Miniature hexapod archio robot

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ABSTRACT

The advancement in technology around the world has a huge demand for walking robots for various applications for the walking control on uneven terrains. This paper designs a hexapod, a six legged spider robot which involves the control of 19 servomotors. The main focus is on the application of ultrasonic and light detecting resistor sensors and the control of servo motors (actuators). The movement is simulated like a 6 foot insect by programming the controller. Shape and mass distribution of the robot is similar to a spider with the purpose of getting stable dynamic walking movement. It has 3DOF (degree of freedom) and all are revolute joints. The feet of hexapod is typically pointed, but also can be tipped with adhesive material or suction tubes which will help to climb walls. This hexapod is designed to turn right, left, forward and backward.

According to the sensors inculcated this robot has a wide range of applications, starting from tracking an obstacle to archeological applications.

KEYWORDS

Hexapod,
DOF-Degree of Freedom,
Inertia Matrix,
Centrifugal Matrix,
Gravitational Vector,
Jacobian.

1. Introduction

1.1 General Information

In order to support human activities in various jobs some intelligence is essential. Sensors act as the eye, wherein the structure acts as the body to this intelligent system. A sensor is a device which collects information around its environment and sends to other electronic device to do the necessary changes according to the information given. Ultrasonic sensors and light detecting resistors have found its applications in various field. Usually to detect an object or an obstacle. When sensors like cameras are inculcated along with these sensors the combination can be used for much wider applications. Any system will have uncertainties, and can be overcome by the use of these sensors.

Compared to wheeled robots where it can perform task on the smooth surfaces, hexapod is a six-legged spider robot which can walk on difficult terrains and uneven surfaces. To control the legged robot, the equation of motion is constructed which is quite complex due to its mathematical equations and finding solutions is difficult. However with the use of the principle of forward kinematics and dynamics, equation of motion can be obtained and the solution for the angle of the end effector position can be derived.

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According to the sensors inculcated this robot has a wide range of applications, starting from tracking an obstacle to archeological applications.

Archeology is the study of human history and prehistory through the excavation of sites and the analysis of artefacts and other physical remains. Archeology in India has a multiple role to play, not only a long literature survey has to be made after the artefacts are found but also finding these in the caves, forests, on or under the earth's surface is very difficult. Excavation of a site has three major steps which includes remote sensing (for example, by aerial photography), soil surveys, and walk-through or surface surveys. Focusing on the walk-through method of surveying the surface; these places are usually very narrow, places where people will not have explored. Walking through these dug holes or into the deep jungles is a difficult task to the human beings. The hazards due to these excavations is more. To name a few

- falls into trenches or excavations
- tripping over equipment

- exposure to underground services or overhead electrical cables
- unstable adjacent structures
- mishandled or poorly placed materials
- hazardous atmosphere (noxious gases/lack of oxygen)
- toxic, irritating or flammable and explosive gases and so on

  To overcome all these hazards it is important to build a mechanism which should be small in size yet do a lot of tasks. Hexapod is one such spider structured robot which can be used to overcome most of problems faced during the process of excavation.

2. Hexapod Design Configuration

Hexapod is a robot with six legs and each leg is symmetrical to one another. The structure has the capacity to hold the weight of small sensors and actuators, hence the use of mini and micro sized sensors becomes important for proper control and working of the robot.

It includes three major functions:

- Can be controlled with the help of a remote control for its motion and action.
- An ultrasonic sensor is used to detect the obstacle in front of it and move in the direction where there is no obstacle.

With the help of LDR (light detecting resistors) also known as photo resistors, intensity of light can be sensed and robot must be able to move in that direction.

Hexapod's movement is simulated like a six feet insect by programming the controller. This involves controlling of 19 servomotors, 1 for face and 3 for each leg (3*6=18). This design is derived from insects in nature, especially the principles of their walking movement. Foot is the motion organ of insects and are divided into front foot, midfoot and rear foot and hexapod follows the same design. It has 3 DOF in each leg and are revolute joints. It uses biological theories about insect locomotion wherein the feet of the hexapod is typically pointed but can also be tipped with adhesive material to help climb walls or wheels so that robot can drive quickly when the ground is flat.

Insect gaits are usually obtained by two approaches: centralized and decentralized control architectures. Centralized controllers directly specify transition of all legs, whereas in decentralized architecture, six legs are connected in parallel network and gaits arise by the interaction between neighboring legs, hexapod uses this control architecture.

The main parts of this project includes

- **RGB LED module:**

  which indicates in which mode the hexapod is operating in : blue indicates remote control mode, red indicates obstacle detecting mode, green indicates light following mode.

- **Photo resistor module**:

  it is a light dependent resistor whose value of resistance is inversely proportional to the intensity of light.

- **32 channel PWM Drive:**

  Servomotor controller whose input range is from 6.5 ~12V and output is 5V and works with a baud rate of 9600 to control multiple motors.

- **Ultrasonic module:**

  it works by emitting sound waves at a frequency too high for humans to hear and receives the reflected sound when a obstacle comes in between and this time is calibrated as distance to know the exact location of the obstacle.

- **NRF24L01 module:**

  it's a single chip radio trans receiver which works in the bandwidth of 2.4-2.5 GHz for wireless communication between the robot and the remote controller.

- **Passive buzzer:**

  which generates a tone using an internal oscillator. Electromagnetic changing input produces sound in the speaker.

Sensors like magneto meters has to be inculcated in this project for detection of artefacts in the process of excavation for archeological applications.

Integrating all these modules together to a controller the dynamic movement of the hexapod can be obtained. The movement of right and left legs are unsymmetrical because for forward walking the right first foot should move and then the left foot has to move front, alternate movement of these legs will cause forward and backward action.

3. Equations and Symbols

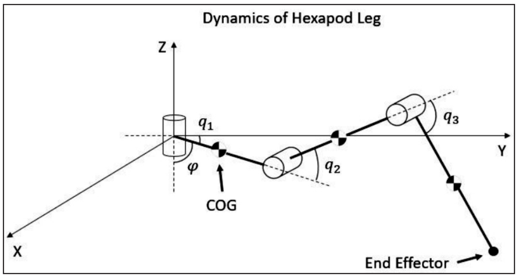

Fig. 1. Mathematical modeling of one leg.

Calculation of homogeneous transformation matric:

Dynamic equation of n DOF manipulator:

T=B(q)q`` + c(q,q`)q`+ G(q) - equation of motion

where

B(q) – Inertia matrix – nxn – function of joint variable

C(q,q') – Centrifugal matrix – nxn – function of joint variable and velocity

G(q) – Gravity vector – nx1- function of joint variable

Let m1,m2,m3 be the masses of the three links

l_1, l_2, l_3, be the length of each link

a_1, a_2, a_3, be the center of mass of each link

θ_1, θ_2, θ_3 are the angles of rotation at the joint

$S_1 = sin\theta_1$, $C_1 = cos\theta_1$, S_{12} = sin $(\theta_1+\theta_2)$, C_{12} = cos $(\theta_1+\theta_2)$,

$_{123}$= sin $(\theta_1+\theta_2+\theta_3)$, C_{123} = cos $(\theta_1+\theta_2+\theta_3)$

manipulator jacobian is given by J= $\begin{bmatrix} Jp \\ Jo \end{bmatrix}$

where Jp= linear velocity (position)

Jo=angular velocity (orientation)

$$J= \begin{bmatrix} Jp \\ Jo \end{bmatrix} = \begin{bmatrix} Jp1 \;\; Jp2 \ldots \ldots Jpn \\ Jo1 \;\; Jo2 \ldots \ldots Jon) \end{bmatrix}$$

In general = $\begin{bmatrix} Jpi \\ Joi) \end{bmatrix} = \begin{bmatrix} Z(i-1) * (P - P(i-1)) \\ Z(i-1) \end{bmatrix}$ for revolute joints

where Z(i-1) is the 3rd column of R^{o}_{i-1} which is a position of T^{o}_{i-1}

Zo is given by a unit vector

Po is a zeroo vector

P is the end effector position given by 4th column of T^{o}_{n}.

P_{i-1}. is the end effector position given by 4th coloumn of T^{o}_{i-1}.

Homogeneous Transformation Matrix :

$$^0_3T = {}^0_1T * {}^1_2T * {}^2_3T$$

where

$$^0_1T = \begin{bmatrix} cos\theta1 & -sin\theta1 & 0 & l1cos\theta1 \\ sin\theta1 & cos\theta1 & 0 & l1sin\theta1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$^1_2T = \begin{bmatrix} cos\theta2 & -sin\theta2 & 0 & l2cos\theta2 \\ sin\theta2 & cos\theta2 & 0 & l2sin\theta2 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$^2_3T = \begin{bmatrix} cos\theta3 & -sin\theta3 & 0 & l3cos\theta3 \\ sin\theta3 & cos\theta3 & 0 & l3sin\theta3 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Calculation of Inertia matrix B(q):

$$B(q)=\sum_{i=1}^{n} \left(m_i Jp^{(li)T} Jp^{li} + Jo^{(li)T} I_{li} Jo^{li}\right)$$

$$B(q)=[(m_1 J_p^{(l1)T} J_p^{l1} + J_o^{(l1)T} I_{l1} J_o^{l1}) + (m_2 J_p^{(l2)T} J_p^{l2} + J_o^{(l2)T} I_{l2} J_o^{l2}) + (m_3 J_p^{(l3)T} J_p l3 + J_o^{(l3)T} I_{l3} J_o^{l3})]$$

where

$$I_{l1} = \begin{bmatrix} I_{x1} & 0 & 0 \\ 0 & I_{y1} & 0 \\ 0 & 0 & I_{z1} \end{bmatrix} I_{l2} = \begin{bmatrix} I_{x2} & 0 & 0 \\ 0 & I_{y2} & 0 \\ 0 & 0 & I_{z2} \end{bmatrix} I_{l3} = \begin{bmatrix} I_{x3} & 0 & 0 \\ 0 & I_{y3} & 0 \\ 0 & 0 & I_{z3} \end{bmatrix}$$

$$J_0^{l1} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix} J_0^{l2} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix} J_0^{l3} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$J_p^{l1} = \begin{bmatrix} -l_1 S_1 & 0 & 0 \\ l_1 C_1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} j_{p1}^{l1} & 0 & 0 \end{bmatrix}$$

$$J_p^{l2} = \begin{bmatrix} -l_1 S_{12} - l_1 S_1 & -l_2 S_{12} & 0 \\ l_2 C_{12} + l_1 C_1 & l_2 C_{12} & 0 \\ 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} j_{p1}^{l2} & j_{p2}^{l2} & 0 \end{bmatrix}$$

$$J_p^{l3} = \begin{bmatrix} l_3 S_{123} + l_2 S_{12} + l_1 S_1 & l_3 S_{123} + l_2 S_{12} & l_3 C_{123} \\ -l_3 C_{123} - l_2 C_{12} - l_1 C_1 & -l_3 C_{123} - l_2 C_{12} & l_3 S_{123} \\ 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} j_{p1}^{l3} & j_{p2}^{l3} & j_{p3}^{l3} \end{bmatrix}$$

1st term

$$(m_1 J_p^{(l1)T} J_p^{l1} + J_o^{(l1)T} I_{l1} J_o^{l1}) = \begin{bmatrix} m_1 l_1^2 + I_{z1} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

2nd term

$$(m_2 J_p^{(l2)T} J_p^{l2} + J_o^{(l2)T} I_{l2} J_o^{l2}) = \begin{bmatrix} (l_1^2 + l_2^2 + 2l_1 l_2 C_2)m_2 + I_{z2} & (l_2^2 + l_1 l_2 C_2)m_2 + I_{z2} & 0 \\ (l_2^2 + l_1 l_2 C_2)m_2 + I_{z2} & (l_2^2)m_2 + I_{z2} & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

3rd term

$$(m_3 J_p^{(l3)T} J_p^{l3} + J_o^{(l3)T} I_{l3} J_o^{l3}) =$$

$$m_3 \begin{bmatrix} l_1^2 + l_2^2 + l_3^2 + 2l_1 l_2 C_{23} + 2l_2 l_3 C_3 + 2l_1 l_2 C_2 + \mathrm{I}_{z3} \\ l_2^2 + l_3^2 + 2l_2 l_3 C_3 + l_1 l_3 C_{23} + l_1 l_2 C_2 + \mathrm{I}_{z3} \\ l_3^2 - l_2 l_3 S_3 - l_1 l_3 S_{23} + I_{z3} \end{bmatrix}$$

$$\begin{matrix} l_2^2 + l_3^2 + 2l_2l_3C_3 + l_1l_3C_{23} + l_1l_2C_2 + \mathrm{I}_{z3} & -l_2l_3S_3 - l_1l_3S_{23} + I_{z3} \\ l_2^2 + l_3^2 + 2l_2l_3C_3 + \mathrm{I}_{z3} & l_2l_3C_3 - l_2l_3S_3 + I_{z3} \\ l_3^2 - l_2l_3S_3 + I_{z3} & l_3^2 + I_{z3} \end{matrix}\Bigg]$$

Therefore,
B(q) matrix is given by the sum of above three terms such as :

$$B_{11} = m_1l_1^2 + I_{z1} + (l_1^2 + l_2^2 + 2l_1l_2C_2)m_2 + I_{z2} + l_1^2 + l_2^2$$

$$+ l_3^2 + 2l_1l_2C_{23} + 2l_2l_3C_3 + 2l_1l_2C_2 + \mathrm{I}_{z3}$$

And so on
With the help of MATLAB programming the final matrix can be calculated and the solution can be obtained.

Calculation of centrifugal matrix C(q):

$$\mathrm{C(q)} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix}$$

$$\mathrm{C_{ijk}} = \mathrm{C_{jki}}$$

$$\mathrm{C_{ij}} = \sum_{k=1}^{n} \mathrm{C_{ijk}}\ \Theta_\mathrm{k}$$

$$C_{11} = -l_1l_2S_2M_2 - M_3[(S_{23}l_1l_2S_2)\Theta_2 - (l_1l_3S_{23} - 2l_1l_3S_3)\Theta_3]$$

$$C_{12} = C_{21} = (-l_1l_2S_2M_2 - M_3(S_{23}l_1l_2S_2)\Theta_1 + [l_1l_2S_2M_2 - l_1l_2S_2M_3]\Theta_2$$
$$+ [l_2l_3S_3M_3 + \frac{1}{2}(-l_1l_3C_{23})\Theta_3]$$

$$C_{13} = C_{31} = -M_3(-l_1l_3S_3 + l_1l_3S_{23})\Theta_1 + [\ \frac{1}{2}M_3(l_1l_3C_{23} +$$
$$2l_2l_3S_3)]\ \Theta_2 + \frac{1}{2}M_3(l_1l_3C_{23})\Theta_3$$

$$C_{22} = -l_2l_3S_3M_3$$

$$C_{23} = -\frac{1}{2}(M_3(-l_1l_3C_{23}) + M_3(l_2l_3 + l_1l_3S_3 - l_1l_3S_{23})\Theta_3$$

$$C_{33} = 0$$

Calculation of gravity vector G(q):

$$G(\theta) = \begin{bmatrix} g_1(\theta) \\ g_2(\theta) \\ g_3(\theta) \end{bmatrix} g_0 = \begin{bmatrix} 0 \\ -g \\ 0 \end{bmatrix}$$

$$g_i(\theta) = \sum_{j=1}^{n}[M_j g_0^T\ j_{pi}^{(l_j)}]$$

$$g_1(\theta) = -\textstyle\sum_{j=1}^{n}[M_1g_0^T\ j_{p1}^{(l_1)} + M_2g_0^T\ j_{p1}^{(l_2)} + M_3g_0^T\ j_{p1}^{(l_3)}]$$

$$= (m_1 + m_2 - m_3)gl_1C_1 + (m_2 - m_3)gl_2C_{12} - m_3gl_3C_{123}$$

$$g_2(\theta) = -\sum_{j=1}^{3}[M_1g_0^T\ j_{p2}^{(l_1)} + M_2g_0^T\ j_{p2}^{(l_2)} + M_3g_0^T\ j_{p2}^{(l_3)}]$$

$$= (m_2 - m_3)gl_2C_{12} - m_3gl_3C_{123}$$

$$g_3(\theta) = -\sum_{j=1}^{n}[M_1g_0^T\ j_{p3}^{(l_1)} + M_2g_0^T\ j_{p3}^{(l_2)} + M_3g_0^T\ j_{p3}^{(l_3)}]$$

$$= m_3gl_3S_{123}$$

Now, equation of motion is given by

$$T = B(q)q'' + C(q, q'')q'' + G(q)$$

$$\begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} \ddot{\theta_1} \\ \ddot{\theta_2} \\ \ddot{\theta_3} \end{bmatrix} + \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} \dot{\theta_1} \\ \dot{\theta_2} \\ \dot{\theta_3} \end{bmatrix} + \begin{bmatrix} g_1(\theta) \\ g_2(\theta) \\ g_3(\theta) \end{bmatrix}$$

With the help of MATLAB programming matrix multiplication can be performed and the solution of the equation of motion can be obtained. By these results respective link length and angle can be given and simulation of a single leg can be obtained and the same applies to the other five legs of the hexapod robot.

4. Illustrations

4.1 Figures and photographs

- *Mechanical structure of hexapod .*
- *Servomotor connections to PWM of controller*

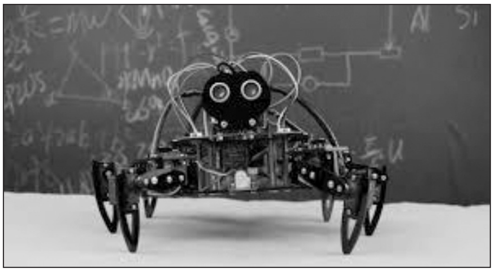

Fig. 2. Mechanical structure of hexapod.

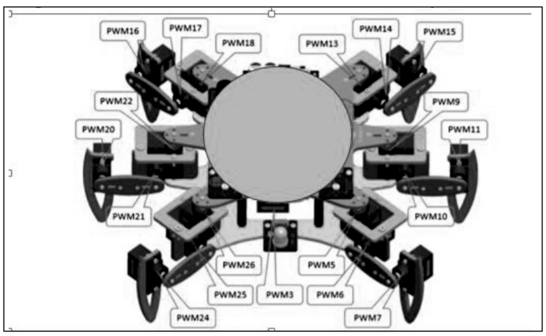

Fig. 3. Servomotor connections to PWM controller.

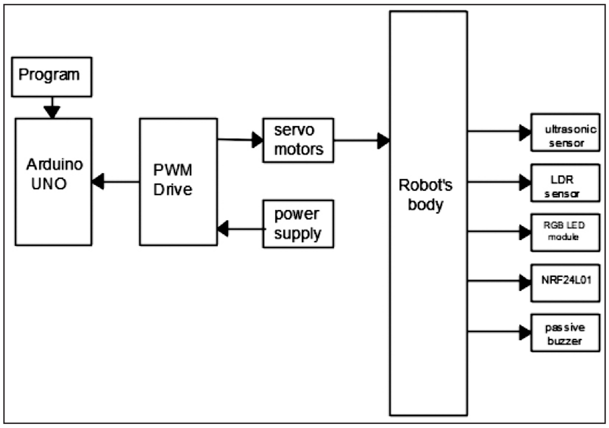

Fig. 4. Block diagram of robot's design.

5. Conclusion

The module is influenced by the need for mobile machining systems to avoid humans from hazardous and dangerous environments, such as in the process of archeological excavation. Hexapod has features like easy walking pattern which follows the pattern of an insect. It has features like obstacle detecting and analyses its movement accordingly. A camera is added to the face of the hexapod such that it must be able to rotate 360 degrees and must move up and down. Using this in any application can reduce a lot of risks for the human beings. Since it is smaller in size, it can move inside smaller holes and will be a great application in the field of archeology. With the help of the camera attached, the person controlling it can monitor the movement of the robot.

6. References

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Suraksha R. is presently pursuing Masters in Electric Vehicle Technology at Rajiv Gandhi Institute of Petroleum Technology. She is a graduate of Electrical Engineering passed out in the year 2020 from Global Academy of Technology. Her academic excellence includes securing "Best Paper Award" at National Conference on Micro System Technology organized by Central Manufacturing Technology Institute for the paper on "Miniature Hexapod Archio Robot". Her areas of interest are electrical motor drives, 3D printing technology, robotics and control. She was elected as the secretary of IEEE power and energy society student Branch-Global Academy of Technology for the year 2019. She has completed various projects which include hexapod, humanoid biped robot for healthcare applications, biped walking control for which she worked at IIT Roorkee.

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