in industry, military and security environments. They also appear as consumer products, for entertainment or to perform certain tasks like vacuum cleaning. Mobile robots are the focus of a great deal of current research and almost every major university has one or more labs that focus on mobile robot research.

Mobile robots are usually used in tightly controlled environments such as on assembly lines because they have difficulty responding to unexpected interference. Because of this most humans rarely encounter robots. However domestic robots for cleaning and maintenance are increasingly common in and around homes in developed countries. Robots can also be found in military applications.

Industrial robots

Industrial robots usually consist of a jointed arm (multi-linked manipulator) and an end effector that is attached to a fixed surface. One of the most common types of end effector is a gripper assembly.

The International Organization for Standardization gives a definition of a manipulating industrial robot in ISO 8373:

"An automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications."

This definition is used by the International Federation of Robotics, the European Robotics Research Network (EURON) and many national standards committees

Service robot

Most commonly industrial robots are fixed robotic arms and manipulators used primarily for production and distribution of goods. The term "service robot" is less well-defined. The International Federation of Robotics has proposed a tentative definition, "A service robot is a robot which operates semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations.

Modular Robot

Modular robots are a new breed of robots that are designed to increase the utilization of the robots by modularizing the robots. The functionality and effectiveness of a modular robot is easier to increase compared to conventional robots. These robots are composed of a single type of identical, several different identical module types, or similarly shaped modules, which vary in size. Their architectural structure allows hyper-redundancy for modular robots, as they can be designed with more than 8 degrees of freedom (DOF). Creating the programming, inverse kinematics and dynamics for modular robots is more complex than with traditional robots. Modular robots may be composed of L-shaped modules, cubic modules, and U and H-shaped modules. ANAT technology, an early modular robotic technology patented by Robotics Design Inc., allows the creation of modular robots from U and H shaped modules that connect in a chain, and are used to form heterogeneous and homogenous modular robot systems. These “ANAT robots” can be designed with “n” DOF as each module is a complete motorized robotic system that folds relatively to the modules connected before and after it in its chain, and therefore a single module allows one degree of freedom. The more modules that are connected to one another, the more degrees of freedom it will have. L-shaped modules can also be designed in a chain, and must become increasingly smaller as the size of the chain increases, as payloads attached to the end of the chain place a greater strain on modules that are further from the base. ANAT H-shaped modules do not suffer from this problem, as their design allows a modular robot to distribute pressure and impacts evenly amongst other attached modules, and therefore payload-carrying capacity does not decrease as the length of the arm increases. Modular robots can be manually or self-reconfigured to form a different robot, that may perform different applications. Because modular robots of the same architecture type are composed of modules that compose different modular robots, a snake-arm robot can combine with another to form a dual or Quadra-arm robot, or can split into several mobile robots, and mobile robots can split into multiple smaller ones, or combine with others into a larger or different one. This allows a single modular robot the ability to be fully specialized in a single task, as well as the capacity to be specialized to perform multiple different tasks.

Modular robotic technology is currently being applied in hybrid transportation, industrial automation, duct cleaning and handling. Many research centers and universities have also studied this technology, and have developed prototypes.

Collaborative robots

A collaborative robot or cobot is a robot that can safely and effectively interact with human workers while performing simple industrial tasks. However, end-effectors and other environmental conditions may create hazards, and as such risk assessments should be done before using any industrial motion-control application.

The collaborative robots most widely used in industries today are manufactured by Universal Robots in Denmark.

Baxter, introduced on September 18, 2012, is a product of Rethink Robotics (whose founder was Rodney Brooks), was an industrial robot selling for about that was designed to safely interact with neighboring human workers and be programmable for performing simple tasks. The robot stopped if its movement encountered a human in the way of its robotic arm and had a prominent off switch, which its human partner could push if necessary. The product, intended for sale to small businesses, was touted as the robotic analogue of the personal computer. Costs were projected to be the equivalent of a worker making an hour.

Military robots

Some experts and academics have questioned the use of robots for military combat, especially when such robots are given some degree of autonomous functions. There are also concerns about technology which might allow some armed robots to be controlled mainly by other robots. The US Navy has funded a report which indicates that, as military robots become more complex, there should be greater attention to implications of their ability to make autonomous decisions. One researcher states that autonomous robots might be more humane, as they could make decisions more effectively. However, other experts question this.

One robot in particular, the EATR, has generated public concerns over its fuel source, as it can continually refuel itself using organic substances. Although the engine for the EATR is designed to run on biomass and vegetation specifically selected by its sensors, which it can find on battlefields or other local environments, the project has stated that chicken fat can also be used.

Manuel De Landa has noted that "smart missiles" and autonomous bombs equipped with artificial perception can be considered robots, as they make some of their decisions autonomously. He believes this represents an important and dangerous trend in which humans are handing over important decisions to machines.

General-purpose autonomous robots

General-purpose autonomous robots can perform a variety of functions independently. General-purpose autonomous robots typically can navigate independently in known spaces, handle their own re-charging needs, interface with electronic doors and elevators and perform other basic tasks. Like computers, general-purpose robots can link with networks, software and accessories that increase their usefulness. They may recognize people or objects, talk, provide companionship, monitor environmental quality, respond to alarms, pick up supplies and perform other useful tasks. General-purpose robots may perform a variety of functions simultaneously or they may take on different roles at different times of day. Some such robots try to mimic human beings and may even resemble people in appearance; this type of robot is called a humanoid robot. Humanoid robots are still in a very limited stage, as no humanoid robot can, as of yet, actually navigate around a room that it has never been in. Thus, humanoid robots are really quite limited, despite their intelligent behaviors in their well-known environments.

Factory Robots

- Car production

Over the last three decades, automobile factories have become dominated by robots. A typical factory contains hundreds of industrial robots working on fully automated production lines, with one robot for every ten human workers. On an automated production line, a vehicle chassis on a conveyor is welded, glued, painted and finally assembled at a sequence of robot stations.

- Packaging

Industrial robots are also used extensively for palletizing and packaging of manufactured goods, for example for rapidly taking drink cartons from the end of a conveyor belt and placing them into boxes, or for loading and unloading machining centers.

- Electronics

Mass-produced printed circuit boards (PCBs) are almost exclusively manufactured by pick-and-place robots, typically with SCARA manipulators, which remove tiny electronic components from strips or trays, and place them on to PCBs with great accuracy. Such robots can place hundreds of thousands of components per hour, far out-performing a human in speed, accuracy, and reliability.

Mining robots

Mining robots are designed to help counteract a number of challenges currently facing the mining industry, including skills shortages, improving productivity from declining ore grades, and achieving environmental targets. Due to the hazardous nature of mining, in particular underground mining, the prevalence of autonomous, semi-autonomous, and tele-operated robots has greatly increased in recent times. A number of vehicle manufacturers provide autonomous trains, trucks and loaders that will load material, transport it on the mine site to its destination, and unload without requiring human intervention. One of the world’s largest mining corporations, Rio Tinto, has recently expanded its autonomous vehicle fleet to the world’s largest, consisting of 150 autonomous Komatsu trucks, operating in Western Australia.

Drilling, longwall and rockbreaking machines are now also available as autonomous robots. The Atlas Copco Rig Control System can autonomously execute a drilling plan on a drilling rig, moving the rig into position using GPS, set up the drill rig and drill down to specified depths. Similarly, the Transmin Rocklogic system can automatically plan a path to position a rockbreaker at a selected destination. These systems greatly enhance the safety and efficiency of mining operations.

Healthcare

Robots in healthcare have two main functions. Those which assist an individual, such as a sufferer of a disease like Multiple Sclerosis, and those which aid in the overall systems such as pharmacies and hospitals.

Robots have developed over time from simple basic robotic assistants, such as the Handy 1, through to semi-autonomous robots, such as FRIEND which can assist the elderly and disabled with common tasks.

The population is aging in many countries, especially Japan, meaning that there are increasing numbers of elderly people to care for, but relatively fewer young people to care for them. Humans make the best cares, but where they are unavailable, robots are gradually being introduced.

FRIEND is a semi-autonomous robot designed to support disabled and elderly people in their daily life activities, like preparing and serving a meal. FRIEND makes it possible for patients who are paraplegic, have muscle diseases or serious paralysis (due to strokes etc.), to perform tasks without help from other people like therapists or nursing staff.

Research robots

While most robots today are installed in factories or homes, performing labor or lifesaving jobs, many new types of robot are being developed in laboratories around the world. Much of the research in robotics focuses not on specific industrial tasks, but on investigations into new types of robot, alternative ways to think about or design robots, and new ways to manufacture them. It is expected that these new types of robot will be able to solve real world problems when they are finally realized.

- Nanorobots

Nanorobotics is the emerging technology field of creating machines or robots whose components are at or close to the microscopic scale of a nanometer (10^{-9} meters). Also known as "nanobots" or "nanites", they would be constructed from molecular machines. So far, researchers have mostly produced only parts of these complex systems, such as bearings, sensors, and synthetic molecular motors, but functioning robots have also been made such as the entrants to the Nanobots RoboCup contest. Researchers also hope to be able to create entire robots as small as viruses or bacteria, which could perform tasks on a tiny scale. Possible applications include micro surgery (on the level of individual cells), utility fog, manufacturing, weaponry and cleaning. Some people have suggested that if there were nanobots which could reproduce, the earth would turn into "grey goo", while others argue that this hypothetical outcome is nonsense.

- Reconfigurable Robots

A few researchers have investigated the possibility of creating robots which can alter their physical form to suit a particular task, like the fictional T-1000. Real robots are nowhere near that sophisticated however, and mostly consist of a small number of cube shaped units, which can move relative to their neighbors. Algorithms have been designed in case any such robots become a reality.

- Soft Robots

Robots with silicone bodies and flexible actuators (air muscles, electro active polymers, and ferrofluids), controlled using fuzzy logic and neural networks, look and feel different from robots with rigid skeletons, and can have different behaviors.

- Swarm robots

Inspired by colonies of insects such as ants and bees, researchers are modeling the behavior of swarms of thousands of tiny robots which together perform a useful task, such as finding something hidden, cleaning, or spying. Each robot is quite simple, but the emergent behavior of the swarm is more complex. The whole set of robots can be considered as one single distributed system, in the same way an ant colony can be considered asuperorganism, exhibiting swarm intelligence. The largest swarms so far created include the iRobot swarm, the SRI/MobileRobots CentiBots project and the Open-source Micro-robotic Project swarm, which are being used to research collective behaviors. Swarms are also more resistant to failure. Whereas one large robot may fail and ruin a mission, a swarm can continue even if several robots fail. This could make them attractive for space exploration missions, where failure is normally extremely costly.

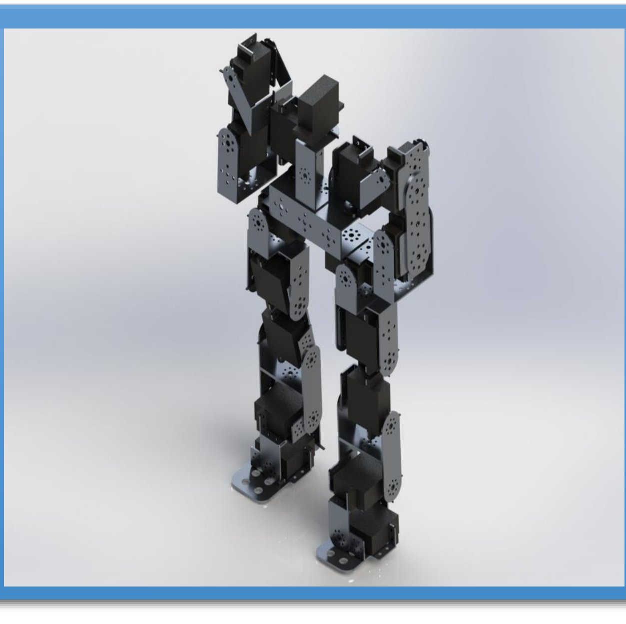
- Haptic interface robots

Robotics also has application in the design of virtual reality interfaces. Specialized robots are in widespread use in the haptic research community. These robots, called "haptic interfaces," allow touch-enabled user interaction with real and virtual environments. Robotic forces allow simulating the mechanical properties of "virtual" objects, which users can experience through their sense of touch.

CHAPTER

2

LITERATURE REVIEW



Chapter 2 – Literature Review

This section presents the literature review for this project. Humanoid robots developed by various laboratories and research in the field of biped locomotion are mentioned.

After ten experimental robots, Honda Company came up with humanoid robots like P1, P2, P3 and ASIMO [1]. P1 is the first Honda prototype of a humanoid robot. This robot can turn electrical and computer switches, grab door knobs, pick up and carry things. The height of P1 is 1.915 m (6’ 3 4/10”) and 175 kg (385 lbs.). P2 is a self- regulating battery-operated android which can walk independently, walk up and down the stairs, and push carts. Wireless techniques were used with a computer torso, motors, battery, wireless radio and other built-in devices. P2 is 1.82 m (5’ 11 7/10”) tall and 210 kg (462 lbs.). P3 has changes in component materials and a decentralized control system which resulted in decrease in height, 1.6 m (5.25 ft.) and weight, 130 kg (286 lbs.). It has 16 joints in total. It has 30 degrees of freedom; 12 for legs, 14 for arms and 4 for hands. The maximum walking speed of P3 is 2 km/hr. ASIMO (Advanced Step in Innovative Mobility) has 26 degrees of freedom. This walking humanoid is 1.2m tall (3’ 11 2/10") and a mass of 52 kg (114.4 lbs.). The walking speed of ASIMO is 0-1.6 km/hr. This robot can recognize moving objects. Other features include posture, gesture, sound, and face recognition.

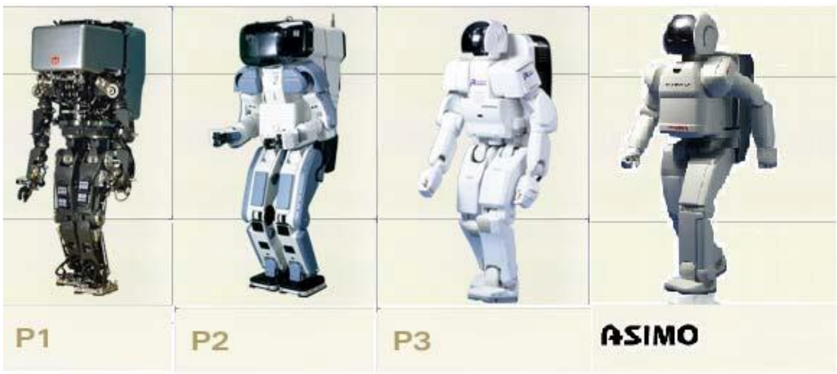


Figure 2-1: Humanoid Robots from Honda Company

Source: http://world.honda.com/ASIMO/

The Humanoid Robotics Institute of Waseda University developed a full scale human-like robot in the 1970s called WABOT-1 [2]. This robot is capable of stable walking by shifting its center of gravity from one leg to another. WABOT-2 is a musician robot that played the piano. WABIAN is a biped with a complete human configuration capable of walking and carrying objects. HALADY is another robot from Waseda University which can interact with humans. It has voice recognition and voice synthesis capabilities along with gesture behavior recognition and conversation capability. HALADY-2 works together with a human partner. Apart from the technology used for HALADY, it also possesses physical interaction functions enabling direct contact with humans. Waseda University has another humanoid robot called iSHA with 26 degrees of freedom mostly driven by electric motors. This robot is capable of two hours autonomous operation. WENDY (Waseda Engineering Designed Symbiont) is a human symbiotic robot. It is capable of physical and emotional interaction with humans. It is a 52 degrees of freedom mechanism with a height of 1.5 m (4’ 11 1/10”) and mass 170kg (374 lbs.). It can recognize the environment using CCD cameras. WAMOEBA (Waseda Artificial Mind on Emotion Base) is designed to emerge intelligence and emotion on par with humans.

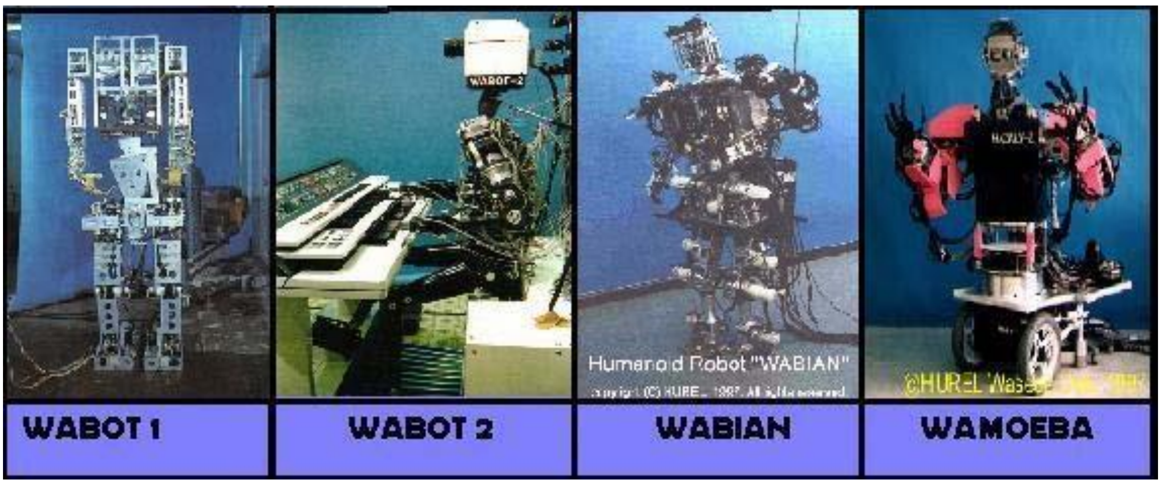


Figure 2-2: Humanoid Robots from Waseda University

Source: http://www.humanoid.rise.waseda.ac.jp

QRIO [3] from Sony Corporation is a biped humanoid robot that can walk on uneven surfaces, dance, recognize faces and voices of people, and also carry on conversations. The pinch detection feature enables QRIO to sense if anything is caught in its joints. A special feature of QRIO is that it reacts to protect itself against an impact. In the event of falling, it gets back up by itself after checking in all directions. The features are attained by Intelligent Servo Actuator (ISA), a drive system with motors, gears, a computer and a set of sensors.

Figure 2-3: QRIO Humanoid by Sony

Source: http://www.sony.net/SonyInfo/QRIO/top_nf.html

Toyota Motor Company has 4 models of humanoid robots called the partner robots and are designed for personal assistance and entertainment. The first robot is designed for walking, assistance, and elderly care. This android is 1.2m (4') tall and weighs 35 kg (77 lbs.). The second model is a mountable robot intended for elderly care and mobility. It stands 1.8 m (6') tall and weighs 75 Kg (165 lbs.). This robot looks like a chair and can carry passengers. The third robot is a rolling version. The areas of application include manufacturing and mobility. It is 1 m (40") tall and also weighs 35 kg (77 lbs.). The fourth model being produced by Toyota is a wire-operated version. It is lighter than the others and can move more quickly. The actuators in the torso act as power sources for arm and leg movements.

Figure 2-4: Partner Robots from Toyota Motor Company

Source: http://www.toyota.co.jp/en/special/robot/

The Massachusetts Institute of Technology has a humanoid COG that has a head, two arms and torso. The head has four eyes, two of which are intended for close-up vision and the other two for distant viewing. The M2 project from MIT's leg lab constructed a set of legs that could be attached to the torso of COG. Coco from MIT is a 15 degree-of-freedom robot. It weighs around 10 kg. The MIT Artificial Intelligence Laboratory has a human-like robotic hand. It has vision and sound input and output, arms and dexterous manipulation. The hand has four fingers, with two joints on with finger and a thumb. These are controlled by tendon like cables. The system is of a human-scale cable-driven tool with actuators and sensors for tactile positioning and torqueing and a computer.

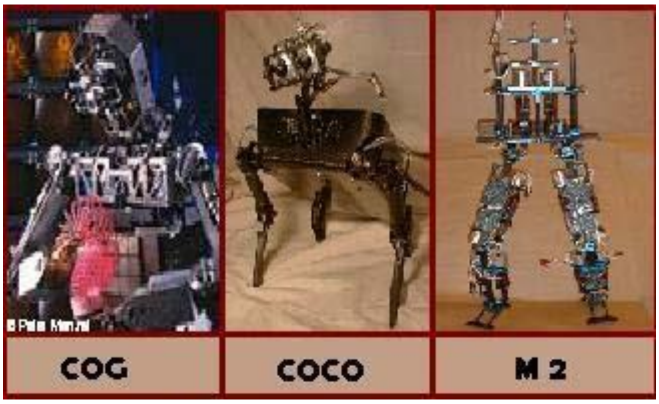


Figure 2-5: COG, COCO, M2 Robots by MIT

Source: http://www.ai.mit.edu/projects/humanoid-robotics-group/
http://www.ai.mit.edu/projects/leglab/robots/m2/m2.html

The GuRoo [4] project of the University of Queensland Robotics Laboratory is a humanoid which capable of balancing, turning, crouching and standing from a prostrate position. It is a 1.2 m robot with a total of 23 joints, fifteen in the legs and abdomen and eight joints in the head and neck assembly. The other 8 joints drive the head and neck assembly and the arms. The joints in the legs and abdomen produce significant mechanical power with large torques and relatively low speeds.

Figure 2-6: GuRoo Humanoid by University of Queensland Robotics Laboratory

Source: http://www.itee.uq.edu.au/~damien/GuRoo/

HRP-2 from Kawada Industries Inc. is a humanoid that is 154 cm (60") tall, weighs 58 kg (127 lbs.) and has 30 degrees-of-freedom. It can cope with uneven surfaces, walk at two-thirds of human speed on a narrow path. HRP-2 is designed to be adult human feminine size. The hip joint of HRP-2 has a cantilever-type structure. It has a waist with 2 degrees of freedom and three CCD cameras inside of a head module.

Figure 2-7: HRP-2 Humanoid by Kawada Industries Inc.

Source: http://www.kawada.co.jp/global/ams/hrp_2.html

CHAPTER 3

METHODOLOGY

3.1 Human Structure

3.2 Proposed Humanoid Robot (MISTBoy)

3.3 Problems for Humanoid Robot

Chapter 3 - Methodology

3.1 Human Structure

The human skeleton is a framework of bones, cartilage, ligaments and joints of the body. Skeletal system of human body provides many levers of movement. A human adult is comprised of 206 bones connected at joints. Skeletal system provides the levers (bones) and axes of rotation (formed due to the joints) about which movements are generated. Hamill and Knutzen (1995) is used for the information about human structure and the related figures in this chapter.

There are three different types: Fixed, partially-movable, and freely movable joints. Fixed joints restricts movement. Examples of these joints are the joints in the adult skull. Slightly movable joints are the joints which allow only a small amount like the joints between the vertebrae.

Most of the joints in the human body are freely movable joints. They are also known as the synovial or the diarthrodial joints. The diarthrodial joints are of seven types based on the type of movement provided and the number of degrees of freedom allowed.

Plane or gliding joints:

Plane or gliding joints are non-axial joints. Due to these joints, the bones can slide over each other. These joints provide flexion, extension, radial deviation, and ulnar deviation. These joints are found at the foot among tarsals and at hand among the carpals.

An example of these joints is shown in figure 3-1.

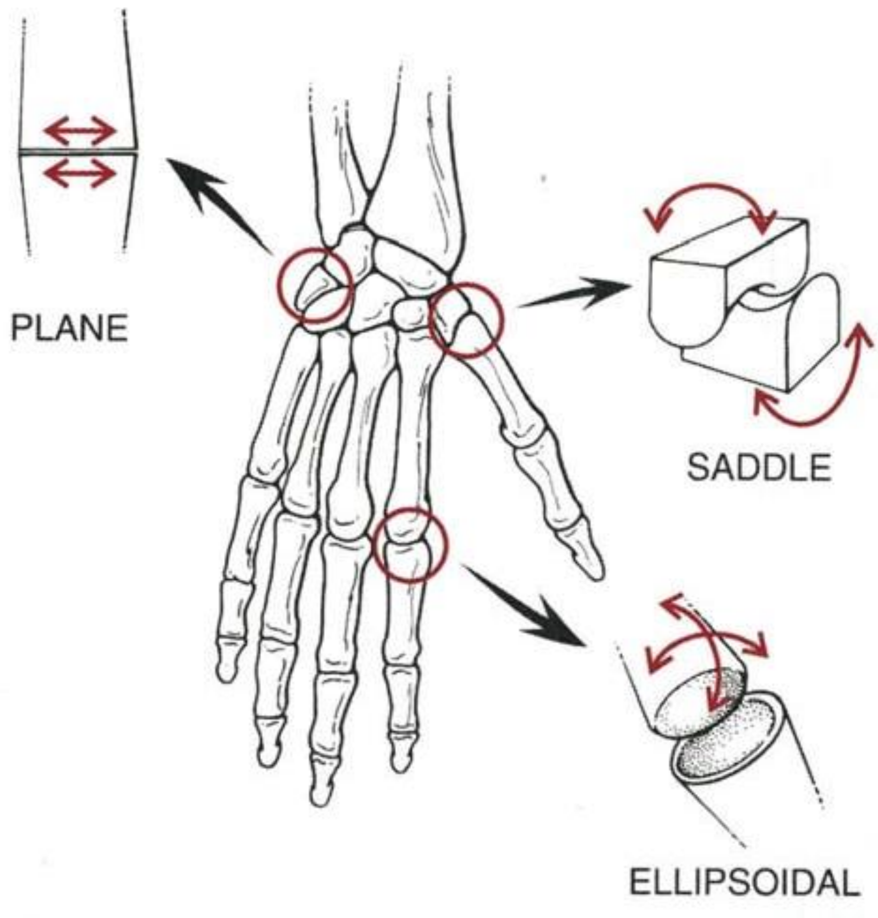


Figure 3-1: Plane, Saddle and Ellipsoidal Joint

Source: Hamill and Knutzen (1995), Page 53

Saddle joints:

These joints are functionally similar to the ellipsoidal joints except that a small amount of rotation is also provided. The carpometacarpal joint of thumb is an example of a saddle joint. Figure 3-1 shows a saddle joint.

Ellipsoidal joints:

These are biaxial joints with two degrees of freedom, providing motion in two planes. Flexion and extension are provided in one plane. The motions in the second plane are abduction and adduction. The radio carpal joint at the wrist is an example of an ellipsoidal joint. Figure 3-1 shows an Ellipsoidal joint.

Hinged joints:

Hinged joints are uniaxial joints with one degree of freedom. Example of such a joint is the ulnohumeral articulation at the elbow. Figure 3-2 gives an example of hinged joint.

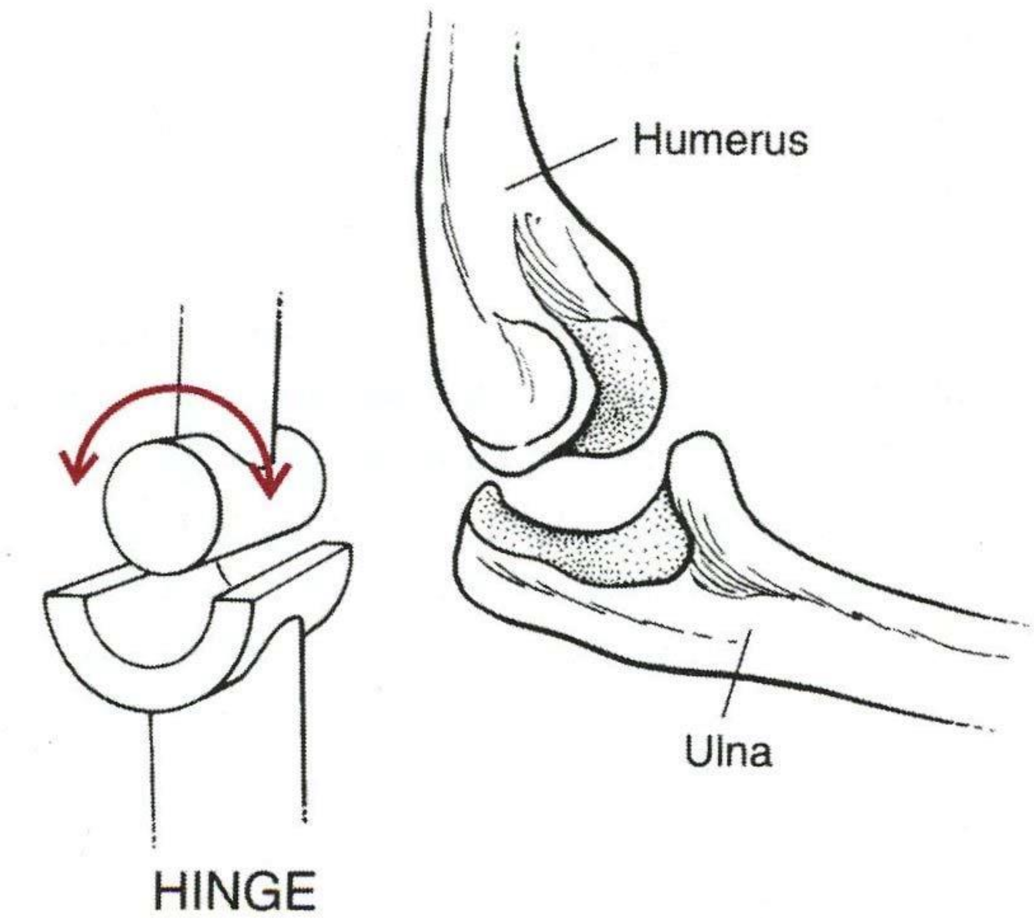


Figure 3-2: Hinge Joint

Source: Hamill and Knutzen (1995), Page 53

Pivot joints:

Pivot joints are also uniaxial with one degree of freedom. The motion provided is rotation, pronation, and supination. These joints can be found at the superior and inferior radioulnar joint. Figure 3-3 shows a pivot joint.

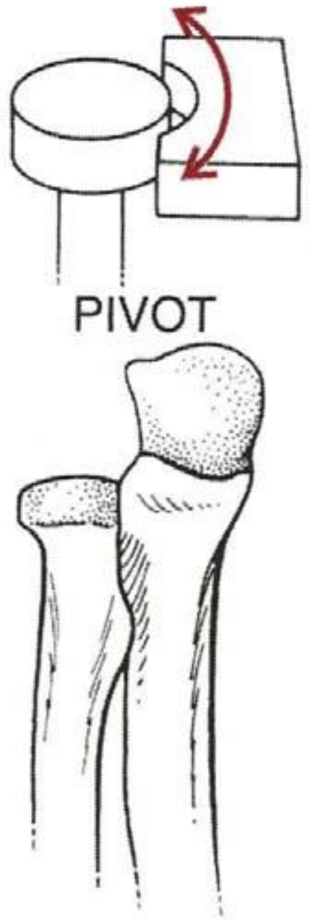


Figure 3-3: Pivot Joint

Source: Hamill and Knutzen (1995), Page 53

Condyloid joints:

Condyloid joints provide primary movement in one plane and a small amount of rotational movement in another plane, giving two degrees-of-freedom. Flexion and extension are provided in the first plane and a limited rotation is provided in another plane. An example for this joint is the knee. Figure 3-4 shows a Condyloid joint.

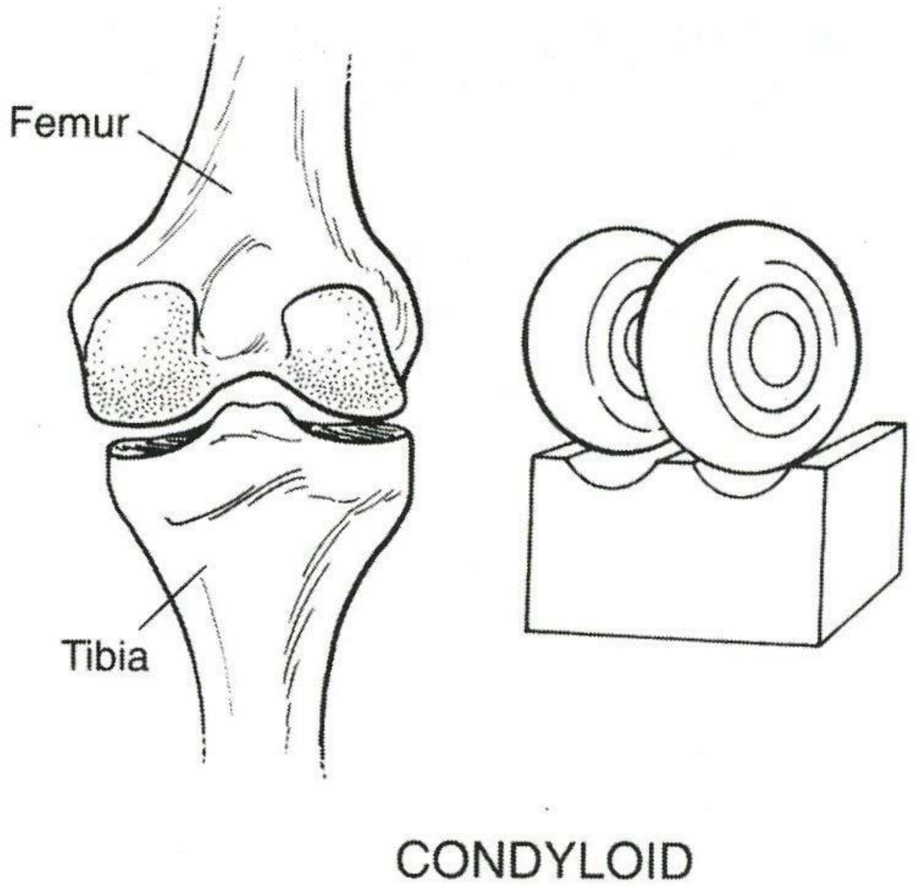


Figure 3-4: Condyloid Joint

Source: Hamill and Knutzen (1995), Page 53

Ball and socket joints:

These are the most mobile joints in the human body with three degrees-of-freedom. The movement is in three planes. Flexion and extension, abduction and adduction, and rotation are the movements provided. Examples of ball and socket joints are the hip and shoulder joints. Figure 3-5 shows a ball and socket joint [5].

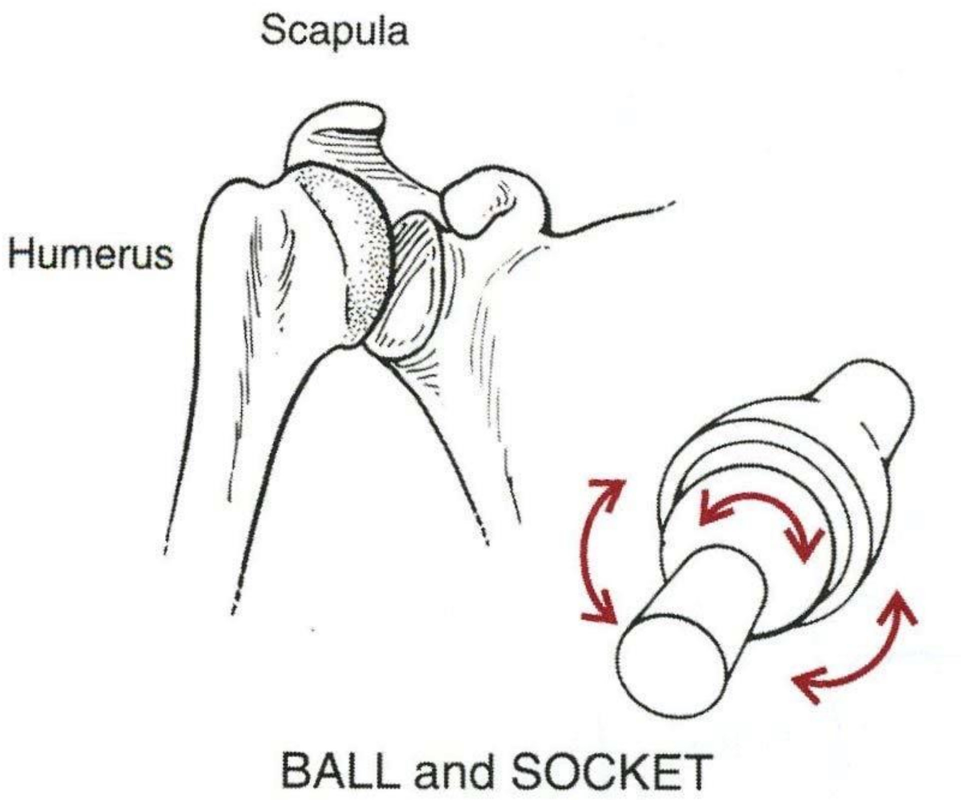


Figure 3-5: Ball and Socket Joint

Source: Hamill and Knutzen (1995), Page 53

3.2 Proposed Humanoid Robot (MISTBoy)

Figure 3-6: MISTBoy

MISTBoy is a humanoid with 17 degree of freedom. Total 17 number of servo's and mechanical links are used to attain human like motion. It is built with cost efficient material Aluminum.

It is lightweight and simple in design.

3.3 Problems for Humanoid Robot

3.3.1 Design Issues

Most of the humanoid robot prototypes present design problems as mainly regarding with:

- Complex mechanical design
- Complex control equipment
- Sensor equipment
- High-cost
- Safety
- Lightweight
- Power consumption
- Human-like or animal-like structure.

Despite of complex mechanical design, most of humanoid robots have a high number of degrees of freedom. They increase the complexity of structures, actuation and control requirements. There are currently two essential ways to design a humanoid robot. The first one models the robot like a set of rigid links, which are connected with joints. At least the functionality of the main components of humanoid such as legs, trunk, shoulders, arms and hands have to be clearly understood in order to design the basic mechanical features, [Carbone et al., 2001]. A second design is emerging in some research works that use the knowledge acquired on biomechanics. In this one, the bottom line of humanoid robots is a complex resemblance of the human skeleton.

Reducing the complexity of the design is a challenge for the development of a low-cost humanoid robot. Each component should not have a complex design in order to have a fairly simple operation, but still with suitable motion capability. The high number of DOFs can be reduced by using proper mechanisms that fulfil the mobility operation of the robot sub-systems.

In addition with complex control equipment, complex actuating systems such as electrical and pneumatic actuators are used in humanoid robot designs. Control systems of these actuation devices require complex hardware that have generally structures with large dimensions. In some cases several personal computers that cann ot be installed on robot structure are used as part of a control system.

A low-cost humanoid robot requires a control hardware that gives a compact design to the structure and also manages successfully the robot system.

Regarding with sensor equipment, the interface between the humanoid robot and environment is obtained by using a sensitization system. In addition, the control system requires sensors for walking with control laws of close-loop. In general, humanoid robots are composed by complex sensor equipment's that monitor the operation of the systems. The sensor equipment for a low-cost humanoid robot must be composed by a suitable number of proper sensors with easy-operation characteristics that give a fitted interface between robot and environment.

Regarding with high-cost, new approaches present special designs that have been developed in order to obtain human-like structures of humanoid robots. In general, the complexity of the systems for a human-like humanoid robots requires high-costs of manufacture.

Regarding with safety, the safety of users has top priority, since the robot will be used in close contact with its users. In many cases the robot may be a danger to its environment and to its users. The risk of unintended collision of robot and users cannot be ruled out completely, even if high operating velocities are demanded.

Regarding with lightweight, humanoid robots must be manufactured by using a lightweight material with high stiffness. Moreover, resulting potential danger of humanoid robot can be reduce by reducing the moving masses and by employing flexible structures for the extremities.

The structure of a low-cost humanoid robot must be composed by a feasible material with proper stiffness and lightweight too. Articulated mechanisms in the robot sub- systems must have a structure with a lightweight design.

Regarding with power consumption, humanoid robots are multi-body systems that are composed by several components. High drive power is necessary for fulfil the actuation requirements of body masses motion for humanoid robot components. A low-cost humanoid robot requires actuators with no-complex systems, lightweight and proper functions that enable successful performances of basic operations of the robot.

Regarding with human-like or animal-like structure, the humanoid robots have to co-exist naturally with human as a partner or a helper in human daily life, or as pet to mentally heal him/her in our living environment. For the co-existence with human, a friendly structure is a very important factor which decides the successful accepting of humanoid robots by the human being.

3.3.2 Operation Issues

The above-mentioned humanoid robots have usually the operation problems regarding with:

- Complex control strategies
- High level skills of users
- Operation robustness
- Stability in locomotion
- Manipulation capabilities
- Level of autonomy.

Regarding with complex control strategies, humanoid robots are generally difficult to operate. In fact, usually they are operated by using complex systems. The existing control schemes for humanoid robots involve basically conventional trajectory-tracking controllers for the joint actuators. The required position accuracy may not be achieved under the existing limitations of force control.

The control algorithms for an easy-operation humanoid robot must be composed by no- complex routines that enable proper functions for sub-systems and to give successful operations for the robot. In the case of close-loop strategies, the interface with the sensor equipment must be no-complex with fitted function.

Regarding with high level skills of user, humanoid robots require expert users with special skills for operating their systems. Sometimes these operators have to monitor continuously the robot operation in order to obtain successful performances or prevent some damages for the robot structure.

Regarding with operation robustness, position accuracy of the sub-systems is demanded in humanoid robots for operating applications. For example, an accuracy level can be demanded for the alignment of the visual system of head and for the gripper positioning, as discussed in [Albers et al., 2003].

In general, a low-cost easy-operation humanoid robot performs motions with unfeasible accuracy that are usually given by the slow answer of the actuators or/and the back age of mechanisms.

Regarding with stability of locomotion, stability is fundamental for a secure operation of a humanoid robot. Controlling humanoid robots to locomote in dynamic manner is one of the most challenging issues for robot designers and control engineers. The robot sub-systems must be able to balance statically and dynamically the weight of the body by keeping the projection of zero movement point within the support area. A proper synchronization between the movements of humanoid module is important in order to obtain the robot structure as equilibrated in the operation. Depending on the terrain and required speed of locomotion, humanoid robots should be able to walk, climb, run and jump.

In general, the theory of Zero Movement Point (ZMP), [Vukobratovic et al., 2004], is used as standard evaluation for stability of humanoid robots. Many researches have proposed generally walking motion that is based on ZMP theory to ensure the dynamic stability. The ZMP is defined as the point on the ground where the total moment of the active forces are equals to zero. Synthesis of a stable gait is based upon the concept of ZMP, expressed by means of three condition**,** Figure 3-7,

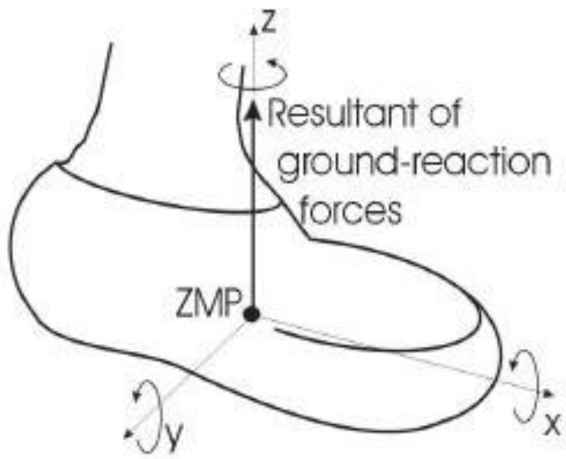


Figure 3-7: Models for Zero movement point- resultant forces on the foot

$T_{x\ (inertia\ and\ gravitational)} = 0$ ... *Equation 3-1*

$T_{y\ (inertia\ nad\ gravitational)} = 0$ ... *Equation 3-2*

$T_{x\ (inertia\ and\ gravitational)} = T_{(foot\ friction)}$ ... *Equation 3-3*

Where T_x is the torque about X axis, T_y is the torque about Y axis, T_z is the torque about Z axis and T is the total applied torque.

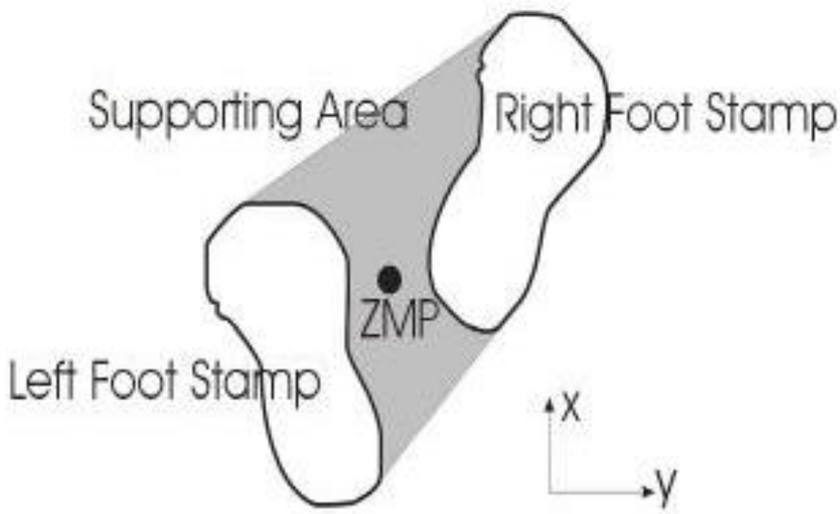


Figure 3-8: Models for Zero movement point-a supporting area in grew color.

If ZMP is in convex hull where $T_x = 0$ and $T_y = 0$ of the foot-support area,

Figure 3-8, then humanoid robot can stand or walking without falling down. The ZMP must always lay in the convex hull of the all contact points on the ground plane since moments in the ground plane are given only by normal forces at the contact points. Those forces are always be possible in the upper vertical direction. Therefore, only if the ZMP stay in the supporting area, the planned walk motion is dynamically possible for a humanoid robot. In general, a desired ZMP trajectory is previously design, then a body motion that comprises with the ZMP trajectory is derived [6].

Since in general the body motion is limited, not every desired ZMP trajectory can be achieved.

The locomotion strategies for an easy-operation humanoid robot must equilibrate the structure with a no-complex algorithm. Keeping the ZMP in the support area by using a no-complex balance strategies is one of the principal problems for the project of a low- cost easy-operation humanoid robot.

Regarding with manipulation capabilities, captured human motion can be a rich source of examples of manipulation tasks. One difficulty is that the problem to be solved with a robot is never exactly the same as that in human beings. The robot will have different sizes and degrees of freedom and its workspace may be more constrained. Humanoid robots are developed to perform human tasks like dirty or dangerous jobs or/and personal assistance where they should be able to assist the sick and elderly people. Thus, a low-cost easy-operation humanoid robot must have the character to manipulate objects of a wide variety of sizes, shapes, and frictional properties, [Kawauchi et al.,2003].

Regarding with level of autonomy, humanoid robots have to prove efficiention in jobs that are very repetitive which may lead to mistakes or accidents due to a lapse in concentration, and other jobs that humans may find degrading. Humanoid robot projects have been focused on creating machines that can engage on behaviors that humans consider intelligent. Researchers design systems which can mimic human by managing themselves the operation. The dream of smart machines is becoming a reality with the development of the Artificial Intelligent (AI) technology. AI is composed of different fields that have in common the creation of machines that can “think”.

In order to have autonomy for a low-cost humanoid robot the control system must be included in the robot structure by still having compact design and lightweight.

CHAPTER

4

KINEMATICS

4.1 Forward Kinematics

4.2 Inverse kinematics

Chapter 4 – Kinematics

Kinematics is the branch of classical mechanics which describes the motion of points, bodies (objects) and systems of bodies (groups of objects) without regard to the forces causing it. The term is the English version of A.M. Ampère's *cinématique,* which he constructed from the Greek κίνημα, kinema (movement, motion), derived from κινεῖν, kinein (to move).

The study of *kinematics* is often referred to as the *geometry of motion.* To describe motion, kinematics studies the trajectories of points, lines and other geometric objects and their differential properties such as velocity and acceleration. Kinematics is used in astrophysics to describe the motion of celestial bodies and systems, and in mechanical engineering, robotics and biomechanics to describe the motion of systems composed of joined parts (multi-link systems) such as an engine, a robotic arm or the skeleton of the human body.

4.1 Forward Kinematics

Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters. The kinematics equations of the robot are used in robotics, computer games, and animation.

The kinematics equations for the series chain of a robot are obtained using a rigid transformation [Z] to characterize the relative movement allowed at each joint and separate rigid transformation [X] to define the dimensions of each link.

The kinematics equations for a serial chain robot are obtained by formulating the loop equations in terms of a transformation [T] from the base to the end-effector, which is equated to the series of transformations along the robot. The result is,

$$[T] = [Z_1][X_1][Z_2][X_2] \dots \dots [X_{n-1}][Z_n] \qquad \dots 4\text{-}1$$

Where [T] is the transformation locating the end-link. These equations are called the kinematics equations of the serial chain.

The kinematics equations for a parallel chain, or parallel robot, formed by an end-effector supported by multiple serial chains are obtained from the kinematics equations of each of the supporting serial chains. Suppose that *m* serial chains support the end-effector, then the transformation from the base to the end-effector is defined by *m* equations,

$$[T] = [Z_{1,j}][X_{1,j}][Z_{2,j}][X_{2,j}] \dots \dots [X_{n-1,j}][Z_{n,j}], \quad j = 1, \dots \dots, m. \qquad \dots 4\text{-}2$$

4.2 Inverse Kinematics

Inverse kinematics refers to the use of the kinematics equations of a robot to determine the joint parameters that provide a desired position of the end-effector. Specification of the movement of a robot so that its end-effector achieves a desired task is known as motion planning. Inverse kinematics transforms the motion plan into joint actuator trajectories for the robot.

Forward kinematics uses the joint parameters to compute the configuration of the chain, and inverse kinematics reverses this calculation to determine the joint parameters that achieves a desired configuration.

CHAPTER

5

ZMP

(ZERO MOMENT POINT)

Chapter 5 – ZMP

Zero moment point is a concept related with dynamics and control of legged locomotion, e.g., for humanoid robots. It specifies the point with respect to which dynamic reaction force at the contact of the foot with the ground does not produce any moment in the horizontal direction, i.e. the point where the total of vertical inertia and gravity forces equals 0 (zero). The concept assumes the contact area is planar and has sufficiently high friction to keep the feet from sliding.

ZMP computation

The resultant force of the inertia and gravity forces acting on a biped robot is expressed by the formula:

$$F^{gi} = mg - ma_G \qquad \text{... 5-1}$$

Where m is the total mass of the robot, g is the acceleration of the gravity, G is the center of mass and a_G is the acceleration of the center of mass.

The moment in any point X can be defined as:

$$M_X^{gi} = \overrightarrow{XG} \times mg - \overrightarrow{XG} \times ma_G - \dot{H}_G \qquad \text{... 5-2}$$

Here, $\dot{H}_G$is the rate of angular momentum at the center of mass.

The Newton–Euler equations of the global motion of the biped robot can be written as:

$$F^c + mg = ma_G \qquad \text{... 5-3}$$

$$M_X^c + \overrightarrow{XG} \times mg = \dot{H}_G + \overrightarrow{XG} \times ma_G \qquad \text{... 5-4}$$

Here F^c is the resultant of the contact forces at X and M_X^c is the moment related with contact forces about any point X.

The Newton–Euler equations can be rewritten as:

$$F^{c} + (mg - ma_{G}) = 0 \quad \text{... 5-5}$$

$$M_{X}^{c} + \left(\overrightarrow{XG} \times mg - \overrightarrow{XG} \times ma_{G} - \dot{H}_{G}\right) = 0 \quad \text{... 5-6}$$

So it’s easier to see that we have:

$$F^{c} + F^{gi} = 0 \quad \text{... 5-7}$$

$$M_{X}^{c} + M_{X}^{gi} = 0 \quad \text{... 5-8}$$

These equations show that the biped robot is dynamically balanced if the contact forces and the inertia and gravity forces are strictly opposite [7].

If an axis Δ^{gi} is defined, where the moment is parallel to the normal vector n from the surface about every point of the axis, then the Zero Moment Point (ZMP) necessarily belongs to this axis, since it is by definition directed along the vector η. The ZMP will then be the intersection between the axis Δ^{gi} and the ground surface such that:

$$M_{Z}^{gi} = \overrightarrow{ZG} \times mg - \overrightarrow{ZG} \times ma_{G} - \dot{H}_{G} \quad \text{... 5-9}$$

With

$$M_{Z}^{gi} \times \eta = 0 \quad \text{... 5-10}$$

Where Z represents the ZMP.

Because of the opposition between the gravity and inertia forces and the contact forces mentioned before, the Z point (ZMP) can be defined by:

$$\overrightarrow{PZ} = \frac{\eta \times M_{P}^{gi}}{F^{gi}.\eta} \quad \text{... 5-11}$$

Here P is a point on the contact plane, e.g. the normal projection of the center of mass.

CHAPTER

6

CAD DESIGN AND ASSEMBLY

6.1 Draft of Individual Part

6.2 Finished Parts

6.3 Body Parts Assembly

6.4 Final Assembly

Chapter 6 – CAD Design and Assembly

Basic designing concept is encouraged by Human motions. Preliminary design is hand drawn and then converted to CAD for better understanding and analysis. CAD design of MISTBoy is done by using SolidWorks 2011.

6.1 Draft of Individual Part

6.1.1 Waist U-Bracket

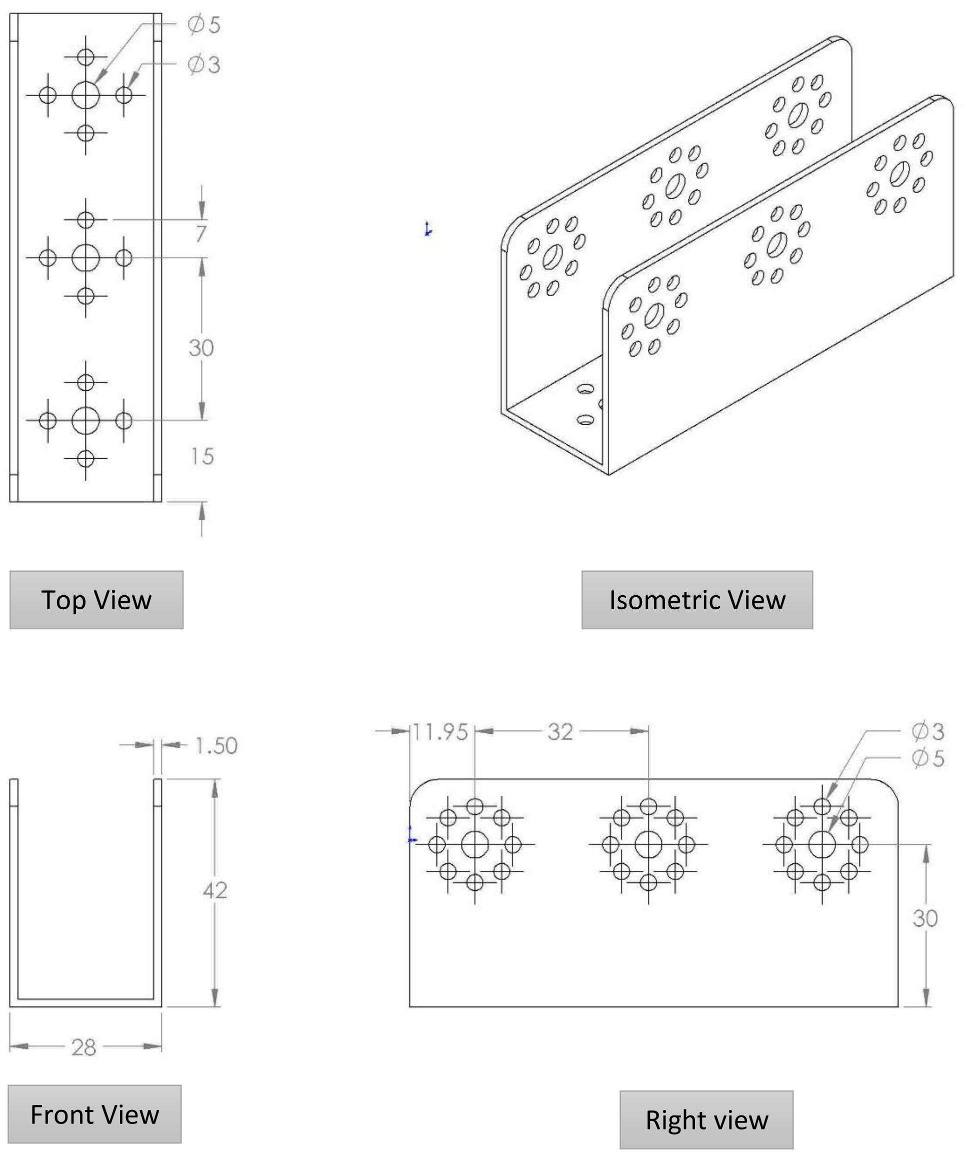


Figure 6-1: Isometric View of Waist U-Bracket

6.1.2 L-Bracket

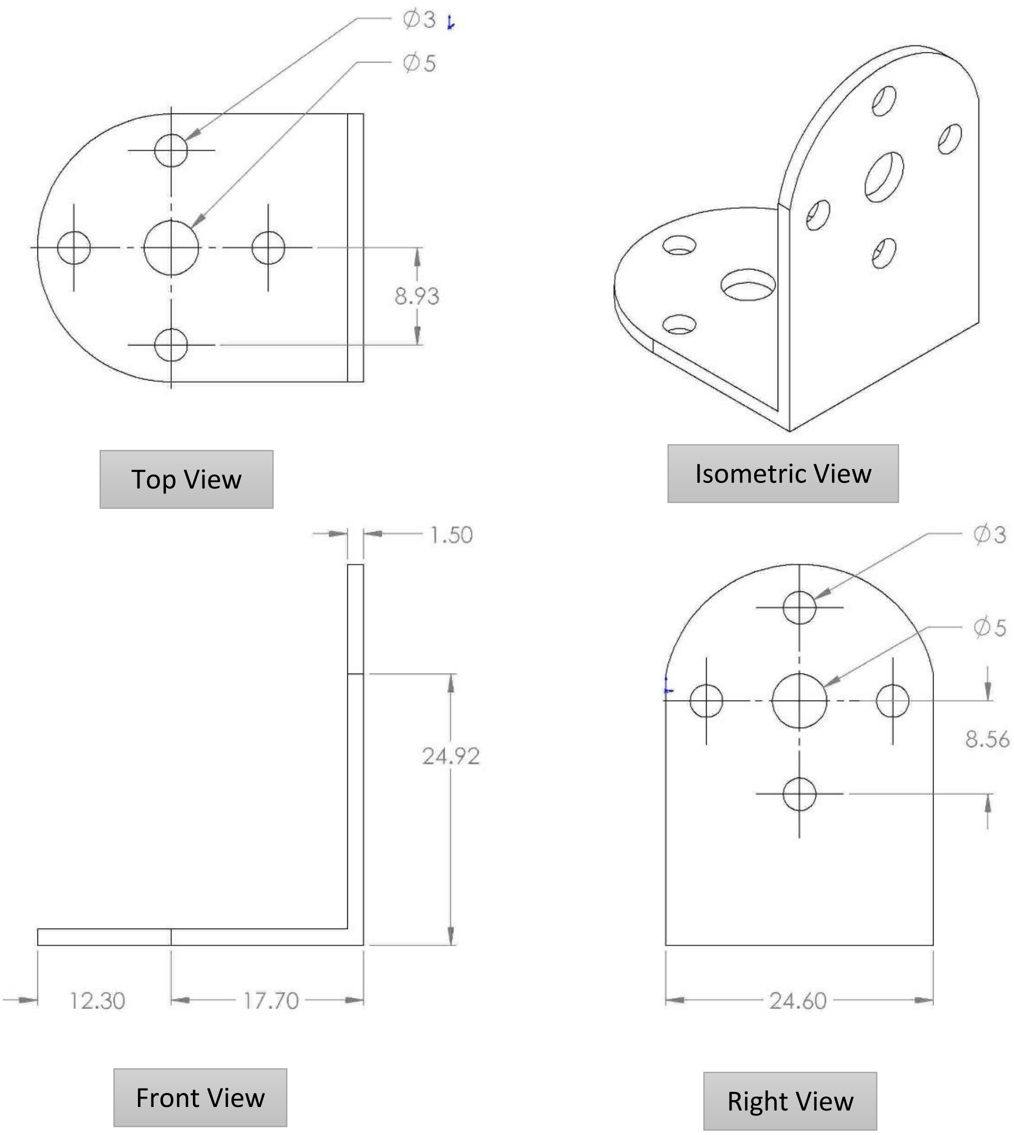


Figure 6-2: Isometric View of L-Bracket

6.1.3 Long U-Bracket

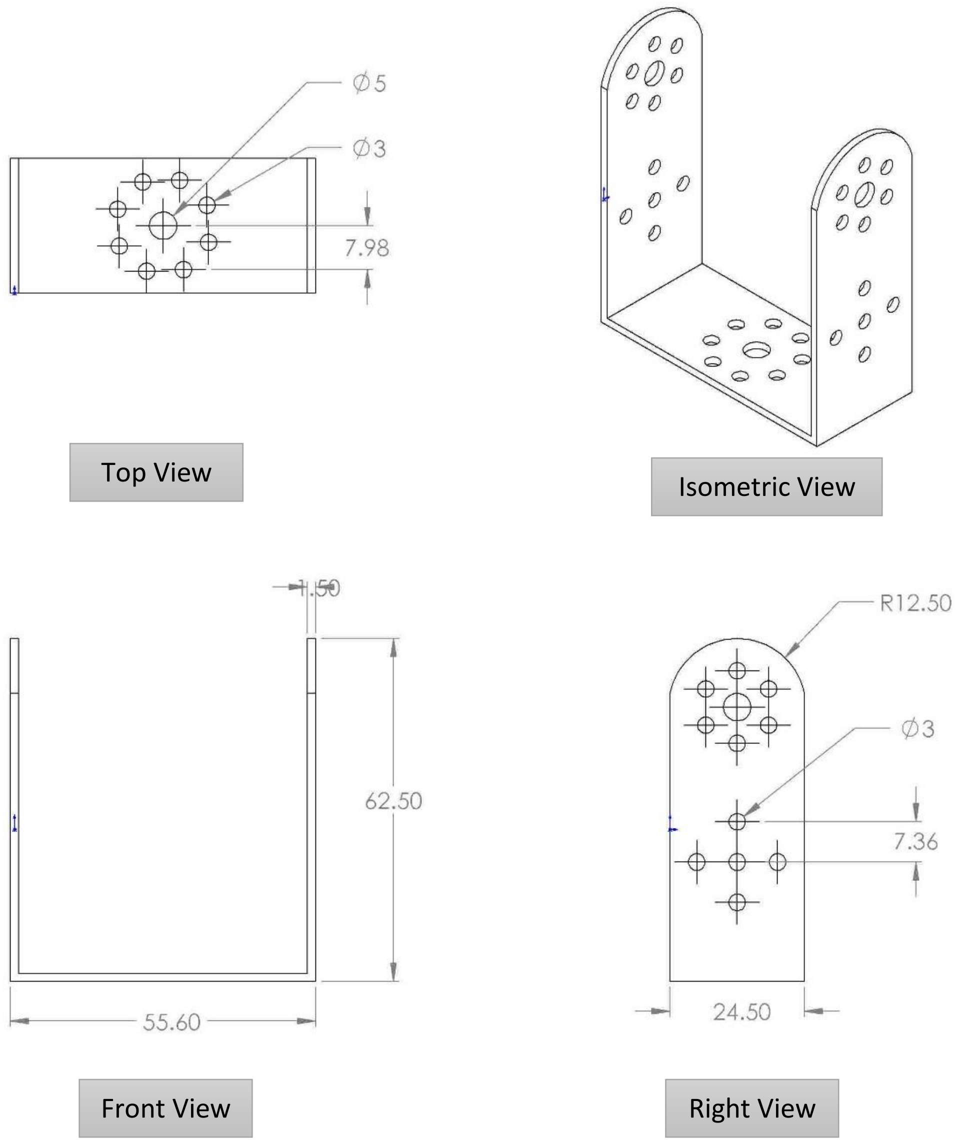


Figure 6-3: Isometric View of Long U-Bracket

6.1.4 Multi-Purpose bracket

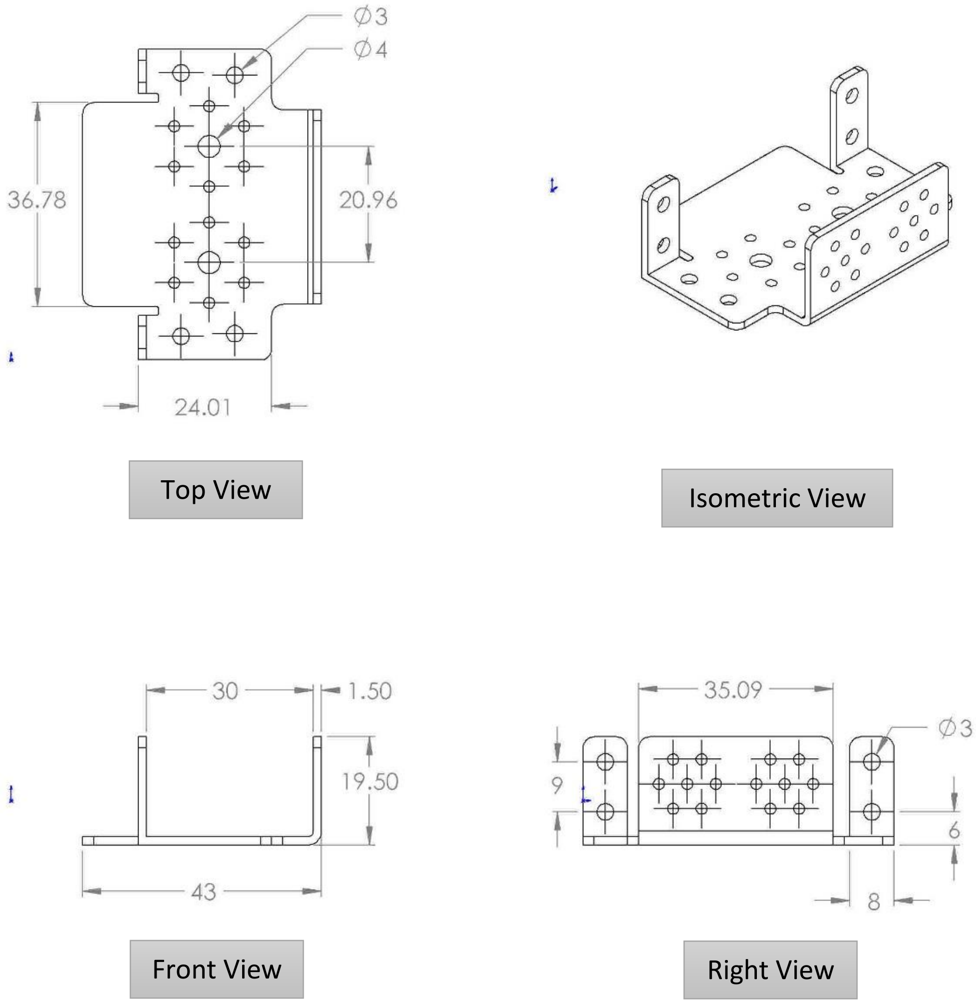


Figure 6-4: Isometric View of Multi-Purpose bracket

6.1.5 Oblique U-Bracket

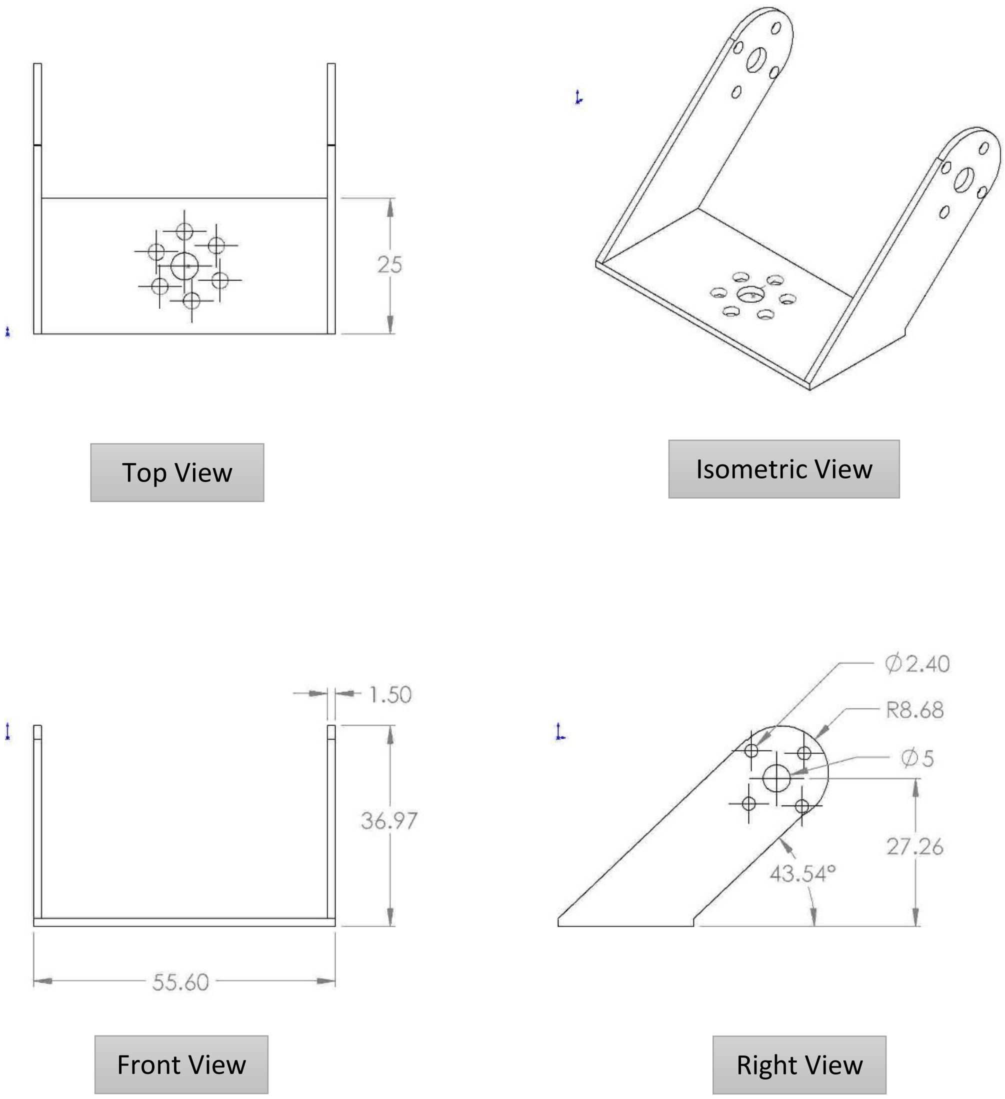


Figure 6-5: Isometric View of Oblique U-Bracket

6.1.6 One-Type Bracket

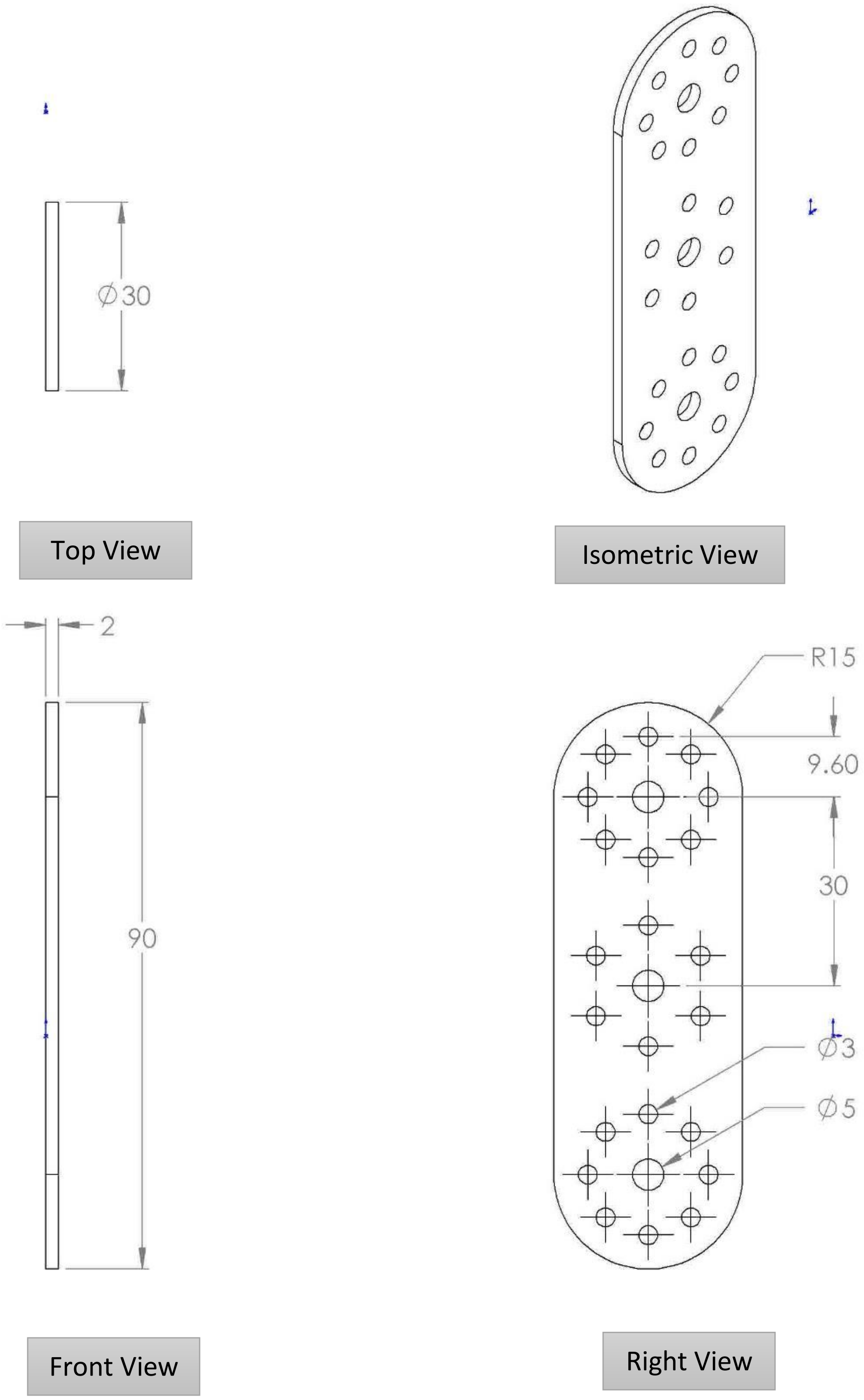


Figure 6-6: Isometric View of One-Type Bracket

6.1.7 Short U-Bracket

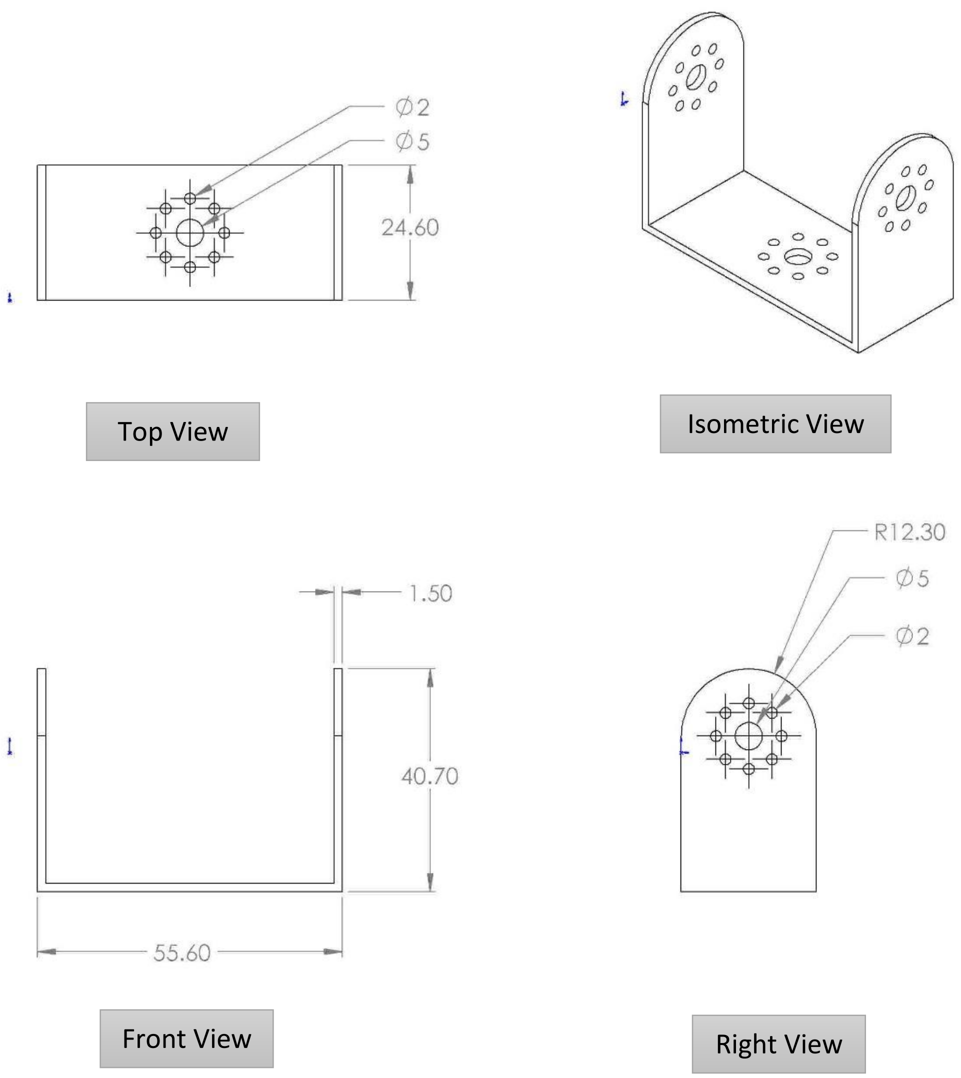


Figure 6-7: Isometric View of Short U-Bracket

6.1.8 Foot Base

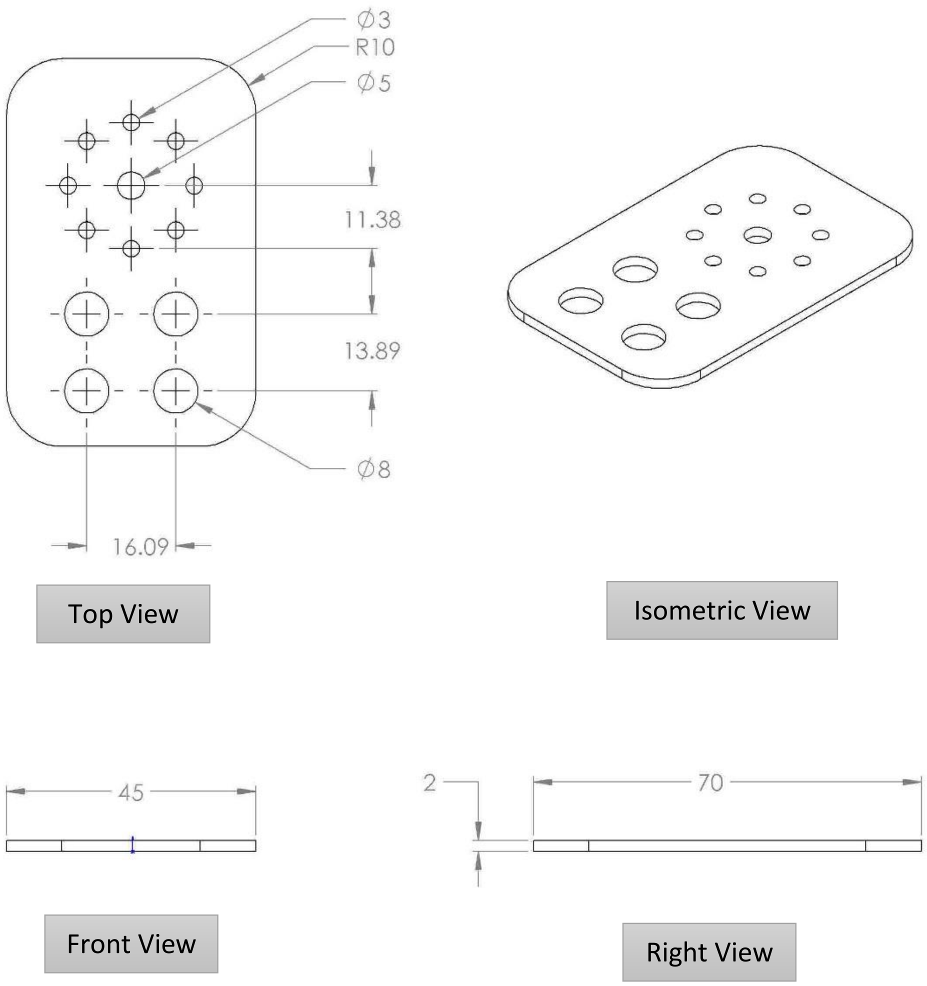


Figure 6-8: Isometric View of Foot Base

6.2 Finished Parts

6.2.1 Waist U-Bracket

Figure 6-9: Waist U-Bracket

6.2.2 L-Bracket

Figure 6-10: L-Bracket

6.2.3 Long U-Bracket

Figure 6-11: Long U-Bracket

6.2.4 Foot Base

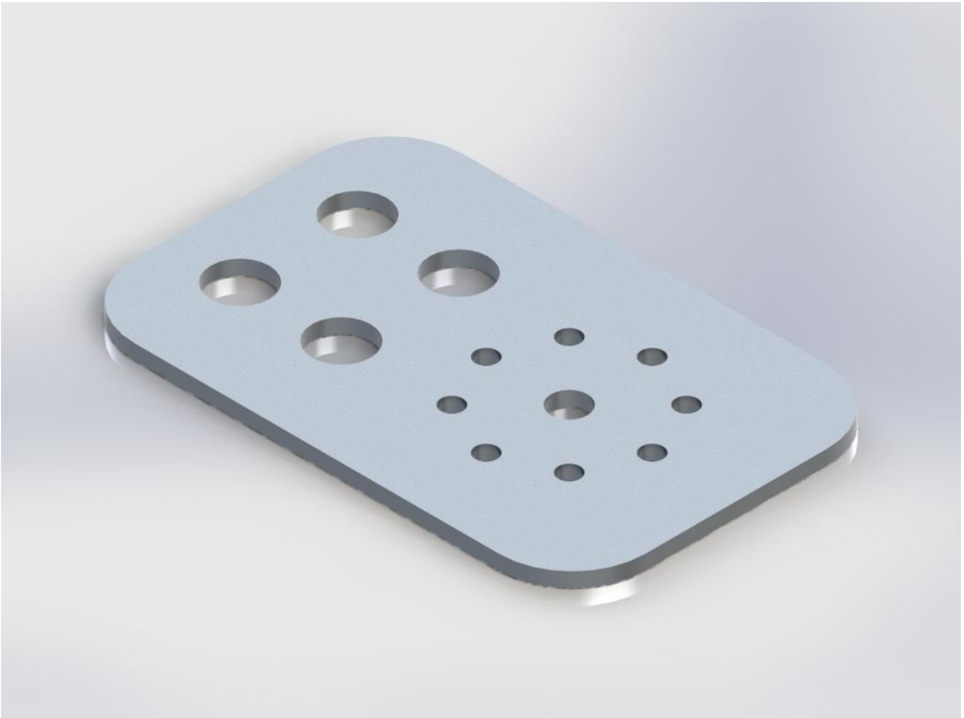


Figure 6-12: Foot Base

6.2.5 Multi-Purpose Bracket

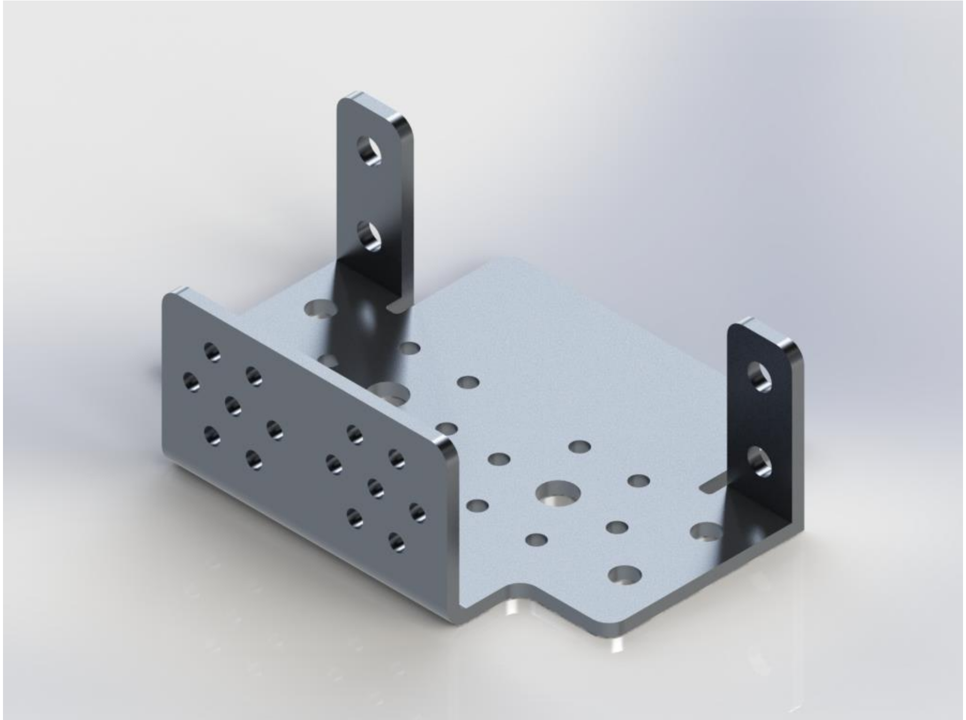


Figure 6-13: Multi-Purpose Bracket

6.2.6 Oblique U-Bracket

Figure 6-14: Oblique U-Bracket

6.2.7 One-Type Bracket

Figure 6-15: One-Type Bracket

6.2.8 Short U-Bracket

Figure 6-16: Short U-Bracket

6.3 Body Parts Assembly

6.3.1 Head and Shoulder Assembly

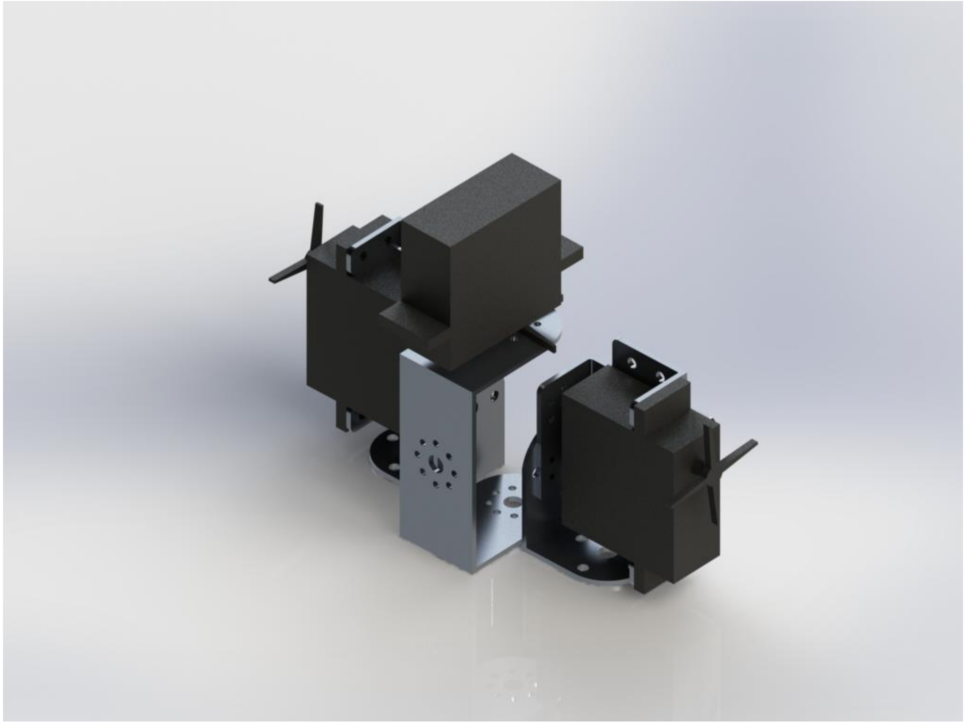


Figure 6-17: Head and Shoulder Assembly

6.3.2 Hand's Assembly

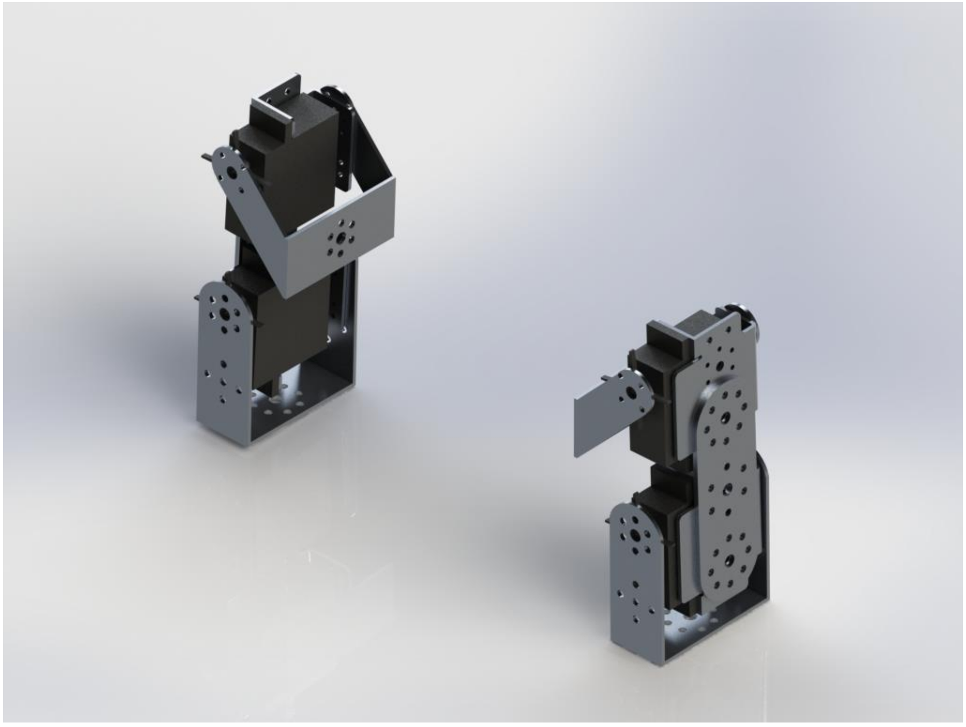


Figure 6-18: Hand's Assembly

6.3.3 Waist and Trunk Assembly

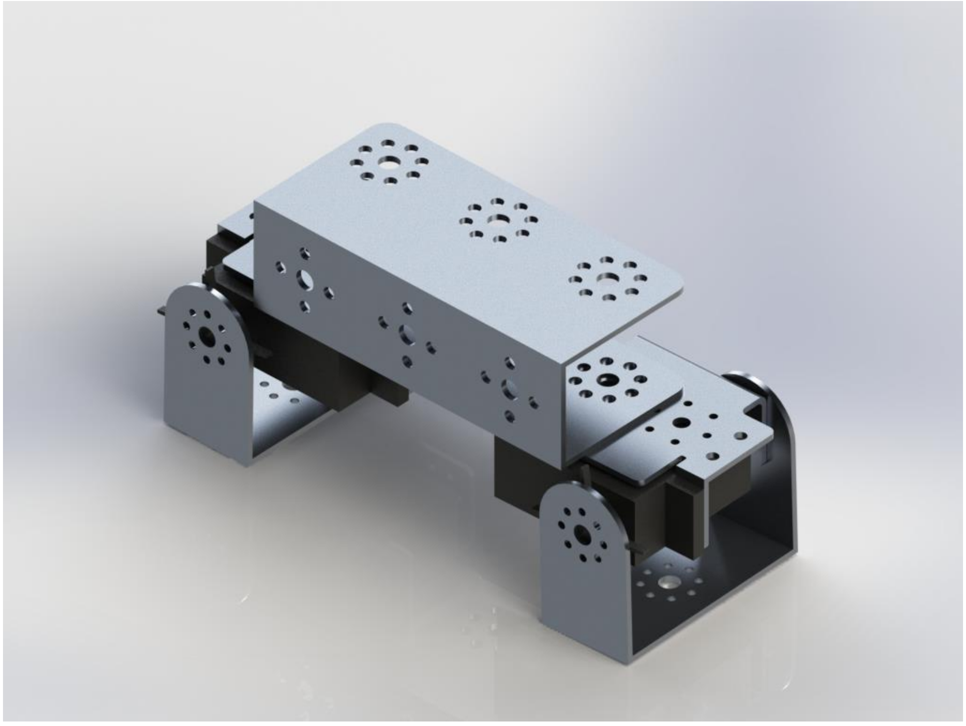


Figure 6-19: Waist and Trunk Assembly

6.3.4 Leg's Assembly

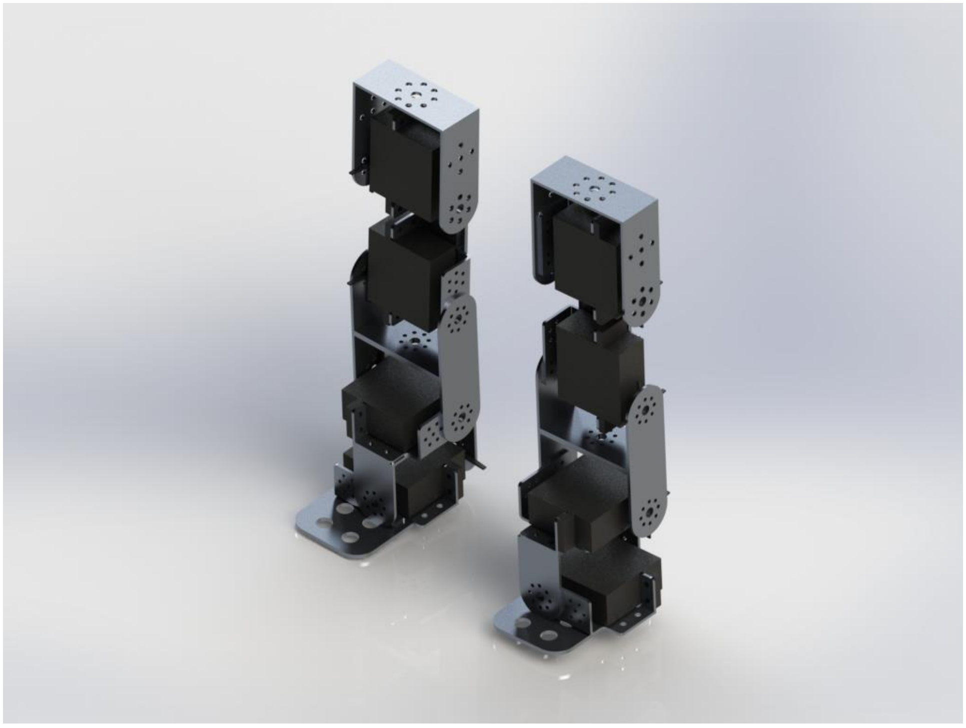


Figure 6-20: Leg's Assembly

6.4 Final Assembly

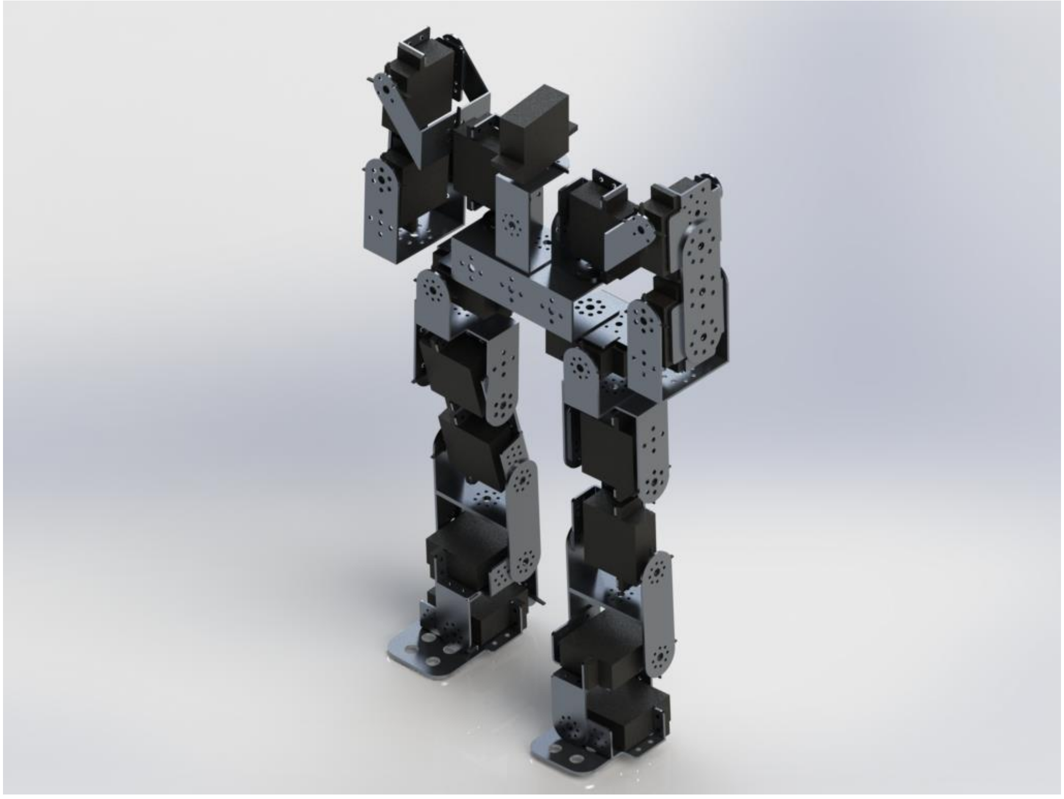


Figure 6-21: Final Assembly

CHAPTER

7

DESIGN ANALYSIS

7.1 Mass Property

7.2 Stress and Strain Analysis

7.3 Fatigue Analysis

Chapter 7 - Design Analysis

7.1 Mass Property

Material: Aluminum Alloy 1060

Mass = 963 grams

Total weld mass = 0 grams

Volume = 6.46e + 005 cubic millimeters

Surface area = 3.89e + 005 square millimeters

Center of mass: (millimeters)

$$X = -1.37$$

$$Y = -89.2$$

$$Z = -24.8$$

Principal axes of inertia and principal moments of inertia: (grams × square millimeters)

Taken at the center of mass.

$$Ix = (-0.00736, 0.999, -0.036) \quad Px = 4.44e + 006$$

$$Iy = (-0.999, -0.00601, 0.0373) \quad Py = 1.36e + 007$$

$$Iz = (0.037, 0.0363, 0.999) \quad Pz = 1.77e + 007$$

Moments of inertia: (grams × square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

$$Lxx = 1.36e + 007 Lxy = -7.3e + 004 Lxz = -1.48e + 005$$

$$Lyx = -7.3e + 004 Lyy = 4.46e + 006 Lyz = -4.78e + 005$$

$$Lzx = -1.48e + 005 Lzy = -4.78e + 005 Lzz = 1.77e + 007$$

Moments of inertia: (grams × square millimeters)

Taken at the output coordinate system.

$$Ixx = 2.19e+007 Ixy = 4.45e+004 Ixz = -1.15e+005$$

$$Iyx = 4.45e+004 Iyy = 5.05e+006 Iyz = 1.65e+006$$

$$Izx = -1.15e+005 Izy = 1.65e+006 Izz = 2.53e+007$$

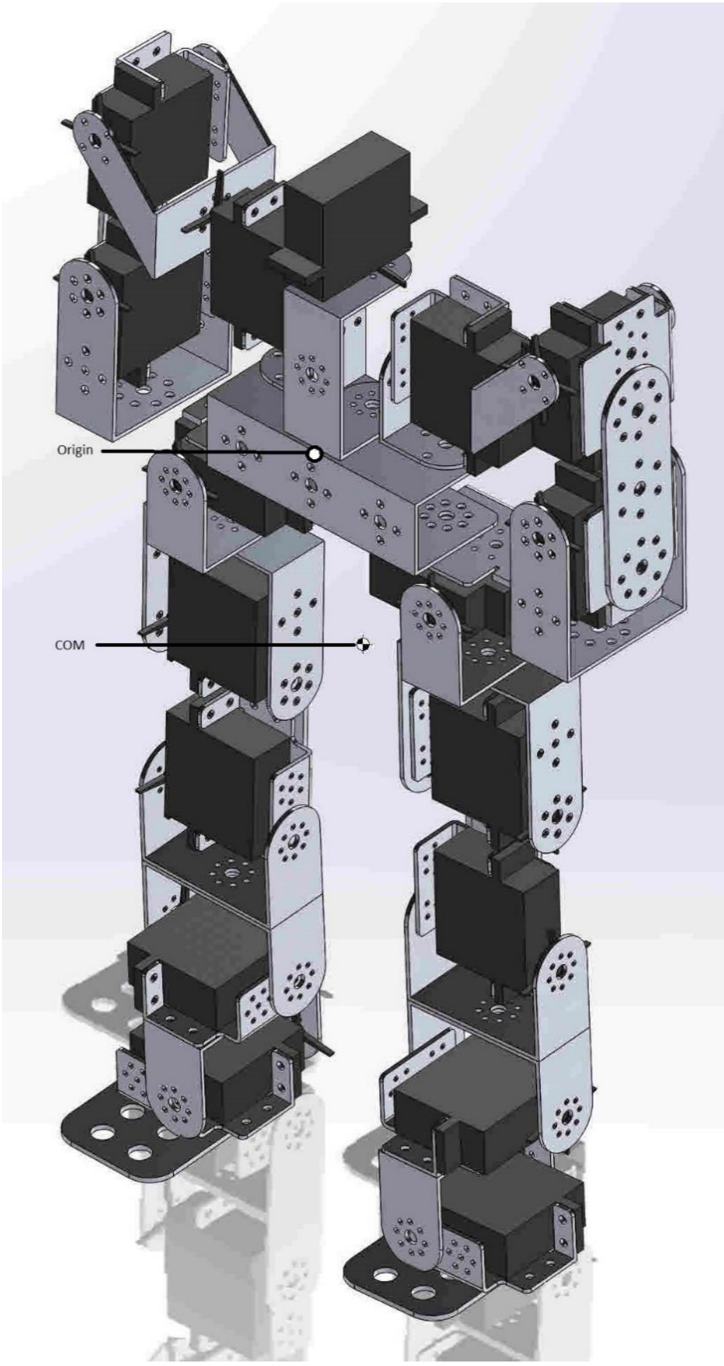


Figure 7-1: Location of Origin and COM

7.2 Stress and Strain Analysis

Analysis Condition:

Fixed geometry:	Foot Base
External Force:	0.2 Newton Force Acting On L-Bracket Each
Gravitational Force:	9.81 m/s^2

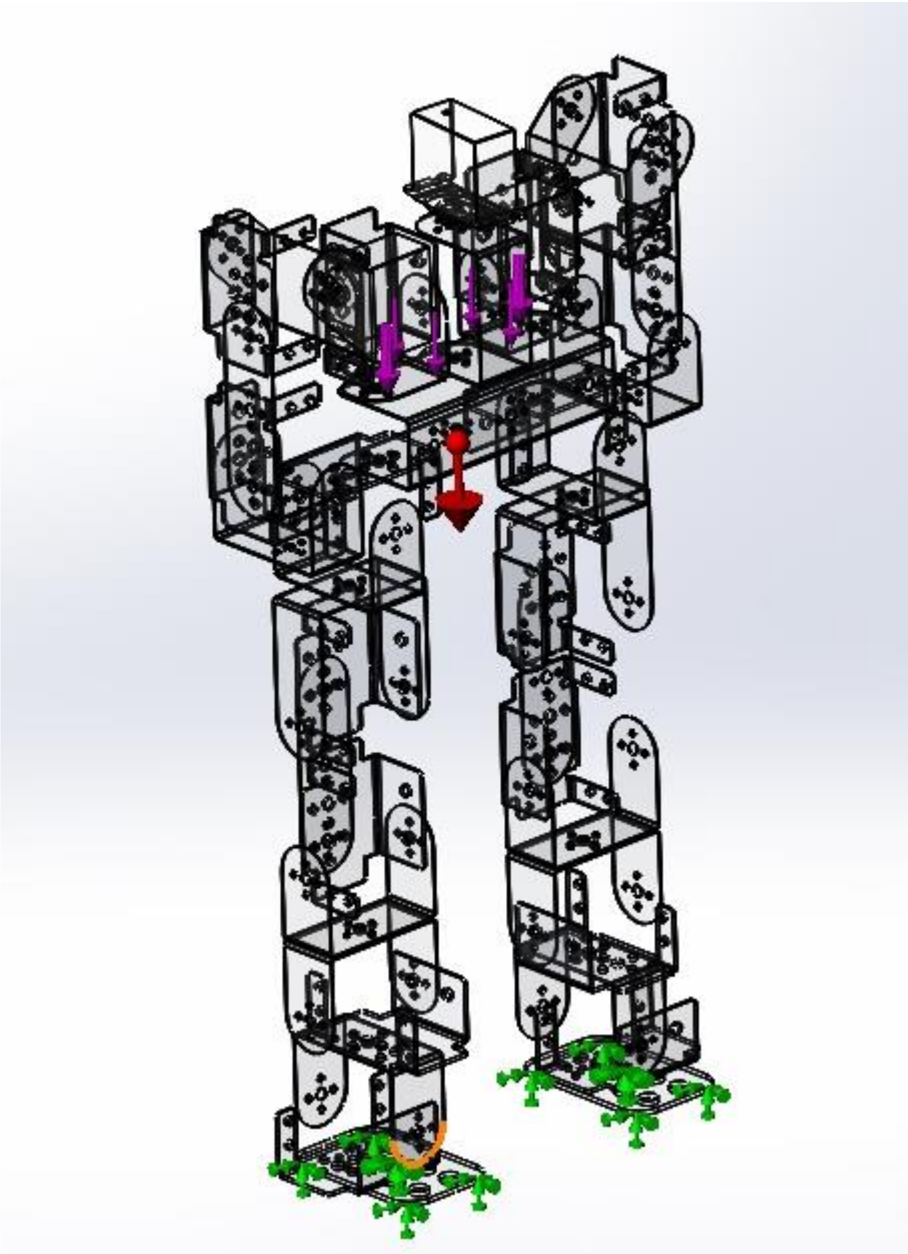


Figure 7-2: Analysis Setup - Fixed Geometry (Foot Base) and External Load on Waist and Gravitational Force Acting on Body

Table 7-1: Model Information

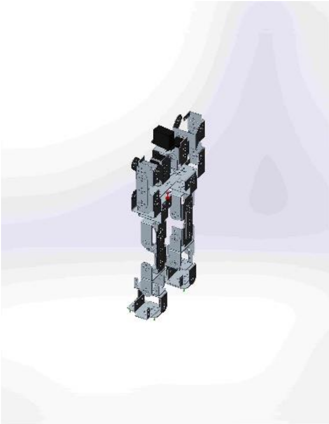
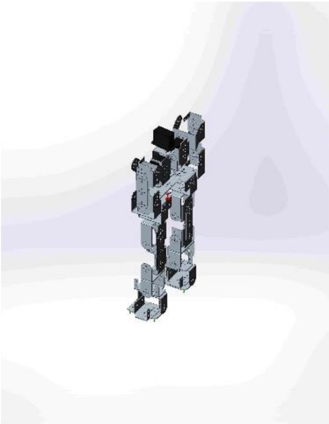
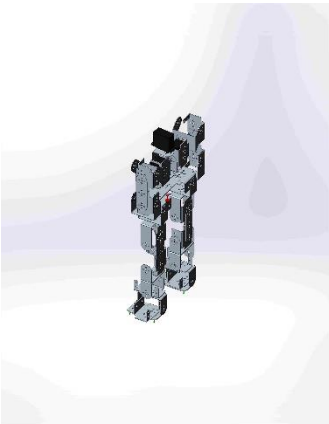
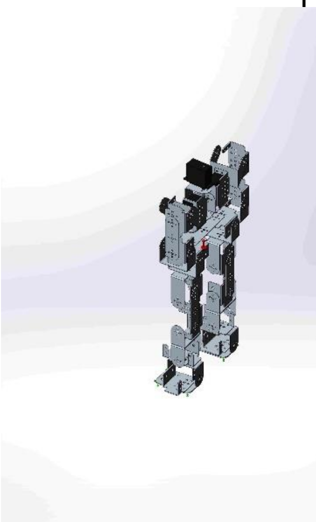
Document Name and Reference	Treated As	Volumetric Properties
Extrude11 	Solid Body	Mass: 0.0435692 kg Volume: 3.11208e-005 m^3 Density: 1400 kg/m^3 Weight: 0.426978 N
Cut-Extrude1 	Solid Body	Mass: 0.0150493 kg Volume: 5.57383e-006 m^3 Density: 2700 kg/m^3 Weight: 0.147483 N
CirPattern2 	Solid Body	Mass: 0.0112408 kg Volume: 4.16326e-006 m^3 Density: 2700 kg/m^3 Weight: 0.11016 N

Table 7-2: Static Study

Study name	Study 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off

Table 7-3: Unit System

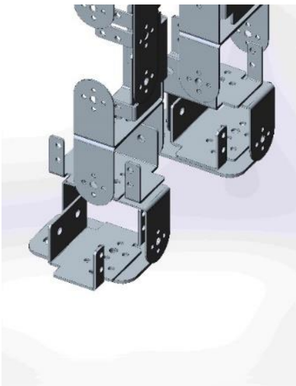
Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Model Reference	Properties	Components
	Name: 1060 Alloy Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 2.75742e+007 N/m^2 Tensile strength: 6.89356e+007 N/m^2 Elastic modulus: 6.9e+010 N/m^2 Poisson's ratio: 0.33 Mass density: 2700 kg/m^3 Shear modulus: 2.7e+010 N/m^2 Thermal expansion coefficient: 2.4e-005 /Kelvin	SolidBody 1(Sketched Bend1) (Bracket servo single_-10), SolidBody 1(Sketched Bend1) (Bracket servo single_-11), SolidBody 1(Sketched Bend1) (Bracket servo single_-12), SolidBody 1(Sketched Bend1) (Bracket servo single_-13), SolidBody 1(Sketched Bend1) (Bracket servo single_-14), SolidBody 1(Sketched Bend1) (Bracket servo single_-15), SolidBody 1(Sketched Bend1) (Bracket servo single_-16), SolidBody 1(Sketched Bend1) (Bracket servo single_-17), SolidBody 1(Sketched Bend1) (Bracket servo single_-18), SolidBody 1(Sketched Bend1) (Bracket servo single_-19), SolidBody 1(Sketched Bend1) (Bracket servo single_-3), SolidBody 1(Sketched Bend1) (Bracket servo single_-4), SolidBody 1(Sketched Bend1)(Bracket servo single_-5), SolidBody 1(Sketched Bend1) (Bracket servo single_-6), SolidBody 1(Sketched Bend1) (Bracket servo single_-7),

		SolidBody 1(Sketched Bend1) (Bracket servo single_-8), SolidBody 1(CirPattern2) (L type-3), SolidBody 1(CirPattern2) (L type-4), SolidBody 1(CirPattern2) (Long U-1), SolidBody 1(CirPattern2) (Long U-2), SolidBody 1(CirPattern5) (One type-1), SolidBody 1(CirPattern5) (One type-2), SolidBody 1(CirPattern5) (One type-3), SolidBody 1(CirPattern5) (One type-4), SolidBody 1(CirPattern3) (Short U-1), SolidBody 1(CirPattern3) (Short U-11), SolidBody 1(CirPattern3) (Short U-12), SolidBody 1(CirPattern3) (Short U-2), SolidBody 1(CirPattern3) (Short U-3), SolidBody 1(CirPattern3) (Short U-4), SolidBody 1(CirPattern3) (Short U-5), SolidBody 1(CirPattern3) (Short U-6), SolidBody 1(CirPattern3) (Short U-7), SolidBody 1(CirPattern3) (Short U-8), SolidBody 1(CirPattern3) (Short U-9), SolidBody 1(CirPattern6) (Waist-2), SolidBody 1(Cut-Extrude1) (foot base-1), SolidBody 1(Cut-Extrude1)

		(foot base-2), SolidBody 1(CirPattern2) (oblique_U_bracket-1), SolidBody 1(CirPattern2) (oblique_U_bracket-2)
	Name: Nylon 6/10 Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 1.39043e+008 N/m^2 Tensile strength: 1.42559e+008 N/m^2 Elastic modulus: 8.3e+009 N/m^2 Poisson's ratio: 0.28 Mass density: 1400 kg/m^3 Shear modulus: 3.2e+009 N/m^2 Thermal expansion coefficient: 3e-005 /Kelvin	SolidBody 1(Extrude11) (MG995-Servo_-1), SolidBody 1(Extrude11) (MG995-Servo_-2), SolidBody 1(Extrude11) (MG995-Servo_-3)

Table 7-4: Fixture and Resultant Forces

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 2 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	7.20131e-007	6.37484	-7.08234e-007	6.37484
Reaction Moment(N·m)	0	0	0	1e-033

Table 7-5: Load Details

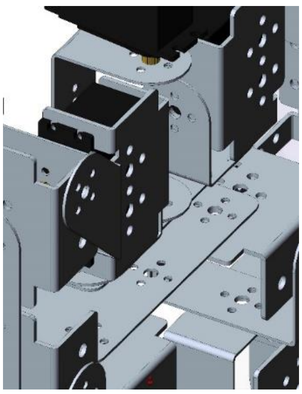
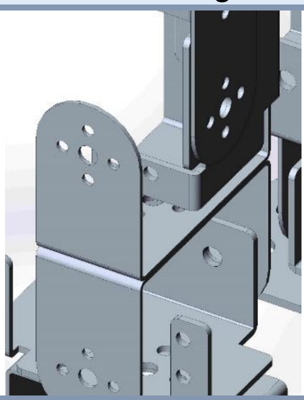
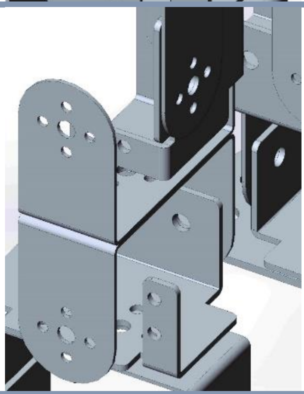
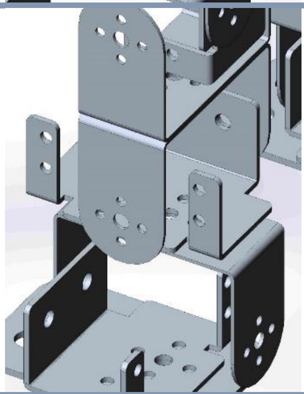
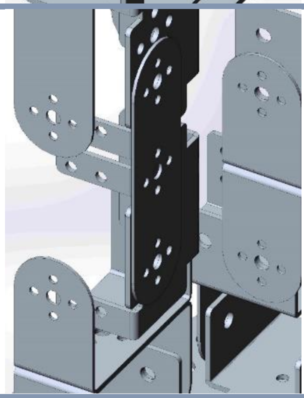
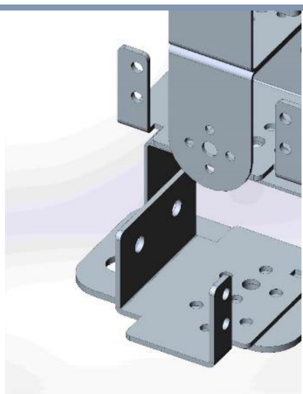
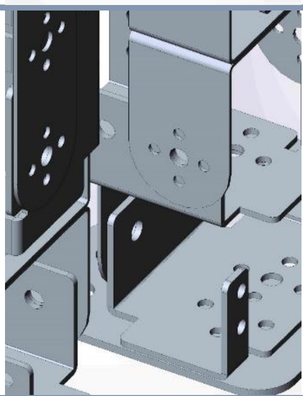
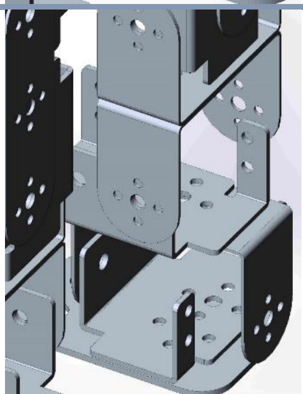
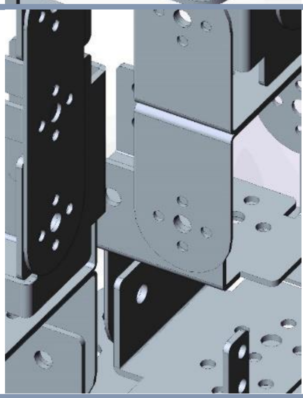
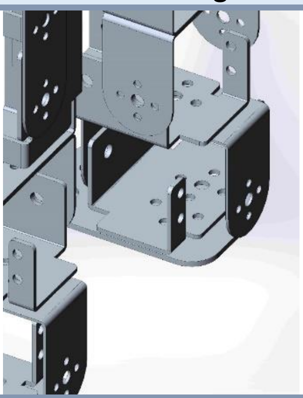
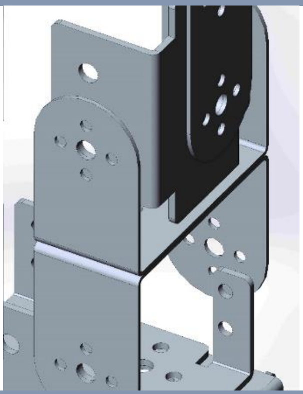
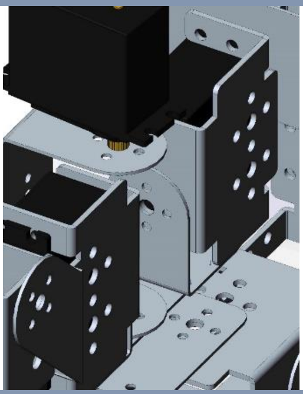
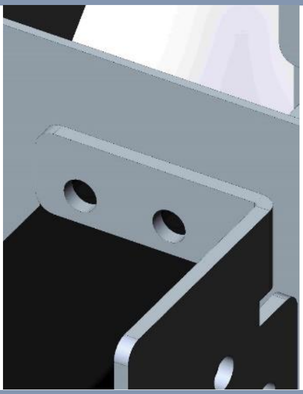
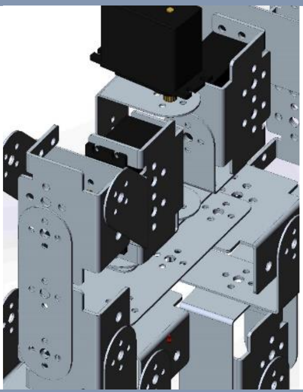
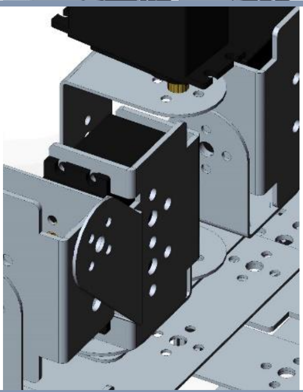
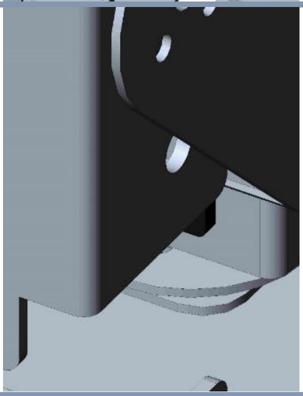
Load name	Image	Load Details
Gravity-1	Top Plane	**Reference:** Top **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 2 face(s) **Type:** Apply normal force **Value:** 0.2 N

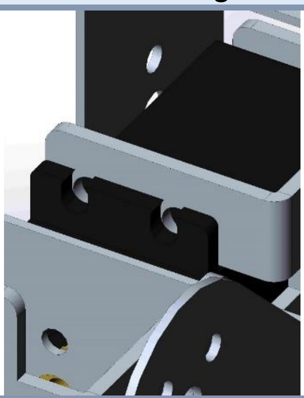
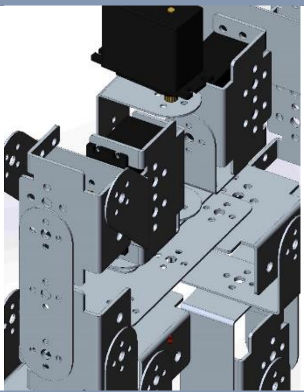
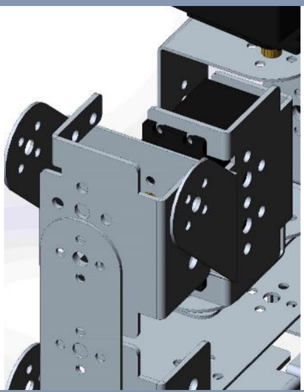
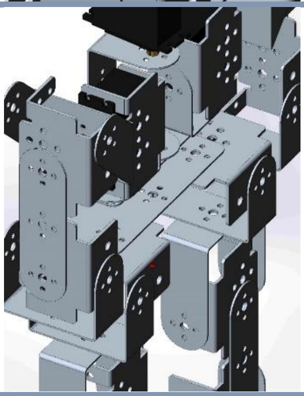
Table 7-6: Contact Information

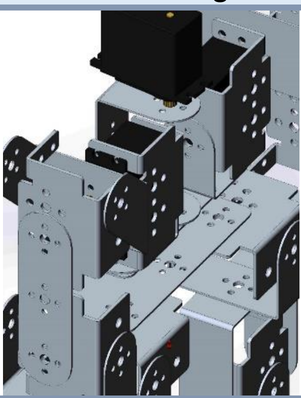
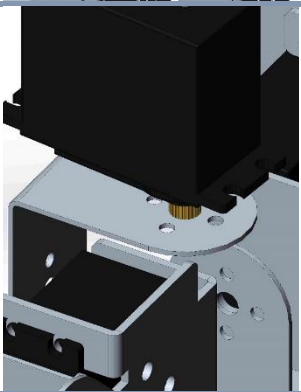
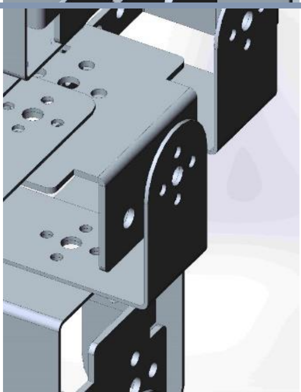
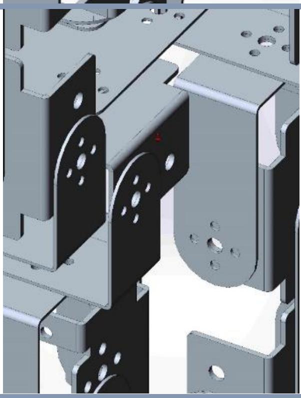
Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-2		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-3		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-4		**Type:** Bonded contact pair **Entities:** 2 face(s)

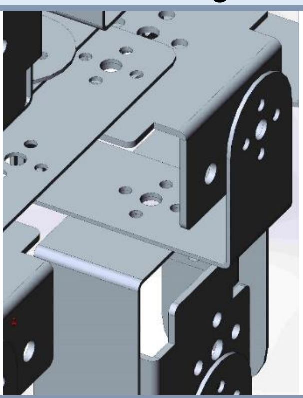
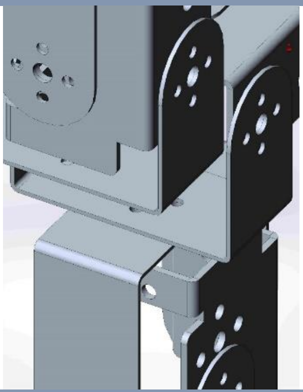
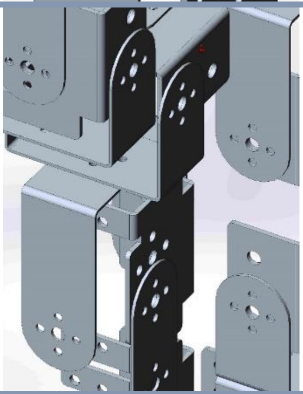
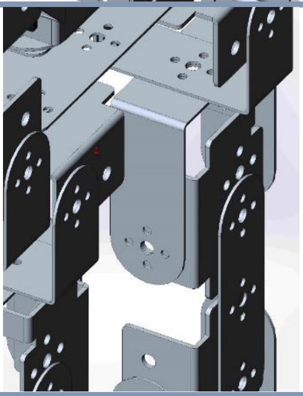
Contact	Contact Image	Contact Properties
Contact Set-5		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-6		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-7		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-8		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-9		**Type:** Bonded contact pair **Entities:** 2 face(s)

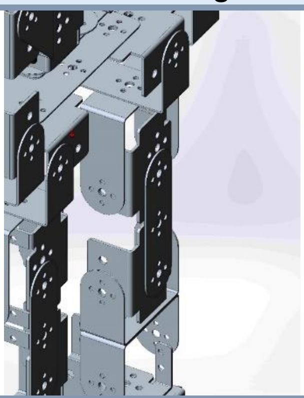
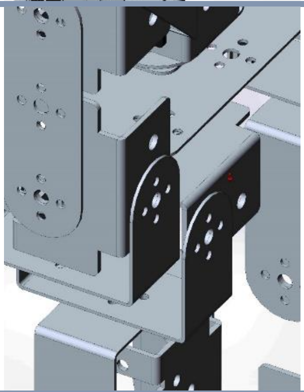
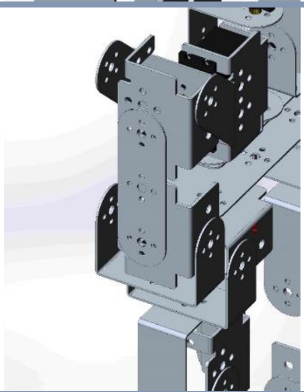
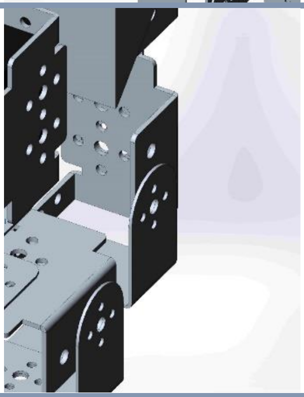
Contact	Contact Image	Contact Properties
Contact Set-10		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-11		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-12		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-13		**Type:** Bonded contact pair **Entities:** 2 face(s)

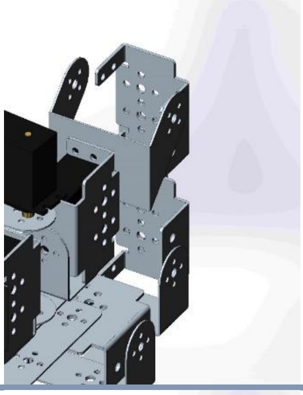
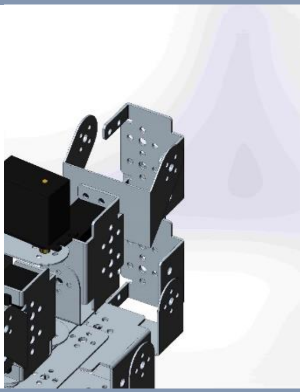
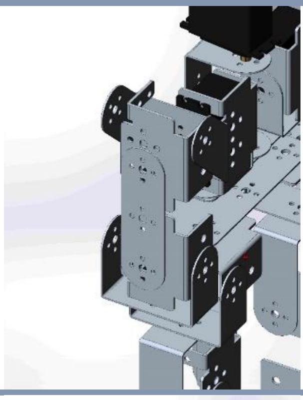
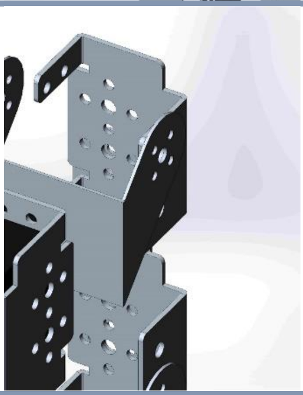
Contact	Contact Image	Contact Properties
Contact Set-14		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-15		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-16		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-17		**Type:** Bonded contact pair **Entities:** 2 face(s)

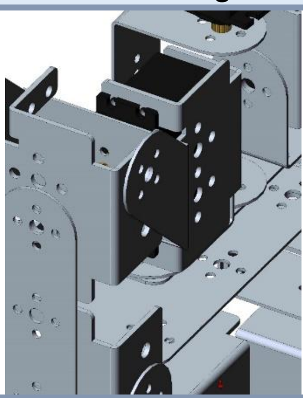
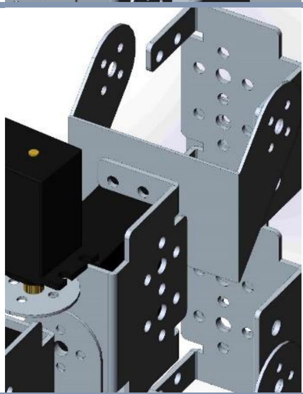
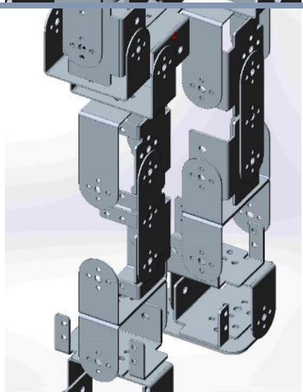
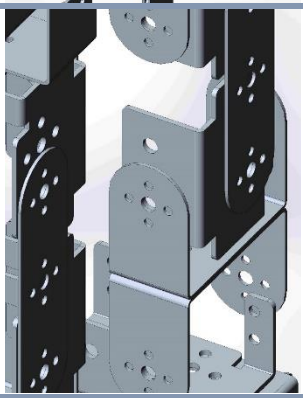
Contact	Contact Image	Contact Properties
Contact Set-18		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-19		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-20		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-21		**Type:** Bonded contact pair **Entities:** 3 face(s)

Contact	Contact Image	Contact Properties
Contact Set-22		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-23		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-24		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-25		**Type:** Bonded contact pair **Entities:** 2 face(s)

Contact	Contact Image	Contact Properties
Contact Set-26		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-27		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-28		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-29		**Type:** Bonded contact pair **Entities:** 2 face(s)

Contact	Contact Image	Contact Properties
Contact Set-30		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-31		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-32		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-33		**Type:** Bonded contact pair **Entities:** 2 face(s)

Contact	Contact Image	Contact Properties
Contact Set-34		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-35		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-36		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-37		**Type:** Bonded contact pair **Entities:** 2 face(s)

Contact	Contact Image	Contact Properties
Contact Set-38		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-39		**Type:** Bonded contact pair **Entities:** 2 face(s)
Contact Set-40		**Type:** Bonded contact pair **Entities:** 3 face(s)
Contact Set-41		**Type:** Bonded contact pair **Entities:** 2 face(s)

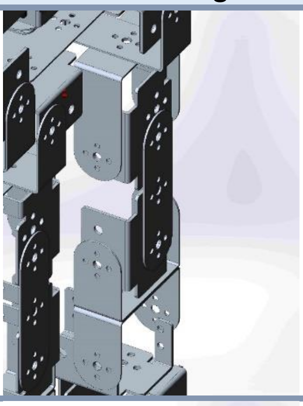
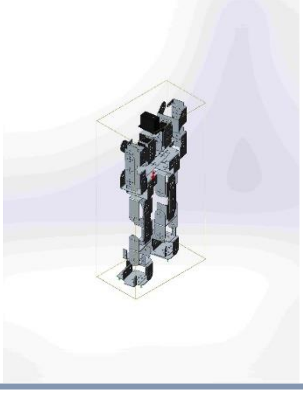
Contact	Contact Image	Contact Properties
Contact Set-42		**Type:** Bonded contact pair **Entities:** 2 face(s)
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Table 7-7: Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Curvature based mesh
Jacobian points	Off
Jacobian check for shell	Off
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Table 7-8: Mesh Information – Details

Total Nodes	105789
Total Elements	51319
Maximum Aspect Ratio	106.77
% of elements with Aspect Ratio < 3	66.5
% of elements with Aspect Ratio > 10	5.36
% of distorted elements(Jacobian)	60.1

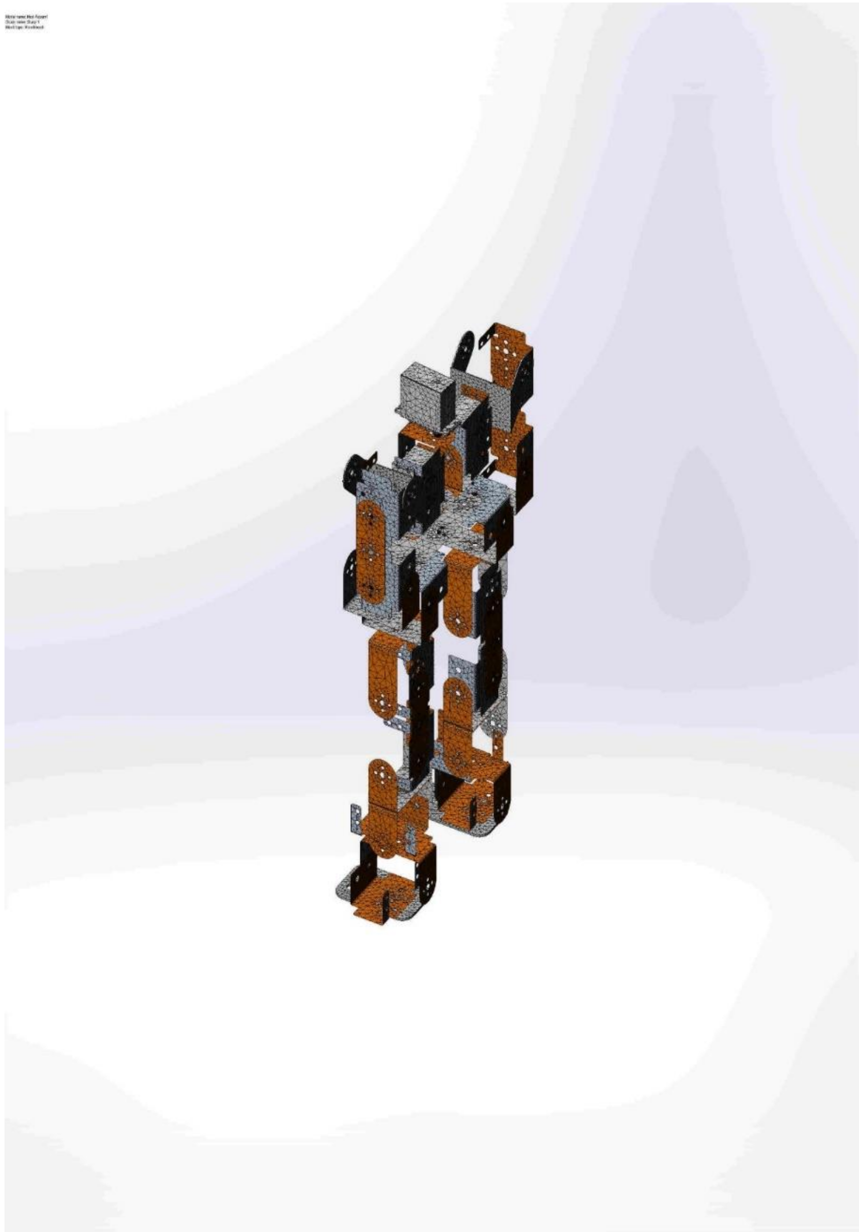
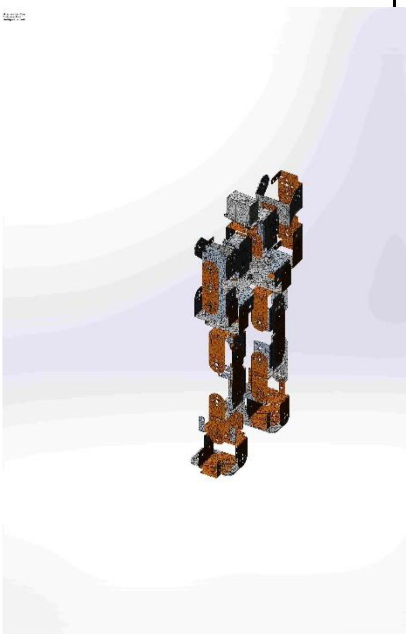


Figure 7-3: Mesh Density

Table 7-9: Mesh Control Information

Mesh Control Name	Mesh Control Image	Mesh Control Details
Control-1		**Entities:** 43 component(s) **Units:** mm **Size:** 1.50158 **Ratio:** 1.5

Resultant Forces

Table 7-10: Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	7.20131e-007	6.37484	-7.08234e-007	6.37484

Table 7-11: Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N·m	0	0	0	1e-033

Study Results

Table 7-12: Stress Analysis (Von Mises)

Name	Type	Min	Max
Stress	VON: von Mises Stress	1.02728 N/m^2 Node: 74527	1.71296e+007 N/m^2 Node: 3869

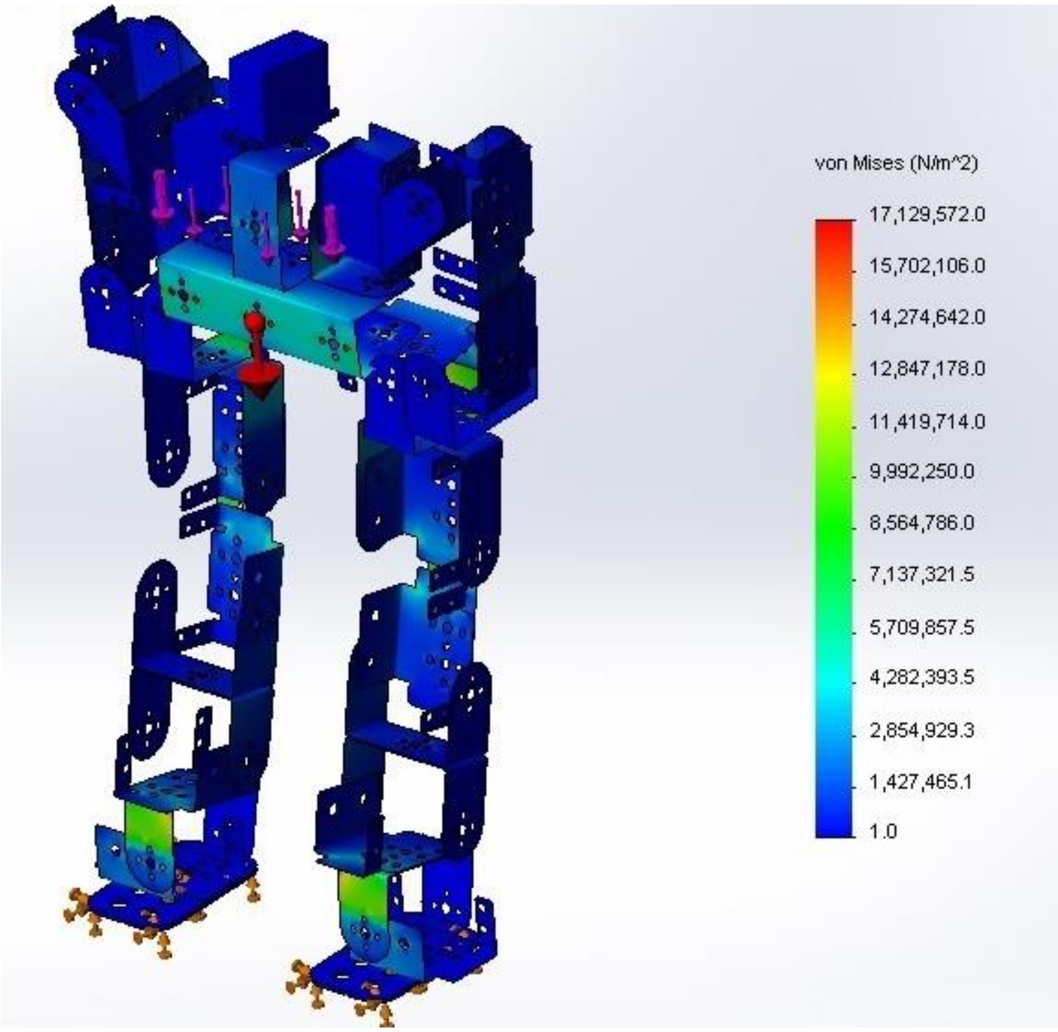


Figure 7-4: Static Stress (von Mises)

Table 7-13: Resultant Displacement

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 48022	1.98065 mm Node: 71820

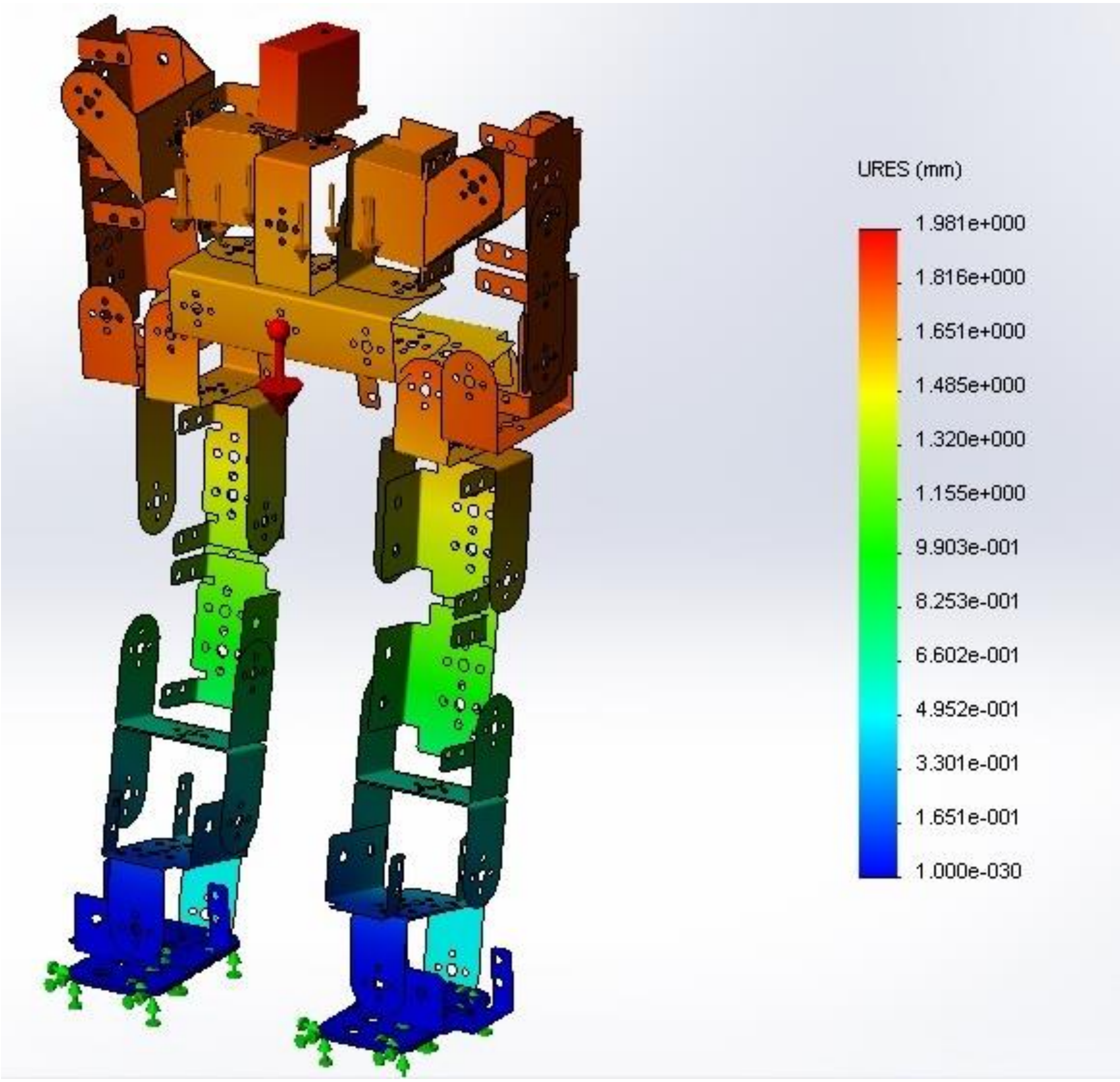


Figure 7-5: Displacement

Table 7-14: Strain Analysis

Name	Type	Min	Max
Strain	ESTRN: Equivalent Strain	2.48225e-011 Element: 2876	0.000183533 Element: 1820

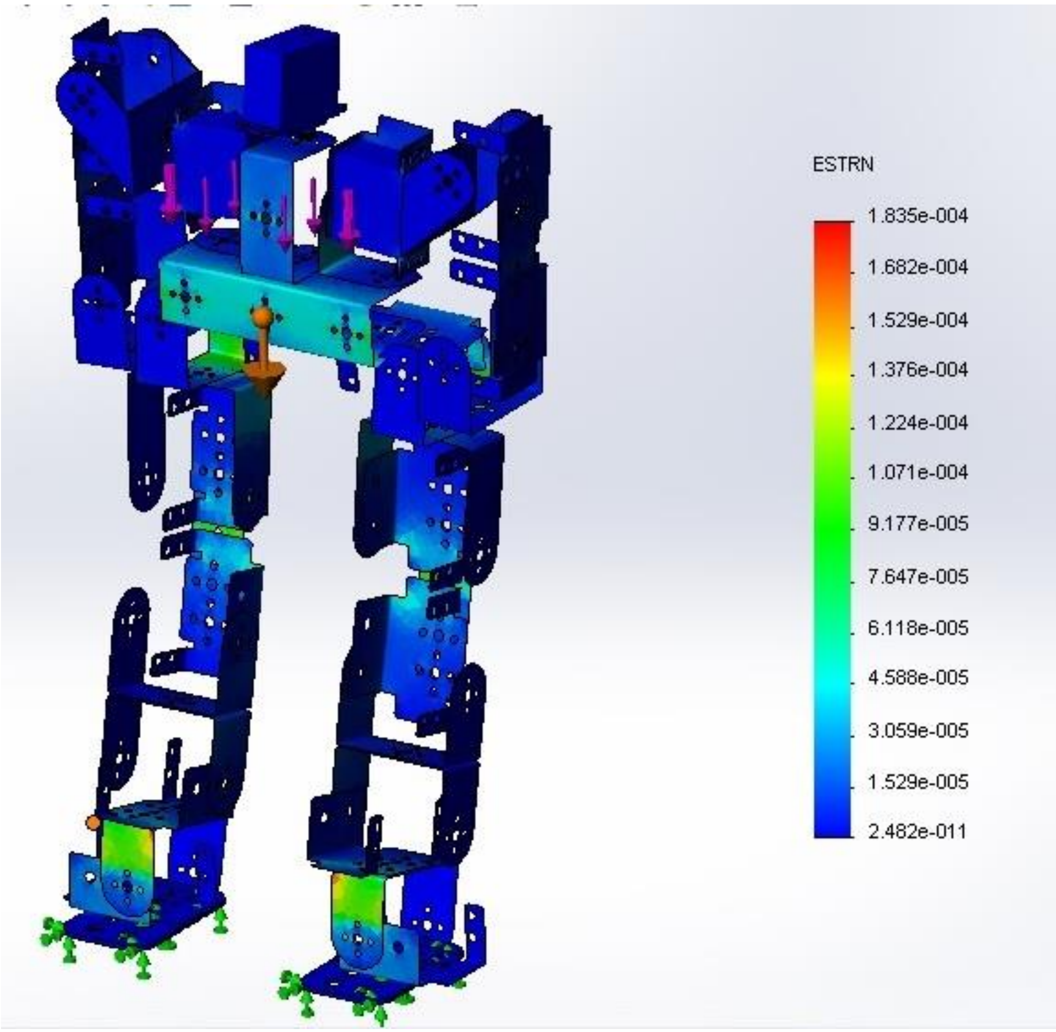


Figure 7-6: Strain

Table 7-15: Deformation Analysis

Name	Type
Displacement1	Deformed Shape

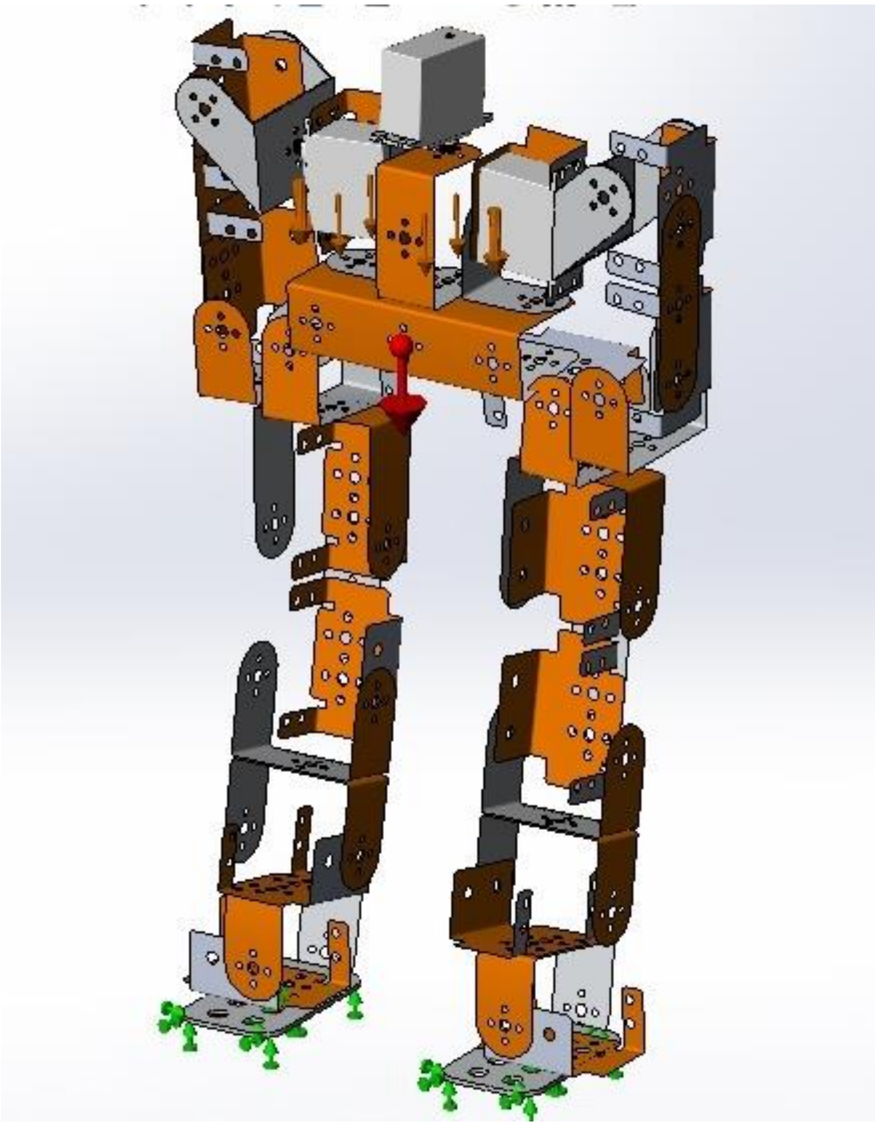


Figure 7-7: Deformed Shape

7.3 Fatigue Analysis

<u>Analysis Condition:</u>

Fixed geometry: Foot Base

External Force: 0.2 Newton Force Acting On L-Bracket Each

Gravitational Force: 9.81 m/s^2

Table 7-16: Fatigue Analysis Study

Study name	Study 2
Analysis type	Buckling
Mesh type	Mixed Mesh
Number of modes	1
Solver type	FFEPlus
Incompatible bonding options	Automatic
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Soft Spring:	Off

Table 7-17: Unit System

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Table 7-18: Fixture Details

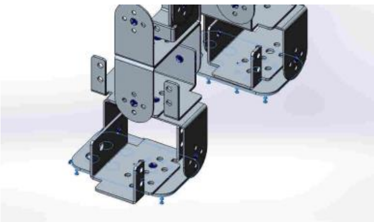
Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 2 face(s) **Type:** Fixed Geometry

Table 7-19: Load Details

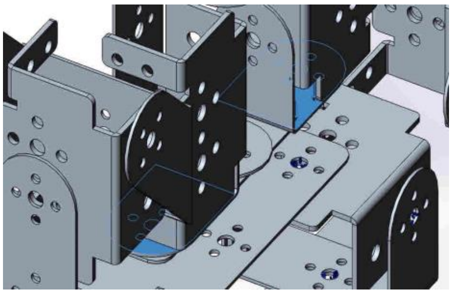
Load name	Load Image	Load Details
Force-1		**Entities:** 2 face(s) **Type:** Apply normal force **Value:** 0.2 N
Gravity-1	Top plane	**Reference:** Top **Values:** 0 0 -9.81 **Units:** SI

Table 7-20: Connector Detail

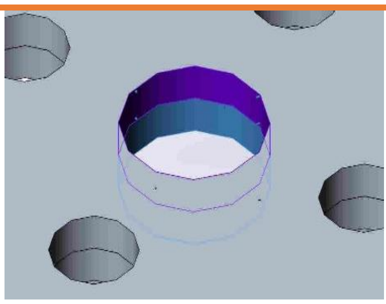
Pin Connector	Connector Details
	Entities: 2 face(s) Type: Pin Connection type: With retaining ring (No translation) Rotational stiffness value: 0 Units: SI

Table 7-21: Global Contact

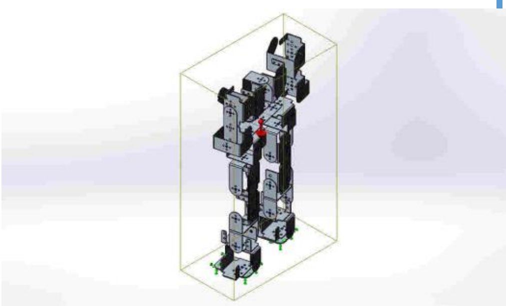
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component (s) **Options:** Compatible mesh

Table 7-22: Mesh Detail

Mesh type	Mixed Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Jacobian check for shell	On
Maximum element size	17.3184 mm
Minimum element size	3.46368 mm
Mesh Quality	High

Remesh failed parts with incompatible mesh	On

Table 7-23: Mesh Information – Details

Total Nodes	88812
Total Elements	42970

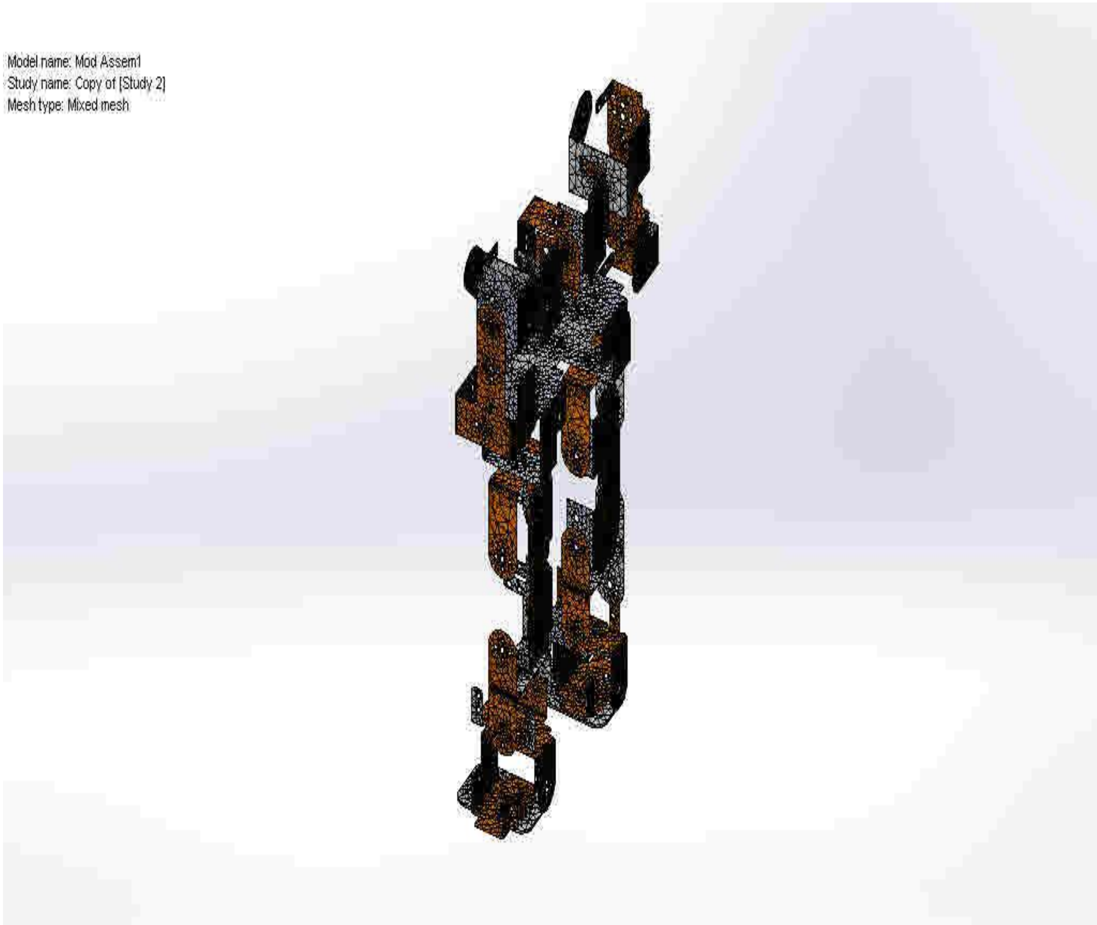


Figure 7-8: Mesh Density

Table 7-24: Displacement

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement Plot for Mode Shape: 1(Load Factor = -56.546)	0 mm Node: 76572	30.5499 mm Node: 37426

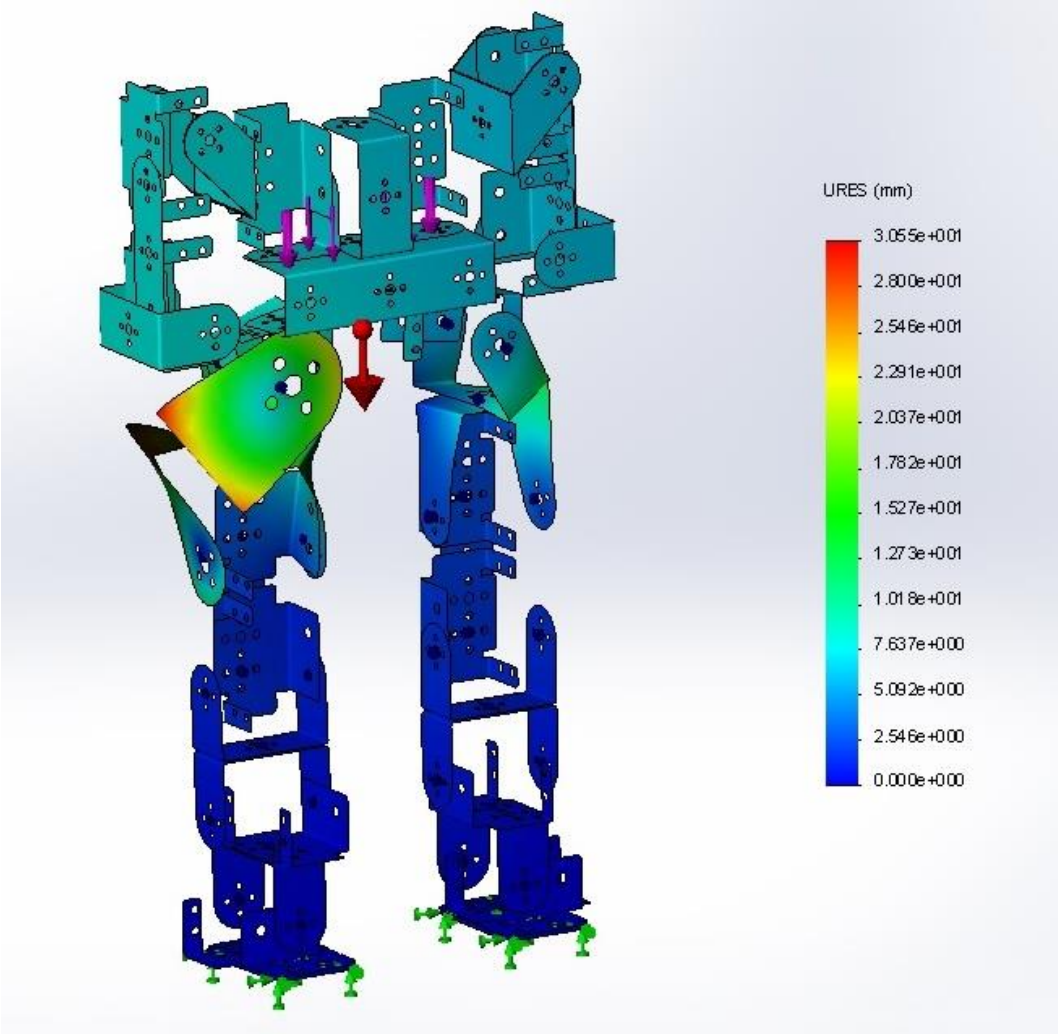


Figure 7-9: Fatigue

Table 7-25: Mode List

Mode Number	Load Factor
1	-56.546

CHAPTER

8

CONCLUSION AND RECOMMENDATION

Chapter 8 – Conclusion and Recommendation

- Conclusion

Human evolution to bipedalism is an option for developing intelligent machines. That way, some progress on walking robotics was explained with the emphasis on the results in the few research groups around the world. Even though walking robotics is an important and attractive research area in robotics, not enough applications have been made yet. For the future of walking bipedal, considering how to improve this situation will be necessary. This was briefly discussed and reconsideration of the goal of walking robotics research was pointed out for the improvement of the situation.

In order to reduce power consumption and increase motion stability, the weight and height are reduced throughout the construction of humanoid robot prototypes. The degrees of freedom (DOFs) are the minimum for high dexterity by using strong, light materials, small electronic but powerful devices, high torque motors, powerful modelling and control algorithms.

The main goal of this work was to develop a bipedal walking method which allows a full-sized humanoid robot to walk. Although there have been many approaches for bipedal walking methods including ZMP method, most of them require the knowledge of contact forces at the feet or forces transmitted through the ankles. Either approach requires developers not only to install sensitive sensors on the robot but also to process and interpret the signals appropriately. Because of these difficulties, the development of a full-sized humanoid robot has been considered one of the most challenging tasks in the field of robotics.

- Recommendation

To make the dynamic model similar to the actual robot. So, the dynamic model could predict closely the real humanoid behavior that prediction contributes to tuning correctly the control parameters.

Hardware and software improvements such better components and the real-time operating system.

Increase the degrees of freedom for the arms in order to have better manipulability, especially in cooperation tasks.

CHAPTER

9

FUTURE WORK

Chapter 9 - Future Work

The main objective of the humanoid robot is the technical feasibility. We work in the thesis to improve the technical ability of the robot. At present our humanoid robot has walking, sensing and visualization capabilities. In future we will improve the capabilities of the humanoid robot in the following way:

Walking: At present our robot moves in forward direction. In future, we are planning to move the robot in backward direction also. In rough surface our robot will withstand and move frequently without difficulty. Our humanoid robot will work efficiently at any environment.

Manipulation: it's contain all systems necessary for the direct interaction with the surrounding environment of the robot. This includes arms and hand of the robot. We will improve the gripping algorithm and manipulation planners.

Power supply: At present, we are using dc power supply with the help of adapter which converts AC to DC power supply. But a humanoid robot can make sense if he is a mobile system with independent power supply. That is why he needs an internal power supply. This power source will enable it a long duration work period. For this reason the requirement of internal power source is high. Our future plan is to use battery as power source which is capable of meet the required demand.

Communication: Humanoid robots need to communicate with real human at work. The user may not be a specialist at robotics. So it need to communicate in natural language with the people around him. And also understand the commands given and respond in natural language. Our future plan is to modify the humanoid robot to understand voice command and respond in natural language.

Perception: this is the ability to sense the surrounding of the robot. A humanoid robot moving in an environments with real human must have a precise idea of the world around him. Therefore he needs to have good external sensor. Optical cameras in often stereo camera systems are preferred today because of their flexibility. High quality of perception is needed because it is not acceptable if the robot confuses a crawling child with stair step. In future our plan is to use Optical cameras to improve perception of the robot.

Another plan is to make two humanoid robots which will play football. By using these robots, we will participate in the different international competitions.

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[6] M. Vukobratovic, A. A. Frank, and D. Juricic, “On the stability of biped locomotion, “Biomedical Engineering, IEEE Transactions on, vol. BME-17, pp. 25 –36, Jan. 1970.

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Websites:

1. http://en.wikipedia.org/wiki/Forward_kinematics [17 Dec, 2013]
2. http://en.wikipedia.org/wiki/Inverse_kinematics [17 Dec, 2013]
3. http://en.wikipedia.org/wiki/Zero_moment_point [17 Dec, 2013]

Glossary

DOF

Degrees of Freedom.

WABOT-1

Human-like robot which is built Humanoid Robotics Institute of Waseda University.

WAMOEBA

Waseda Artificial Mind on Emotion Base.

QRIO

“Quest for cuRIOsity", originally named Sony Dream Robot or SDR) was a bipedal humanoid entertainment robot developed and marketed (but never sold) by Sony to follow up on the success of its AIBO toy.

COG

COG was a project at the Humanoid Robotics Group of the Massachusetts Institute of Technology.

GuRoo

GuRoo is a humanoid robot developed at the Mobile Robotics Laboratory in the School of Information Technology and Electrical Engineering at the University of Queensland.

Femur

Thigh bone, is the most proximal (closest to the center of the body) bone of the leg in tetrapod vertebrates capable of walking or jumping, such as most land mammals, birds, many reptiles such as lizards, and amphibians such as frogs.

Tibia

Shinbone or shank bone, is the larger and stronger of the two bones in the leg below the knee in vertebrates (the other being the fibula), and it connects the knee with the ankle bones.

ZMP

Zero Moment point. The point where the total of vertical inertia and gravity forces equals 0 (zero).

COM

Centre of Mass. In physics, the center of mass of a distribution of mass in space is the unique point where the weighted relative position of the distributed mass sums to zero.

Stress

Stress is a physical quantity that expresses the internal forces that neighboring particles of a continuous material exert on each other.

Strain

Strain**,** in physical sciences and engineering, number that describes relative deformation or change in shape and size of elastic, plastic, and fluid materials under applied forces.

Yield Strength

A yield strength or yield point of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically.

Tensile strength

Tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking.

Modulus of Elasticity

An elastic modulus, or modulus of elasticity, is the mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it.

Poisson's Ratio

$$\nu = -\frac{d\varepsilon_{trans}}{d\varepsilon_{axial}}$$

ν , is the resulting Poisson's ratio,

ε_{trans} , is transverse strain (negative for axial tension (stretching), positive for axial compression)

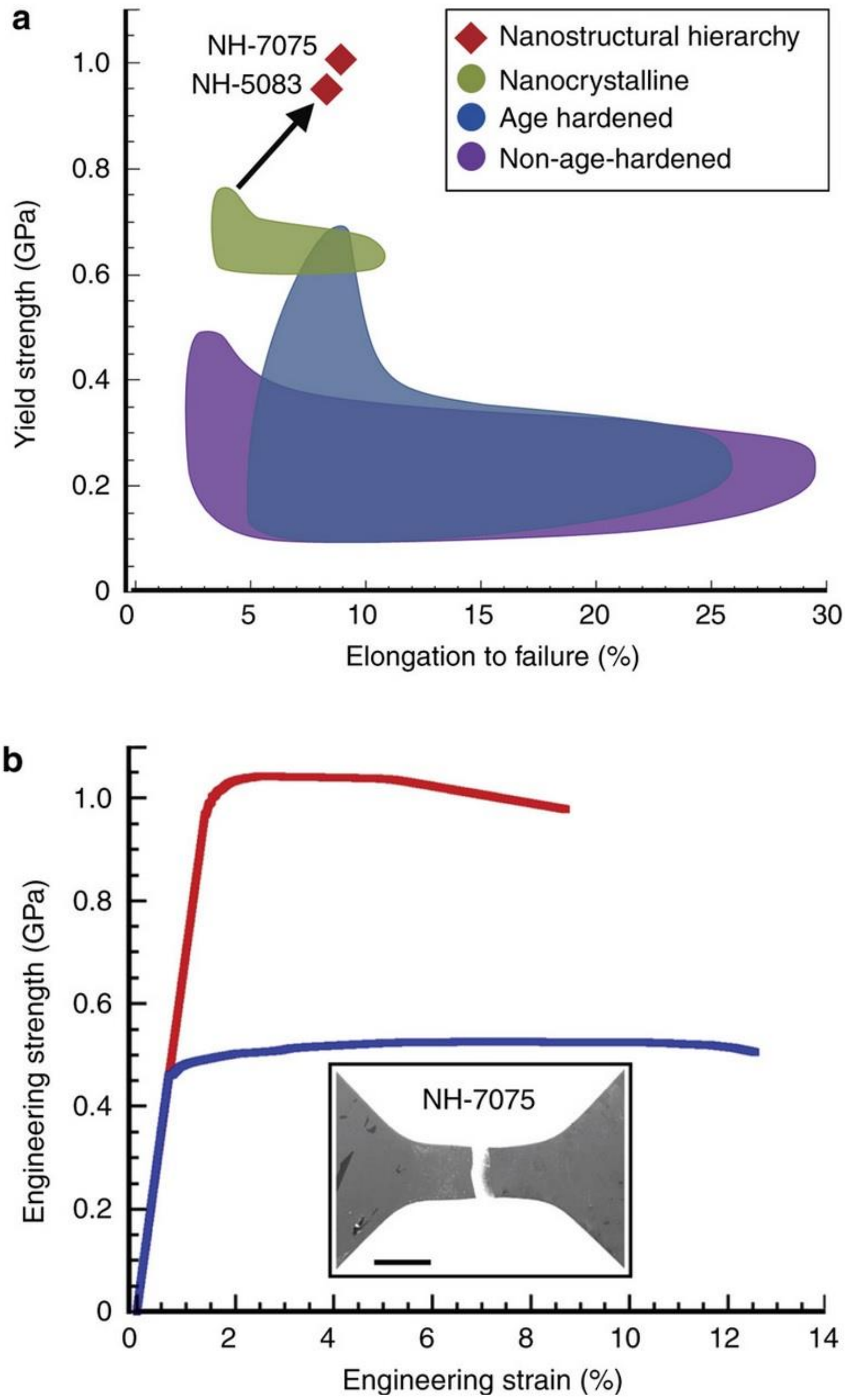
ε_{axial} , is axial strain (positive for axial tension, negative for axial compression).

SolidWorks

CAD and Simulation software.

Appendix-A

Property of Aluminum



A list of publications produced by candidate as a result of the project

Journal paper:

1. Alamgir Hossain, Rahid Zaman, Miftahur Rahman, Raihan Masud, Niloy Arafat and Fardan Abdullah: “Design and kick analysis of a Soccer Robot,” in”*Applied Mechanics and Materials Journal* “*(ISSN: 1660-9336)*.*)*, Sydney Australia, 2013.

Conference Paper:

1. Alamgir Hossain, Rahid Zaman, Miftahur Rahman, Raihan Masud, Niloy Arafat, Mizanur Rahman and Fardan Abdullah, Aziz Rahman: “Development of an Integrated Vision system to Control a Soccer Playing Humanoid Robot ”(accepted) in Proc 4th Global Engineering, Science and Technology Conference (ISSN 2201-6848), Dhaka, Bangladesh, 201