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RESEARCH ARTICLE

DESIGN AND DEVELOPMENT OF AN ANTHROPOMORPHIC BIPED WALKING ROBOT

Prakash Karamari[1], B.B.Kotturshettar[2], B.S.Kakol[3]

1. Student, Department of Industrial and Production engineering, B.V.Bhoomaraddy college of engineering and technology, Karnataka, India
2. Professor, Department of Industrial and Production engineering, B.V.Bhoomaraddy college of engineering and technology, Karnataka, India
3. Assistant Professor, Department of Industrial and Production engineering, B.V.Bhoomaraddy college of engineering and technology, Karnataka, India

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Corresponding Author

Prakash Karamari

Abstract

Biped walking robot with the anthropomorphic design and human like walking configuration is designed, developed and presented in this paper. The biped robot mechanism for straight walking is proposed, its walking principle and mobility are explained. A prototype is developed and experiments are carried out to validate the straight walking gait of the biped walking robot. Biped walking robot dimensions are based on anthropometry of human legs, biped walking robot has one prismatic joint at knee and one revolute joint at the hip of each leg and has 5 degrees of freedom for both the legs. Kinematic and dynamic analysis is carried out for the biped waling robot. The simple forward kinematic and inverse kinematic equations are developed for the model. Dynamic analysis involves the calculations of forces impressed upon different parts of the mechanism, therefore the zero moment point (ZMP) is being used as criteria to check walking biped robot stability. Graphical results have been plotted for the biped walking robot which involves graph of position, velocity and acceleration of different parts of the robot. Performance measures are carried out for biped robot with the use of prismatic joint. The virtual model, analysis and simulation of biped robot are carried out in MSC-ADAMS and 3DS-MAX.

INTRODUCTION

In the recent years, a great amount of scientific and engineering research has been devoted to the development of legged robots whose gait patterns more or less similar to human beings. In addition to research concerning bipedal robots, efforts were also made to develop mono pedal and quadruped robots. Today, there are many bipedal robot projects in the world, and the number of active projects is growing rapidly. Here, this report is on an anthropomorphically designed linear motion actuated having 5 degree of freedom walking robot, will brief you on Biped locomotion design, some of the analysis work in bipedal robot. The report will mainly focus on design and analysis of Biped robot in design and analysis software such as Solid edge, Autodesk 3DS Max and ADAMS/View for walking robots. This walking robot having simple design with 5 degrees of freedom, prismatic joint operated and simple to control, which has the walking gait similar to the human beings and weight balancing as that of the human being is developed and the experimental results are discussed. The walking gait of this robot is easy to control and stable hence this robot can walk on rough, decline, incline surfaces and some attempts are planned to make this robot climb the stairs. This biped robot can be used without a special change to the working environment because it has similar movements to those of human being. There are several good reasons for developing bipedal walking robots, despite the fact that it is technically more difficult to implement algorithms for reliable locomotion in such robots than in e.g. wheeled robots. First, bipedal robots are able to move in areas that are normally inaccessible to wheeled robots, such as stairs and areas littered with obstacles that make wheeled locomotion impossible. Second, walking robots cause less damage on the ground than wheeled robots. Third, it may be easier for people to interact with walking robots with a humanoid shape rather than robots with a nonhuman shape. It is also easier for a humanoid robot to function in areas designed for people (e.g. houses, factories), since its humanlike shape would allow it to reach shelves etc.

The reference number should be shown in square bracket [1]. However the authors name can be used along with the reference number in the running text. The order of reference in the running text should match with the list of references at the end of the paper.
Eg1: As per Kong, the density of X increases with Y [9].
Eg 2: It is reported that X increase with Y [45].

1.1 Literature review

The Studies on biped robots have been continually carried out in robotic areas since the 1970's to provide robots in dangerous environments, similar to those which human beings would be normally in. Study on biped robots has been generally executed in two areas on actual manufacturing and performance improvement. With respect to the actual manufacturing and the performance improvement, Kato and his researchers have successfully created the first [2] walking biped robot, WL-5. Now, through more advanced studies, a humanoid robot called WABIAN was created. Zheng conducted a study in which his robot SD 2 walks on flat surface walks up stairs and ramps by using 4 hip joints and 4 ankle joints. The more advanced study on robot is conducted by Honda. They introduced ASIMO which walks almost the same as human. [5] The Myong-ji lab implemented the biped walking robot with low power using MBR-S1 (Myong-ji Biped Robot- Static Walking) in 1999, the biped walks up the stairs using MBR-S2, the upgraded model of MBRS1 in 2000, and the biped fast walking using MBRF, with an architecture different from those of MBR-S1 and MBR-S2. In the fast walking of MBR-F, the reducing structure for the upper body is needed to solve the problems of fast walking and moment compensation. To reduce the structure of the upper body, [10] Myong-ji used FPGA, and a new model of a biped robot using FPGA named MBR-3 was designed. MBR-3 has a total of 12 DOF. As a 12 DOF biped robot, MBR-3 can walk more like human beings.
In late 2003, both Iguana Robotics and Sony announced (separate) experimental demonstrations of running for bipedal robots with revolute knees. In early 2004, running was announced for another humanoid robot, HRP-2LR, and in December 2004, Honda's robot, ASIMO, achieved running. [11] The controllers of the Sony and Honda robots are based on the ZMP, that of Iguana Robotics is based on central pattern generators (CPGs) and HRP-2LR uses "resolved momentum". To the best knowledge, only two other bipeds with revolute knees have been designed to perform running—Johnnie in Munich, Germany and RABBIT in Grenoble, France.

Inputs from literature review

In the literature survey the existing designs of the Biped walking robots were studied along with the methods of walking, their construction, controlling, analysis to be done and the simulation. The following information came to light.
- The designs of existing walking robots are complex which results in increased complexity of controlling the robot.
- The number of joints and the number of actuators increases with the complexity of the design and leads to high cost of building the robot.
- It is observed that balancing is the key issue in the design of the walking robot and only few of the robots could achieve this.
- Walking on uneven surfaces is a difficult task for Biped robots; this research focuses on designing the foot which suits the walking on uneven floors.

Hence this research focuses on development of an anthropomorphic biped walking robot having simple design with 5 degrees of freedom.

1.2 Collection of Anthropomorphic data of human and study of walking gait

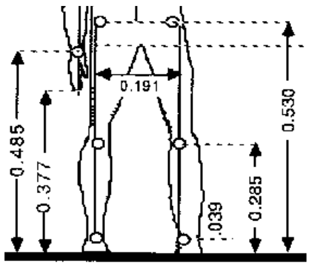

Fig 1.1 Anthropomorphic data of human Body

Human walk has a double support phase in which the body weight is supported by both legs. See the screen capture below. It shows the z translations of the right and left foot Controls together. [1] The durations of stance phases are longer than swing phases throughout a neutral walk animation. The stance/swing ratio is 3:2 on average. As the walking speed increases, the swing phase gets longer and the stance phase gets shorter. In running the stance/swing ratio reverses and double support phases disappear.

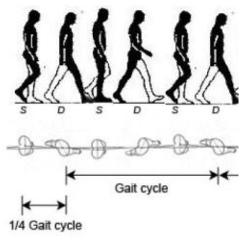

Fig 1.2 Anthropomorphic data of human walking gait

2. ROBOT STRUCTURE DESIGN

The robot consists of trunk, 2 legs with knees and a balancing weight, consists of 5 degree of freedom (2 at the limbs, 2 at the trunk and 1 at the upper body), made of 2 prismatic joints at the limbs of two legs and 2 revolute joints at the trunk and 1 sliding joint at the upper body to shift it during the walking cycle.

2.1 Degrees of freedom

F= 3(n-1)-2l-h

F= 3(5)-10

F=5

Where

F = total degrees of freedom in the mechanism,

n = number of links (including the frame),

l = number of lower pairs (one degree of freedom)

h = number of higher pairs (two degrees of freedom

Joint description:

Revolute joint- there is two revolute joints in this robot each having 1 DOF, this joint provides the rotational motion to the robot trunk making the robot to move forward and backward.

Actuator used here are the 2 electric DC motors which have the torque to rotate the trunk of the robot to the distance in terms of angle of rotation between axis of rotation of both the legs. These 2 actuators rotate one after the other in order to rotate the trunk of the robot about axis to make the move by an angle of α degree in first step and 2α degree in second and so on.

Prismatic joint- The robot consists of two prismatic joints at each knee joint of both legs, each of these joints have 1 DOF at joint. These joints are operated by 2 electric linear actuators, these electric linear actuators help the robot to lift the leg from the ground and hold it till the robot move forward there after brings the leg back to the ground.

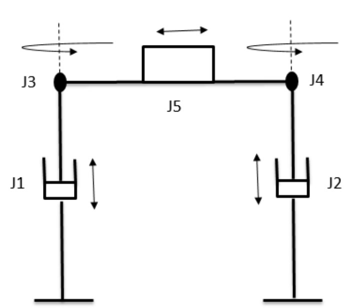

Fig 2.2 Figure showing different joints of the walking robot

2.3 Design of robot links:

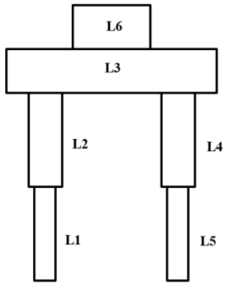

Fig 2.3 Figure showing different links of the walking robot

The robot consists of the 6 links which are made of aluminium material, aluminium is chosen so as to have light weight of the links and easy to the assembly of the robot. The lengths of these links is directly taken from the Anthropomorphic data collected of the human being, for the sake of the fabrication the link lengths are just altered and can be seen in the table 4.1, The table showing the length, mass and inertia of the different parts of the robot. Mass is calculated from the weight of the each multiplied by acceleration due to gravity (9.81), and inertia is calculated.

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4. ANALYSIS OF WALKING ROBOT

Table -1: Name of the Table

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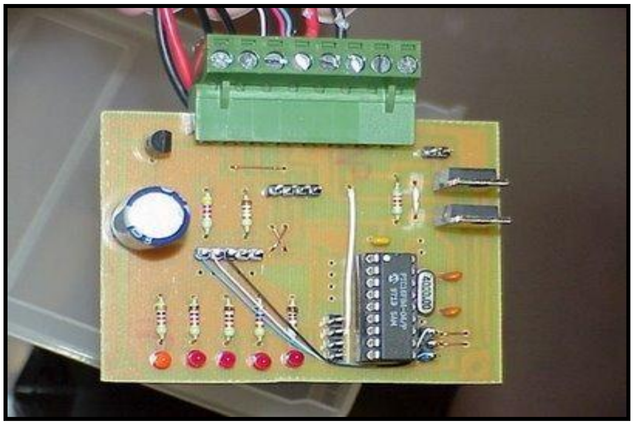

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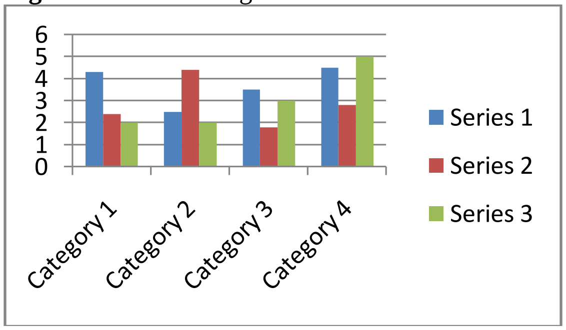

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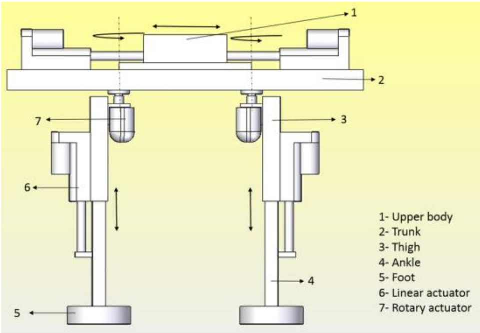


Fig 2.1 CAD model of the walking robot showing the parts of the robot

Links	Length in mm	Mass in kg	Inertia (10^{-4}) in kg-m
1	142.5	0.15	0.304
2	197	0.17	0.659
3	190	0.25	0.902
4	197	0.17	0.659
5	142.5	0.15	0.305
6	150	5.9	0.063

Table 2.1 Design details of the walking robot

3.1 Kinematic analysis

Robot kinematics is mainly of the following two types: forward kinematics and inverse kinematics. Forward kinematics is also known as direct kinematics. In forward kinematics, the length of each link and the angle of each joint is given and have to calculate the position of any point in the work volume of the robot. In inverse kinematics, the length of each link and position of the point in work volume is given and have to calculate the angle of each joint. They are detailed below.

3.1.1 Forward kinematics

Forward kinematics is the method for determining the orientation and position of the end effectors, given the joint angles and link lengths of the robot arm. The forward position kinematics solves/n the following problem: "Given the joint positions, what is the corresponding end effectors". In the Biped robot, the solution is always unique: one given joint position vector always corresponds to only one single end effectors pose. The FK problem is not difficult to solve, even for a completely arbitrary kinematic structure.
In this robot here are two end effectors at the foot of the two legs.

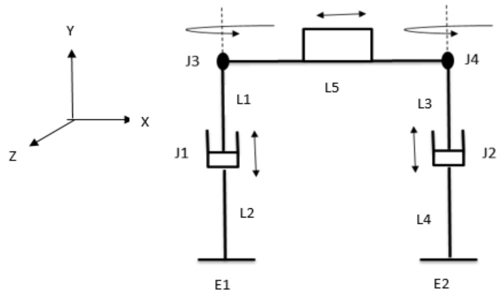


Fig 3.1 Figure of forward kinematics of the robot

Here, E1, E2 are the end effectors, L1, L2, L3, L4, L5 are the links of the robot, J1, J2, J3, J4 are the joints, α1 is the angle of rotation of the robot trunk, α2 is the angle between trunk and the leg.

L1 =15cm, L2 =21cm, L3 =17cm, L4 = L5 =

α1 = 30° α 2 = 90°

Point E1 = (x1, y1, z1)

From figure

X1= 0 Y1= - (L1+L2) Z1=0

Co-ordinates of point E1= (0, - (L1+L2), 0)

Point E2 = (x2, y2, z2)

X2= (L5 cos α1 + (L3+L4) cos α2)

Y2= (L5 sin α1 - (L3+L4) sin α2)

Z2= (L5 tan α1)

Co-ordinates of point E2= {(L5 cos α1 + (L3+L4) cos α2), (L5 sin α1 - (L3+L4) sin α2), (L5 tan α1)}

Hence,

E1 = (0, - (L1+L2), 0)

E2= {(L5 cos α1 + (L3+L4) cos α2), (L5 sin α1 - (L3+L4) sin α2), (L5 tan α1)}

3.1.2 Inverse kinematics

Inverse kinematics is the opposite of forward kinematics. This is when you have a desired end effectors position, but need to know the joint angles required to achieve it. The inverse position kinematics solves the following problem: "Given the actual end effectors pose, what are the corresponding joint positions?" In contrast to the forward problem, the solution of the inverse problem is not always unique: the same end effectors pose can be reached in several configurations corresponding position vectors. Although way more useful than forward kinematics, this calculation is much more complicated too.

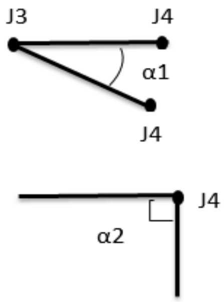
In inverse kinematics α1, α2 have to be found out

Z2= (L5 tan α1)

tan α1 = Z2/L5

α1 = tan-1 (Z2/L5)

And α2 = 90° is a constant angle between leg and the trunk.



3.2 Development of walking Gait for the Robot

In general, there are two types of bipedal gaits: static walking, where the projection of the centre of mass of the robot is kept within the area of the supporting foot, and dynamic walking where this is not the case. Static walking is easier to implement, but is usually unacceptably slow, with individual steps taking several seconds. In dynamic walking posture control based on dynamic generalizations of the concept of centre-of-mass, such as the zero-moment point (ZMP) is used for generating stable bipedal gaits.

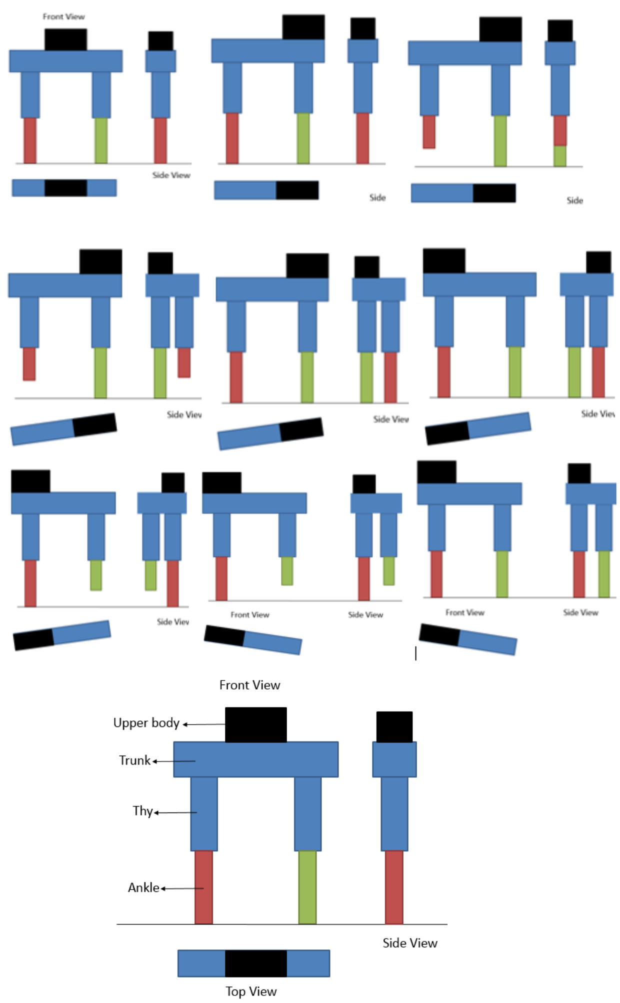


Fig 3.2 Figure of walking gait of the robot

One walking cycle:

Balancing weight to axis of leg - leg lift - rotation of trunk about the axis of leg - leg extend back to ground – balancing weight moves to axis of opposite leg – opposite leg lift – rotation of trunk about axis of opposite leg – opposite leg back to ground – balancing weight moves to centre of robot.

3.3 Zero Moment Point of the biped walking robot:

ZMP is a concept related with dynamics and control of legged locomotion. 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 horizontal direction. The most important task of locomotion mechanism during walking gait is to preserve the dynamic balance, which is achieved by ensuring the foot's whole area and not only the edge, is in contact with the ground. The foot relies freely on the support and the only contact with environment is realized via friction force and vertical force of the ground reaction.
Let us consider the locomotion mechanism in the single support phase as depicted in figure with the whole foot being on the ground. To facilitate the analysis we can neglect the part of the mechanism above the ankle of the support foot i.e. point A and replace its influence by the gravitational force F_A and moment M_A shown in fig.
Whereby the weight of the foot itself acts at its gravity center called as point G. the foot also experiences the ground reaction at point P, whose action keeps the whole mechanism in equilibrium. To keep whole body in balance the total ground reaction consists of three components of the reaction force R ($R_{X,}$ RY, RZ) and moment ($M_{X,}$ MY, MZ). Since the friction force acts at the point of contact of the foot with the ground and the foot on the ground is at rest, those components of the force R and moment M that act in the horizontal plane will be balanced by friction. Therefore, the horizontal reaction force ($R_{X,}R_Z$) represents the friction force that is balancing the horizontal component of the force $F_{A,}$ whereas the vertical reaction moment M_Z represents the moment of friction reaction forces shown in fig. that balances the vertical component of the moment M_A and this moment is caused by the force $F_{A,}$ due to a unidirectional nature of the connection between the foot and the ground, horizontal components of all active moments can be compensated for only by changing position of the reaction force R within the support polygon. Therefore the horizontal component of the moment will shift the reaction force to the corresponding position P, to balance the additional load which is shown in figure. Assuming that there is no slip on the foot-floor contact, the static friction will compensate for the horizontal force components ($R_{X,}$ RZ) and vertical reaction torque (M_Z).

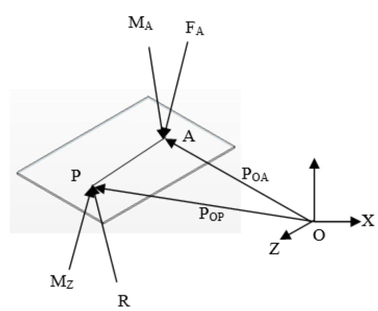


Fig 3.2 Forces acting on the robot ZMP

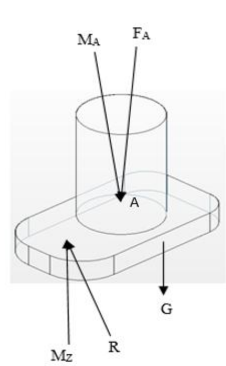


Fig 3.4 Zero moment point of the robot foot

Before deriving the equilibrium equations, i.e. the static balance equations, a few remarks about the point P. first of all: to compensate or the horizontal components of $M_{A,}$ i.e.(M_{AX},M_{AZ}), the point P is shifted in such a way that component of reaction force R_Y is fully compensated for them. This implies that the horizontal components of moment M i.e. (M_X, MZ) are reduced to zero.

Hence
M_X=0
M_Z=0
Since both the components relevant to the realization of dynamic balance are equal to zero. All the time the reaction of the ground due to the foot resting o it can be reduced to the force R and vertical component of the moment M_Z; the point P at which the reaction force is acting represents ZMP.
Secondly, incase if the support polygon is not large enough to encompass the appropriate position of the force R to balance the action of external moments, the reaction force R will act at the foot edge and the uncompensated part of the horizontal component of the reaction moment will cause the mechanisms rotation about the foot edge, which can result in the mechanisms overturning. Therefore, we can say that the necessary and sufficient condition for the locomotion mechanism to be in dynamic equilibrium is that for the point P on the sole where the ground reaction force is acting.
$R+ F_A=0$
$P_{OP}*R+ M_A+ M_Z+ P_{OA}* F_A=0$
The terms P_{OP} and P_{OA} in the above equation are the vectors from the base frame origin O_{XYZ} to respectively points P and A as shown in figure. If the base frame origin is placed on the XZ plane i.e. the horizontal plane, then equation becomes:
$(P_{OP}*R)_{XZ}+ (M_A)_{XZ} + (P_{OA}* F_A)_{XZ} =0$
This equation represents the foot equilibrium, gives the ZMP position that ensure dynamic equilibrium for the overall mechanism of the Biped Walking Robot.

3.4 Static stability analysis:

The mass of the robot and the distribution of mass throughout the body of the robot is related to the forces operating on and within the robot. More importantly, the mass distribution within the robot also effects the balance of the robot, since this determines the location of the COM.
In order to stabilise the robot as much as possible, this robot places the COM as low as possible while still allowing the trunk to be useful for compensating for the movements of the lower limbs. Furthermore, it is likely to minimise and restrict the movement of the COM in a predictable manner, so that directly can control this as a method to balance the robot. To do this the ratio of the combined mass of the leg links to the combined mass of the upper body as small as possible. In this manner, movements of the leg will affect the position of the COM marginally, and even then only in the reference plane. This can control the side balance of the robot by swaying the trunk in the lateral plane.

Mass distribution of the robot:

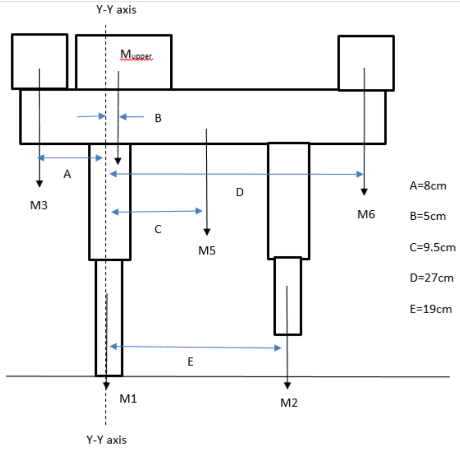


Fig 3.5 Mass distribution of the walking robot

To find the mass of the upper body
Let,
Mass of the upper body be Mupper
Mass of linear actuators be M3, M6 =750 grams
Mass of legs with actuators be M1, M2 =750 grams
Mass of trunk be M5 =150grams
To calculate the upper body mass
Let us consider the masses about y-y axis
M3 x A + M1 x 0 = MUPPER x 5 + M5 x 9.5 + M2 x 19 + M6 x 27
The only unknown here is the M_{UPPER}, so we can solve this to get this value
0.75 x 8 + 0.75 x 0 = M_{UPPER} x 5 + 0.15 x 9.5 + 0.75 x 19 + 0.75 x 27
6 = M_{UPPER} x 5 + 35.925
5 M_{UPPER}= - 29.925
M_{UPPER} = - 5.985 kg-cm (negative sign is neglected as its mass of the upper body)

3.5 Torque at the Trunk/Hip of the robot:

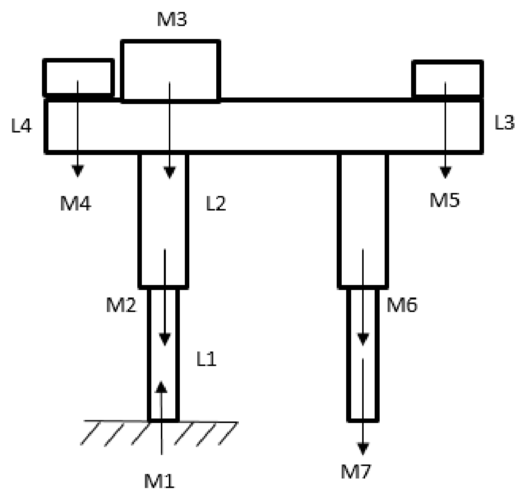


Fig 3.6 Torque at hip of the walking robot

Here M1, M2, M3, M4, M5, M6, M7 are the masses
L1, L2, L3, L4 are the link lengths
We know that
M1 = M3 + M2
Assuming:
- The robot is supported at the mass M1 and it is in standing position
- There is no movement at the ankle of the supported leg
- α is the angle of rotation of the hip

We can write,
ΣM ankle = 0 = - M1 x g x L1 x cos α + M4 x g x (L4-L4cos α) + M5 x g x (L3 – ………………….L3cos α) + M6 x g x (L3 – L3cos α)
= - 926.35cos α+ 58.86 – 58.86cos α + 198.65 – 198.65 cos α + ………………………….198.65 – 198.65 cos α
456.16 = 1382.51 cos α
α = 70.7 degrees
Now the torque at the hip joint
ΣM hip = T hip+ M4 x g x (L4+L4cos α) + M5 x g x (L3+L3cos α) + M6 x g x ………….. (L3+ (L1+L2) cos α) = 0
= T hip + 78.28 + 264.20 + 281.08
T hip = - 6.23 N-m

3.6 Real Biped walking robot experimentation photographs :

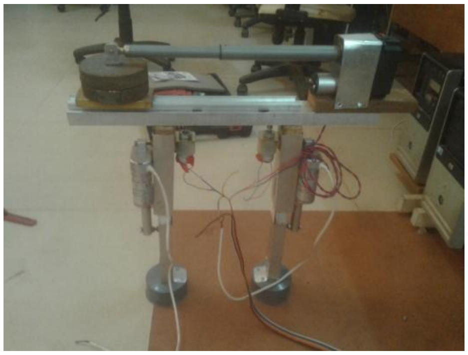


Fig 3.7 Image of the real experimentation of the walking robot

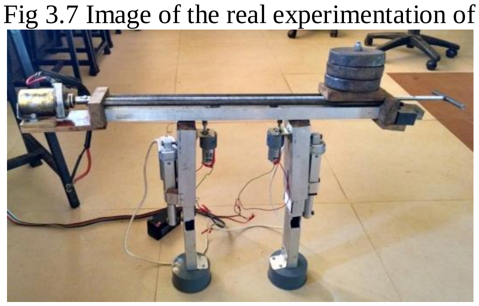


Fig 3.8 Image of the real experimentation of the walking robot

4. CONCLUSION

The anthropomorphic walking robot has a simple configuration which resulted in simple design and reduced complexity of control compared to the existing walking robots. The simulation and analysis of the walking robot which are performed yielded exact results. The walking gait of the robot is achieved the way it is designed through the prismatic joint movements. The robot was able to walk slowly on the straight floor for one cycle of walking. Hence achieving the design and development of anthropomorphic biped walking robot.

REFERENCES

Acosta-M´arquez, C. and Bradley, D. (2000). Provision of gait assistance for individuals with lower limb impairments, In: Proc. of the 7th Mechatronics Forum International Conference, Pergamon Press.

Adams, B., Breazeal, C., Brooks, R. and Scassellati, B. (2000). Humanoid robots: A new kind of tool, IEEE Intelligent Systems **15**(4): 25–31.Albert, A., Suppa, M. and Gerth, W. (2001). Detection of stair dimensions for the path planning of a bipedal robot, In: Proc. of the IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1291–1296.

Arakawa, T. and Fukuda, T. (1996). Natural motion trajectory generation of biped locomotion robot using genetic algorithm through energy optimization, In: Proc. of the 1996 IEEE International Conference on Systems, Man and Cybernetics, pp. 1495–1500.

Espiau, B. and Sardain, P. (2000). The biped robot BIP2000, In: Proc. of ICRA 2000, pp. 3996–4001.

Fujimoto, Y. and Kawamura, A. (1998). Simulation of an autonomous biped walking robot including environmental force interaction, IEEE Robotics and Automation Magazine **5**(2): 33–42.

Fujimoto, Y., Obata, S. and Kawamura, A. (1998). Robust biped walking with force interaction control between foot and ground, In: Proc. Int. Conf. on Robotics

Goswami, A. (1999). Postural stability of biped robots and the foot rotation indicator (FRI) point, International Journal of Robotics Research **18**: 523–533.

Huang, Q., Nakamura, Y. and Inamura, T. (2001a). Humanoids walk with feed forward dynamic pattern and feedback sensory reflection, In: Proc. of the IEEE International Conference on Robotics and Automation, pp. 4220–4225.

Kato, I. and Tsuiki, H. (1972). The hydraulically powered biped walking machine with a high carrying capacity, In: Fourth Symposium on External Extremities. Dubrovnik: Yugoslav Committee for Electronics and Automation.
Raibert, M. (1986). Legged robots that balance, MIT Press, Cambridge, MA. Shan, J., Junshi, C. and Jiapin, C. (2000). Design of central pattern generator for humanoid robot walking based on multi-objective GA, In: Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 1930–1935.