

Cerberus the Humanoid Robot: Part I – Design

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ABSTRACT

The motive behind building humanoids is to design a robot that can duplicate the complexities of human motion, decision making, be able to help people and even accomplish tasks that cannot be carried out by humans. Building humanoids has always attracted scientists throughout the world but although the aim is seemingly simple, the task is never easy. In this series of articles, we are going to present the concept of a humanoid robot, named Cerberus, that walks like a biped and then switches its mode to a quadruped walker/crawler. In Part I, desirable system criteria, design alternatives, final design selection and kinematics of the robot are presented along with the humanoid robot's simulations.

Keywords

Humanoid Robot, Cerberus Robot, Biped, Quadruped.

1. INTRODUCTION

The motive behind building humanoids is simply to design a robot that can duplicate the complexities of human motion and genuinely help people. Although the motive is this simple, the task is never easy. For example it took Honda's ASIMO more than 18 years of persistent study, research, and trial and error before Honda engineers achieved their dream of creating an advanced humanoid robot [1].

Walking process can be branched into two main groups as static and dynamic walking. Static walking in bipedal humanoids involves the complete shifting of the COG of the body over to the base foot area when the other is lifted to move forward. Such robots are designed and controlled from a kinematic standpoint (trajectory, or displacement-controlled), and as a consequence, they have relatively large feet and walk at a slow speed. A static-walking biped, such as the Honda P3 Humanoid, "does not move quite like people do and is energetically inefficient... it moves with a nonpendular appearance and uses about 2 kW during walking (Honda 2000), more than 20 times the muscle work rate of a walking human of the same size" [1]. Dynamic stability is needed to walk quickly and over varied terrains. The center of gravity lies outside the supporting leg base area during walking; the robot tumbles forward to its next step in dynamic equilibrium.

Passive-dynamic walking can be a third group added to different type of walking process. Un-powered toy soldier or penguins were constructed as early as a century ago that would walk down a gentle incline without any motor control. Through the careful selection of the lengths and masses of their arms and legs, these

toys maintain their balance while consuming very little energy (from gravity) when walking. Such models walk in a rigid manner, but their constructions are simple. Using this as the starting point, more DOF's can be added, these being powered and controlled, a more fluid walking motion can be achieved.

The aim for this study is toward the simple design that can do more functions. For this reason we selected a static walker with the capability of changing its mode from a biped to quadruped walker. The following section gives a brief history of the humanoid studies up to now. In the next section, various conceptual designs are introduced. Lastly, the final design concept selection procedure, detailed explanation of the final design and the preliminary gait definitions are presented.

2. HISTORY OF HUMANOIDS

Robotic studies and applications have shown a great increase in the past thirty years. Robots are started to be used for industrial purposes in assembly lines. Then as they evolved and as they became more intelligent, their interaction with humans in daily life increased.

Humanoid studies are accelerated as the intelligence level in robots is increased to be a part of the daily life of humans. The list below shows the evolution of the robotics from some simple mechanisms to humanoids that act and look like humans [2].

An ancient Greek engineer named Ctesibus made organs and water clocks with movable figures.

1774, Swiss inventors Pierre and Henri-Louis Jacquet-Droz created some of the most complicated automatons of this period. In 1774 their Automatic Scribe was unveiled. This lifelike figure of a boy could draw and write any message up to 40 characters long. A robot woman playing a piano was another one of their great inventions.

1801, Joseph Jacquard invents a textile machine, which is operated by punch cards. The machine is called a programmable loom and goes into mass production.

1830, American Christopher Spencer designs a cam-operated lathe.

1892, Seward Babbitt creates a motorized crane with gripper to remove ingots from a furnace.

1921, The first reference to the word "robot" appears in a play staged in London, called "R.U.R." or "Rossum's Universal

Robots" written by the Czech writer Karel Čapek. (Mr. Čapek is also known as the 'inventor' of the science-fiction genre). The play introduces the word robot from the Slovak language 'robota', which means a serf or one in subservient labor or forced labor.

1941, Science fiction writer Isaac Asimov first used the word "robotics" to describe the technology of robots and predicted the rise of a powerful robot industry.

1946, George Devol patents a general purpose playback device for controlling machines. The device uses a magnetic process recorder. In the same year the computer emerges for the first time. American scientists J. Presper Eckert and John Mauchly build the first large electronic computer called the Eniac at the University of Pennsylvania. A second computer, the first general-purpose digital computer, dubbed Whirlwind, solves its first problem at M.I.T.

1948, "Cybernetics," an influence on artificial intelligence research was published by Norbert Wiener, a professor at M.I.T. It describes the concept of communications and control in electronic, mechanical, and biological systems.

1951, A teleoperator-equipped articulated arm is designed by Raymond Goertz for the Atomic Energy Commission.

1954, The first programmable robot is designed by George Devol, who coins the term Universal Automation. He later shortens this to Unimation, which becomes the name of the first robot company in 1956.

1956, George Devol and Joseph Engelberger formed the world's first robot company.

1959, Computer-assisted manufacturing was demonstrated at the Servomechanisms Lab at MIT. Also Planet Corporation markets the first commercially available robot.

1961, The first industrial robot was on a production line a General Motors automobile factory in New Jersey. It was called UNIMATE.

1963, The first artificial robotic arm to be controlled by a computer was designed. The Rancho Arm was designed as a tool for the handicapped and its six joints gave it the flexibility of a human arm.

1964, Artificial intelligence research laboratories are opened at M.I.T., Stanford Research Institute (SRI), Stanford University, and the University of Edinburgh.

1965, Dendral was the first expert system or program designed to execute the accumulated knowledge of subject experts.

1968, The octopus-like Tentacle Arm was developed by Marvin Minsky. Also in that year, SRI builds and tests a mobile robot with vision capability, called Shakey. Shakey was the first mobile robot that could think independently and interact with its surroundings.

1969, At Stanford University a robot arm is developed which becomes a standard for research projects. The arm is the first electrically powered computer-controlled robot arm and becomes known as The Stanford Arm.

1970, Shakey is introduced as the first mobile robot controlled by artificial intelligence. It was produced by SRI International.

1970, In the 1970's Edinburgh University's Freddy robot was the vehicle for the Informatics Department's early artificial intelligence work on what might be termed hand/eye co-ordination in assembly robotics. The most noteworthy achievement was the Versatile Assembly Program, which enabled the robot to construct a toy boat and a toy car from a heap of mixed parts tipped onto the table. This experiment demonstrated that it was very difficult to devise successful assembly programs for a sensor-based robot, when the robot was programmed in terms of sequences of positions of its end-effector in Cartesian space. This is still the method used in commercial assembly robots today.

1973, The first commercially available minicomputer-controlled industrial robot is developed by Richard Hohn for Cincinnati Milacron Corporation. The robot is called the T3, The Tomorrow Tool.

1974, A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was designed. Professor Scheinman, the developer of the Stanford Arm, forms Vicarm Inc. to market a version of the arm for industrial applications. The new arm is controlled by a minicomputer.

1976, Robot arms are used on Viking 1 and 2 space probes. Vicarm Inc. incorporates a microcomputer into the Vicarm design.

1977, ASEA, a European robot company, offers two sizes of electric powered industrial robots. Both robots use a microcomputer controller for programming and operation. In the same year Unimation purchases Vicarm, Inc.

1978, The Puma (Programmable Universal Machine for Assembly) robot is developed by Unimation from Vicarm techniques and with support from General Motors.

1979, The Stanford Cart crossed a chair-filled room without human assistance. The cart had a TV camera mounted on a rail, which took pictures from multiple angles and relayed them to a computer. The computer analyzed the distance between the cart and the obstacles.

1994, CMU Robotics Institute's Dante II, a six-legged walking robot, explores the Mt. Spurr volcano in Alaska to sample volcanic gases.

1995, Intuitive Surgical formed by Fred Moll, Rob Younge and John Freud to design and market surgical robotic systems. Founding technology based on the work at SRI, IBM and MIT.

1997, NASA's Mars PathFinder mission captures the eyes and imagination of the world as PathFinder lands on Mars and the Sojourner rover robot sends back images of its travels on the distant planet. Also in the same year, Honda showcases the P3, the 8th prototype in a humanoid design project started in 1986.

2000, Honda showcases Asimo, the next generation of its series of humanoid robots. Sony unveils humanoid robots, dubbed Sony Dream Robots (SDR), at Robodex and also the second generation of its Aibo robot dog.

2001, Built by MD Robotics of Canada, the Space Station Remote Manipulator System (SSRMS) is successfully launched into orbit

and begins operations to complete assembly of International Space Station.

2004, Mark W. Tilden developed the interactive, articulate, animated and above all fully programmable humanoid, Robosapien™.

Below some of the biped projects that are built by various universities and researchers are presented.

The National University of Singapore has a bipedal walking robot project underway. This project is being lead by C.M. Chew of the Mechanical Engineering Department. Their robot has 12 DOF and stands 1.2 meters tall. It is driven by DC motors [9].



Figure 1. Biped by National University of Singapore

The University of Brussels in Belgium has a bipedal walking robot project underway. This project is being lead by D. Lefeber of the Mutlibody Mechanics Research Group of the Mechanical Engineering Department. Their robot is called “Lucy.” It is 150 cm tall and weighs 30 Kg [10].



Figure 2. Biped by University of Brussels

Alexander Vogler from Vienna, Austria has a very nice bipedal android which he calls V-3. It is about 12" or 30cm tall and weighs 1.2 Kg. It has 12 DOF [11].

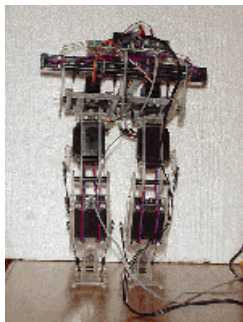


Figure 3. Biped by Alexander Vogler

Below, some of the commercially available humanoids are listed with their specifications.

Lynxmotion Biped Robot Scout: The Lynx Scout robot manufactured by Lynxmotion is a twelve servo biped walker featuring six degrees of freedom (DOF) per leg. The robot can walk forward or backwards and turn in place left or right with variable speed. The advanced leg design features flexibility [3].



Figure 4. Lynxmotion biped

Kondo KHR-1 Humanoid Robot Kit: The KHR-1 Robot kit from Kondo open the door to multiple humanoid experimentation and competition. This 17-DOF platform is quite unique: it can perform a wide range of motions, such as walking, kung-fu fighting, sucker kicks and acrobatics. It can be controlled with a PC via RS-232 cable (or wirelessly (if hacked). It can also be hacked to integrate microcontroller and program autonomous behaviors [4].



Figure 5. Kondo KHR-1 Humanoid

Wow Wee RoboSapien: Loaded with attitude and intelligence, Robosapien is the first robot based on the science of applied biomorphic robotics. Designed by the scientist Mark Tilden and is manufactured by Wow Wee [5].



Figure 6. Robosapien

HRP-2: The total robotic system was designed and integrated by Kawada Industries, Inc. together with Humanoid Research Group of National Institute of Advanced Industrial Science and Technology (AIST). Yaskawa Electric Corporation provided the initial concept design for the arms and AIST 3D Vision Research Group and Shimizu Corporation provided the vision system. HRP-2's height is 154 cm and mass is 58 kg including batteries. It has 30 degrees of freedom (DOF) including two DOF for its hip. The cantilevered crotch joint allows for walking in a confined area. Its highly compact electrical system packaging allows it to forgo the commonly used "backpack" used on other humanoid robots [6].



Figure 7. HRP-2

HONDA ASIMO: Has a total of 26 DOF, weight of 52 kg and a height of 1.20 meters [1].

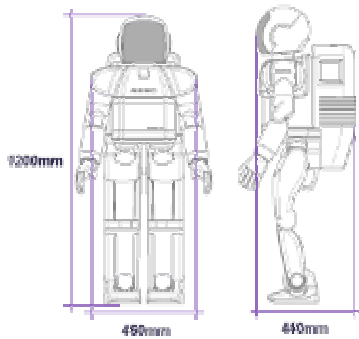


Figure 8. HONDA ASIMO

SONY QRIO: Can walk on two feet and dance dynamically. To make its arms and legs strong, and yet able to move fluidly, it was necessary to develop an entirely new joint actuator. The realization of this Intelligent Servo Actuator (ISA) made it possible to build a robot with compact body design that could move its body smoothly and dynamically [7].



Figure 9. SONY QRIO

3. CONCEPTUAL DESIGNS

The main concept of the Cerberus is that it will have the capability to walk in biped mode and then change its mode to a quadruped walker. Having this main idea, two conceptual designs are developed.

3.1 Design Concept 1

The concept of this design is to make the humanoid robot walk as a two-legged robot and then make it change its mode automatically to a four-legged robot and walk. For the process of kneeling down and changing mode to a four-legged robot, the robot needed 3 DOF on each leg. Although it has this many DOF's on each leg, it can't go side ways or turn but it can only go forward and backward. To add the features described in the previous sentence, at least one more DOF should be added to each leg (which operates about the roll axis). The DOF on the torso is used for balancing the robot while it is walking in two feet as it is shown in the figures below.

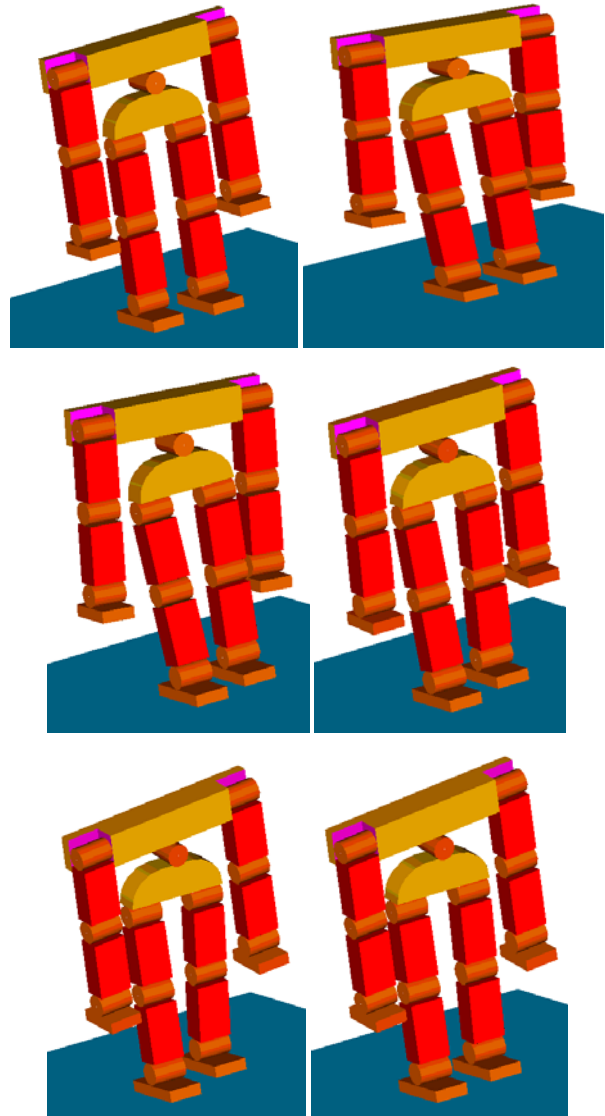


Figure 10. Bipedal walking gaits of design concept 1

The arms architecture is almost the same as the legs for the sake of using the same type of modules for all the robot links. They have also 3 DOF, which will only be used in full when changing the mode to four-legged robot and walking in four feet. The motion of the robot on four feet will be smooth and in balance since the arms and the legs to actuate the motion are almost identical. The only differences between them are the distance to one another and the area of the feet and the hand. In all the figures the cylinders resemble the joints and the rectangular parts are the links of the humanoid.

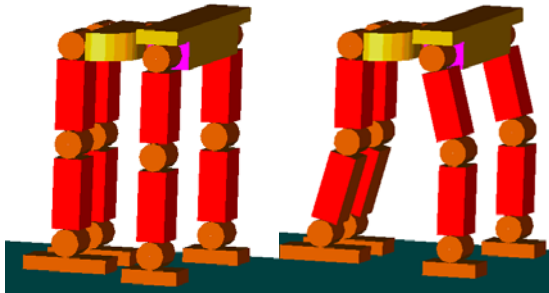


Figure 11. Quadruped mode of design concept 1

3.2 Design Concept 2

The concept of this design is to create a robot that is able to walk on two legs and also able to become a quadruped. Once the robot has all four extremities on the ground, it propels itself forward by moving its rear legs in a crouched walking position while its upper limbs roll the wheels at the end of each extremity.

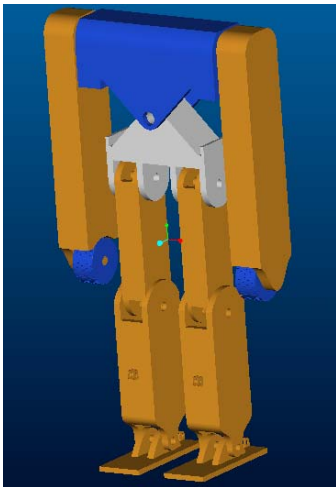


Figure 12. Design concept 2

As seen from the figure above, the Cerberus robot has 8 degrees of freedom:

- 3 degrees of freedom on each leg (ankle, knee, hip) X 2
- 1 degree of freedom at the waist
- 1 degree of freedom at the arms

By running the proper algorithm, the robot will be able to crouch down, maintaining its balance, and place the upper extremities on the floor. It will then place joints in the proper position in order to continue moving by pushing its arms/wheels with its legs.

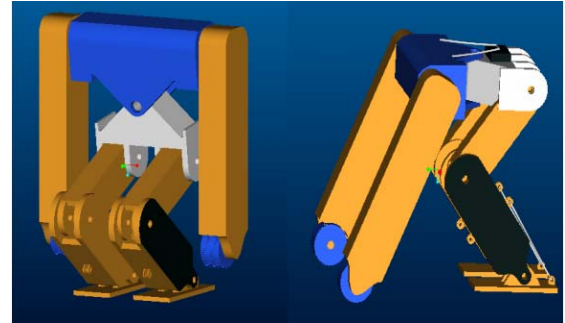


Figure 13. From biped to quadruped mode

In order for the robot to walk, it uses its waist to shift the center of gravity from one side to the other as the corresponding leg takes a step. The design keeps the distance between legs to a minimum in order to reduce moments created about the center of gravity when a step is taken.

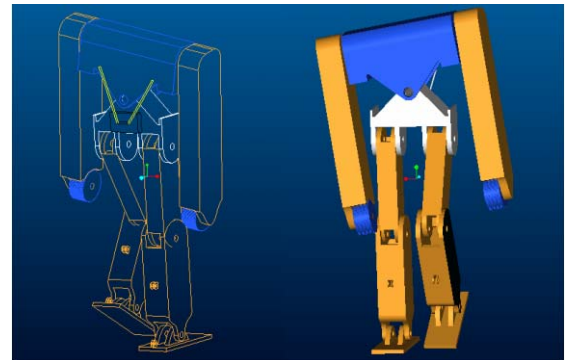


Figure 14. A gait of design concept 2

A servo mounted on the back and attached to two links controls the motion of the upper waist, which is pivoted along the mid plane of the robot.

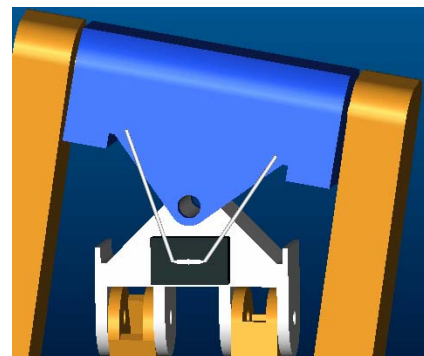


Figure 15. Waist actuation of design concept 2

A similar concept is used to articulate the ankle. In this case only one link is used to manipulate the pitch motion of the ankle.

4. FINAL DESIGN DESCRIPTION

A rating table to compare both designs is prepared. The following table rates the three design concepts from one to three (one being a low mark and three a high mark) on different parameters and criteria considered essential in designing the biped robot.

The ability of the robot to maintain its stability while walking is an important design criterion. Both designs 1 and 2 are “static walkers”, where the robots keep their center of gravity within the zone of stability. The abilities of design 1 & 2 to become quadrupeds give them the ability to walk over a greater variety of surfaces. Design 1 has 13 DOF and design 2 has 8 DOF. The more degrees of freedom, the more complex and costly the design will be.

Table 1. Rating table of concepts

Concept	Stability when walking	Ability to walk on varying surfaces	Degrees of freedom	Simplicity of Design	Cost
1	2	3	1	2	1
2	2	2	2	3	2

The final score for concept 1 is 9 and concept 2 is 11. Taking this rating into account concept 2 is selected to be the final concept for this work. The final design concept has the following features:

- Total of 8 degrees of freedom:
 - 3 dof on each leg
 - 1 dof on the waist
 - 1 dof for the arm actuation
- Reconfigurable: Biped to quadruped and quadruped to biped walking
- Controller: Basic Stamp II
- Servos: Basic hobby servos with potentiometer

For the preliminary selection of the servos, the biped walking shown in Figure 16 can be considered as the worst-case scenario. The total humanoid center of gravity can be assumed to be at the middle of the humanoid 0.15 m up from the ground and the weight can be estimated as 12 N as it is in [11]. While taking a step, it can be assumed that the COG is shifted by 10^0 . In this static case the moment acting at the ankle servo of the right leg can be calculated as: $M_{ra} = 12 \times 0.15 \times \sin(10) = 0.312 \text{ Nm}$ or 44.2 oz-in.

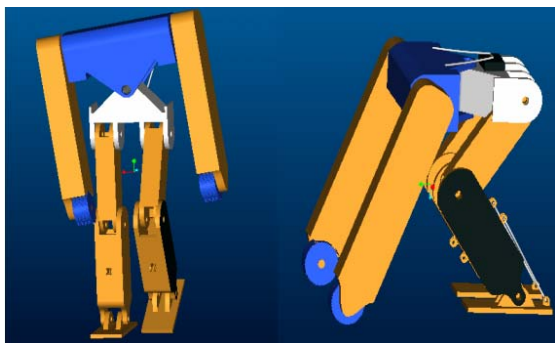


Figure 16. Final design concept

5. KINEMATIC ANALYSIS

It was important that since we are still early in the design phase of the project, that deciding on the exact amounts for the link lengths was not advisable. Therefore, the robot’s proportions were chosen in terms of a unit length and checked to make sure the robots workspace requirements could be fulfilled.

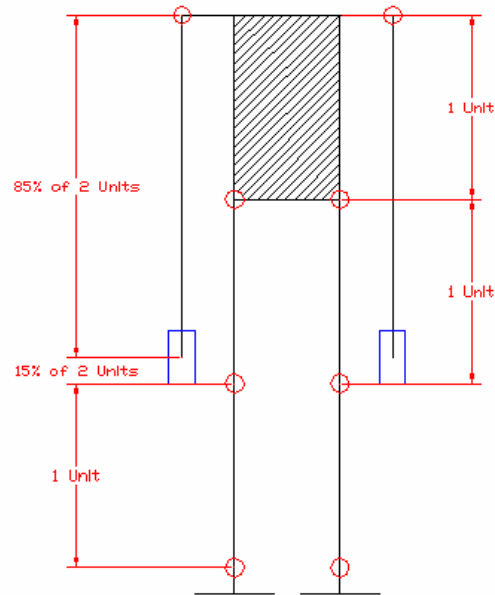


Figure 17. Humanoid proportions

The figure shows how the robots are based on a unit value. All dimensions are multiples of that unit value. In our case, the upper and lower legs, and torso all each have a dimension equal to 1 unit, while the arms are 2 units each. The preliminary unit value selection, based on the servo size and controller is $1 \text{ unit} = 10 \text{ cm}$.

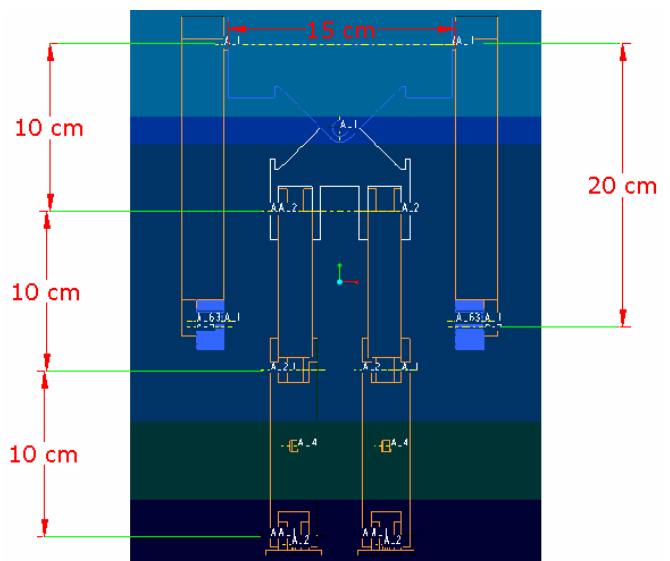


Figure 18. Cerberus humanoid robot preliminary dimensions

The servos chosen have a max range of motion of 180 degrees. The figure below shows the desired range of motion at each joint.

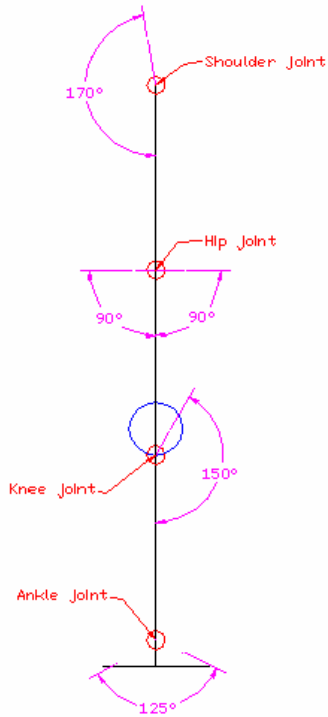


Figure 19. Humanoid range of motion

As the figure shows, none of the joints range of motion exceeds the servos maximum range.

6. GAIT ANALYSIS

Preliminary gait analysis is done to see if the range of motion defined previously meets the requirements to walk in biped mode, to change the mode from biped to quadruped and finally to walk in quadruped mode.

6.1 Biped Gait Analysis

The walking pattern synthesis is based on Zero Moment Point (ZMP). The ZMP is defined as the point on the ground about which the sum of all the moments of the active forces equals zero. If the ZMP is within the convex hull of all contact points between the feet and the ground, the biped robot is possible to walk. Hereafter, this convex hull of all contact points is called the stable region. As seen below the basic idea involves shifting the waist to the side opposite to the leg in motion in order to maintain stability.



Figure 20. Waist motion for stability in biped walking

By using previously derived formulas for hip and foot positions and knowing the foot angles as it leaves and arrives (q_b & q_f), a stable walking pattern can be achieved [8].

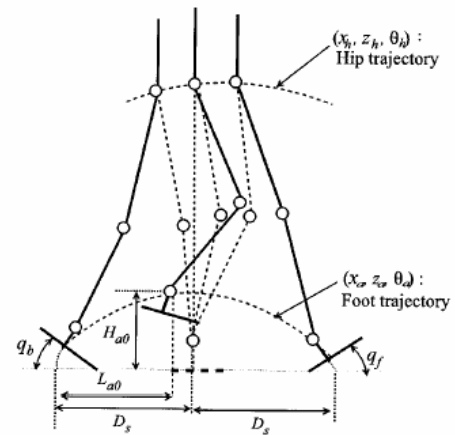


Figure 21. Biped walking foot trajectory

The figures below are a visual representation of how the walking gait for biped locomotion.

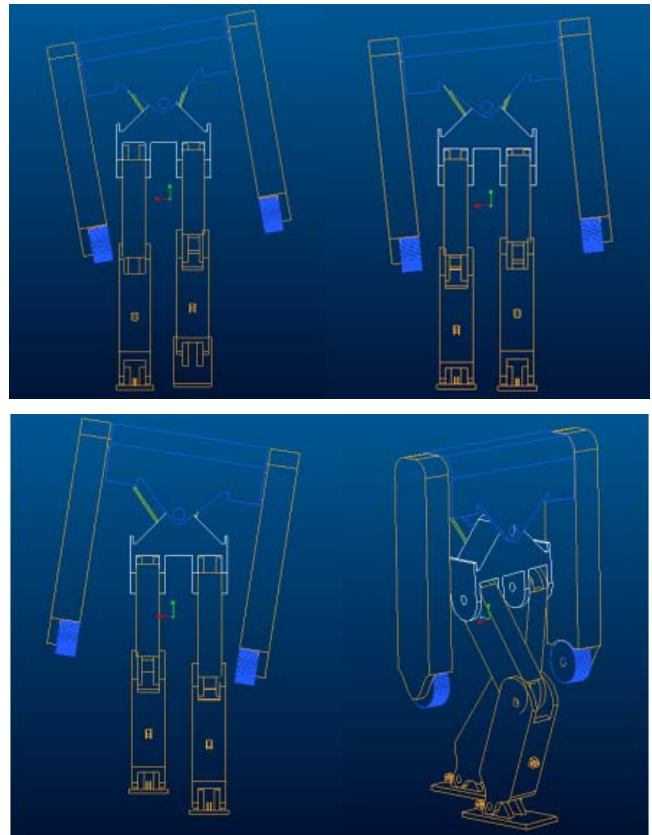


Figure 22. Biped walking gaits

6.2 Mode Changing Gait Analysis

A general gait analysis was done graphically. The purpose was to check to see that the leg and arm workspace was acceptable, check for limiting positions, and use data from gait “snapshots” as guides for controller algorithm development.

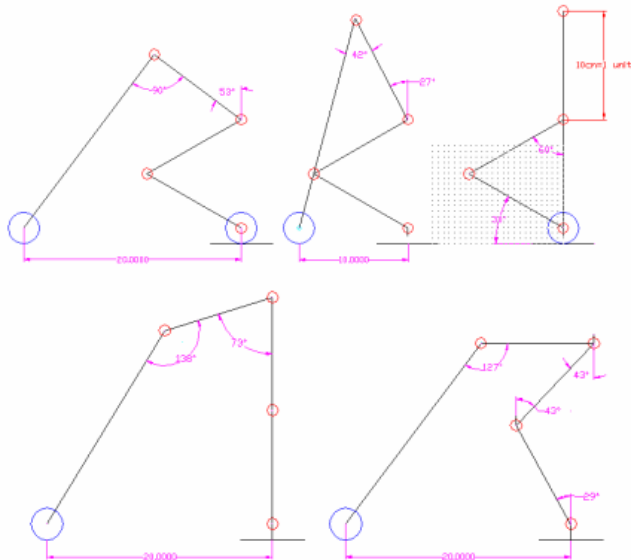


Figure 23. Gaits for changing from biped to quadruped walking

6.3 Quadruped Gait Analysis

The next figures are snapshots of the robot quadruped walking gait pattern. As the figures show, the end positions for the first and second steps are the same; hence, the walking motion is a repetition of this gait.

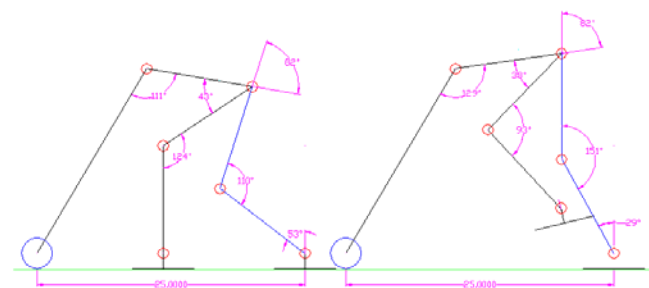


Figure 24. First step – left leg

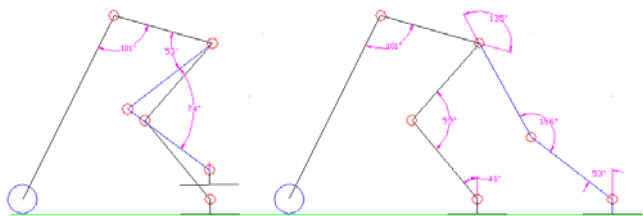


Figure 25. Second step – right leg part 1

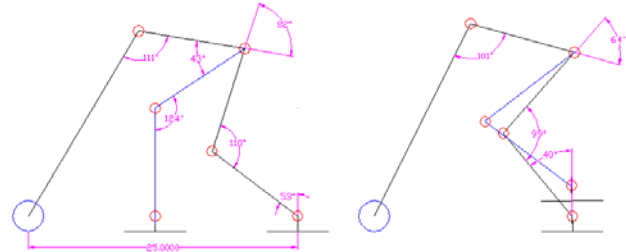


Figure 26. Second step – right leg part 2

7. CONCLUSIONS

The conceptual design, kinematic model development and analysis of a biped humanoid robot is presented. The robot, named Cerberus, is capable of biped and quadruped walking as well as configuring itself from one mode into the other. The robot uses eight servos controlled through a Basic Stamp controller.

Initially, a brief review of the research work carried out on humanoid robot development has been presented. Later, two conceptual humanoid robot designs were introduced and they were evaluated against several design criteria. Finally, for the selected final design, several robot gaits were studied for biped and quadruped walking. The next step in this study is the selection of the components and construction of the Cerberus robot.

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