Indian Journal of Engineering, Vol. 14, No. 35, January-March, 2017 ANALYSIS

ISSN 2319–7757 EISSN 2319–7765

Indian Journal of Engineering

# Anatomical Characterization of a Humanoid Robot

Priyadarshi Biplab Kumar[1], Animesh Chhotray[2], Dayal R Parhi[3]

1. Robotics Laboratory, Mechanical Engineering Department, NIT Rourkela, Odisha 769008, p.biplabkumar@gmail.com
2. Robotics Laboratory, Mechanical Engineering Department, NIT Rourkela, Odisha 769008, chhotrayanimesh@gmail.com
3. Robotics Laboratory, Mechanical Engineering Department, NIT Rourkela, Odisha 769008, dayalparhi@yahoo.com

Publication History

Received: 07 October 2016

Accepted: 03 November 2016

Published: January-March 2017

Citation

Priyadarshi Biplab Kumar, Animesh Chhotray, Dayal R Parhi. Anatomical Characterization of a Humanoid Robot. *Indian Journal of Engineering*, 2017, 14(35), 1-6



## ABSTRACT

Being an interdisciplinary research topic, human robot interaction has gained immense interest among various researchers. From the last few decades, the developments in the field of humanoid robots has graduated at a very high pace. In this investigation, the feasibility of constructing a humanoid robot by using the current technology is focussed. The justification of adopting a humanoid form as compared to other form of robots is specified. The primary aim is to construct a humanoid robot with the capabilities of a human that can be trained to mimic the human behaviour. In order to be able to perform all the tasks as done by a human being, the size, mass, weight and power of the robot needs to be coherent to the human body. A robot that is intended to be used in industrial applications or complex environments can be made in any form, but the advantages of the humanoid form over other forms are discussed here. This research can also be extended towards selection of best suited materials and equipment for fabrication of a humanoid robot.

Key Words: Humanoid Robots, Human Robot Correlation, Technology Transfer, Human Movement Science

## 1. INTRODUCTION

Human beings always try to ease out living by discovering new ideas and technologies. Starting from the discovery of wheel in the Neolithic era to the development of a humanoid robots, human mind has always shown gradual development and prosperity. Humanoid robots have become an integral part of life in developed and developing countries. These robots have gained applications in various industries such as automobiles, manufacturing, mining exploration, etc. They can also be used for entertainment and medical purposes. Among all the available forms of robots, the humanoid form is the most accepted one. This paper investigates the actual justifications for adopting a humanoid form. The advantages of a humanoid form of robot over other forms are also justifies through the current investigations. Starting from the introduction of humanoid robots to the robotics world till today, there has been immense development in the technologies applied for humanoid preparation. In this paper, the use of an existing basic technology is focussed for feasible production of a standard humanoid robot. From the very beginning, it should be kept in mind that this work focusses on the use of existing technology for humanoid form and not on any analysis of motion or forces applied on the humanoid robot. In this paper, it is assumed a philosophical statement that nature knows the best. Unless until there is no sufficient need, the humanoid is always kept coherent with the human body. In propose the anatomical characterization of a humanoid robot, it is important to understand several aspects of human behaviour towards several goals they attain in daily life. In the following sections, first human behaviour is analysed and then corresponding robotics replication has been attempted.

Before discussing in detail about the current work, some available literatures regarding the current topic may be cited here. Seward et al. [1] proposed an anatomy of a humanoid robot to justify the feasibility of constructing a humanoid by the use of existing technologies. Breazeal [2] tried to focus on the social and emotional aspects of a humanoid robot both in communicative and learning purposes. Starting from ZMP theory, a revolutionary approach derived by Vukobratovic and Borovac [3], helped in simplifying not only mathematical approaches concerning kinematic analysis of robots but also provided the basis for formulation of many more algorithms that came up later to facilitate robust balancing of robot. Oztop et al. [4] tried to correlate the humanoid robots with the humans and analysed the perceiving capacity of a humanoid robot. Chen et al. [5] discussed about the collaborative approach between human and humanoids used to enable the humanoid robots to explore several applications. Behnke [6] reviewed about the history of humanoid robots and speculated some future developments in the field of humanoid robots. Dahiya et al. [7] studied about the tactile sensing of humanoid robots and discussed about various aspects in the sensory behaviour of the humanoids. Ivaldi et al. [8] discussed about the control networks used to navigate the humanoids based on optimization approaches. Walker et al. [9] discussed about machine learning, software engineering and computer vision associated with a humanoid robot.

The advantages of making a robot in the humanoid form are as follows:

- Humanoid robots can work in the same environment as that used by humans. They can have the ability to negotiate the doorways, stairs and obstructions in the same way as humans.
- Humanoids can use the machines and tools used by humans. This allows humans to intervene and take over a task if it gets beyond the capability of a humanoid and vice versa.
- They can use conventional forms of transport.
- Humanoids can be more socially acceptable when sharing same environments with humans.

## 2. ANATOMY

Anatomy of any object refers to the detailed investigation of the interior parts focussing on both their structural and functional aspects. The anatomical features of a humanoid robot may include the strength considerations, power requirements, motors, actuators, etc. In the following sections, various anatomical features are discussed in detail for the humanoid robot with their coherence to the human body.

### 2.1. Size and Mass

Humans exist in various forms and yet they perform their tasks quite satisfactorily that implies the dimensional parameters do not play a major role on the performance measures. For this purpose of analysis, a sample human male of 31 years of age having 80 kg weight is considered. The height of the considered human is 1.8 m. The following figure 1 shows the coordinates of each section of the human body and how it can be implemented in the geometrical aspects of a humanoid form.

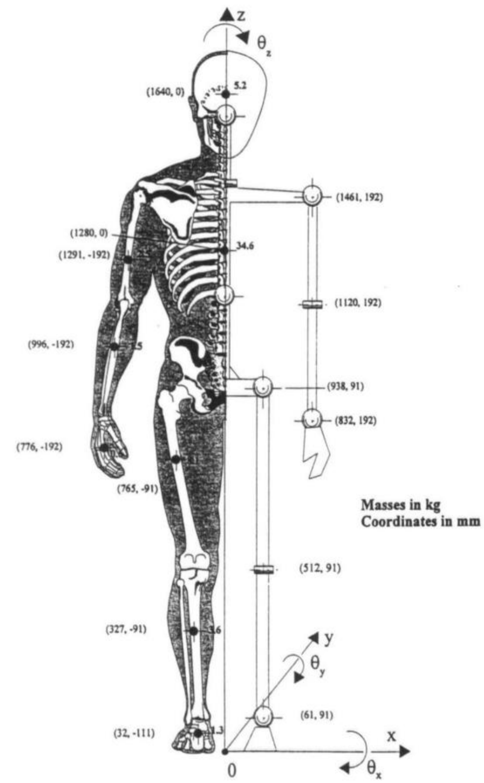


**Figure 1** Back view of Joint coordinates

## 2.2. Bones

In any structure capable of taking loads, the skeletal system bears an important role. It is most fundamental unit of design aspect that demands major attention.

### 2.2.1. Human Bones

Bones are the building blocks of human body. They are the primary members of the human skeletal system. They carry almost all the weight of the human and the external loads that are acting on the human body. Bones are the members that enable the human body to apply force on the external world. Hence the structural strength of the humanoid frame must match the strength of the human body. Out of all the bones in the human body, the bones of the limbs carry maximum percentage of loads. As the jelly like substance present inside the bone do not contribute to the strength criteria, the bone can be taken as a hollow cylindrical structure.
As per the available literature [10], the strength parameters of a typical femur bone are as follows:

Tensile Strength $\sigma$= 100 MPa
Young's Modulus E= 7 GPa
Density $\rho$= 1700 Kg/m3
Outside diameter of femur bone= 36 mm
The diameter of the hollow section can be taken as half of the outside diameter
Moment of Inertia

$$I = \frac{\Pi}{4}(18^4 - 9^4) = 77300mm^4 \qquad (1)$$

Elastic Modulus

$$Z = \frac{I}{y} = \frac{77000}{18} = 4278mm^3 \qquad (2)$$

Maximum allowable bending moment

$$M = \sigma Z = 100 \times 4278 = 0.4278 KNm \quad (3)$$

A similar calculation for the humorous bone considering the outside diameter as 24 mm gives the maximum allowable bending moment as 0.1237 KNm.

#### 2.2.2. Robot Frame

The most appropriate material for the artificial analogue of bones are the reinforced polymer composites or else known as fiberglass. Carbon fibers can also be used to replace the glass fibers. Typical mechanical properties of a glass fiber can be listed as below [1, 11]:

Tensile Strength= 100 MPa
Shear Strength σ= 99.75 MPa
Young's Modulus E= 72.5 GPa
Density ρ= 1800 Kg/m3

By using these properties, to match the strength properties of the femur bone, the diameter of the tube will be around 45 mm if the wall thickness of the tube is taken as 1 mm. Similarly, 30 mm diameter tube can be used to replace the humorous bone.

### 2.3. Joints

The bones of the human body are connected by joints. There are several types of joints present in the human body such as hinge joints, double hinge joints and ball and socket joints. Hinge joints can move in one plane only and are present on the fingers. Double hinge joints can rotate about two axes and are present on wrists. Ball and socket joints are present in the hips and shoulders which can allow some amount of axial rotation along with two axis movement. Apart from these basic movements, there can be many smaller movements occurring in the human body. For example, the movement of the vertebral column is very much complicated. Movements occurring in the individual fingers are not totally independent. Hence there can be several arguments about consideration of number of joints. For example, in case of humans, while raising the hands, the required flexibility is attained by both the motion of ball and socket joint in the shoulder and the movement of shoulder blades. In a humanoid form, this problem can be solved by an extension of shoulder blades and fixing the arm with the shoulder. By this type of design, the humanoid may not be able to shrug the shoulder, but it is clearly evident that the humanoid doesn't require the above function. In case of a humanoid, required number of movements can be achieved by individual actuators and motors. Depending upon the type of work the humanoid is supposed to perform, the degrees of freedom can be increased by addition of extra number of motors and actuators.

### 2.4. Muscles

To give enough amount of power to perform any task, the muscles play an important role staring from blinking of the eye to the lifting of a heavy object.

#### 2.4.1. Human Muscles

Muscles are the effectors present in the human body that convert chemical energy into mechanical work. The muscles are the forms of linear actuators joined to bones at each end by the help of tendons. The tensile force produced by the muscles are generated by the muscle contraction which signifies that they work in opposing pairs to give two-way motion. Enoka [12] reported an approach to calculate the muscle forces which can be described as follows. An average human can raise the Centre of gravity of the body around 324 mm ($h_1$) from the ground from a static squat jump. This jump involves initial bending of knees about 200 mm ($h_2$). If it is assumed that by using only leg muscles, human applies the force required to accelerate the body over a distance of 200 mm, then the power required can be calculated as:

Speed of lift off

$$v = \sqrt{2gh_1} = \sqrt{2 \times 9.81 \times 0.324} = 2.52 m/s \quad (4)$$

Acceleration $a = v^2 / 2h_2 = 2.52^2 / 0.4 = 15.9 m/s^2$ (5)

Force required

$$F = (g + a)m = (9.81 + 15.9) \times 80 = 2057 N \quad (6)$$

Work done

$$W = Fh_2 = 2057 \times 0.2 = 412 J \quad (7)$$

Time taken

$$t = \sqrt{2h_2 / a} = \sqrt{2 \times 0.2 / 15.9} = 0.159s \qquad (8)$$

Power required

$$P = W / t = 412 / 0.159 = 2591W \qquad (9)$$

As the knee and hip muscles contribute about 50 % of the work in the vertical jumping, each muscle would contribute around 650 Watts.

### 2.4.2. Robot Actuators

The above calculations of human muscle power are actually average calculations. In actual practice, human beings use several muscles simultaneously to do any work more efficiently. In case of a humanoid, the muscles of the human body can be replaced by servo motors. For an example, Tower Pro MG996R Servo Motor Digital High Torque Metal Gear Ball Bearing 55g RC is taken as a reference. The specifications of this servo motor are much above the required torque and revolution for individual joint of a human body; hence it can replace the joints as a potential candidate. More no. of motors can be used if higher no. of degrees of freedom are required. A typical arrangement of motors in a humanoid form can be shown as below.

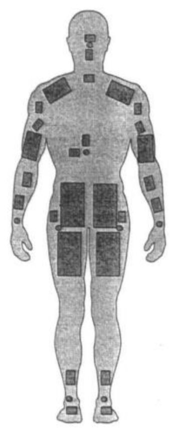

**Figure 2** Typical arrangement of Humanoid motors

## 2.5. Total Energy and Power Requirements

The total energy and power requirement is one of the most important aspect while designing a humanoid in coherent to the actual human. The power of the humanoid should be sufficient enough to account for the requirements by the motors, actuators fitted with the robot frame.

### 2.5.1. Human Power

The duration of any activity performed determines the total amount of power required by a human body. There are two types of skeletal muscle fibres present in the human body; fast twitch and slow twitch fibres. Fast twitch muscles have their store of energy which is capable of producing energy for instant use. Slow twitch fibres take relatively longer time to activate. They do not have their power house; rather they depend upon the supply of glucose and glycogen through the blood flow in the body. In the above calculations, it was demonstrated that a jumper while performing a basic squat can exert about 2.591 KW of power. As per the reports prepared by Enoka [12], about 1.8 KW amount of power can be generated by a weight lifter. In another example, if a person of 80 Kg weight having a pack of 30 Kg has to climb a mountain of 1000 m in 120 minutes, then the power requirement would be:

Power Requirement=

$$\left(110 \times 9.81 \times 1000\right) \div \left(120 \times 60\right) = 149.875W \qquad (10)$$

By the above calculations, it can be summarized that the humans can produce different ranges of power over different applications. But this generated power gradually degrades considering sustained activity.

#### 2.5.2. Humanoid Power
Several options can be made available to supply the required energy and power to a humanoid robot, but batteries can serve best among all other alternatives. The lithium ion batteries used in a modern humanoid can be as light as 200 grams and can provide a power output up to 2.15 Ah.

### 2.6. Skin
Skin acts as a self-healing and self-cleaning agent and a protective layer of the human body. It is responsible for the sensations produced in the human body. The outermost covering of the humanoid should be tough enough to account for the protection of inner parts, and it can also be incorporated with different type of sensors to provide the humanoid the required kind of sense ability.

## 3. DISCUSSIONS
In the above analysis, several aspects have been considered for correlating the humanoids with the humans. The structural and functional features of humans have been analysed and expressed using engineering terms. Similar calculations have been performed for the humanoid robots. The use of existing technology has been tested for design and fabrication of a humanoid. The justifications for adopting a humanoid form are also discussed along with the advantages of using the humanoid form over other forms of robots.

## 4. CONCLUSIONS
Starting from the structural aspects to functional aspects, it was observed that the preparation of a humanoid robot that is capable of performing the tasks as performed by the humans is feasible. The strength calculations and motion constraints can well be satisfied by using the available resources of current robotics world. It can also be proved that a humanoid prepared by the above discussions will be very light in weight and will be able to mimic the human behaviour accordingly. The same concept can also be extended towards the sensory and vision aspects by incorporation of various sensors and cameras in the body of a humanoid to navigate smoothly in an unknown terrain.

## REFERENCES

1. The anatomy of a humanoid robot, Seward, D. W., Bradshaw, A., & Margrave, F, Robotica, Volume No. 14, Issue No. 4, pp. 437-443, 1996.
2. Emotion and sociable humanoid robots, Breazeal, C, International Journal of Human-Computer Studies, Volume No. 59, Issue No. 1, pp. 119-155, 2003.
3. Zero-moment point-thirty-five years of its life, Vukobratović, M., & Borovac, B, International Journal of Humanoid Robotics, Volume No. 1, Issue No. 1, pp. 157-173, 2004.
4. Human–humanoid interaction: is a humanoid robot perceived as a human?, Oztop, E., Franklin, D. W., Chaminade, T., & Cheng, G, International Journal of Humanoid Robotics, Volume No. 2, Issue No. 4, pp. 537-559, 2005.
5. Human-robot collaboration: A literature review and augmented reality approach in design, Chen, X., Billinghurst, M., Green, S. A., & Chase, G. J, 2008.
6. Humanoid Robots-From Fiction to Reality?, Behnke, S, KI, Volume No. 22, Issue No. 4, 2008.
7. Tactile sensing-from humans to humanoids, Dahiya, R. S., Metta, G., Valle, M., & Sandini, G, IEEE Transactions on Robotics, Volume No. 26, Issue No. 1, pp. 1-20, 2010.
8. From humans to humanoids: the optimal control framework, Ivaldi, S., Sigaud, O., Berret, B., & Nori, F, Paladyn, Volume No. 3, Issue No. 2, pp. 75-91, 2012.
9. The NUbots Team Description Paper, Walker, J., Houliston, T., Annable, B., Biddulph, A., Fountain, J., Metcalfe, M., & Mendes, A, 2015.
10. Dynamic finite element analysis of impulsive stress waves propagating from distal end of femur, Sarai, T., Inoue, T., Fujiwara, K., & Kuramoto, K, Acta Medica Okayama, Volume No. 66, Issue No. 5, pp. 409-405, 2012.
11. A study on tribological behavior of alumina-filled glass–epoxy composites using Taguchi experimental design, Biswas, S., & Satapathy, A, Tribology Transactions, Volume No. 53, Issue No. 4, pp. 520-532, 2010.
12. Neuromechanics of human movement, Enoka, R. M, Human Kinetics, 2008.