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Research Article

Mechatronic Design, Fabrication and Analysis of a Small-Size Humanoid Robot "Parinat"

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Abstract

This paper describes the mechatronic design of a small size humanoid robot, developed under the project 'Parinat' at IIT Bombay. The robot has 12 degrees of freedom (DoF), with 3 DoF in each limb. The height of the robot is 30cm and it weighs around 1.8kg. It is capable of demonstrating basic human like motions such as walking, dancing etc. without any torso arrangement or weight shifting mechanism. The mechanical structure is made up of modular U-shaped brackets, manufactured in-house, for mounting servo motors which are used as actuators. The walking speed of Parinat-1 is around 30mm/sec. The robot is able to turn through 5 degrees in each unit step. Detailed design process of the robot, simulations for calculating torque requirements of servo motors, walking gait analysis, power supply and control systems are presented in this paper.

Keywords: *Gait Analysis, Humanoid, Mechatronic design*

1. Introduction

A humanoid is a robot that resembles a human being in its appearance i.e. it has a head, 2 legs, 2 arms and a torso. The most interesting aspect of making a humanoid is that it gives a great insight into the way our body functions while performing any kind of motion in terms of stability and actuation. The design and fabrication of humanoid robot involves multidisciplinary aspects including, but not limited to mechanical engineering, electronics and computer science.

1.1 About the 'Parinat' Project

'Parinat'- pronounced as 'pəɽInəθ'– sanskrit for 'Transform'-is a small humanoid robot development project undertaken by a team purely consisting of students from various departments of Indian Institute of Technology-Bombay. The long term goals of the project are inspired by an ideological mash up of the movies 'Transformers' and 'Real Steel'. We are aiming to make a humanoid which can transform into a vehicle and is also capable of mimicking the user, in the long term.

As a first step towards accomplishing these goals, the design and fabrication of first prototype, hereafter called 'Parinat-1' has been completed, which is capable of demonstrating basic human like motions such as walking and dancing without any torso arrangement or weight shifting mechanism. It has 12 degrees of freedom (DoF), with 3 DoF in each limb. Fig.1 shows the 3D CAD model of Parinat-1.

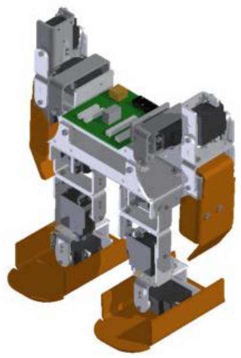

Fig.1 CAD model of Parinat-1

1.2 Overview of Paper

This section has described the goals and current progress of 'Parinat' project. Section-2 will describe the mechanical design of Parinat-1, which includes size and degrees of freedom (DoF) description, design of modular links, torque estimations for servo motors and fabrication of model. Section-3 will deal with the electronics and control part, which consists of power supply, circuit design and

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user interface. Section-4 will look at the walking gait of Parinat-1, including the simulation results for finding imposed torques by actuators in a walking cycle. Finally some concluding remarks are presented in Section-5.

2. Mechanical Design

Mechanical design is a key step in making a small humanoid robot. In our case, the design process involved following steps:-

1) Deciding degrees of freedom based on objectives of the robot
2) Fixing dimensions of different body parts
3) Designing links for body parts
4) Making detailed CAD models
5) Calculating torque requirements for servo motors

2.1 Degrees of Freedom and Sizing

The primary goal of Parinat-1 robot was to demonstrate the human motion of walking. For walking minimum 3 DoF are required in each leg. So based on the available budget of project in which cost of actuators was a major component, the following Degrees of Freedom (DoF) configuration was chosen (shown in Fig. 2). Parinat-1 has 3 DoF in each leg and 3 DoF in each arm.

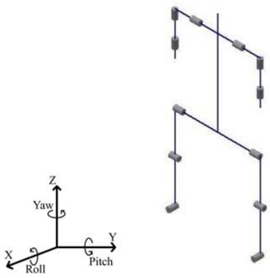


Fig.2 DoF configuration of Parinat-1

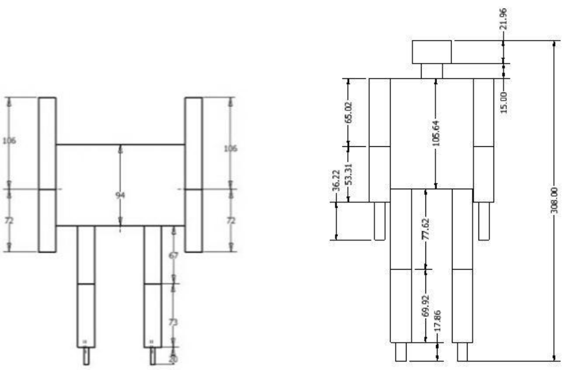


Fig.3 Comparison of Parinat-1 dimensions with actual human body segments

The height of the robot is 0.308 m. The dimensions of all body parts were chosen as closely proportionate as possible with the actual biomechanical data of human figure. But due to the limitations of servo motor sizes some dimensions had to be compromised. In Fig. 3, the comparison of dimensions of Parinat-1 and that of an average human figure scaled to the same height as that of Parinat-1 is shown. From comparison it can be seen that, Parinat-1 is somewhat wider than average person and has smaller limbs.

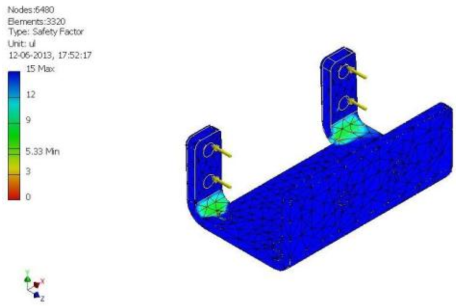
2.2 Design of Modular brackets

In order to simplify the fabrication of different body parts, modular brackets were designed for mounting servo motors. After making various conceptual designs for bracket links and analyzing them for load bearing capacities and ease of connection, the design shown in Fig. 4 was finalized.

Fig.4 Servo holding bracket and Output Bracket links

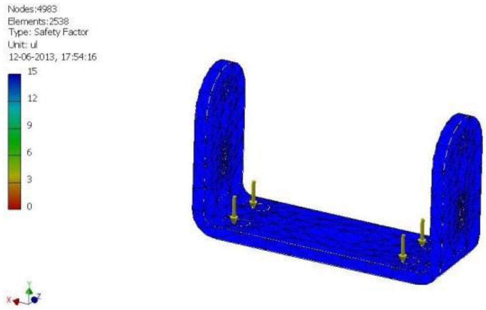
2.3 Stress analysis of Bracket links

The stress analysis of both the links was carried out in "Autodesk Inventor-Stress analysis utility", to find out the safety factors under maximum possible load. Fig. 5a and 5b show the results for links made up of Polymethyl Methacrylate (PMMA) material. The minimum safety factors for 15N load (estimated maximum load) were found to be 5.33 and 15 respectively for A and B bracket links, which are well beyond any risk of failure.



(Constraints: Bottom face is fixed) (Load: 15N at positions shown by arrows)

Fig.5a Stress analysis of servo holding link

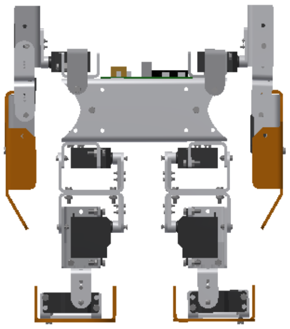


(Constraints: Holes at top are fixed) (Load: 15N at positions shown by arrows)

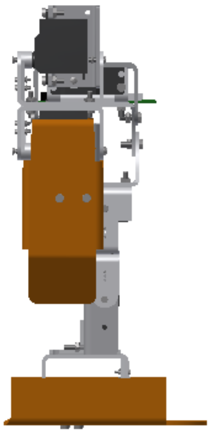
Fig.5b Stress analysis of output bracket link

2.4 CAD Model

Detailed CAD models of Parinat-1 were made to realize the placement of servo motors and connection of body parts, considering the DoF's and segment proportions identified earlier. Fig. 6 shows the Autodesk Inventor CAD model of Parinat-1 robot.



Front View



Side View

Fig.6 Front and Side view of Parinat-1 CAD model made in Autodesk Inventor

2.5 Fabrication of the robot

Fig.7 Fabricated model of Parinat-1 robot

The parts of Parinat-1 robot were fabricated from Polymethyl Methacrylate (PMMA) sheets of 3mm thickness. The sheets were cut using standard laser cutting manufacturing process and then bending was done with application of heat. The fabricated model is shown in Fig. 7.

3. Walking Gait

3.1 Gait Phases

Walking is a cyclic movement consisting of two main phases-

1) Double support phase
2) Single support phase.

The single support phase consists of toe off, swing phase, heel strike. These two phases alternate on both legs (shown in Fig.8). Also in order to start walking from a standing position, one half step is required.

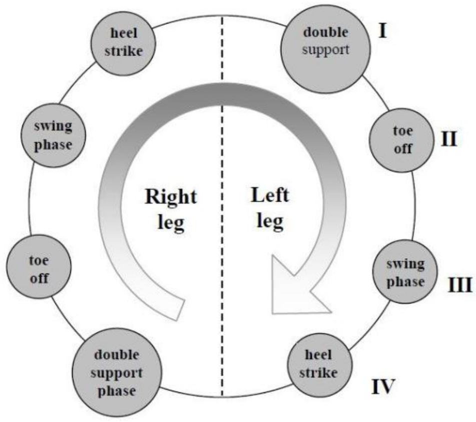


Fig.8 The cyclic phase rotation of biped walking

3.2 Parinat-1 Gait Simulations

The transition of Parinat-1 robot from double support phase to single support and then back to double support is shown in Fig. 9. Simulations were performed in "Autodesk Inventor - Dynamic Simulation utility" to find out the torques imposed by servo motors during walking cycle of Parinat-1.

Double Support *Single Support*

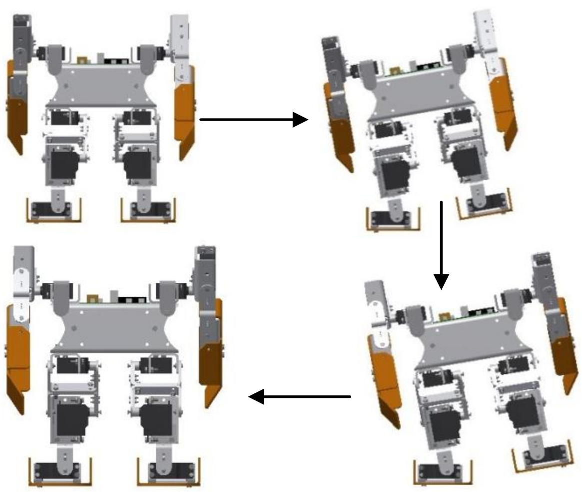


Fig.9a Walking cycle of Parinat-1 robot (Front View)

Double Support *Single Support*

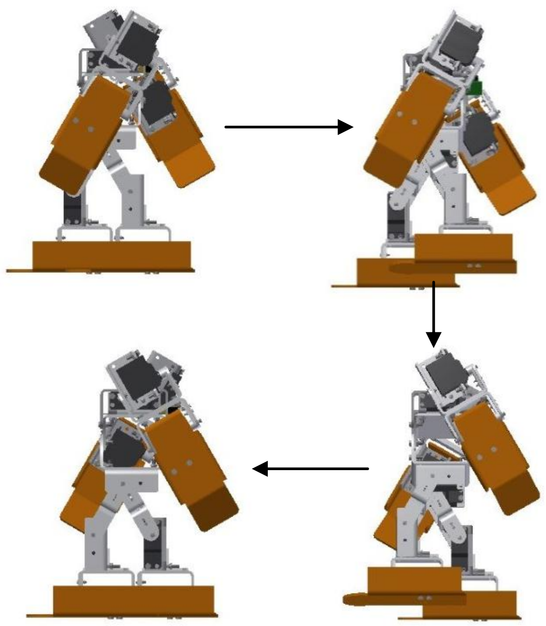


Fig.9 b Walking cycle of Parinat-1 robot (Side View)

In the simulations, each full step consists of Toe-off phase for 1 sec, full Swing for 2 sec and heel-strike phase for 1 sec. Fig. 10 shows the results of simulation for full step.

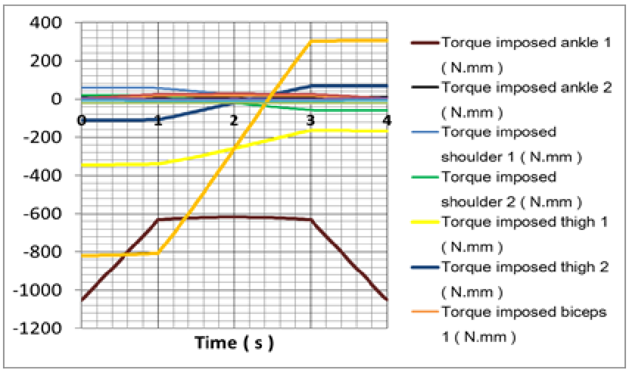


Fig.10 Simulation results showing imposed torques at various joints during walking cycle of Parinat-

The mass of actuators and the volume required to house them have an effect on the overall mass and mass distribution of the robot. The torque requirements of servo motors can be obtained from this distribution. The mass and dimensions of servo motors were taken directly from the documentation provided by supplier. The mass of brackets was calculated from their density and shape.

Mass of servo motor = 0.077 kg

Dimensions of servo motor = 0.0407m x 0.0205m x 0.0395m

Density of Polymethyl Methacrylate = 1180 kg/m3

Table 1 summarizes the results of simulations. After several simulations and torque analysis, the choice of motors seemed evident; however, there is a trade-off between torque and economic considerations. The resultant choice of motors was NRS-995, a High Torque RC servo motor with metal gears, capable of delivering 1.67 N.m torque at 6V with maximum speed of 6.9 rad/s. These are controlled by giving pulse width modulated signals as input.

Table 1 Summary of simulations for finding torque requirements of each joint of Parinat-1 robot

Joint	Max. Torque (N.m)
Ankle	1.05
Knee	0.819
Thigh	0.345
Shoulder	0.059
Biceps	0.028
Elbow	0.010

4. Electronics and Controls

4.1 Power and Circuits

Parinat-1, with its 12 servo motors, consumed a massive 5V/ 18A power to be able to operate normally, as each servo motor had a stall current of 1.5A at 5V. Therefore, a 5V/25A switched mode power supply was used to energize it.

In order to accomplish the simultaneous motion of multiple joints, a circuit consisting of a TLC5940 (LED driver chip) which could simultaneously give out pulse width modulated signals (PWM signals) on 20 unique channels, driven by an Arduino Pro-Mini microcontroller was developed. Fig 11 shows the design of printed circuit board (PCB) for the same.

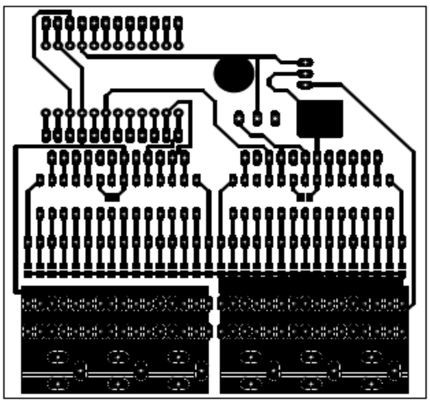


Fig.11 Design of PCB for Parinat-1 in Eagle

4.2 Virtual Interface (shown in Fig. 12)

A virtual interface is developed in Java on Processing IDE, which takes the user input for angles of each joint of the humanoid. This input is then encrypted and transmitted to the microcontroller.

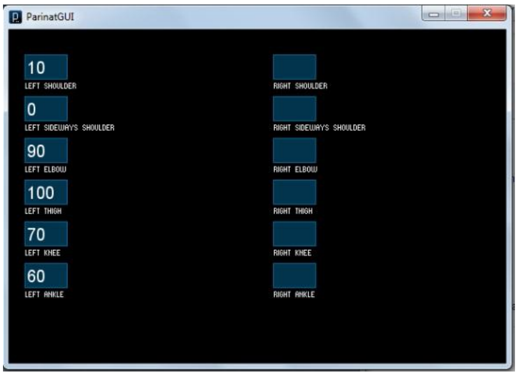


Fig.12 Screenshot of virtual interface for Parinat-1

Conclusion and Future work

This work presented the steps involved in design of a small size humanoid robot. It provides an insight into the greater challenges involved in making a transforming and mimicking humanoid, which is the main goal of 'Parinat' project. The step-by-step design process followed in this project can be implemented in designing humanoid robots of larger size also. The current model is able to demonstrate basic human motions like straight walking and turning. The walking speed of Parinat-1 is around 30mm/sec. The robot is able to turn through 5 degrees in each unit step. The ongoing work on different control mechanisms will be implemented in future versions with advanced functionalities like autonomy, steadier gait and enhanced user interaction.

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