IIT Madras
Centre For Innovation

bola ww ?`

Project Quadruped

iBot CLUB

Tanzir , Raghu

Team Members

	Shashank Tirumala The Project head

	ED19B064	V.Easwar
	Although i was from the electrical module, as working on it was not possible online, i worked along with the software module to deal with the control and motion planning simulation of the quadruped bot. I worked on simulating a robotic arm in PyBullet using PID by giving it various trajectories. Email : easwarv100@gmail.com	
	ME17B179	Chella Thiyagarajan N
	I, Chella, currently pursuing my 4th year Mechanical Engineering, I worked in the Robotic Software aspect of this quadruped project. Our software team deals with the control and motion planning simulation of the quadruped bot. I worked in PID and RL control aspects of the animal gait motion simulation. PyBullet is our weapon in hand, which helped us massively during simulations. I cherish my memories working with the head and the team. Email : thiyagutenysen@gmail.com	

<table>
<tr><td rowspan="2"></td><td>ME19B067</td><td>Aastha Mishra</td></tr>
<tr><td colspan="2">I am Aastha, a second year mechanical engineering undergraduate. I was working on the mechanical aspect of the quadruped robot, along with two other teammates. I spent the first few weeks learning Fusion 360 and doing some assignments on it, like modelling the slider crank mechanism and Oldham’s Coupling. We also read a few research papers and looked at previous quadruped models to decide upon the kind of leg manipulator to be used. Next we used Python to model four bar linkage and then simulated the movement of the leg of the robot using inverse kinematics equations, to decide on the link length best suited for the trajectory we wanted to achieve.

Email : aasthamishra311@gmail.com</td></tr>
<tr><td rowspan="2"></td><td>ME19B180</td><td>Thurkapally Anogna</td></tr>
<tr><td colspan="2">I was part of the mechanical module of the project. During the initial days of the project we learnt different softwares including Fusion 360 , Ansys, python. Then me along with my teammates used Python to model four bar linkage and then simulated the movement of the leg of the robot using inverse kinematics equations.

Email : anognathurkapally@gmail.com</td></tr>
</table>

<table>
<tr><td rowspan="2"></td><td>ME19B178</td><td>T.S.N.S. Vanditha</td></tr>
<tr><td colspan="2">I was part of the mechanical module of the project. During the initial days I have learnt How to analyse stress deformations using Ansys and did a couple of Fusion 360 assignments. Then along with my teammates, We have worked on simulating the movement of the leg of the robot.
Email : vanditha2002@gmail.com</td></tr>
<tr><td></td><td colspan="2">ME19B132 M SAI KIRAN

I am Sai Kiran, Mechanical Engineering Sophomore. I was part of software module in quadruped project. I have worked on path planning simulations of bot where I have simulated motion of the robotic arm in different trajectories using pybullet. Through this project, I have learned reinforcement learning, Pybullet, PID control, Policy gradient etc.. Working on this quadruped project was a very wonderful experience.

Email : saikiranm3636@gmail.com</td></tr>
</table>

Table of Contents

S.NO	Contents	Pg. No.
1	Title of Invention	5
2	Field of Invention	5
3	Background of Invention	6

4	Object of Invention	7
5	Design History and Overview	7
6	Market Analysis	8
7	What did we learn?	10
8	Acknowledgement	11
APPENDIX		
A	Data Sheets and Calculations	
B	Electrical Schematics / CAD Models	
C	Source Code	11
	Bibliography	

Title of Invention:

Quadruped is a 4 legged robot which can run on complex terrains .Our aim to build a similar 4 legged robot which can run on comparatively complex terrains along with carrying some payload. This type of robot can be used in regions like mining and the military where use of drones becomes difficult.

- 

Field of Invention:

- This prototype is mainly made for mining areas. It can also be implemented in military areas which can be used by soldiers to reach in **areas where humans cannot reach.**
- One of the main reasons is that it **reduces human loss.** Hence it comes under Disaster management field.
- It will have technologies like mapping, object detection, agile movement irrespective of type of surfaces.

Background of Invention:

The main feature of the quadruped is that it can walk comfortably on all terrains and it can reach places where humans can't reach also by carrying a decent payload.

- It is mainly inspired from the project MIT-Cheetah. They can provide assistance during a chemical, biological, radiological, nuclear or explosive event, and help with search and rescue operations.This technology can even be used to help detect and extinguish wildfires and high-rise building fire response.

- Our model is better than its competitors in size. And it is very cost effective compared to that of a big dog($75k).

- The MIT-Cheetah robot developed at MIT's Biomimetic Robotics Lab first grabbed attention when it was announced back in 2009. In the years that followed few details emerged about its progress, until finally in July 2012 the lab posted videos of the robot walking on YouTube. After that at the IEEE International Conference on Robotics and Automation, the MIT team showed its cheetah-inspired robot running at a respectable 22 km/h (13.7 mph). And more. the robot has an energy efficiency that rivals that of real running animals.
- That speed makes it the second fastest legged robot in the world, beaten only by Boston Dynamics' Cheetah (which can run twice as fast). The MIT Cheetah knocks the Planar Biped, developed at the

MIT Leg Lab in 1989, which achieved 21 km/h (13 mph) down to third place. It's worth noting that both the MIT Cheetah and Boston Dynamics' Cheetah are attached to horizontal bars that constrain them along the sagittal plane (preventing roll and yaw movement). So,hopefully we'll see these robots running free sometime in the future.

Object of Invention:

We have already explained the aspects in which the project we would take up would be more beneficial than its competitors, and the main reason for which we are making it.
The estimated price of our project is around 50K. Which is far less than its competitors.

Design History and Overview

Mechanical Module :

After studying a few research papers and the models like MIT Cheetah, previously designed by other organizations and institutes, we plan to design a prototype with a 2R planar manipulator, which is easier to manufacture and cost-efficient as compared to 3R spatial manipulator. We use a four bar mechanism with an open link as the motors can be placed next to each other, to reduce rotational inertia. High inertia would lead to slower reaction and walking. We will be using servo motors looking at the torque/weight ratio and the cost, though they have poor backdrivability and hence would not be very stable while performing tasks which require greater torque like climbing stairs. The approach we have taken up till now is - we have simulated the movement of the open manipulator by coding inverse kinematic equations on

Python and have decided the link lengths best suited for the trajectory we want to achieve. Next, we plan to model the structure of the robot on Fusion 360 and decide upon the best design. In the long run, we aim to 3D print the prototype which will be able to walk, gallop, run and traverse difficult terrains efficiently and with good stability.

Software Module :

The basic Approach was to first simulate the leg and check its trajectory using a pybullet. To write a Inverse kinematics Code for n number of links. We wanted to use Reinforcement learning. We tested various trajectories followed by a robotic arm using PID. Our future plan was to do a PID for a complete Quadruped Bot. We planned to Improvise in walking, running and galloping of the robot by ensuring its stability.

Market Analysis

The quadruped robot which we plan to build will be used for traversing difficult terrain and carry payload in places where humans can not reach. We aim to reduce the noise which previously designed big quadruped robots like Big Dog, generally make and ensure the robot is not too heavy and big. The advantage of using legged robots is that they can traverse difficult paths more easily when compared to wheeled robots. Our model will also be able to travel to places where drones can't reach. Our model would also be cost-effective as compared to models like Big Dog (75k$) and MIT super Mini-Cheetah (10k$) - we plan to build the model at approx. 667$.

Quadruped Robots which have been designed earlier for different purposes by various organizations :

1.**Big Dog** (discontinued now): Manufacturers: Boston Dynamics, Foster-Miller, JPL, and the Harvard University Concord Field Station

Year first prototype was released: 2005

Purpose: To accompany soldiers to carry payload in places where vehicles can't be used.

Features:

1.4 legged to enable easier movement, sensors to detect joint position, gyroscope and stereo vision system

2.Joints are powered by hydraulic actuators

3.Can perform various kinds of movements- stand, sit, crawl, walk by lifting diagonal legs, trot etc.

4.A computer onboard controls the locomotion by taking input from sensors attached to actuators. (Both high level and low level controls)

5.Sensors measure various parameters like altitude, acceleration, engine speed, temperature, hydraulic pressure

6. Later versions could lift objects of weight of 50kg

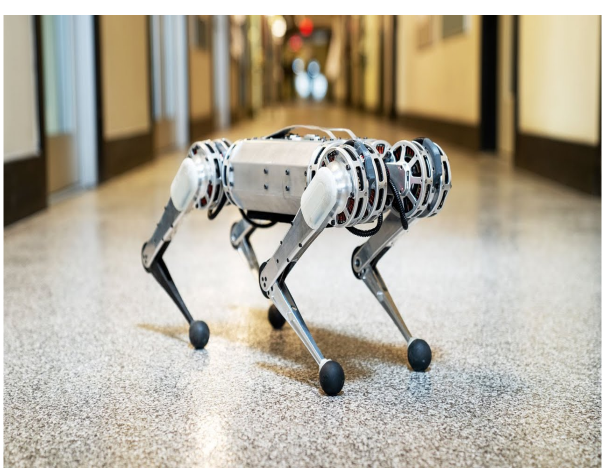
Discontinuation: In 2015, use of BigDod was discontinued due to the amount of noise it created during combat and its weight.

Specifications: 3 feet (0.91 m) long, 2.5 feet (0.76 m) tall, weighs 240 pounds (110 kg)-about the size of a small mule. Runs at four miles per hour (6.4 km/h), carries 340 pounds (150 kg), and can climb a 35 degree incline.

Source : https://en.wikipedia.org/wiki/BigDog

2.MIT **Cheetah** : Manufacturers : MIT's Biomimetic Robotics Lab,Benjamin Katz and Jared Di Carlo.

:



Year first prototype was released 2012

Purpose:

They can provide assistance during a chemical, biological, radiological, nuclear or explosive event, and help with search and rescue operations.This technology can even be used to help detect and extinguish wildfires and high-rise building fire response.

Features:

1. Mechanically robust design that can survive high-impact falls and accidents.
2. Large range of motion at each joint allows operation forwards, backwards, or upside-down.
3. High speed, high torque actuators let the robot perform extremely dynamic maneuvers like backflips.
4. Omnidirectional movement with trotting, pronking, bounding, and pacing gaits.

Specifications:

Height: 30cm
Length: 48 cm
Width : 27 cm
Weight : 9 kg
Speed: 8.8 kmph

Source: https://robots.ieee.org/robots/minicheetah/

What did we Learn?

In the mechanical module, we learnt how to:

- Use Fusion 360 to model mechanisms, design leg manipulator
- Decide on appropriate type of motor to be used based on our requirement and cost, research on what has been used in already designed models
- Decide on link lengths based on the trajectory we want to achieve by coding inverse kinematics equations on Python

Acknowledgement

We would like to thank CFI, IIT Madras and iBot club for providing us an opportunity to work on this project. By working on this project, we have learnt many technical and managerial aspects of the workplace.

Appendix

Source Code

Mechanical Module :

Four bar Leg mechanism simulation:

```
import math
import matplotlib.pyplot as plt
import numpy as np
from matplotlib import animation
import matplotlib as mpl
pi=math.pi
fig = plt.figure()
fig.set_dpi(100)
fig.set_size_inches(7, 6.5)
ax = plt.axes(xlim=(-10, 10), ylim=(-10, 10))
patch = plt.Rectangle((5, 5), 1,1, fc='y')
```

```
P1=np.array([[0],[0]])
P2=np.array([[0],[0]])
P3=np.array([[0],[0]])
P4=np.array([[0],[0]])
P5=np.array([[0],[0]])
x_new=[P2[0],P5[0],P4[0],P1[0],P2[0],P3[0]]
y_new=[P2[0],P5[0],P4[0],P1[1],P2[1],P3[1]]

ln, = plt.plot(x_new,y_new,'r', linewidth = 3.0)
def inverse_kinematics(x, y, l1, l2, branch=1):
    a = 2*x*l2
    b = 2*y*l2
    c =  l1*l1 - x*x - y*y  - l2*l2
    psi = math.atan2(b, a)
    d = -c/math.sqrt(a*a + b*b)

    if (d < -1) or (d > 1):
        print("Position out of workspace.")
        return False, [0,0]
    if branch == 1:
        theta12 = psi + math.acos(-c/math.sqrt(a*a + b*b))
    else:
        theta12 = psi - math.acos(-c/math.sqrt(a*a + b*b))

    theta1 = math.atan2((y - l2*math.sin(theta12))/l1, (x - l2*math.cos(theta12))/l1)
    return True, [theta1, theta12-theta1]
def forward_kinematics(theta1, theta2, l1, l2):
    x = (l1*math.cos(theta1) + l2*math.cos(theta1 + theta2))
    y = -(l1*math.sin(theta1) + l2*math.sin(theta1 + theta2))
    return [x, y]

def init():
```

```
    plt.grid(color='black', linestyle='-.', linewidth=1.0)
    return ln,
def animate(i):
    l1=5
    l2=5
    L1=2
    theta1 = i*pi/360
    theta2 = pi/4+5*i*pi/180

    [x, y] = forward_kinematics(theta1, theta2, l1, l2)

    valid, [t1,t2]=inverse_kinematics(x,y,l1,l2,branch=1)
    print(t1)
    P1=np.array([[0],[0]])
    P2=np.array([[l1*np.cos(t1)],[l1*np.sin(t1)]])
    P3=np.array([[x],[y]])
    P4=np.array([[-L1],[0]])
    P5=np.array([[-L1+l1*np.cos(t1)],[l1*np.sin(t1)]])
    x_new=[P2[0],P5[0],P4[0],P1[0],P2[0],P3[0]]
    y_new=[P2[1],P5[1],P4[1],P1[1],P2[1],P3[1]]
    ln.set_data(x_new, y_new)
    return ln,


anim = animation.FuncAnimation(fig, animate,
                               init_func=init,
                               frames=20,
                               interval=100,
                               blit=True)
plt.show()
```

Code files for learning and iterating:
https://github.com/thiyagutenysen/IBOT_Quadruped

The Actual project Github repo:
https://github.com/sashank-tirumala/synquad

Simulation videos of learning:
https://drive.google.com/drive/folders/1ZQRhcHpUg54ad7WSJgplqtsoKATF5xPr?usp=sharing

Code + Video:
https://drive.google.com/drive/folders/1jiynmBumZnPAAVG2hkcU7GoXdJ6yv1Lk?usp=sharing