International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 22249-22263

http://www.ripublication.com

Design and Fabrication of A Four-Legged Robot For Fertilizer Spraying

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Abstract

As the world's population is increasing, the need for food is also increasing. But day by day food yield from the agriculture is decreasing. The main problem is the inability of the soil and also the plants are affected by different type of diseases. The soil does not contain enough amount of vitamins which help the plants to growth efficiently. To overcome this problem we have to use fertilizers to increase the yield. By adding fertilizer to the soil we can improve its yield. By the application of fertilizers on plants we can prevent the diseases which affect the plants. But fertilizers are dangerous. Human should not approach fertilizers directly. So, here we are going to use robots for fertilizer spraying. In this paper, we dealing with locomotion, control, obstacle avoidance and design factors such as inverse and forward kinematics of a four-legged robot. The ability of the robot to produce multiple gait sequences makes travelling across irregular terrain patterns possible. The important feature of the developing model is that the robot has to spray the fertilizer on agricultural plant and has good control actuations. Good control actuations enable the robot to move efficiently through various obstacles. This robot can climb on mud surface for spraying the fertilizer by using dc pump and it detects the presence of obstacles by using ultrasonic sensor.

Keywords: Link Coordinate Diagram, Tool Configuration Vector

Introduction

In general, we are using the legged robot for locomotion on different types of surfaces such as on rocks, uneven terrain, sand. And also in nature, crab has eight legs with two degrees of freedom in each legs[1]. Here robot has four legs with structure of crab legs[8]. By increasing the area of contact with surface we can increase possibilities of survive on any kind of surface such as mud, soggy surface, etc.. Two revolute degree of freedom using to make the motion on legs.

This work aims at developing a crab type robot with four legs and outlines expectations for future development. These robots may one day play a crucial role in all agricultural operations. The highly articulated body with proper center of gravity and control the multi legs allows the robot to traverse difficult terrains such as mud and soggy surface[2][10][11].

This robot could make its way through agricultural land for spray the fertilizer with amount of water and fertilizer with it. Here we are using dc pump to make the fertilizer spraying even and forcefully. A ultrasonic sensor serving for robot to avoid the obstacles[6]. A P-IR sensor is used for detecting the presence of human. By using the arm processor, the robot controlling the locomotion and decision making efficiently than using the 8051 microcontroller.

The potential application of the four-legged robot can be found in defense, industries, search, agriculture and space operation. The current and future use of four-legged robots whether in industries or any sector proves to be rewarding. It could change the view of current operation of automation. The robot could reach restricted areas with less effort, no matter how difficult the terrain is. Also, the robot could move in rhythmic motion, as compared to wheeled robots.

In agriculture, the development of four- legged autonomous robot will be likely to take on the task of workers in multi locomotion[and has to spray the fertilizer on agricultural land especially in mud area. The robot can be made scalable where it can be made large or small as a subsystem to a larger platform. Their functions include manipulating an object, fertilizer spraying, weight carriying.etc.

The application of four-legged robot in fertilizer spraying operation will increase the effort of the operation as the robot could be adaptable and flexible in moving through difficult mud spaces of agricultural land. With two revolute degree of freedom for each leg the robot could move through an environment of unstructured and technically challenged area shaped by natural forces with less effort. Equipped with ultrasonic sensing module, the robot will have 100% chances of success in finding and avoiding the obstacles. Equipped with servo system module, the robot will have improvised locomotion and fertilizer spraying capability[7]. The light weight design which is used to manufacture the robot, make it weightless[5]. Low power consumption will make the robot for work long duration[9]. fast movement of robot will save the time of formers[3].

Methodology

The complete process has been split into different steps which start from designing, modeling, fabrication and controlling of the robot. First is identifying the problem. The second step is developing the concept to overcome the problem which has been identified in the first step. Once the concept is developed for the identified problem, the different possibilities of the concept is sketched out and studied. The optimum solution for the concept is arrived after the studies. we have to create a four leg robot in a 3 dimensional model using modeling software. The various calculations are done such as kinematic parameters. Then analysis of the complex model in order to identify fundamental properties had been carried out.

Next stage is to fabricate the robot. Then an algorithm is to be developed for the locomotion of the four-legged robot for the purpose of spraying operation and for the obstacle avoidance.

The four-legged robot will be separated into three different parts of tasks, namely the mechanical part, the electronics & electrical part, and the programming part. The programming part will include the control for locomotion of the four-legged robot by programming the servo motor, response to the sensors feedback, respond to user command, and able to lift the body in particular application like stair climbing and cross over the obstacles.

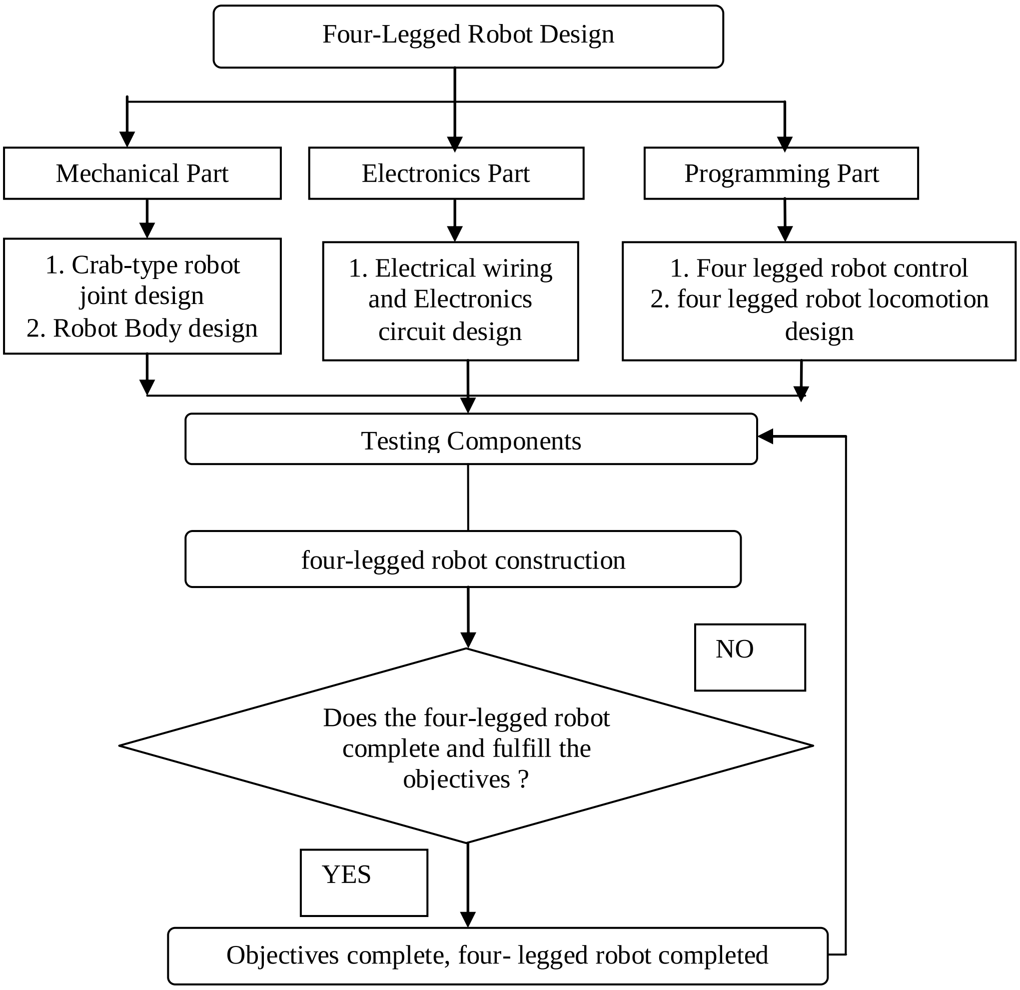

Figure 1: The glow graph for the Four-leg robot design project

Robot Design

A. Structure of the leg[4]

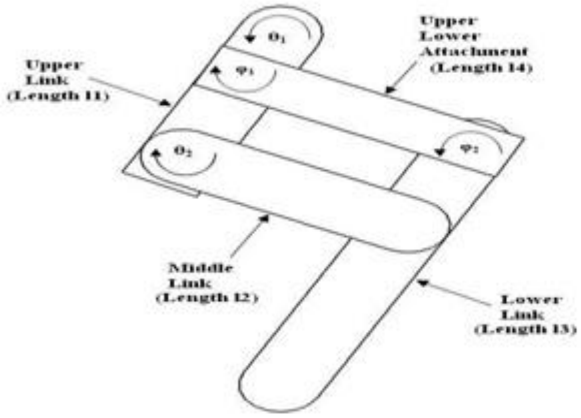

Figure 2: Structure of robot leg with four bar link

For locomotion, quadruped robot needs an appropriate leg mechanism. Four bar chain mechanism can be used in modified form as a leg mechanism. As shown in Fig. 2, robot leg involving four bar kinematic chain consists of four elements viz. Upper link, Middle link, Upper lower attachment and Lower link. Input force and motion can be provided to any link to obtain desired output motion. Smallest links are preferred.

B. Four-Legged Robot direct Kinematics[4]

Before proceeding to forward kinematics, a Link Coordinate Diagram (LCD) is given for robot leg. Then coordinate frames are assigned to each link using D-H algorithm. In the given case, where robot leg is a modified four bar chain Link coordinate Diagram (LCD) with coordinate frame assigned is as shown in Fig. 3 below. As shown in Fig. 2 above, θ_1 and θ_2 are active joint variables and are known. All link lengths are known. φ_1 and φ_2 are passive joint variables and are unknown. But relation between active and passive joint variables is known. Quadruped robot leg which is a four bar closed chain mechanism is broken into two kinematic chains which are nothing but 2R serial manipulators. These two 2R serial manipulators are left 2R manipulator and right 2R manipulator. For both the manipulators, the D-H parameters are determined. This is followed by derivation of transformation matrix.

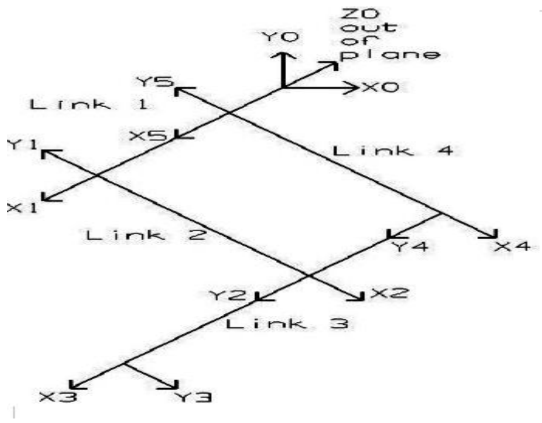

Figure 3: Link coordinate diagram of robot leg

The D-H parameter table and transformation matrix for both the 2R serial manipulator chains are given below

Table 1: D-H parameter table for left 2R manipulator chain

Link	D-H parameters			
	d_k	θ_k	a_k	α_k
1	0	θ_1	l_1	0
2	0	θ_2	l_2	0

Transformation matrices for first and second row of D-H parameter table for left 2R manipulator (Table 1),

$$^{0}T_{1}=\begin{bmatrix} \cos\theta 1 & -\sin\theta 1 & 0 & l1*\cos\theta 1 \\ \sin\theta 1 & \cos\theta 1 & 0 & l1*\sin\theta 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\text{......} \qquad (1)$$

$$^{1}T_{2}=\begin{bmatrix} \cos\theta 2 & -\sin\theta 2 & 0 & l2*\cos\theta 2 \\ \sin\theta 2 & \cos\theta 2 & 0 & l2*\sin\theta 2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\text{.....} \qquad (2)$$

The transformation matrix $^{0}T_{2}$ for mapping coordinate frame at point 2 with coordinate frame at point 0 is found to be,

$$^{0}T_2=\begin{bmatrix} \cos(\theta1+\theta2) & -\sin(\theta1+\theta2) & 0 & l2*\cos(\theta1+\theta2)+l1*\cos\theta1 \\ \sin(\theta1+\theta2) & \cos(\theta1+\theta2) & 0 & l2*\sin(\theta1+\theta2)+l1*\sin\theta1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Table 2: D-H Parameter Table For Right 2R Manipulator

Link	D-H parameters			
	d_k	θ_k	a_k	α_k
1	0	φ_1	l_4	0
2	0	φ_2	l_3	0

The transformation matrix $^{0}T_2$ of coordinate frame at point 3 with respect to coordinate frame at point 5 can be found for right 2R manipulator in the same way from Table 2 and is found to be,

$$^{0}T_2=\begin{bmatrix} \cos(\varphi1+\varphi2) & -\sin(\varphi1+\varphi2) & 0 & l2*\cos(\varphi1+\varphi2)+l1*\cos\varphi1 \\ \sin(\varphi1+\varphi2) & \cos(\varphi1+\varphi2) & 0 & l2*\sin(\varphi1+\varphi2)+l1*\sin\varphi1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

For mapping coordinate frame at point 3 (which is also an endpoint of robot leg) on right manipulator with coordinate frame at point 0 (which is also a point on base) on left manipulator transformation matrix required, involves 4 degrees of freedom viz. θ_1, θ_2, φ_1 and φ_2. To reduce it to 2 degrees of freedom viz. θ_1 and θ_2 assume from geometry shown in Fig. 2,

$\phi_1=\theta_2$..... (5)

$\phi_2=-\theta_2$..... (6)

Final transformation matrix after reducing degrees of freedom is,

$$^{0}T_3=\begin{bmatrix} \cos\theta1 & -\sin\theta1 & 0 & (l3+l5)*\cos\theta1+l4*\cos(\theta1+\theta2) \\ \sin\theta1 & \cos\theta1 & 0 & (l3+l5)*\sin\theta1+l4*\sin(\theta1+\theta2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\ldots \quad (7)$$

C. Four-Legged Robot inverse Kinematics[4]

Inverse kinematic problem involves determining active and passive joint variables, given the geometry and position & orientation of the endpoint of robot leg with respect to base [7]. For inverse kinematics, the input required is of Tool Configuration Vector

(TCV). It is the compact representation of position and orientation of endpoint of kinematic chain. From Tool configuration vector taken from the arm matrix determined above in (7), x and y coordinates of point 3 with respect to base are given by,

$X_3=(l_3+l_5)*\cos\theta_1+l_4*\cos(\theta_1+\theta_2)$....... (8)

$Y_3=(l_3+l_5)*\sin\theta_1+l_4*\sin(\theta_1+\theta_2)$....... (9)

Where, X_3 and Y_3 are known,
Solving (8) and (9) for θ_2,

$$\theta_2=\cos^{-1}\left[\frac{X_3^2+Y_3^2-(l_3+l_5)^2-l_4^2}{2*(l_3+l_5)*l_4}\right]....... \quad (10)$$

Rearranging (8) and (9), converting those to matrix form as shown below. $\begin{bmatrix}X_3\\Y_3\end{bmatrix}=$

$$\begin{bmatrix}(l_3+l_5)+l_4*\cos\theta_2 & -l_4*\sin\theta_2\\ l_4*\sin\theta_2 & (l_3+l_5)+l_4*\cos\theta_2\end{bmatrix}*\begin{bmatrix}\cos\theta_1\\ \sin\theta_1\end{bmatrix} .....(11)$$

Solving (11) by Cramer's rule, we get,

$$\theta_1=\tan^{-1}\left[\frac{[(l_3+l_5)+l_4*\cos\theta_2]*Y_3-[l_4*\sin\theta_2]*X_3}{[(l_3+l_5)+l_4*\cos\theta_2]*X_3+[l_4*\sin\theta_2]*Y_3}\right].... \quad (12)$$

Again from (5) and (6),

$$\varphi_1=\theta_2\ \&\varphi_2=-\theta_2..... \quad (13)$$

Thus, all joint variables are found.

LOad Analysis

Load analysis is important thing in the designing processes. Because water, fertilizer, tank and dc pump weights and all will act on the robot in the fertilizer spraying process. The load analysis can divide into two for legged robots.

1. load analysis for robot leg.
2. load analysis for robot base frame.

D. Load Analysis For Robot Leg

When take the load analysis for robot leg, the weight of robot also has to consider with other weights. But the total load is divided by number of legs in this case. Because number of legs will share the load. For four leg robot, the total load is divided by four. Let consider that 1 liter of water is filled in the tank. So weight of 1liter water is 1kg, due to the gram being defined in 1795 as one cubic centimeter of water at the temperature of melting ice. Weight of the robot is 3kg alone. Weight of all other things like tank, dc pump is 350g. So total weight acting on the leg is 4.35kg. In one leg 4.35/4=1.0875kg weight will act. By solid works simulation software 1.0875kg load is applying on robot leg to find the failure spots or weak spots on the robot leg. Before apply the load, material type should be choose as aluminum sheet. Minimum and maximum amount stress-strain of robot leg is given in Table 3.stress distribution on leg is shown in Fig. 4 below. The strain distribution on leg also shown in Fig. 5 below.

Table 3: Minimum and maximum stress-strain durability of robot leg

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5.1905e-009 Element: 3245	0.00666485 Element: 7313
Stress1	VON: von Mises Stress	531.02 N/m^2 Node: 6148	6.1238e+008 N/m^2 Node: 11688

E. Load analysis for robot base frame

When take the load analysis for robot base frame, other than the weight of robot all other weights has to consider. But the total load will not divided by number of legs in this case. Because number of base frame is one. Total weight acting on the base frame is 1.35kg. By solidworks simulation software 1.35kg load is applying on robot leg to find the failure spots or weak spots on the robot leg. Before apply the load, material type should be choose as aluminum sheet. Minimum and maximum amount stress-strain of robot base frame is given in Table 4.stress distribution on base frame is shown in Fig. 6 below. The strain distribution on base frame also shown in Fig. 7 below. After the load analysis, dimension of the robot leg and base frame has been edited to maintain the stress and strain values in between the minimum and maximum stress and strain values when load is acting on robot leg and base frame.

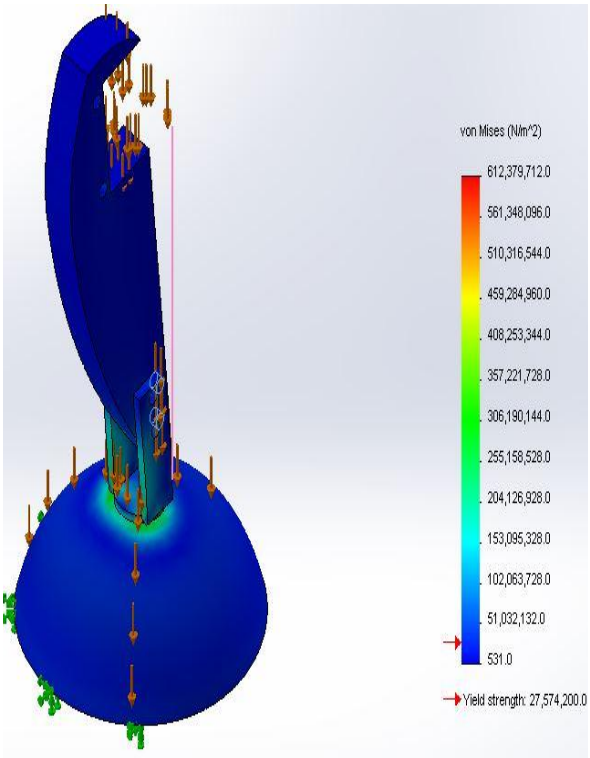

Figure 4: Stress displacement of robot leg when load apply

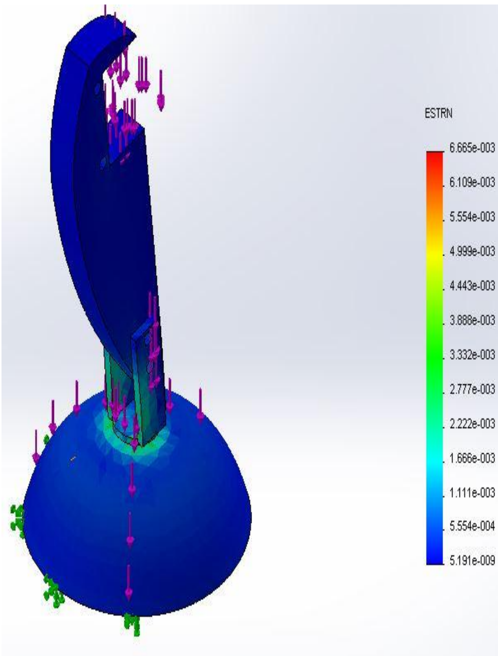

Figure 5: Strain displacement of robot leg when load apply

Table 4: Minimum and Maximum Stress-Strain Durability of Robot Base Frame

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.218593 N/m^2 Node: 8815	5.03271e+008 N/m^2 Node: 23
Strain1	ESTRN: Equivalent Strain	3.22072e-012 Element: 3066	0.0033756 Element: 6796

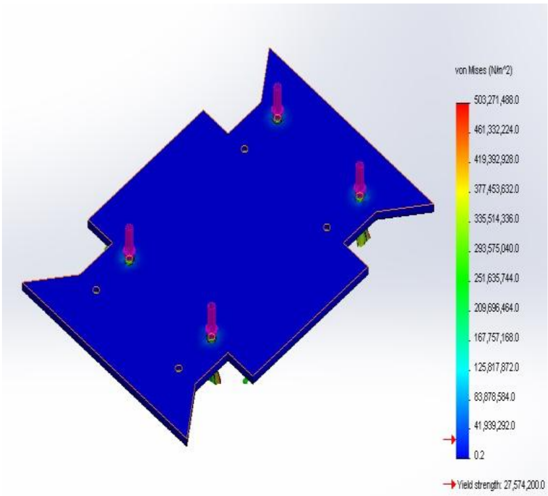

Figure 6: Stress Displacement of Robot Base Frame When Load Apply

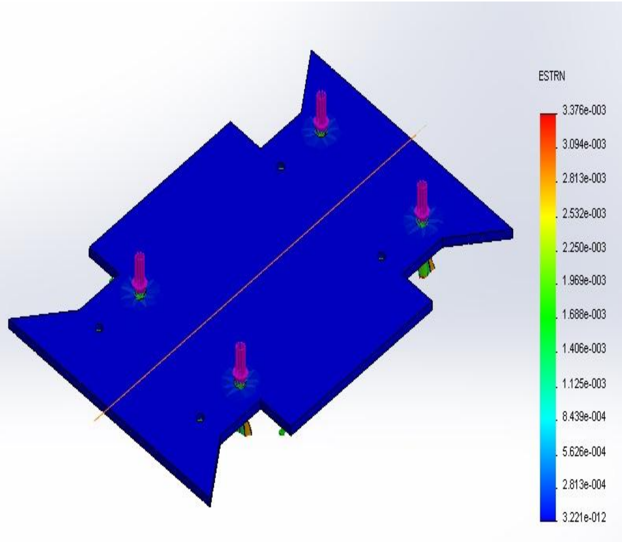

Figure 7: Strain Displacement of Robot Base Frame When Load Apply

Locomotion

Robot locomotion is very important, because robot has to move on mud and soggy surface with fertilizer weight. Here additionally, we give leg bushes to the leg to increase the area of contact. So it can easily survive on mud and soggy surface.

F. Reactive standing

Reactive standing describes that the body of the robot stand-in-place

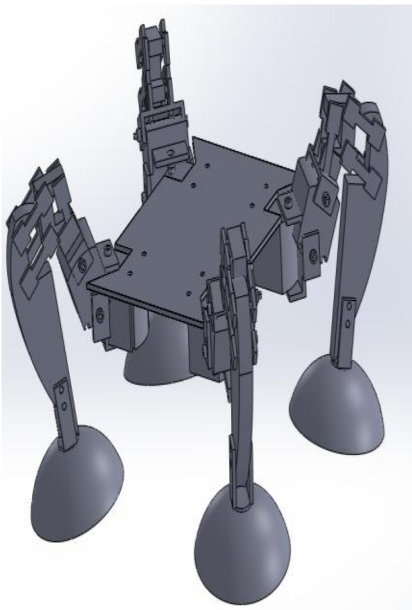

Figure 8: Legged Robot Performing A Reactive Stand on Flat Terrain

G. Robot locomotion

It is very important to know what locomotion to be applied to the four-legged robot beforehand. Therefore, the theory behind the possible locomotion must be clearly understood so that will ease troubleshooting and brainstorming time for better design.

The robot legs are numbered as one, two, three, four. For the right side legs R symbol is added before number. As right side legs left side legs has L symbol before number. It is useful to understand the robot legs actuation while moving in forward direction or during turnings. Numbered robot legs are shown in Fig. 9 below.

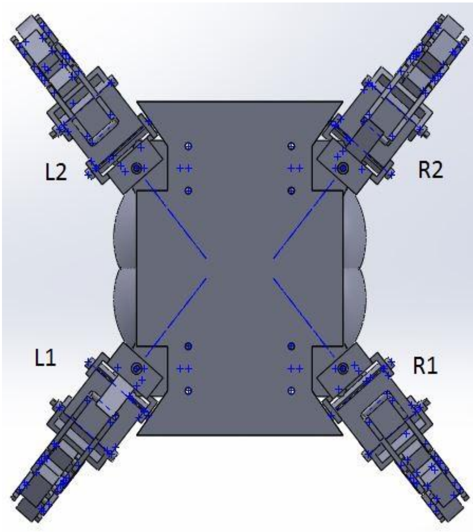

Figure 9: Top view of robot with numbered legs

In the forward motion, R1 leg will actuated first. So R1 leg will move into the forward direction. Then R2 will actuate. So R2 also will reach the forward position. And L1 and L2 will actuated in the order. After L1 and L2 reaches forward position, all legs will actuate finally at a time and take the robot into the front side.

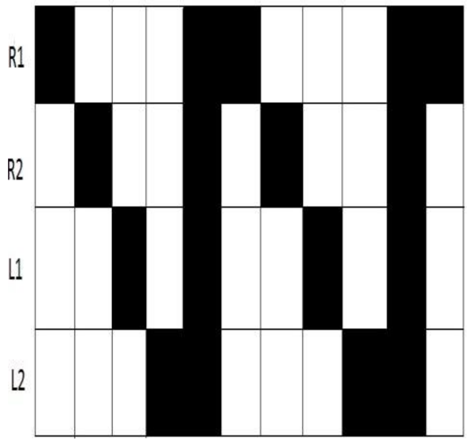

Figure 10: Robot Leg Actuation Sequence During Forward Motion

Fig. 10 shows the robot actuation sequence when the robot move in the forward motion. In the Fig. 10 black mark is shows the actuation of the leg. White shows the rest position of the leg. This same process continues till ultrasonic sensor senses any obstacles. By using obstacle avoidance sensor the robot will move on agriculture land in the forward motion. If any obstacles found by the sensor it will take right or left motion as per program.

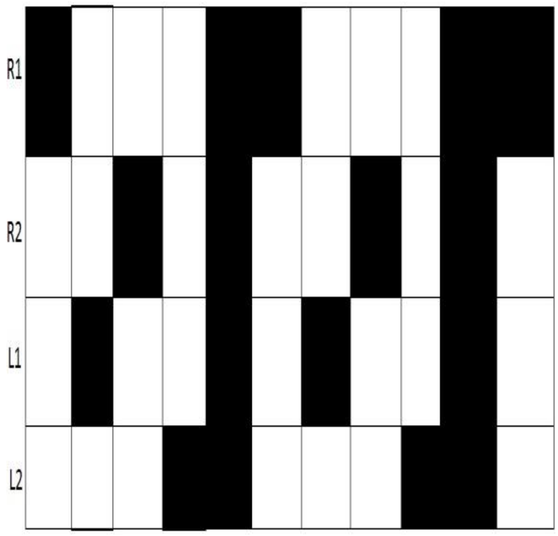

Figure 11: Robot Leg Actuation Sequence During Right Side Motion

As shown in Fig. 11, In the right side motion R1 leg will actuated first. So R1 leg will turn in some angle. Then L1 will actuate. So L1 also will turn in some angle. And R2 and L2 will actuated in the order. After R2 and L2 turns into some angle, all legs will actuate finally at a time and make the robot turn in right side.

By this method we are controlling the robot to cover each and every place in the agriculture land. How the robot will move on the agriculture land is shown in fig. 12. First the robot will be introduced in a corner of agricultural land. In agricultural land, there is no more chances for obstacles. But we have some obstacles artificially at the end of the robot path. So when the robot reaches a end of a path it will face a obstacle which is created artificially. So it will take left or right motion as per the program.

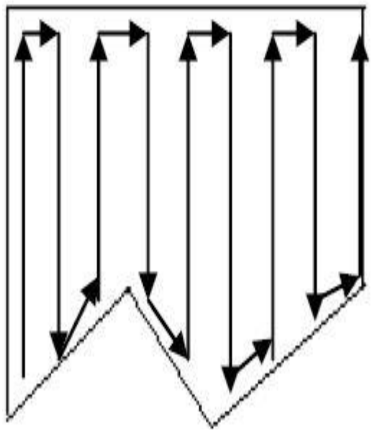

Figure 12: Robot locomotion path on agricultural land

Spraying Process

For the spraying process dc pump, plastic tank, spraying nozzle are used. The plastic tank is used to carry the water and fertilizer. Dc pump is used to pump the water from one place to another place. In the dc pump some vacuum is created in the chamber which is having rotating blades. Outlet water pressure will differ by based on the speed of rotating blades. Spraying nozzle act a important role in this spraying process. When high pressure water go through a very small hole, liquid molecules are divided into small parts. So the liquids are come out from the nozzle like small parts and covers the much areas. In normal agricultural process formers using pressure inside the water tank to take out the fertilizer. If the pressure reduces inside the tank the spraying speed also will reduce. So uniform spraying is not obtain by formers. But in the dc pump pressure is not given into the water tank. So spraying speed and amount of fertilizer coming out from the sprayer is even and uniform. Let assume that amount of liquid filled in the tank is 1 liter. Through nozzle 2.5g of liquid is coming out for 1sec. So 1liter takes 7 minutes to come out through nozzle. Fig. 13 below shows the spraying unit

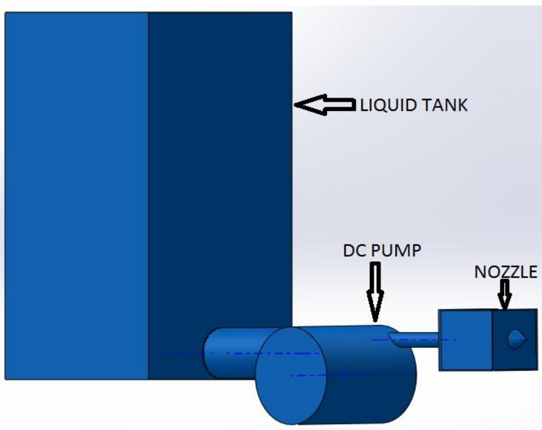

Figure 13: Assemble View of Spraying Nozzle, Dc Pump And Liquid Tank

H. Pseudo Code

```
command(0x80);lcd_dis(" FOUR LEG ",16);
command(0xc0);lcd_dis("-----ROBOT------",16);
motor_ON;
delay(5*1000000);
T1TCR = 0x02; //reset counter
T1IR = 0xff;
T1MCR = 0x0003; //interrupt and reset on        MR0
T1MR0 = 0x00000BB8;   // EA60
VICVectCntl0 = 0x00000025; //use it for Timer 0 Interrupt:
VICVectAddr0 = (unsigned)IRQ_Routine;
                    //set interrupt vector in 0
VICIntEnable = 0x00000020; //enable TIMER0 interrupt
T1TCR = 0x01;
```

The above program is used in the robot to control its locomotion. As per the program the motor is turned on initially. By default forward motion is given in the program. When it faces the obstacles timer gives an important role. The robot and fertilizer spraying process has stopped. If the obstacle has been sensed, after a particular time it starts to turn in to the another direction. When the robot turn into the another direction other direction control program to motor is actuated. After the turn, timer has been reset by itself. After complete the turning process the spraying process will be started. This process is continues till it reaches the end position.

Conclusion and Future Work

In this paper design and fabrication of the four-legged robot, fertilizer spraying unit and the robot locomotion with the pseudo code of program is explained. This robot will move on the mud surface if the mud level is below 5cm. The weight carrying capacity is also somewhat less because of dimension of robot and power of servo motors. In this robot ultrasonic sensor and IR sensors are used to find the obstacles. In future, if vision sensor and GPS are added up with robot, the robot can navigate the robot easily and it can find the affected areas in the agricultural land by using vision sensor. So robot will apply fertilizer on required areas. So amount of fertilizer apply on the agricultural land will be controlled by robot. If the motor power is increases and if the stepper motor is used instead of servo motor, the weight carrying of the robot will increase. But the height of tank increases, length of the robot also has to increases for maintain the stability of robot while walking.

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