Semi-Autonomous Pneumatic Pick-Place and Autonomous Electrically Actuated Quadruped Robots

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Abstract*—This paper describes the techniques used for implementing a pneumatic based pick-place robot and servo controlled autonomous four-legged robot. The former is a semi-autonomous robot which transfers a token to the latter one and throws an object of around 700 grams into a designated landing zone. It is semi-autonomous in the sense that it is capable of switching between automatic line following mode and manual control mode established via a Bluetooth interface between the robot and a PS3 remote controller. Pneumatic actuating cylinders are used to grab and throw the object. The second robot is an autonomous four-legged robot which incorporates servo-based leg drive mechanism providing three degrees of freedom for each leg. The obstacle detection and navigation system comprises of laser ranging sensors to avoid or cross the obstacle and allows the robot to traverse through unknown terrains. In addition to this, a control system consisting of three Arduino mega boards featuring Inter-Integrated Circuit (I2C) control for managing the dynamic behaviour, gait generation and transition method of the quadruped robot.

Keywords **-PS3 controller, Solenoid valve, Bluetooth, Bionic motion, I2C control, Servo mechanism.**

I. INTRODUCTION

Humans have limited capabilities when it comes to performing strenuous physical work in industries. Also, owing to natural human tendency, we are bound to undergo fatigue after some amount of time. This is where machines or robots step in to ease out the job for us. The industry robots are designed to improve accessibility in areas which possess health hazards. At any given point of time, robots do have higher accuracy, flexibility and precision as compared to its human counterparts.

The use of mobile robots instead of humans to work in complex and dangerous environments such as underground mines, nuclear power stations have been increasing tremendously. Legged robots are found to have an added advantage over wheeled robots in situations where they need to traverse over rough terrains which enable it to cover a majority of the earth's land mass. A comparison of various legged robots drew a conclusion that even number of legs and especially four-legged robot provide better stability with optimum power utilization as compared to other even-legged robots. The complexity involved in designing and implementing a legged robot increases with an increase in the number of legs. [1]

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The main challenge in designing a quadruped robot is to achieve a stable motion in keeping up with the momentum and this can be achieved by proper selection of gait.

A. Actuating Systems

Actuating systems are the elements of control systems which are responsible for transforming the output of a microcontroller or control system into a controlling action on a machine or device. [2]

i. *Hydraulic Actuators*

Any hydraulic mechanism comprises of a cylinder or fluid motor which uses hydraulic power for facilitating the mechanical operation.

The mechanical motion provides associate degree output in terms of linear, turn or oscillating motion. The hydraulic cylinder is made up of a hollow cylindrical tube on that a piston will slide. The piston can move in only one direction. Usually, the return stroke is provided by means of a spring. [3]

ii. *Pneumatic actuators*

A gas mechanism converts energy shaped by vacuum or compressed gas at air mass into either linear or motion. It comprises of a piston fitted inside a hollow cylinder. Pressure from associate degree external mechanical device or manual pump moves the piston within the cylinder. As pressure increases, the cylinder moves on the axis of the piston, exerting a linear force. The piston returns to its neutral position by the back force of the spring. [4][5]

iii. *Electric actuators*

Electric actuators are devices use motors to convert electrical energy into mechanical torque. As no oil is involved, electrical actuators are one of the cleanest and readily available forms of actuators. [6]

B. Gait

Gait is defined as the sequential lifting and placing of the feet and the relative time between the movements. Animals use a variety of gaits, based on speed, terrain, the need to manoeuvre, and use energy efficiently. Similarly, the robot adapts a gait to maintain stability and provide maximum power efficiency. There are various types of gait such as walk, trot and pace. These gaits are classified on the basis of the speed of locomotion and number of legs lifted at a time.

II. PROPOSED SYSTEM

A. Pneumatic Pick-Place Robot

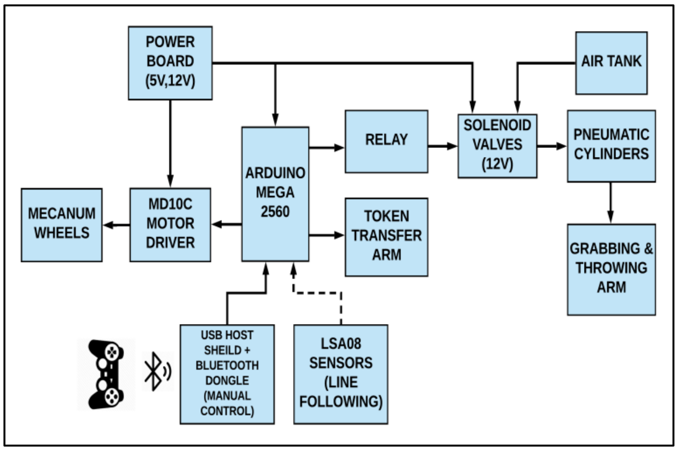

Figure 1. Block diagram of Pneumatic Pick-Place Robot

The robot chassis is made of aluminium having a weight of 13 kg and dimensions of 1210x710x720mm (length x width x height).

Figure 1 gives an overview of the implementation of the said system. The Arduino controls the operation of all the end devices. The PS3 controller has inbuilt Bluetooth capability and hence is used to transmit data wirelessly to the Arduino board for controlling the motion of the robot. Along with motion, the different switches on PS3 controller are assigned to perform specific tasks viz opening and closing of the gripper for token transfer, picking up of the object and throwing it. As all of these actions are wirelessly controlled, there is no much complexity of wiring that is involved.

The mecanum wheels used in this design do not entirely turn its body for moving towards right or left. Instead it performs a lateral shift.

The solenoid valves are used to control the switching of the pneumatic Double Acting Cylinder (DACs). As the moving of the arm is bidirectional, Double Acting Cylinders are preferred over Single Acting Cylinders since they allow the user to have full control over the system. The switching of the solenoid valve is controlled with the help of a 8-channel relay.

The entire assembly is powered using rechargeable Lithium-Polymer (LiPo) batteries which have a rating of 11.1V and 3300mAh.

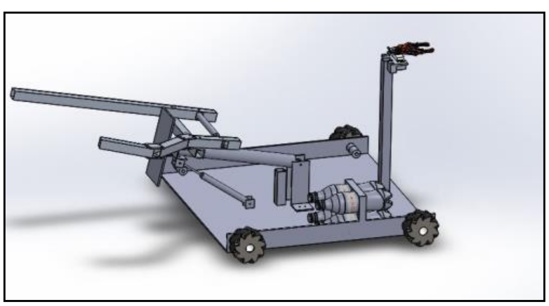

Figure 2. Chassis implementation of Pneumatic Pick-Place robot in SolidWorks

The working of different sections of the robot can be described in sections as mentioned below:

i. Motion

The robot can make a transition from the automatic line following mode to the manual controlled mode or vice versa, when an override switch is pressed on the PS3 controller.

a. Line following automatic mode

As an attempt to traverse the maximum area in the shortest time possible the initial journey of the robot is made automatic by incorporating line following algorithm. The robot consists of three auto-calibrating line sensors (LSA08) which are mounted on the centre, left and right of its body. All these sensors are configured to follow the white line and communicate serially with the Arduino.

One essential part of line following algorithm is implementing PID control for the robot (Proportional Integral and Derivative). PID calculates the deviation of robot with respect to the line, and corrects its alignment by varying the speed of the motors.

For its implementation, the middle value of the sensor array was decided as the set point. The robot always tries to adjust itself to centre at the set point. LSA08 supports a range from 0 – 70 in the analog mode, so 35 was decided as the set point value, and the target of the PID controller was to make sure that it achieves the position 35 in shortest time possible.[7]

b. Manual control mode

As Arduino by itself does not support Bluetooth communication, the Bluetooth control for manual operation of the robot is achieved using USB host shield connected to the Arduino board. The USB host shield is fitted with a receiver dongle which receives commands from a PS3 remote controller. The amount by which we move the joystick on the controller, decides the speed of the robot hence establishing PWM control.

ii. Token transfer arm

It is located on the backside of the robot. The robotic arm used for transferring the token consists of a parallel jaw robotic gripper made of aluminium alloy with an overall opening span of 55mm. This gripper is mounted on a column like structure. The servo motor reacts to the signal it receives from Arduino. This causes the rotation of the shaft to the commanded position. Servo motors can turn 90 degrees in either of the direction from its neutral position. Two separate switches on the PS3 controller are responsible for the opening and closing of gripper.

iii. Grabbing the object

Using the joystick control of the PS3 remote controller, the robot is instructed to move closer to the object. The grabber has one fixed arm and the movement of the other arm is controlled by a pneumatic actuator of stroke length 100mm. A solenoid valve is used as direction control valve (DCV). When the grabber is open, the pneumatic pick-place bot goes ahead and places the object in between the grabber arms following which the DCV switches to the opposite end and the grabber arm closes thus holding the object in its arms firmly. The movable arm of the grabber is curved to adjust to the bigger radius of curvature of the object. Once the object is picked up, the robot is made to go to a particular location before releasing it.

iv. Throwing of object

After holding the object, grabber arm is lifted up by 30° using class-III lever mechanism where effort is given by pneumatic actuator of stroke length 100mm mounted at the base. A second pneumatic actuator of stroke length 300mm is used as a lever on which the grabber is mounted. For throwing of the object, the grabber opens and simultaneously the second pneumatic actuator pushes the object in the forward direction.

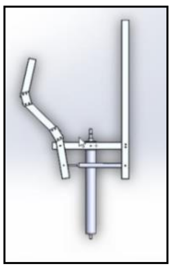

Figure 3. Top view of grabbing and throwing arm

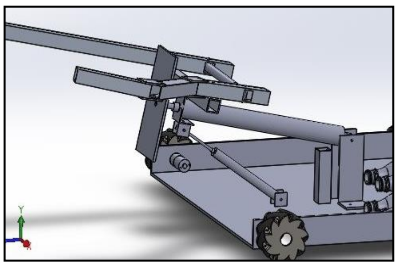

Figure 4. Side view of grabbing and throwing arm

B. Autonomous Four-legged Robot

i. Mechanical Design

The material used for the framework of the robot is an aluminium alloy, Aluminium 4130. The choice of the alloy is made on the basis of its improved characteristics such as higher tensile strength, lightweight and weldability**.** The system was modeled and simulated using Solidworks software.

The overall dimension of the robot is 500x700x622 mm. The weight of the system is 8 kg. It has four legs each consisting of a thigh plate, crus (limb extending from knee to ankle) and foot. Each leg exhibits three degree of freedom by using three servo motors. The structural limbs of the robot are made up of links and actuators; where links form the bones and actuators form the muscles. These structural limbs, when combined with a driving mechanism imitate the motion of a normal leg.

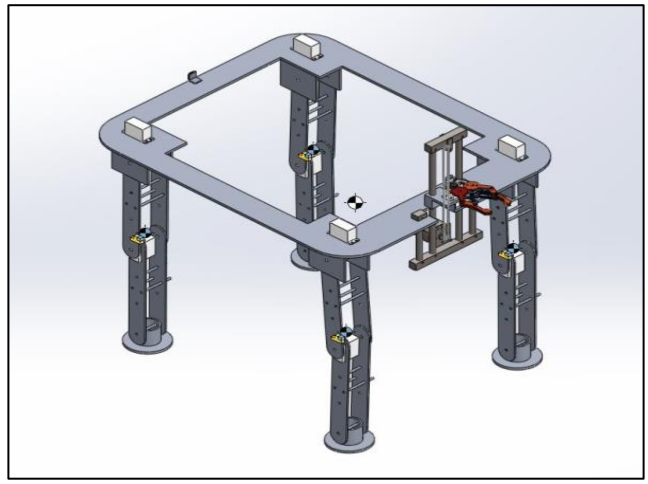

Figure 5. Chassis implementation of an Autonomous Quadruped robot in SolidWorks

ii. Electrical System

a. Power System

In order to satisfy the current requirement of the system, the robot is powered using lithium polymer batteries having a voltage rating of 7.4V and current rating of 1500mAh.

b. Leg Drive Mechanism

The proposed robot follows a ‘trot’ gait for walking and a ‘walk’ gait for obstacle crossing. The ‘trot’ gait is a symmetric gait, where two feet are on the ground at any time instant. The diagonal pairs of legs move almost simultaneously. The ‘walk’ gait is an asymmetric type of gait, where three feet are on the ground at any moment. These gaits have better stability and speed required for the locomotion.

Electric actuators used to control the position and movement of the limbs are metal gear servo motors. For the walking mechanism, each leg is equipped with 3 servo motors. One servo that connects the robot frame with the leg at the hip area is used to control the rotation of the entire leg, which helps in direction control. The remaining servo motors are placed at the hip and the knee joint of the leg for forward movement. The circular base along with the coupler acts as the foot of robot, and provides an axial motion, thus maintaining the stability of the robot. The base also helps in smooth transitions and adjusts itself according to the land surface.

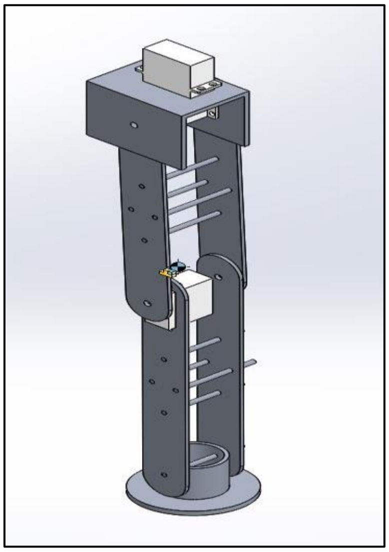

Figure 6. Leg of Quadruped robot showing position of servo motors

c. Control Mechanism

The control system incorporated in robot consists of three Arduino Mega boards of which one acts as the master interfaced with two slave Arduino Mega boards thus featuring I2C control. All the sensors are connected to the master controller. For the forward motion, the front slave controller controls the servos attached to the front two legs and the back slave controller controls the servos connected to the hind legs. For taking turns, the directional servo motor attached to the main body is rotated till the leg gets aligned parallel to the edges of the path.

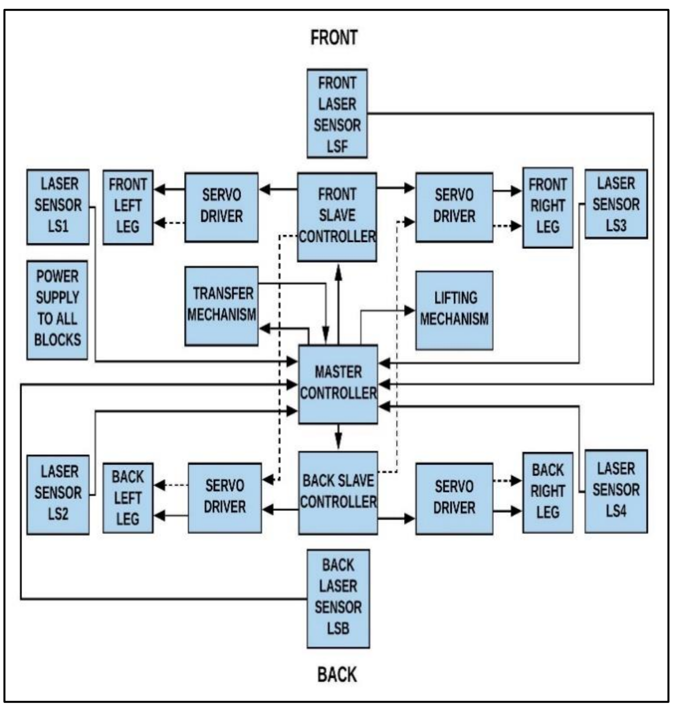

Figure 7. Block Diagram of an Autonomous Quadruped robot

d. Navigation System

Laser ranging sensor VL53L0X is used for navigation and obstacle detection. The four laser sensors LS1, LS2, LS3 and LS4 are placed on the four legs of the robot (one on each leg) to help navigate through the arena. These sensors detect the edges of the path and determine the distance between the leg and the edge on each side. The readings are then compared and used to determine the action of the robot. Another pair of these sensors placed at the front and back of the robot and are used for obstacle detection. The front laser sensor (LSF) detects the obstacle on the path and sends the signal to the master controller. The back laser sensor (LSB) is used to check if the robot has crossed the obstacle.

e. Obstacle Detection and Crossing Mechanism:

The front laser sensor (LSF) detects the obstacle as the distance from the ground reduces. The signal is then sent to the master controller which sends the command to the slave controller indicating a gait change. For crossing the obstacle, the robot lifts one leg at a time following a walk gait. The leg is lifted to a greater height in order to cross the obstacle. The back laser sensor (LSB) checks whether the robot has crossed the obstacle by monitoring the distance from the ground.

f. Token Transfer and Raising Mechanism:

The legged robot remains in the wait state till the gripper receives a token from pick-place robot. The legged robot is put into action when the output of the IR sensor, placed near the grabbing mechanism, goes high. For token lifting at the end of the course, the gripper holding the token is raised by using a linear actuator in vertical direction.

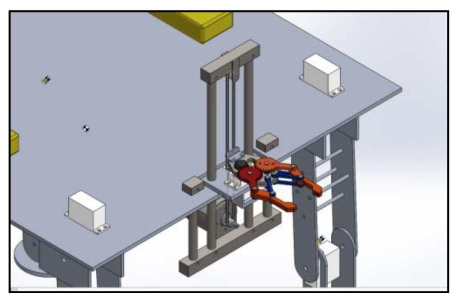

Figure 8. Token transfer and raising mechanism

III. RESULTS AND DISCUSSION

During the motion testing of the semi-autonomous robot, the motion was found to be jerky which caused the bot to deviate from its predetermined path. Hence PWM was incorporated which ensured its smooth movement.

PID based line following has been achieved using the LSA08 sensors placed on each side of the bot. The response of the line following sensor varies depending upon the ambient lighting conditions. Hence, proper packing is provided to the sensor to prevent external light to affect its readings.

The grabbing and the throwing arm as expected successfully exhibited one degree of freedom i.e. in the upward-downward direction. There was no problem encountered with the arm bearing the weight of the object and was able to catch hold of the same.

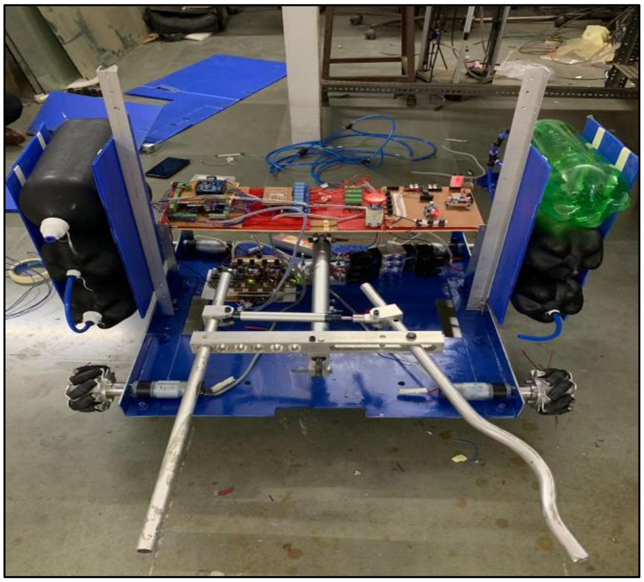

Figure 9. Final implementation of Semi-Autonomous Pneumatic based Pick-Place robot

The autonomous robot can carry a weight of 180 grams and can cross the path and obstacles with a wobble of 12.5 % of the total height. The token can be lifted at a height of about 20 cm above the body level.

In order to perform alternate leg motion in trot gait, three Arduino controllers are successfully integrated to achieve I2C control.

The sensing system comprising of laser ranging sensors VL53L0X provides appropriate signals to the master controller which are compared to decide the motion of Quadruped robot.

The motors on the quadruped robot have excessive current requirement which is satisfied by using Lithium polymer batteries in parallel.

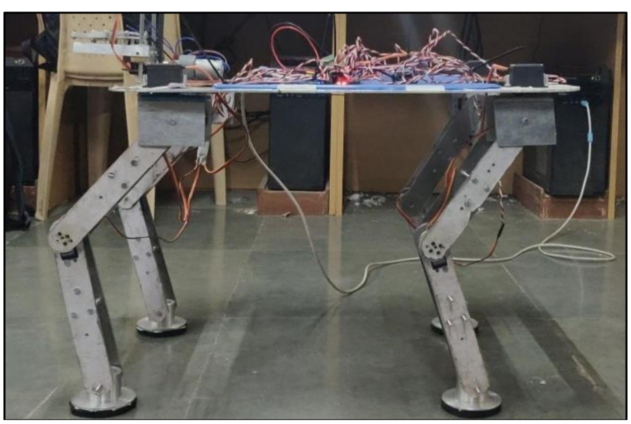

Figure 10. Final implementation of an Autonomous Servo-mechanism based four-legged robot

IV. CONCLUSION

The semi-autonomous pick-place robot was successfully able to follow a line with a delay of less than half a second. The grabber arm was able to lift up a weight of 700 grams. It can be modified better to lift increased payloads. The traditional gripping mechanism can be replaced with suction gripper to seize the objects. Height adjustable arms can ensure access between different levels of the racks to facilitate fast and even arrangements of the items.

The autonomous quadruped robot implemented imitates the bionic motion of a mammal walking on four legs by following a walk or trot gait. The servo motors provide three degree of freedom and facilitate stable motion. The sensing system of robot allows it to traverse unknown paths independently. The system can be made power efficient by using alternate actuating system such as pneumatics. The robot can be modified to work in complex and dangerous environments such as underground mines, nuclear power stations.

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