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WALKING ANALYSIS OF BIPEDROBOT

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Abstarct:

This article presents a development plan for a simple bipedal walking robot. The robot walks in a manner that is similar to that of a huma. The mechanical design, as well as strategies for walking and balance recovery, have been presented. This robot considered six D.O.F in the lower body, one at each hip, one at each knee, and one at each ankle. It walks rhythmically, as if it were a human, by balancing the C.O.M.

The designs of leg drive mechanisms, hardware architecture, and leg control algorithms for robot walking are detailed in this research. By studying numerous joints, linkages, sensors, and degrees of freedom in legs, brief guidelines for the design of leg mechanisms have been offered. Following that, research of several robot leg systems is conducted to determine their uses and benefits.

Keywords: Bipedal Robot leg; Biped Walking; Dynamixel; ZMP; Stability.

Introduction

The major goal of this project is to analyze a bipedal robot's walking style and link those robotic legs to a wheelchair so that it can easily mount the stairs. The robot imitates human walking patterns. The mechanical design, as well as methodologies for walking and balance recovery, have been discussed. Six D.O.F in the lower body were considered for this robot, two at the hip, one at each knee, and one at each ankle. It moves rhythmically, as if it were a person, by balancing the C.O.M. The study began with the prototype two-legged robot walking straight and still.

The walking and balance recovery controllers will use the concepts of Capture Points and the Capture Region to determine where to step A Capture Point is a spot on the ground where a biped may halt, and the Capture Region is the locus of such points.

A very important control concept in bipedal robotics is the concept **called "Zero** Moment **Point,"** or **ZMP for short. It** is a point **in the contact zone of** the foot and **the** ground where dynamic stability is achieved.

Bipedal robot locomotion differs from human locomotion. It performs the leg motions according to the sequence of actuators and maintains precise positioning to walk steadily, while human locomotion is flexible at any angle and with any desired speed.

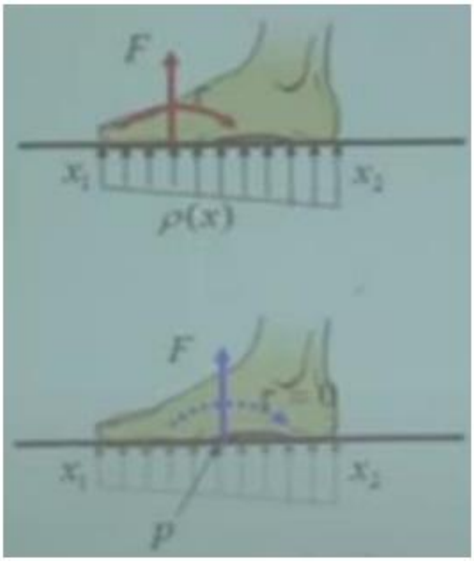
This study aims to develop a basic bipedal walking robot that can walk while maintaining its body balanced. This project entails selecting the material and thickness, selecting actuators for joint actuation, limiting actuator motions, and addressing the issue of actuators drawing high currents.

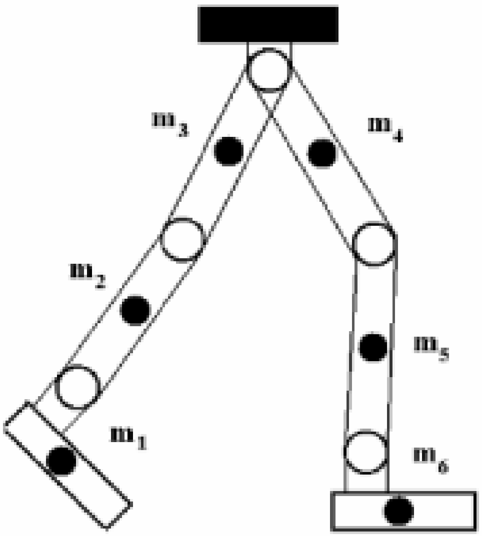
Methodology and Design

- Robotic legs resemble human legs in appearance.
- As a result, a wheelchair may ascend and descend the staircase.
- We cannot use a wheelchair if the floor is uneven, but this wheelchair can be used on any surface.

Mass Distribution

Mechanical parameters such as length and mass distributions may have a greater effect on the human gait (refer to Fig). As a result, it is critical to evaluate the robot's proportions, such as leg link length and mass distribution across the body. The forces acting on and inside the robot are connected to its mass and the distribution of mass across its body. If the robot's mass is too great, it will not react to the control system quickly enough, and it may even malfunction, particularly if the servos used are not strong enough. More crucially, the mass distribution inside the robot impacts the robot's balance since the COM's placement is determined by this. The absolute mass distribution will change when the robot links move about one another, which means the location of the COM inside the robot will change throughout the walking gait. Because the COM's movement will substantially impact the robot's stability, it is also critical to consider the mass distribution while accomplishing dynamic walking.





Stability:

In traditional legged robots, stability is maintained by having at least three contact points with the ground surface at all times. With biped robots, only two points are in contact with the ground surface. To resolve the biped robot's stability while walking, a simplified model with foot force sensors feedback can input a controller, thus maintaining stability while walking. Nevertheless, the purpose of the mechanical design is to ensure that the foot robot reaches dynamic balance. The control algorithm partly provides dynamic balancing; however, the mechanical design plays a crucial role in the robot's ability to make the correct movements. A way to reach it is by finding the proper mass distribution on the robot. Thus, the robot will be able to achieve stability while walking. These movements can then be performed quickly without generating significant moments that would further destabilize the robot. To achieve this goal, the COM must be placed in a low position to stabilize the robot inertially but high enough to be moved only in small amounts to correct undesired behaviour. The proper placement for the COM is the lower part of the chair, similar to humans. This provides stability and allows the chair to be moved, shifting the COM to archive desired accelerations to counteract existing undesired accelerations.

ZMP (Zero Moment Point)

- It is a hypothetical point where the sum of all moments is equal to zero.
- It is a point w.r.t dynamic reaction of forces $(\sum F\ equal\ to\ zero)$ at the contact of the foot with the ground and does not produce any moment in the horizontal direction.
- At this point, total horizontal inertia and gravity force is equal to zero.

- The position of the ZMP is computed by finding the point (X,Y,Z) where the total torque is zero.
- It is a vector quantity.

Assumptions

- Area of contact is planar and has sufficiently high friction to avoid sliding.
- The biped robot consists of "n" rigid links.
- All kinematic information, such as the position of COM, link orientation, velocities, etc. are known and calculated by forward kinematics.
- The floor is rigid and motionless.

Design and Development

The design focuses primarily on walking movement using dynamixel actuators. Dynamixel actuators offer adequate flexibility when walking. Planar motion is another important parameter to balance walking and motion. The robot is featured with three degrees of freedom per leg. The actuators were placed to the hip, knee, and ankle joints to get a leg configuration similar to humans.

The actuators to the hip, ankle, and knee have the same axis of rotation. The ankle joint has been chosen to rotate in this manner in order to balance the centre of gravity while the hip and knee joints were designed to balance the robot in the forward and backward directions.

Biped Walking

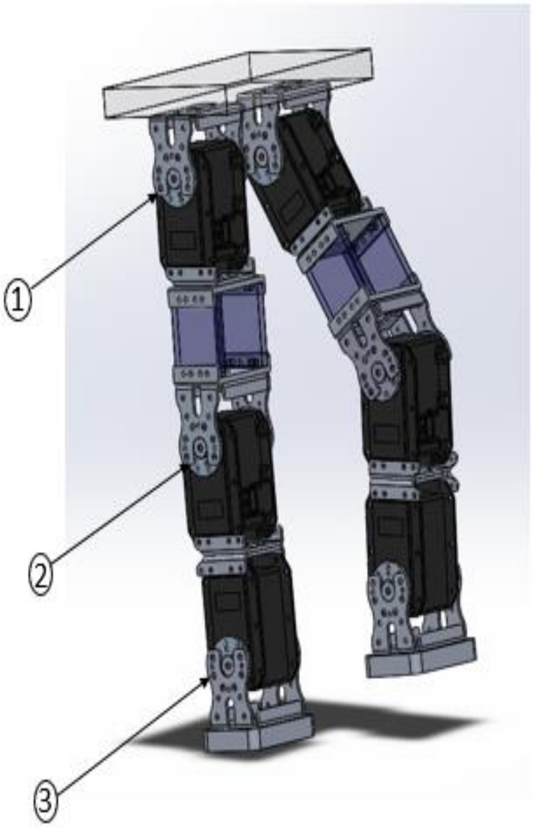
- In order to understand the mechanical bipedal robot's design, it is necessary to understand the walking process.
- Walking Cycle: It consists of two phases:

1) SSP (Single Support Phase)

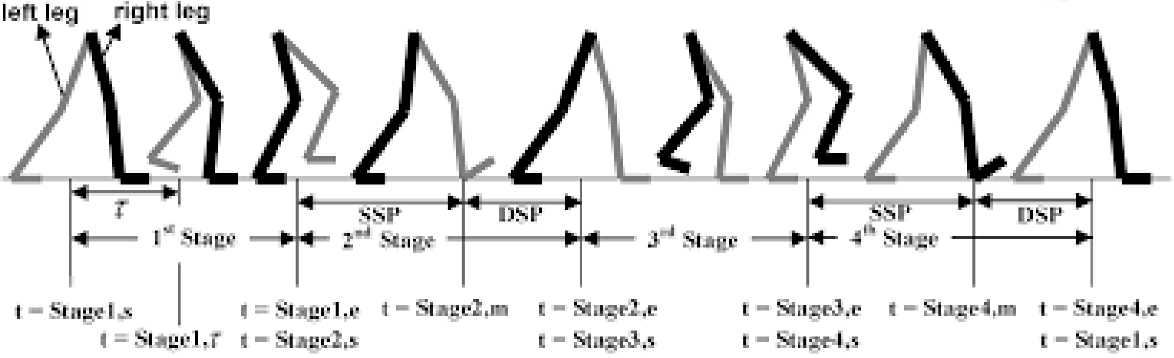
2) DSP (Double Support Phase)

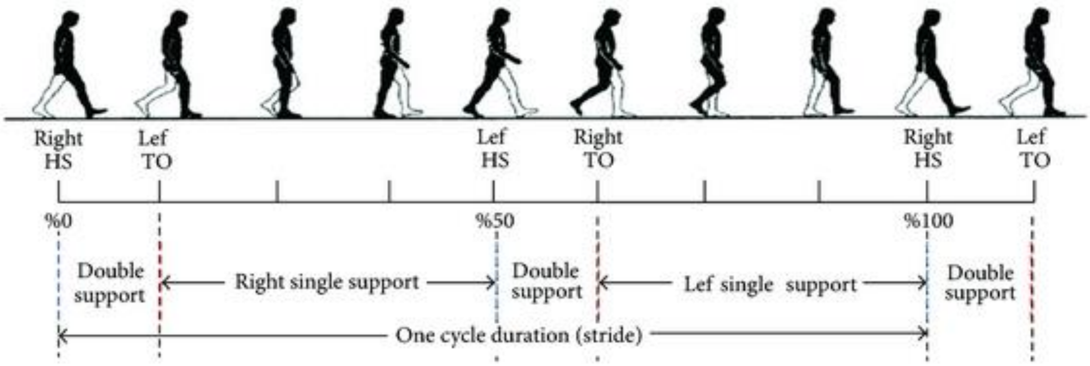
- Single Support Phase (SSP): In this phase only one foot will be on the ground and another foot will be in air.
- Double Support Phase (DSP): In this phase both legs will be on the ground.

Static Walking



Static walking is walking with a very low speed, walking speed must be low so that inertial forces are negligible. During static walking, the robot can stop the walking motion any time down. The robot is statically stable in this case, which indicates that if all motion is halted, the robot will remain in a stable posture forever. This kind of walking requires large feet, strong ankle joints and can achieve only slow walking speeds.



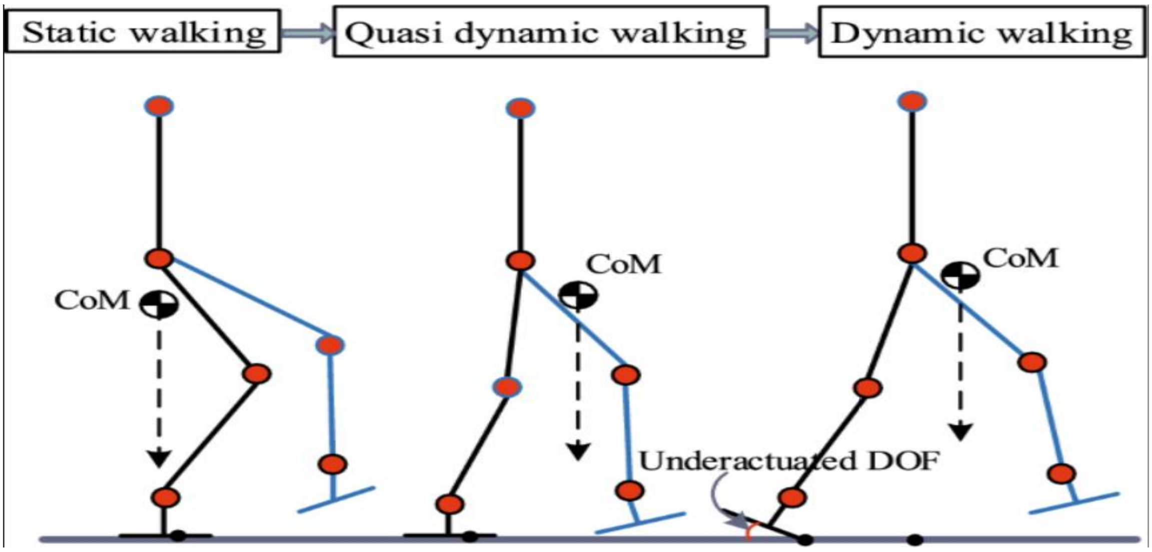


Dynamic Walking

- It is quick walking, with each stride taking less than a second. Even while making minor body movements, dynamic walking is smoother and more active if dynamic balance can be maintained. A biped robot may quickly tumble down if the inertial forces created by the robot's acceleration are not properly managed. The walking action cannot be abruptly stopped. In order to manage inertial forces, the concept of ZMP (Zero Moment Point) was developed.

Dynamic Balance Analysis

- The ZMP is the point where the robot’s total moment at the ground is zero. As long as the ZMP is in the stance zone, walking is considered dynamically stable as this is the



only case in which the foot can control the robot's posture.

- Dynamic walking is achieved by ensuring that the robot always turns around a point in the support zone.
- If the robot spins around a point outside the support zone, the supporting foot will either lift off the ground or be forced against it, causing instability in both scenarios.

Calculation:

- Torque of leg $\tau = I_i * \omega_i$
- Force along 'x' Direction = $m_i * x_i$
- Force along 'z' Direction = $m_i * z_i$
- Gravitational Force = $m_i * g$

- We consider 'O' is zero moment point:

$$-\sum_{i=1}^{7} m_i\,(z_i - g)(x_{ZMP} - x_i) - \sum_{i=1}^{7} m_i\; x_i\; z_i + \sum_{i=1}^{7} I_i\; \omega_i = 0$$

- No. of Links = 7

➢ $x_{ZMP} = \frac{\sum_{i=1}^{7}(I_i\,\omega_i + m_i x_i (z_i - g) - m_i x_i z_i)}{\sum_{i=1}^{7} m_i (z_i - g)}$

Staircase Ascending

Double Support Phase

- Double Support Phase = 2 Single Support Phase

- When the biped robot is ascending steps there will be reaction force, this is going to act through this ZMP.
- (DMB)system = Sw - X1 + X2 + L7 - 2|ZMP|

- X_{ZMP} should lie within the foot.
  - ➢ X_{DBM} (Dynamic Balance Margin) = $\frac{L_7}{2} - |x_{ZMD}|$

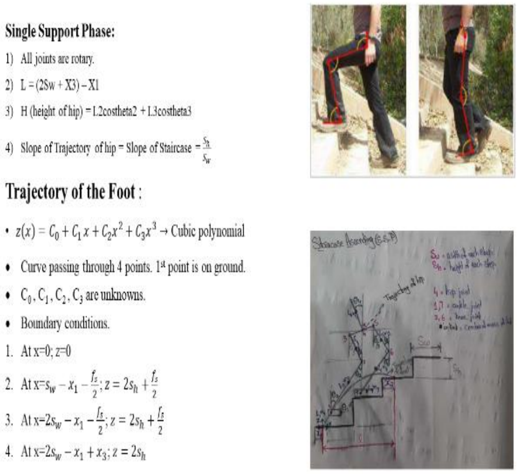
Mechanical Considerations and Specifications

The mechanical design process entails the formulation of requirements that will ensure the success of the selected walking model. This is not a simple process; numerous factors must be taken into account to guarantee that the biped robot remains stable when walking.

The design chosen is formed by a biped robot configured of two legs, each having 3 degrees of freedom (DOF). Two of these are rotational on the pitch axis at the knee and ankle.

As the chair is moved to the angle calculated by the controller, the centre of mass (COM) position will change to a point where the robot's structure is stable.

Configuration:



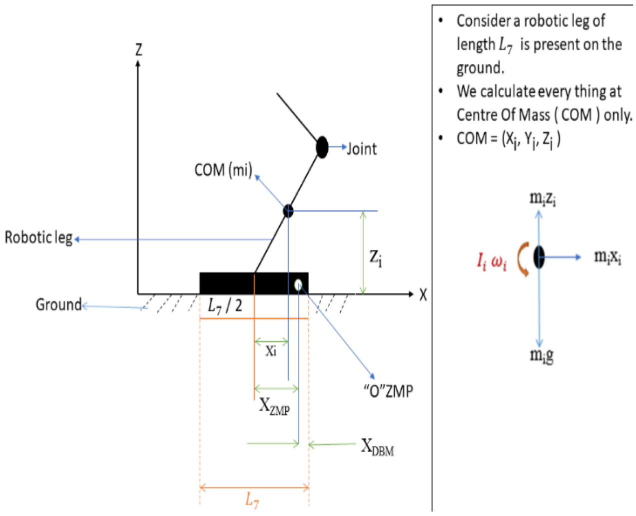
Single Support Phase:

1) All joints are rotary.
2) L = (2Sw + X3) – X1
3) H (height of hip) = L2costheta2 + L3costheta3
4) Slope of Trajectory of hip = Slope of Staircase = $\frac{S_h}{S_w}$

Trajectory of the Foot :

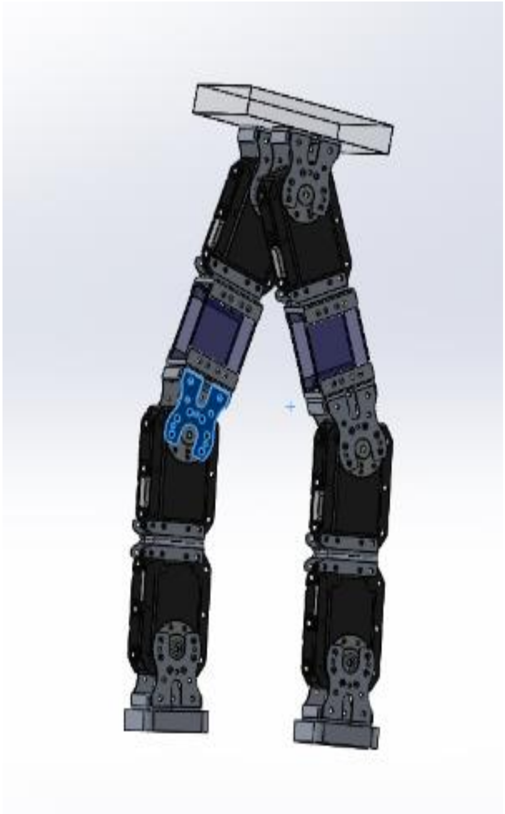
- $z(x) = C_0 + C_1 x + C_2 x^2 + C_3 x^3 \rightarrow$ Cubic polynomial
- Curve passing through 4 points. 1st point is on ground.
- C_0, C_1, C_2, C_3 are unknowns.
- Boundary conditions.

1. At x=0; z=0
2. At $x = s_w - x_1 - \frac{f_s}{2}; z = 2s_h + \frac{f_s}{2}$
3. At $x = 2s_w - x_1 - \frac{f_s}{2}; z = 2s_h + \frac{f_s}{2}$
4. At $x = 2s_w - x_1 + x_3; z = 2s_h$



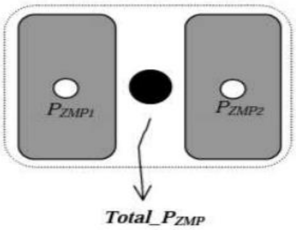
- Consider a robotic leg of length L_7 is present on the ground.
- We calculate every thing at Centre Of Mass (COM) only.
- COM = (X_i, Y_i, Z_i)

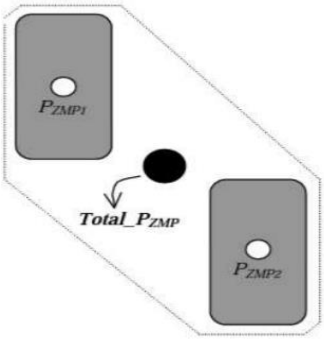
- Degrees of Freedom = 6 (3 for each leg).
- One at ankle
- One at knee
- One near the hip



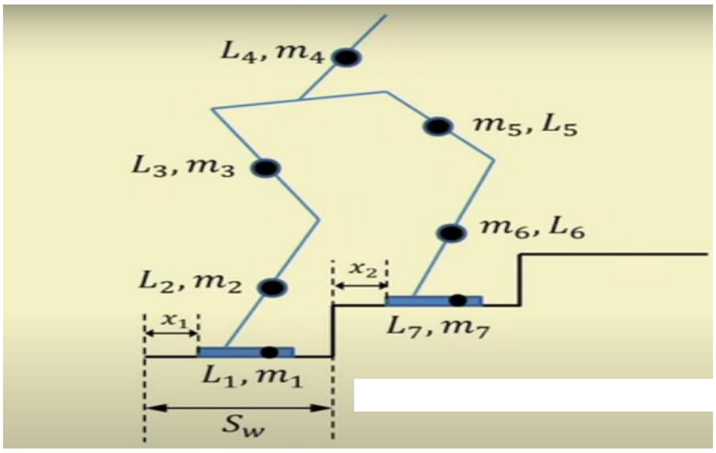
Dynamixel:

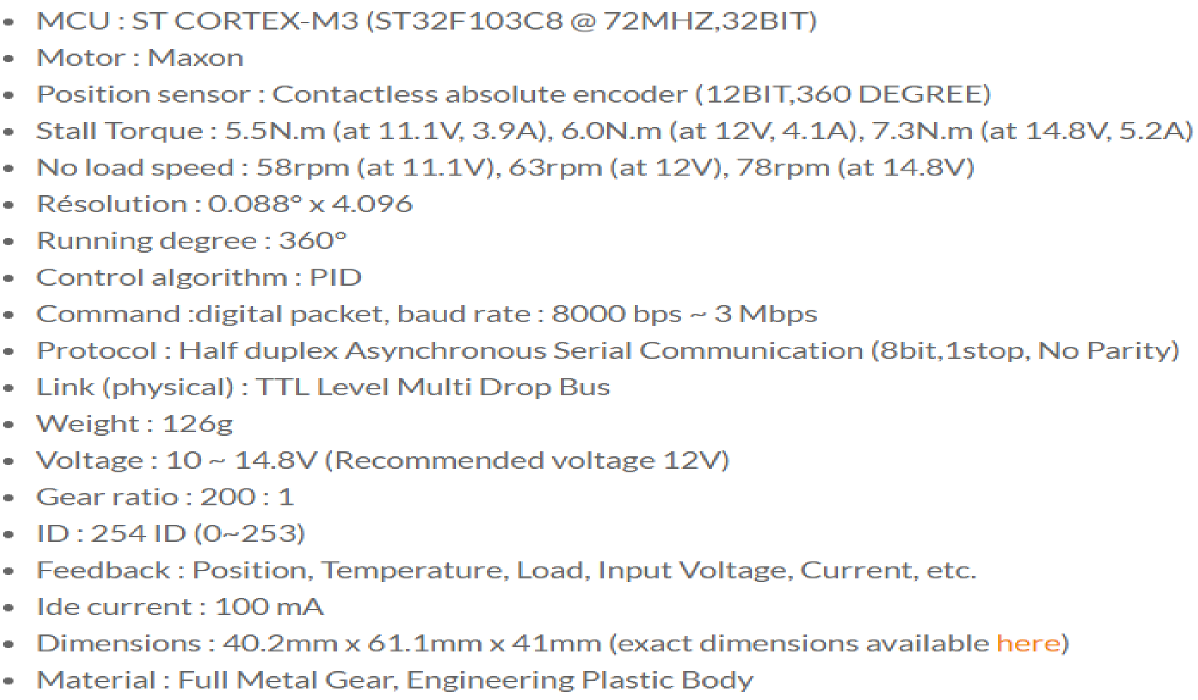
- Dynamixel MX64T actuator is a required component.
- DYNAMIXEL is a unique intelligent robot actuator with fully integrated DC motor + gearbox + controller + driver + network in one DC module.
- MX-series is a new concept of DYNAMIXEL with advanced functions, such as precise control, PID control, 360° of position control, and high-speed communication.
- The micro-controller receives the action control from serial communication that can vary depending on the model.
- The micro-controller with a PID controller will control the position of the robot.





Technical specifications of the Dynamixel MX-64T actuator:





- MCU : ST CORTEX-M3 (ST32F103C8 @ 72MHZ,32BIT)
- Motor : Maxon
- Position sensor : Contactless absolute encoder (12BIT,360 DEGREE)
- Stall Torque : 5.5N.m (at 11.1V, 3.9A), 6.0N.m (at 12V, 4.1A), 7.3N.m (at 14.8V, 5.2A)
- No load speed : 58rpm (at 11.1V), 63rpm (at 12V), 78rpm (at 14.8V)
- Résolution : 0.088° x 4.096
- Running degree : 360°
- Control algorithm : PID
- Command :digital packet, baud rate : 8000 bps ~ 3 Mbps
- Protocol : Half duplex Asynchronous Serial Communication (8bit,1stop, No Parity)
- Link (physical) : TTL Level Multi Drop Bus
- Weight : 126g
- Voltage : 10 ~ 14.8V (Recommended voltage 12V)
- Gear ratio : 200 : 1
- ID : 254 ID (0~253)
- Feedback : Position, Temperature, Load, Input Voltage, Current, etc.
- Ide current : 100 mA
- Dimensions : 40.2mm x 61.1mm x 41mm (exact dimensions available here)
- Material : Full Metal Gear, Engineering Plastic Body

Conclusion:

- In this article, we have presented the design and performance of the bipedal robot mechanism. Walking robots have a massive advantage over wheeled robots in that they can negotiate considerably more challenging terrain and change their stability to accommodate changing terrain conditions. Here, design and simulation analysis of legged walking robots have been addressed by using modelling and simulation in the Solid works environment. According to this paper, Dynamixel actuators can operate simultaneously one after one using an algorithm by the microcontroller to generate the walking motion of the robot. The angular velocities of the hip, knee and ankle joints are controlled through programming for walking of a bipedal robot. The bipedal robot will walk by the balancing of the centre of mass (COM) calculated above.
- Future work will be based on the implementation of the position control algorithm on a bipedal robot with an upper limb and on the experimentation with faster walking speeds. In the development of robots to work in human environments, human walking appears to be the most suitable form of locomotion as the robot has to move around in an environment with obstacles and climb up and downstairs. The same prototype can be used for making motions like climbing up a stair or climbing up in a slope with maintaining postural stability. At this time the system becomes highly nonlinear and the number of parameters to be controlled increases with complexity. Hence to analyse the system high-level programming is required and in addition to its advanced controller algorithm to be used for maintaining walking stability in bipedal robots.

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