Design and Fabrication of a Smart Quadruped Robot

Shivani Verma, Amit Agrawal, Pankaj Kumar Meena, Ashish B. Deoghare

***Abstract*—**Over the decade robotics has been a major area of interest among the researchers and scientists in reducing human efforts. The need for robots to replace human work in different hazardous fields such as underground mining, nuclear power station and war against terrorist attack has gained huge attention. Most of the robot design is based on human structure popularly known as humanoid robots. However, the problems encountered in humanoid robots includes low speed of movement, misbalancing in structure, poor load carrying capacity, etc. The simplification and adaptation of the fundamental design principles seen in animals have led to the creation of bio-inspired robots. But the major challenges observed in naturally inspired robot include complexity in structure, several degrees of freedom and energy storage problem. The present work focuses on design and fabrication of a bionic quadruped walking robot which is based on different joint of quadruped mammals like a dog or cheetah. The proposed design focuses on the structure of the robot body which consists of four legs having three degrees of freedom per leg and the electronics system involved in it. The robot is built using readily available plastics and metals. The proposed robot is simple in construction and is able to move through uneven terrain, detect and locate obstacles and take images while carrying additional loads which may include hardware and sensors. The robot will find possible application in the artificial intelligence sector.

***Keywords*—**Artificial intelligence, bionic, degree of freedom quadruped robot.

I. Introduction

IN last few years a significant change has been seen in the field of robotics and automation Bionics is the application of biological methods and systems pre-existent in nature to the study and design of engineering systems and ongoing technology [1]. Nature is one of the best source of learning starting from a small creatures to a big animals. Ideas from nature are thus quite practical for a robotic design [2]. Animal kingdom provides the greatest ideas for building mobile robots. Locomotion is an integral part of an animal's life which is an essential function for their survival. It includes Robotic Arm inspired Elephant Trunk, Bat-Inspired Spy Plane, Bird Skulls Inspire Lighter, Stronger Building Materials, Bullet Train inspired from Nose Like Kingfisher Beak, Computer Takes Cues from Cat Brains, Bat Sonar device for visually impaired patients, Radio Chip Mimics the Human Ear, Gecko inspired Sticky-bot Feet for climbing, Deer Antlers inspired Super-Tough Materials, Contact Lenses Inspired by Gecko Eyes, Human Eye Inspires Cameras with Wider Field of View [3]. The simplification and adaptation of the fundamental design principles seen in animals has led to the creation of these bio-inspired robots [2]. Scientists and researchers have deployed their time and research in reducing the limitations with respect to speed, stability, capacity to carry loads and independent motions encountered in these bionic robots [4]. Hence gradual alterations are still going on their design, building and locomotion.

Legged robots, which are a type of mobile robots, entail mechanical limbs for their motion. They have an advantage over wheeled robots with respect to their versatility and movability on different terrains but at the same time their structural complexity and power consumption requirement are increased. These robots can be classified based on number of legs such as Monopod, Biped and Multi legged Robots [5]. The robot having four feet is commonly known as quadruped robot. These robots have high reliability and their motion can be controlled easily as compared to biped and hexapod robots.

The present work deals with design and fabrication of a bionic quadruped walking robot which is based on different joints of quadruped mammals like a dog or cheetah [6]. The structure is prepared using acrylic which is low cost and light in weight and motion is mimicked using controlled programming language [7].

II. Materials and Methods

Cast acrylic sheet being light-weight (weighs half as much as the finest optical glass), greater expansion and contraction characteristics, flexibility, surface and electric resistance properties, optical characteristics, it is used as the building material for the robot body [7]. For effective performance, overall weight of robot is estimated to be in range of 0.2 kg to 0.25 kg and hence to mitigate the same a 2ft x 2ft acrylic sheet of 2 mm thickness is used. All the components including clamps, torso frame and leg base are cut from it followed by addition of electronic circuit.

Locomotion of the robot requires movement of different links at proper time and at proper angle of rotation which can be achieved by incorporating servo motors to its different links. Keeping weight constraint in mind 8 light weight MG90S (13.4 gm.) servo motors are used. These motors are small in dimensions (22.5 x 12 x 35.5 mm), requires a starting torque of 1.8 kgf·cm (4.8 V), 2.2 kgf·cm (6 V) and current input of 0.25 approximately. These servos are programmed through a motor driver connected to Arduino board.

Shivani Verma is with the National Institute of Technology Silchar, Assam (788010), India (e-mail: shivani4116@gmail.com).

Amit Agrawal is with the National Institute of Technology Silchar, Assam (788010), India (e-mail: amitagrawal732@gmail.com).

Pankaj Kumar Meena is with the National Institute of Technology Silchar, Assam (788010), India (e-mail: pankajakhed@gmail.com).

Ashish Deoghare is with the National Institute of Technology Silchar, Assam (788010), India (e-mail: ashishdeoghare@gmail.com).

Since a normal Arduino board contains maximum 4-6 Pulse Width Modulation (PWM) (PWM) pins and hence driving 8 motors through these PWM pins are not possible. So a 16 PWM pin, PCA9685 servo controller is used out of which only 8 pins are utilized to transfer signal from Arduino board to servo motors. This chip is compact in size (60 mm x 25 mm), 12 gms in weight and requires 5-6 V DC for its operation. The signal flow diagram is shown in Fig. 1.

The fabrication of the quadruped robot as mentioned in the proposed work includes the following steps:

1 Development of CAD model
2 Fabrication of body parts and assembly

In order to accommodate all the mountings and accessories the length, breath and height of the robot are approximated to be 26 cm, 24 cm, and 20.2 cm respectively.

A. *Development of CAD model*

Fabrication of the quadruped robot necessitates development of a CAD model as its prerequisite. In this research work, CAD model of the robot is developed on "SolidWorks 2013" software platform. It help in figured out the positions of different parts, dimensions and several properties and the robot as well. The model of robot is shown in Fig. 2.

B. *Fabrication of quadruped structure*

Quadruped elements are fabricated using Cutting, Drilling, Bending and finishing operations. Fabrication process involves making of different types of U clamps, torso frame and leg base from acrylic sheet. Once its completed parts are connected together by fixed joints and revolute pairs. Then servo motors, electronic connections are made and finally through programming commands it is tested for different actions. Design of the assembly robot is shown in Fig. 3

The properties of parts are shown below in the Table 1-

TABLE I

Sl. No.	Parts	Description
1.	Mass of torso frame	73.08 gm.
2.	Mass of Small U clamps	(4.61*4) = 18.44 gm.
3.	Mass of Medium U clamps	(6.33*4) = 25.32gm
4.	Mass of Long U clamp	(7.33*4) = 29.32gm
5.	Mass of leg bases	5.88gm
6.	Total mass of robot including electronic parts	152.76gm ≈ 200gm
7.	Torso size	24cm x 26cm
8.	Small U clamp size (l*b*h)	4.8 cm x 2.5 cm x 2.2 cm
9.	Medium U clamp size (l*b*h)	4.8 cm x 2.5 cm x 4.2 cm
10.	Long U clamp size (l*b*h)	4.8 cm x 2.5 cm x 5.2 cm
11	Leg Base (height)	2.0 cm

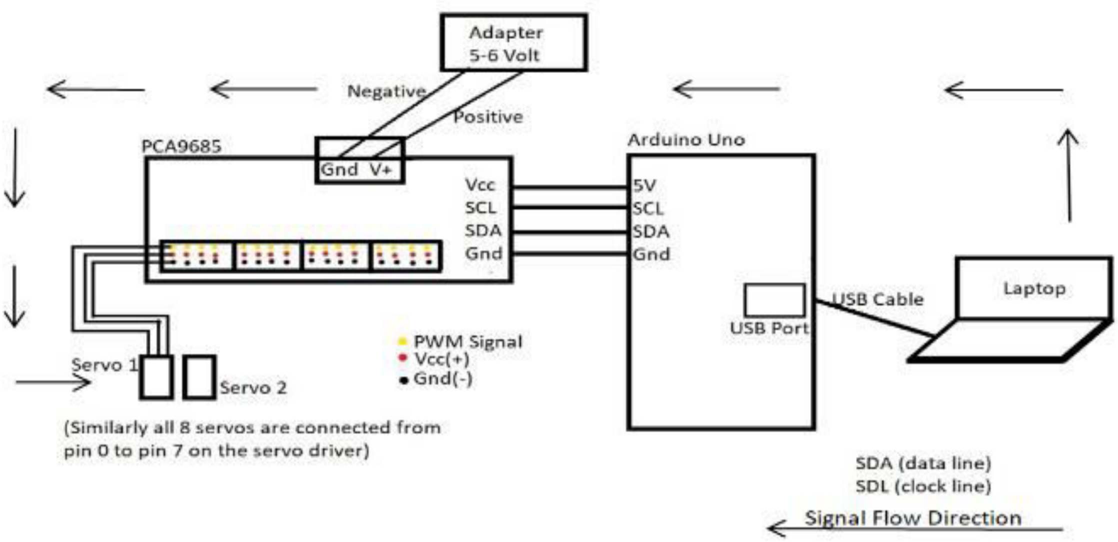

Fig. 1 Signal flow Diagram

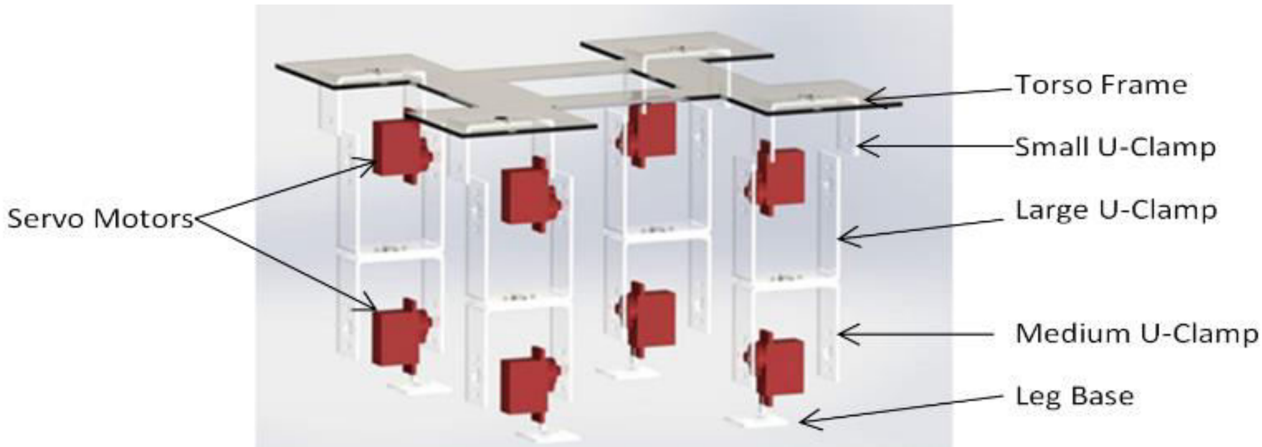

Fig. 2 CAD model of quadruped

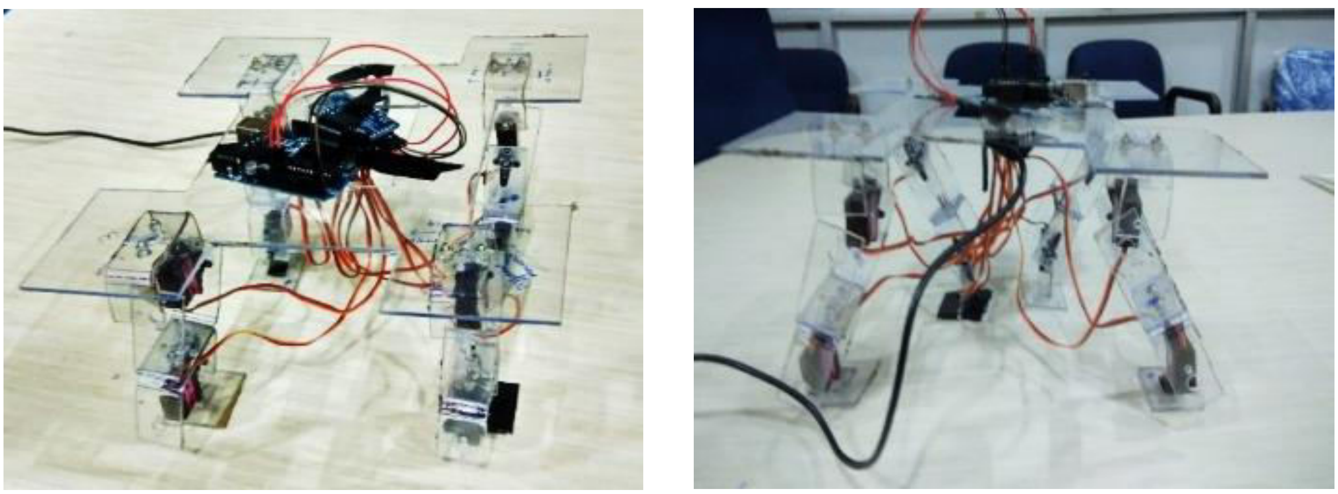

Fig. 3 Assembly of quadruped robot

When the robot moves in forward direction, the diagonally opposite pair of legs function simultaneously followed by the other two. For simplicity in calculation the following assumptions are made.

1. There is no friction between legs and contacting surface
2. The total weight of all the body parts are concentrated to the torso frame
3. The reaction forces from ground have only vertical component at its legs
4. Legs are connected to ground by fixed joint

The torque calculation is carried out considering the worst case scenario where the robot is standing on two legs and other two at their maximum lift up position. And hence total load is supported by two legs only.

Let N_1 and N_2 be the normal reaction force from ground to the leg base

M_1 and M_2 be the required torque on upper and lower link respectively

$$N_1 = N_2 = \frac{Mg}{2} = \frac{0.2\times 9.81}{2} = 0.981\,N \quad (1)$$

$$M_1 = N_1(l_4 + l_3 + l_2) \quad (2)$$

$$M_1 = .981 \times (2.0 + 4.2 + 5.2) \times 10^{-2} = 0.112\,Nm$$

$$M_2 = N_1 \times l_4$$

(3)

$$M_2 = 0.981 \times 2.0 \times 10^{-2} = 0.021\,Nm$$

The values of moments M_1 and M_2 come out to be 0.112 Nm and 0.021 Nm respectively which is less than the rated torque of the motors (MG90S Servo) used which is 0.176 Nm.

III. RESULTS AND DISCUSSION

For better stability along with speed, alternate legs are moved together. Each leg has two joints named Hip joint (Top joint) and Knee joint (Bottom joint). Following syntax used in programming through Arduino platform is shown below to ensure the sequential operation of legs.

1. The part below the knee of two alternate legs (say 1 and 3) will be lifted first by approximately 45 degrees in the direction of motion. The body weight will be equally distributed on the other two legs.

```
  // Step 1 and setting all servos to mean position as per their calibrated values
  for (uint16_t pL1 = 290, pL2=290,pU1=280 ; pL1 <= 350; pL1++,pL2--)
// varying pulsewidth to achieve the desired angles
  {
pwm.setPWM(servo3, 0, pU1); // function to set servo to a particular pulse width
pwm.setPWM(servo4, 0, pU1);
pwm.setPWM(servo1, 0, pL1);
  pwm.setPWM(servo2, 0, pL2);
pwm.setPWM(servo5, 0, pU1+20);
pwm.setPWM(servo6, 0, pU1+10);
pwm.setPWM(servo7, 0, pU1-10);
 pwm.setPWM(servo8, 0, pU1-15);
   delay(5);   // giving delay of 5 milliseconds
  }
    delay(1000);
```

2. The legs 1 and 3 will be lifted completely by moving hip joint by approximately 30 degrees in the direction of motion. Hence the leg 1 and 3 will be lifted.

```
  // Step 2
for (uint16_t pU1=280, pU2=280; pU1>=240; pU1--,pU2++)
{
    pwm.setPWM(servo3, 0, pU1);
   pwm.setPWM(servo4, 0, pU2);
    delay(5);
}
delay(500);
```

3. Then the base of knee part of leg 1 and 3 is positioned parallel to ground by moving the knee joint by 75 degrees in opposite direction.

```
//Step 3
     for (uint16_t pL1 =350, pL2=230; pL1 >= 250; pL1--,pL2++)
  {
     pwm.setPWM(servo1, 0, pL1);
      pwm.setPWM(servo2, 0, pL2);
    delay(5);
  }
  delay(500);
```

4. Then leg 2 and leg 4 moves backward till the bases of all 4 legs touch the ground. They move approximately by 30 degrees in a direction opposite to the direction of motion.

```
  // Step 4
  for (uint16_t pU3=300, pL3=290; pU3 >= 250; pU3--,pL3--)
  {
     pwm.setPWM(servo6, 0, pL3);
      pwm.setPWM(servo5, 0, pU3);
     delay(5);
  }
  delay(500);
// Step 4
   for (uint16_t pU4=300, pL4=295; pU4 <= 320; pU4++,pL4++)
  {
     pwm.setPWM(servo8, 0, pL4);
     pwm.setPWM(servo7, 0, pU4)
     delay(5);
  }
  delay(500);
```

5. Then the bot lifts body weight on leg 1 and leg 3 and the 4 motors of leg 1 and leg 3 come to their mean position.

```
// Step 5
     for (uint16_t pU1=240, pU2=320,pL1=250,pL2=325; pU1<=280; pU1++,pU2--,pL1++,pL2--)
{
   pwm.setPWM(servo3, 0, pU1);
   pwm.setPWM(servo4, 0, pU2);
 pwm.setPWM(servo1, 0, pL1);
   pwm.setPWM(servo2, 0, pL2);
      delay(5);
  }
 delay(500);
```

6. Finally leg 2 and leg 4 also move back to their mean position.

```
//Step 6
  for (uint16_t pU3=250, pL3=240,pU4=320, pL4=315; pU3 <= 300; pU3++,pL3++,pU4--,pL4--)
  {
      pwm.setPWM(servo6, 0, pL3);
    pwm.setPWM(servo5, 0, pU3);
         pwm.setPWM(servo8, 0, pL4);
     pwm.setPWM(servo7, 0, pU4);
    delay(5);
  }
  delay(500);
```

The above procedure provides forward motion of the robot. Similar step is repeated for the other set of alternate legs. The repetition of the above two steps creates a forward motion for the robot. Figure 4 illustrates the motion of robot for one complete cycle.

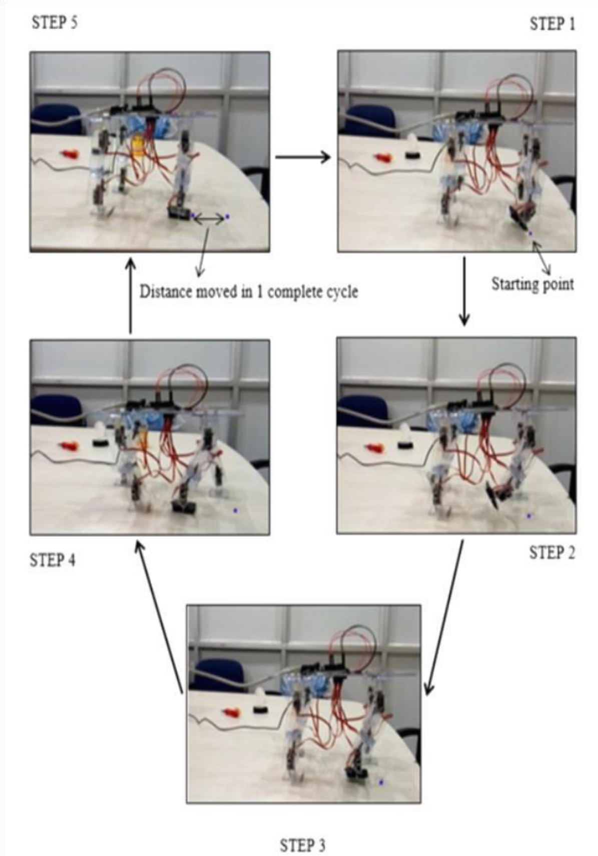

Fig. 4 Motion of robot for one complete cycle

IV. CONCLUSION

The above research work comprises of both mechanical and electronic aspects of engineering. The mechanical design reduces its complexity, lighten its weight whereas electronic features provide it automation through programming language. All the components of the quadruped body with its design and dimensions are also specified. Fabrication of the quadruped is simple and modular in terms of time, operations as well as cost incurred. The quadruped mechanism fabricated is successfully programmed for its forward motion only. The mean speed of the robot from experiment is obtained to be 30 mm/s which can be further increased or decreased as required by the operator simply by modifying the programming codes.

If the proposed robot is fabricated from steel or any tough material which has higher anti corrosion property, more structural rigidity, flexibility, heat resistance etc. then it can also be used in mining sectors, petroleum industries or for underground work.

The work will be further extended for the design of a robot with an Ultrasonic module for obstacle detection and a small camera mounted on body which is capable of taking images and has application in surveillance. Being lightweight the design enables future incorporation of additional components as per its requirements in various fields. The developed quadruped robot will serve as a platform for implementation in real world applications.

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