Structural design of zoomorphic robot

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Abstract. In recent years many Zoomorphic robots have come into usage and these robots have an Animal based structure and they are known as social robots. The mechanical legs base gives the robot have amazing manoeuvrability so, the flexibility that decides the commands can be executed. Naturally, where these flexible components in ligaments largely add to the amazing headway abilities, the zoomorphic robot is assembly. This novel work deals with the design and development of a zoomorphic robot structure. The Kinematics Solutions are determined for the created structure utilizing a specially designed 3D printing robot. An Arduino application has used, to control the robot for its locomotion and positioning of the legs.

1. Introduction
A large amount of legged robots has built during the past decades all over the world [1]. These robots are diverse in size, structure, and function. There is something fundamental in common among them because animals inspire most legged robots, except a few single-legged robots [7]. Most of the mechanical structure of robotic legs [2] can be classified into a particular type based on the number of legs. Legged robots consisting of two and four legs are most popular and representative today, the other types such as the single-legged robot and multi-legged robots that have more than four legs exist, but those Robots usually have defects due to the lack of structural complexity.

The zoomorphic robots are the more complex parts of individual legs. These mechanical legs are design based on the links length, shape and size of the body structure [4]. The legs structure is mainly the connected one after another one. The activation system is required to activate or to move the required motions to use the electrical, hydraulic and pneumatic systems that are used [9]. Compared to all these one electrical systems or servomotors are better to achieve the required position and move.

The structural design to test the simulation software to moves the robot legs and motion to get smooth. The simulation process to plan the gait pattern. The creep type gait gives the legs moments for structural one-leg moves the forwards the first time and the rest of the legs are connected to the ground [10]. The programming purpose of the Arduino ide is used to control all the servomotors using drivers.

The main points are the statically stable gait during zoomorphic robot walking. Their gaits will be repeated the ability of step sequence and stability in territories Ares. Centre of gravity, Support Polygon, and Stability Margin these are the stability criteria elements for the gait of creeping. The gait of the zoomorphic robot can be divide into two groups [11]; the first one is the statically stable gait and the second is Dynamic running gait, depending on the type of gait. The zoomorphic body must be stable from moving one position to another for transition gait. The statically stable gait is slower contrast with dynamic gaits. It identifying the centre of gravity of the projection of zoomorphic robot is on the ground at instance time is inside in support polygon. Because of these properties, the
zoomorphic robot meets the necessity of force at the walking gait and this is said to be statically stable gait. Dynamic gait such as the trotting gait aims to the fact that if the centre of importance projection of the zoomorphic robot on the ground was not inside support polygon frame by legend [12]. The quadruped robot is in an uneven period and has a propensity of dumping. At that point the quadruped robot if there should arise an occurrence of the dynamic running gaits needs to fulfil the powerfully steady prerequisite as opposed to static steadiness examination. The vast majority of the quadruped robots can be considered as statically steady, when there are three legs, at any rate, ought to remain in contact with the ground at a similar moment time while another leg is swinging noticeably all around. The most organic statically stable gait that coordinates the creatures or creepy crawlies is the creeping gait.

In this paper, the issue of static stability analysis is accomplished. During the development of the quadruped robot, the movement will be steady if the body focal point of the centre of gravity is either inside the supporting triangle. The zoomorphic robot strolls with stable advances if the dependability edges have positive qualities, another case the robot will be flimsy and the strolling stride will fall flat. Some of the robots have already existed in recent years like a big dog, spot mine, etc [2]. These robots good stability and more performance.

2. Kinematics solutions

The kinematics solutions study the mechanical structure of the geometry system [17]. In that, one forward kinematics is the performance from the body base frame to the end of the legs frame. To move the robot in the forward direction.

![Figure 1. Coordinate frame for one leg of the zoomorphic robot.](image)

To move the robot legs one after another one to analyze the Denavit-Hartenberg performance to calculate the base frame to the end frame of the leg as shown in table 1. Now the four legs end position is to consider as the points from the forward kinematics give them.

| S.No | LINKS | α₀ | a₁ | d₁ | θ₁ |
|------|-------|----|----|----|----|
| 1    | Link1 | 90 | l₁ | d₁ | θ₁ |
| 2    | Link2 | 0  | l₂ | 0  | θ₂ |
Where $d_1 = 30\text{mm}$, $L_1 = 70\text{mm}$, $L_2 = 85\text{mm}$. $d_i$ is the distance from the robot body joint to the ground. $a_i$ is the leg link length. $\alpha_i$ is the twist angle.

Now, finding overall matrix transformation by making a product of two-transformation matrix as the following:

$$t_i^1 = t_i^0 \ast t_2^1$$  \hspace{1cm} (1)$$

The transformation matrix for one zoomorphic robot leg is describing as shown:

$$t_1^0 = \begin{bmatrix} c_1 & 0 & s_1 & l_1 c_1 \\ s_1 & 0 & -c_1 & l_1 s_1 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$  \hspace{1cm} (2)$$

$$t_2^1 = \begin{bmatrix} c_2 & 0 & s_2 & l_2 c_2 \\ s_2 & 0 & -c_2 & l_2 s_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$  \hspace{1cm} (3)$$

By multiplication the equation (2) and (3)

$$t_3^1 = \begin{bmatrix} \frac{c_1 c_2}{s_1} & s_1 & l_1 c_1 + l_2 c_1 c_2 \\ s_1 c_2 & -c_1 & l_1 s_1 + l_2 s_1 c_2 \\ s_2 & 1 & -c_2 & l_2 s_2 + d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$  \hspace{1cm} (4)$$
Where:

\[ C_1 = \cos \theta_1, \quad S_1 = \sin \theta_1, \quad C_2 = \cos \theta_2, \quad S_2 = \sin \theta_2. \]

Form Figure (1) and by using the equation (4), the coordinate position of each leg-end can be calculated as the flowing:

\[
x = l_2 \cos \theta_1 \cos \theta_2 + l_1 \cos \theta_1 \\
y = l_2 \sin \theta_1 \cos \theta_2 + l_1 \sin \theta_1 \\
z = l_2 \sin \theta_2 + d_1
\]

Where \( l_1 \) and \( l_2 \) are the link lengths

Equation 1, 2 and 3 are the forward direction the robot leg move. The inverse kinematics solutions were formulated the joint angles and end-tip positions [17]. Forward kinematics gives these positions and orientation. The main objective is to find the leg two joint angles \( \theta_1 \) and \( \theta_2 \). To apply the simple geometrical equations to solve the solutions for the inverse kinematics.

The inverse kinematics equation is given as shown below

\[
\theta_1 = a \tan 2(x, y) \\
\theta_2 = a \cos 2(\sqrt{x^2 + y^2} - l_1)
\]

The above equations 4 and 5 are used for finding the leg position in setting an angle. Both the angles are formatting the required direction and to get into the body motions

3. Zoomorphic robot design

Zoomorphic robot is specifically design a simple servomotors and components. Effects and impedance from the outside may act powers the vertical and parallel way of the robot body. The leg structure plan of the robot needs to meet the capacity prerequisite to lift itself and stand up in the wake of falling. For this model design solid work software is used.

As indicated by the after-effects of anatomical and morphological examinations, the leg structure of zoomorphic for the most part comprises two joints: hip and knee. Each joint comprises of a few degrees of freedom that enabling tetrapod to alter their stance and step flexibly to more readily adjust to different geographical changes. As shown in figure 2.
The zoomorphic robot is a design based on the legs links are the length link 1 = 70 mm, link 2 = 85 mm. The entire structure used u clamp based because the two sides the structure of links supported joints are fixe. It properly tight and to make proper stability. The servomotor can be rotated at the required angle. The final output requires torque to calculate 7 N-m. The servo motors can be choose based on the action and the moving links proper ways and making the joint motions concerning the entire base body structure. As shown in figure 3 and figure 4.

![Zoomorphic structure](image1)

**Figure 3.** Zoomorphic structure.

![Zoomorphic structure model](image2)

**Figure 4.** Zoomorphic structure model.

4. **Structural analysis of zoomorphic robot**

   Structural analysis is to find the required design structure bear the loads, forces and torque if applied more and more it may safe or not. The analysis is applied to the single part to find the part of the components with safe the required dimensions of the shape. For the analysis purpose, solid work software is used, it is directly finding the results.

   The structural analysis applies to the structure links and after the first chooses the calculations of force and torque. The required amount of torque calculates and applies the torque on the link rotating parts. After the stress formed as shown in figure 3, it bears the required amount of torque.
The structural analysis applies to the link 2 and the part at rotating member torque. Then after stress developed on the as shown in figure 5. These stresses are fine for the required design members. These are the torque and force that can be useful to choose motors.

The structural analysis process used as PLA (Polylactic acid) material is use for the fabrication. This material is good for 3D printing materials. Withstanding the proper structure of the robot. The PLA material strength is 37 Mpa. it is more than design components 22Mpa.

The analysis process considers mesh size is 2mm because it is small size the legs for the two-dimensional finite element, three nodes and three sides linear triangular element use. The figure 6 shows the bottom is fixe the boundary and apply the torque on the top side of holes.
5. Control scheme
The robot movements are controlled by a pre programmed flow for individual leg movements the interface of the product is as shown in figure 7.

![Diagram](image)

**Figure 7.** Software control structure.

Arduino is one of versatile micro-control that consistency both analog and digital input and output of that has been used to control and command the robot’s motion concerning its movement. This robot movement required to move the legs. The servomotors are connected to the Arduino board to write programming in software as per the required.

These servo motors moving the one after another one in proper ways. Zoomorphic robot moving the forward direction the leg movement right back leg first and after the other legs move. The body moves the same way to achieve one cycle to complete the movement. Servomotors are moving according to the required motion and the moving robot to go the moving the give the motors to making them.

6. Simulation
The simulation performance on mechanical design structural robot in Adams software. This gives the dynamic stability of the robot's legs movements. This can move on the virtual environment proper way to achieve smooth motions. Now, the first solid design file converts into .xt files and too impotent into simulation software. The links connected with the motion joints and rotation move to assign. The motion to achieve the using step function to give the time variables. In the step, the function gives the required angles of the legs for the inverse kinematics solutions. The function can be used for the required motion and the statics motion to fix the ground. To run the setup and motion as shown in figure 8. The motion joints like the hip and knee joints, its two degrees of freedom to moves the legs.
7. Gait pattern

The gait pattern is the main thing in the zoomorphic robot to move in the forward direction [11]. To move in this direction first one leg up and swing the required direction and to connect the ground and the center of gravity always to check the center position and after other legs move this type of gait called creep gait. The some-more gate pattern also they are the trot, pace and bound. In these other gaits, patterns are the robot legs are two only connected ground.

![Figure 8. Simulation module.](image)

![Figure 9. Gait pattern of the zoomorphic robot.](image)

The creep gait pattern three legs were connected to the ground. It can walk the more stable than another pattern to apply the inverse kinematic solution on here to achieve a better stable walk. To apply the hip and knee joints on the particular solutions of them to move the legs in the particular motion to achieve.

The zoomorphic robot moving in the simulation result in figure 9 shows the a, b, c, and d on design robot moving the creep gait pattern moving the legs. This is the legs balancing the overall movements of the body.
The gait pattern is generated by using the mathematical model as in figure 8. The 4 points P1, P2, P3, P4 are the initial position and after the leg1 move P1 to P11 for forward direction at the time the other legs are supporting the ground. Now the forming triangle with P2, P3 and P4 points. As shown in figure 10.

The 3 points of triangular centroid (L)

\[
L = (x_1+x_2+x_3/3, z_1+z_2+z_3/3) \quad (10)
\]

For leg moving one step

\[
L_1 = (x_{11}+x_2+x_3/3, z_{11}+z_2+z_3/3) \quad (11)
\]

Then the spouting x, z values in equation (1)

\[
L_1 = (-12+12+12/3, -7.5+7.5+7.5/3) = (4.0, 2.5)
\]

\[
L_2 = (x_{11}+x_3+x_4/3, z_{11}+z_3+z_4/3) = (4.3, 2.5) \quad (12)
\]

\[
L_3 = (x_{11}+x_{22}+x_4/3, z_{11}+z_{22}+z_4/3) = (4.0, 2.5) \quad (13)
\]

\[
L_4 = (x_{11}+x_{22}+x_{33}/3, z_{11}+z_{22}+z_{33}/3) = (4.3, 2.5) \quad (14)
\]

The L is the initial position of the triangular centroid of P1 point where it is moved in a forward direction with an angle \( \theta_1 \) of 5 degrees, and \( \theta_2 \) of 10 degrees, by using the inverse kinematic solution the \( \theta \) angle is denoted. Where the other L1, L2, L3, L4 are the four leg positions for P1, P2, P3, P4 points respectively. The initial point of P1 moves from its position and forms a triangle with the other two points P2 and P3 respectively. Similarly, the other three points P2, P3, P4 also form a triangle element with the other two corresponding points.
Figure 11. Gait pattern of the zoomorphic robot top view.

Figure 12. Gait pattern of the zoomorphic robot top view.

Form the figure 10, 11 The L initial position triangular elements are P1, P4 and P3 are triangular centroid O (4.0,2.5) after move one step L1 position triangular elements are P11, P4 and P3 are triangular centroid O1 (4.3,2.5) as shown in figure 9 and 10. Based on the triangular centroid the legs moving the one after another one, leg sequence is L1, L2, L3, L4 (L1=leg1, L2=leg2, L3=leg3, L4=leg4).

For each leg as a two servomotors, these are activated the sequence as show flowing table 2.

Table 2. Gait pattern sequence of zoomorphic robot.

| Legs     | Leg1 | Leg2 | Leg3 | Leg4 |
|----------|------|------|------|------|
| Angles   | θ11  | θ12  | θ21  | θ22  |
| Values   | 5    | 10   | 5    | 10   |
| in       |      |      |      |      |
| degrees  |      |      |      |      |

Where θ11, θ21, θ31, θ41 are the upper joints. θ12, θ22, θ32, θ42 are the lower joints of the zoomorphic robot legs.
8. Results and discussions

The zoomorphic structure robot to simulation to find the required torque for joints. This torque used to find the selection of motors and to need to solve the structural analysis to get the optimum stability walking to achieve.

![Figure 13. The right leg of joint 1 torque.](image1)

![Figure 14. The right leg of joint 2 torque.](image2)

The torque can find out software output joint 1 and joint 2 for the robot right front leg as shown in above

The static analysis method used for base on mass and links lengths. This method the body fixe to some support and to move the robot legs. For time taken for 7 sec because of to complete to the cycle of leg movement on x-axis y-axis force in N-mm.
9. Conclusion
A structural zoomorphic robot was designed, analyzed, and simulated in simulation software. The design process was to do many link parameters to be taken like length, height, etc. by using the design/CAD software to use the links and the shape of the hip and knee joints of the body. The analysis was performed with these design parts. The structural analysis applies to the parts and is the result of the performance of structure resist and some of the mainframe design. The kinematics equations apply to a system like to find the forward and backward or inverse kinematic equations to find the theoretical process. Motion simulation to achieve the smooth and the legs can be move one after one and the result plotted them.

The way by which to separate the quadruped robot crawling step strolling and later to decide, the robot is statically steady during strolling. The objective of this work, first, the connection between sliding advance progression made for this robot and the geometric appearing of robot legs-tip has been completely inferred for discovering all the static steady quality edges during walking. The outcomes display that the heartiness edges have the positive attributes that insistence to keep robot Machine gear-piece inside the supporting triangle during the swing time of one leg while different legs are on the ground. Furthermore, future work improvement is want to investigate and update the quadruped robot walking around the hard and extraordinary scene.

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