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MODELING AND SIMULATION OF SPIDER'S WALKING

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ABSTRACT

Currently robot designers are ever more inspired by nature to develop and design legged robots to mimic the walking style of insects over uneven and rough surfaces. In this work, walking behavior and method of a kind of spider *Araneus diadematus* are investigated. Image processing techniques are used to obtain kinematic parameters of the spider's legs. The positions of defined points on the spider's legs were recorded in terms of time. After extracting the necessary data, a linkage mechanism of the legs was designed. By using the position of defined points on spider's legs as input to our model and implementation of trigonometric relations, parameters such as angle, angular velocity, and angular acceleration of each link were obtained. Then, a model of linkage mechanism for the spider's legs in SIMULINK environment of MATLAB was created. By allocating mechanical properties of linkages such as mass and moment of inertia to the model, quantities of torque in joints, which were needed for producing the traversed path of spider's legs, were obtained. These quantities can be used for selection and control of actuators in the novel robotic system in order to mimic the spider's walking style.

1 INTRODUCTION

Today there exist many challenges to fabricate robots that mimic insect's movements. The reason behind this requirement is that wheeled robots are unable to go over different obstacles like uneven surfaces. Wheeled robots have higher efficiency in terms of energy consumption and their control is also easy. On the other hand, legged robots due to the fact that they can move over uneven surfaces that are closer to human's real world environment would be more effective. Based on these advantages, the tendency of engineers towards fabrication of legged robots which are inspired from insect walking has noticeably increased. In this regards, several investigations on different insects such as cockroaches [1–15], ants [16–21], and crickets [22–30] have been carried out. Mean while another insect which has shown a higher level of flexibility and performance during walking, has been the spider which has high mobility over uneven and irregular surfaces. Note that the animals move the greatest distance while using minimum energy [31]. Therefore, it is very important to carry out an accurate study on the spider's walking and its mobility. Also it is crucial to determine and analyze parameters involved in its movements in order to develop the model for fabrication of legged robots.

In this paper, first the traversed path of the spider's legs will be investigated. Then, the position of defined points on the spider's legs and parameters relating to its movement will be determined using image processing methods. By using this data as input to an equivalent linkage mechanism of spider's legs and employing trigonometric relations, the angle between each linkage with respect to horizontal axis will be obtained. Then, by using numerical derivation, the quantities for angular velocity and angular acceleration of the linkages will be calculated. Finally, a model of the mechanism in SIMULINK environment of MATLAB will be developed. By giving obtained parameters to this model and having mechanical properties of each link such as moment of inertia and mass, the spider's walking will be simulated and legged robot which can mimic spider's walking style will be developed.

By implementing sensors in each joint of model in SIMULINK environment, quantities of torque in the joints which are required to traverse the path of spider's legs can be obtained.

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As a result, by choosing actuators in equivalent linkage mechanism of spider's legs, the spider's walking method can be mimicked with such legged robot; these actuators will produce the given path for specified points on spider's legs.

2 MTERIALS AND METHODS

In this section, we first discuss the type of spider used, and the tools which are necessary for data acquisition will be introduced. Then the process and algorithm of image processing will be presented. After acquisition and filtering of data, the graphs obtained from different positions of defined points will be shown.

2.1 Animal and materials

The Latin name of the spider used in this research is *Araneus diadematus*. Epoxy paint was used to mark specific points of spider legs. Also, in order to move the spider in a straight path without deviation, an acrylic transparent channel with rectangular sections was used. The camera used in the study had a wide angle lens (78° angle) to cover a complete cycle of a stride during spider's walking.

2.2 Data acquisition and image processing

Since it is not easy to implant sensors in the spider's legs, therefore, in order to determine the kinematic parameters in different points of its body an image processing technique was adopted.

Considering this point, a computer program was written using visual basic language in order to capture spider's walking behavior.

To use the image processing technique, specific points of spider's leg were colored with epoxy paint. Then, the recorded video images taken from spider's walking inside the transparent channel were given to the computer program. This program first detects the colored points on the spider's leg and then will produce the position of the points with respect to the specified origins of coordinate systems as an output in relation to time.

Figure 1 illustrates a simple model of an image processing system. The transfer function of each component is obtained either through experiment or manufacturer's specifications. For instance, the camera's lens can have a nonlinear geometric mapping of the image. But ultimately, the computer and processing program is the only sub-sequence in this figure, which is completely under the user's control [32].

The main control over spider's walking is done by its four rear legs, and due to its importance, this subject will be discussed in more detail.

As shown in Fig. 2, because of symmetry, four points on the two spider's legs are marked with two different colors. In order to distinguish each of these points in the plane which the spider moves, a computer program is developed. The plane is divided into two geometric zones based on the movement limitation of each point (see Fig. 3).

The two zones are selected so that they should not overlap with each other; secondly, it preferably should cover the moving zone of the spider. The selected regions for the geometrical zones can be given as sample frame to the computer program and entered to the program as an input.

In order to distinguish the colored points, a type of color filter with certain range of R, G, and B for each pixel is employed. For example, to distinguish the yellow point, the R, G values must be more than 200 and value of B less than 150. After defining the limits in the program in each geometrical zone, the geometrical location of red and green color can be determined for each frame.

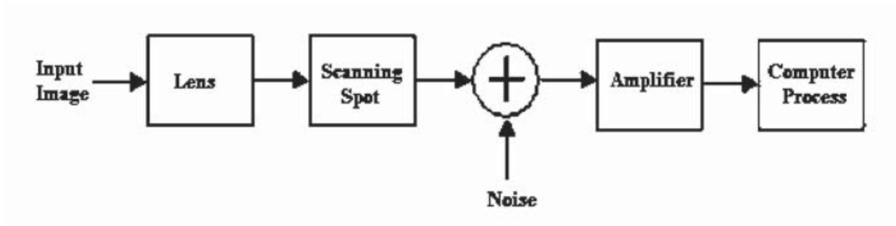

Figure 1: The elements of an image processing system.

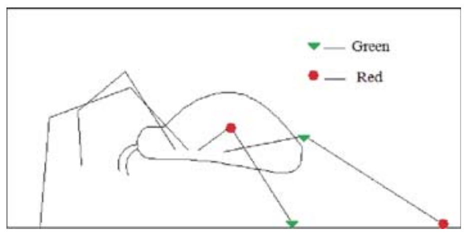

Figure 2: Four points of spider's legs.

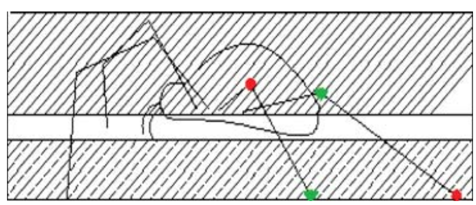

Figure 3: Geometric zones.

As a result in the higher and lower geometrical zone, the marked points of spider's leg can be recognized. The color space of this process is shown in Fig. 4 [33].

In the channel on which the spider moves, two marked points 5 cm away from each other are contrived in order to establish a criterion to convert pixel units to centimeter. In fact, the position of points are obtained in terms of pixel, then the ratio between the number of pixels in the two marked points, and a coefficient for converting pixel to centimeter can be obtained; so that the position of points will be converted into centimeter.

The obtained positions for these points are in terms of absolute coordinate system (left up corner of the image) while the goal is to obtain these points in terms of the spider's center of mass, therefore, after acquiring the position of spider's center of mass with respect to absolute coordinate system and deduction of specified position of points from center of mass; the position of these points in relation to center of mass will be obtained. Suppose that the spider's center of mass is located over its center of geometry, by coloring the spider center of geometry with a different color from the color of points on the spider's legs, the position of the center of geometry in terms of absolute coordinate system will be determined.

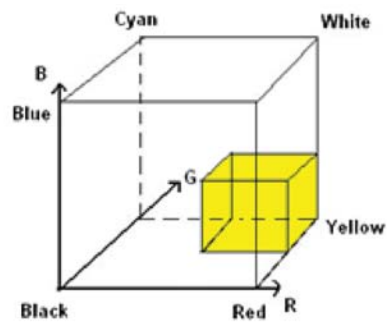

Figure 4: Rectangular color space and yellow space.

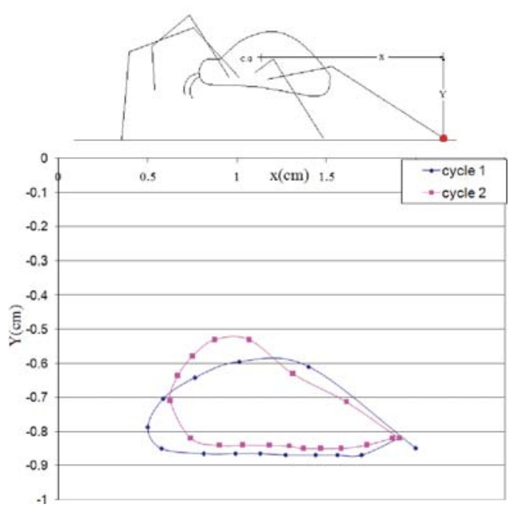

Figure 5: Vertical displacement (Y) versus horizontal displacement (X).

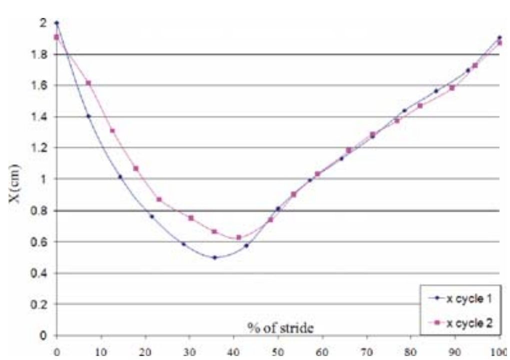

Figure 6: Horizontal displacement (X) versus % of stride.

The accuracy of points depends on the resolution of the camera and the distance between the image and object planes. The camera's resolution determines the distance of sample in the array. Since the lens function is linear, the accuracy depends only on the object plane, and the points will appear as a small colored area and the center of that area is the position of defined points.

The result of position of the spider's defined points, are presented as graphs in terms of percentage of spider's stride in Figs. 5–16. The percentage of spider's stride is explained by considering the beginning and end time of a complete cycle of the spider's stride in each cycle. In this method we can determine the position of each point in terms of percentage of stride.

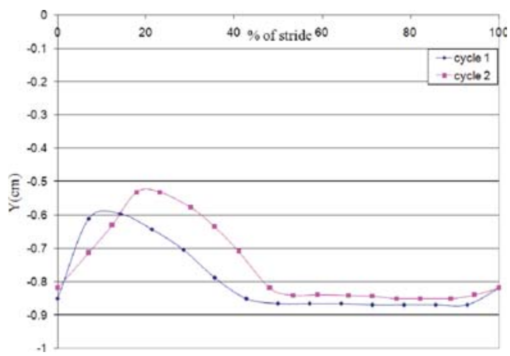

Figure 7: Vertical displacement (Y) versus % of stride.

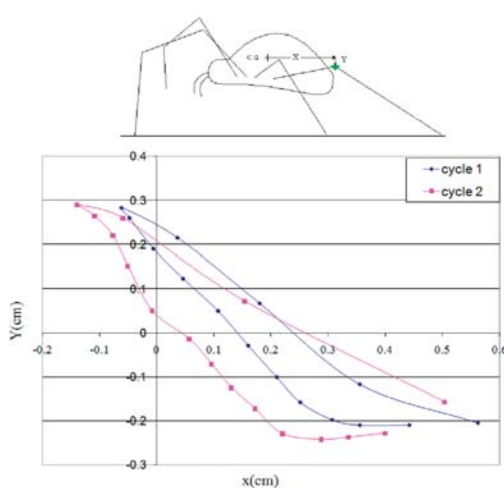

Figure 8: Vertical displacement (Y) versus horizontal displacement (X).

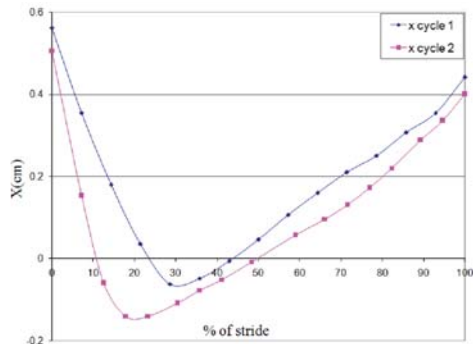

Figure 9: Horizontal displacement (X) versus % of stride.

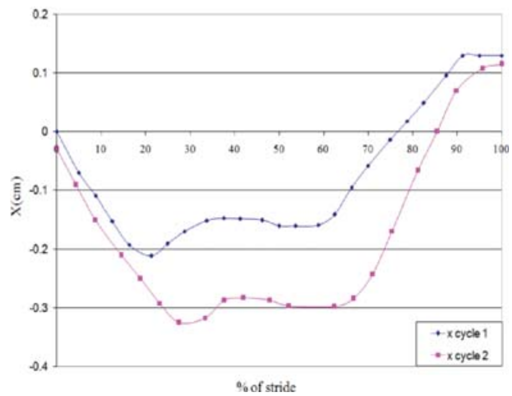

Figure 10: Vertical displacement (Y) versus % of stride.

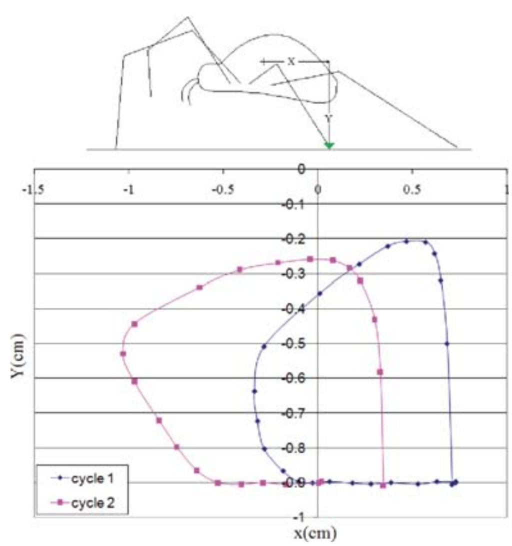

Figure 11: Vertical displacement (Y) versus horizontal displacement (X).

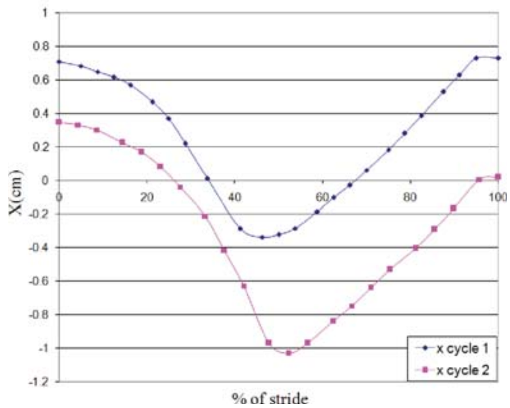

Figure 12: Horizontal displacement (X) versus % of stride.

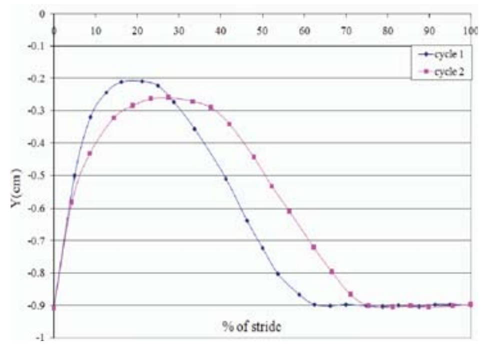

Figure 13: Vertical displacement (Y) versus % of stride.

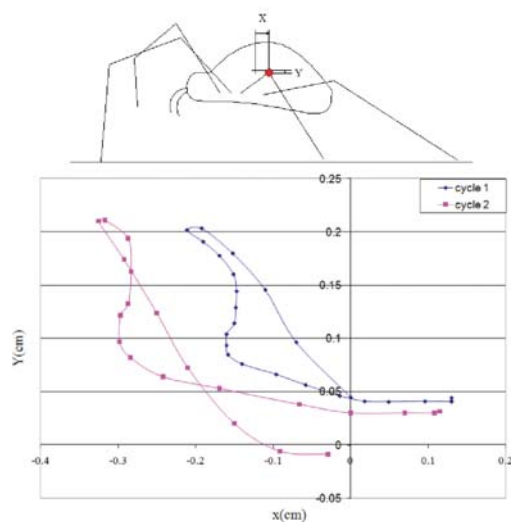

Figure 14: Vertical displacement (Y) versus horizontal displacement (X).

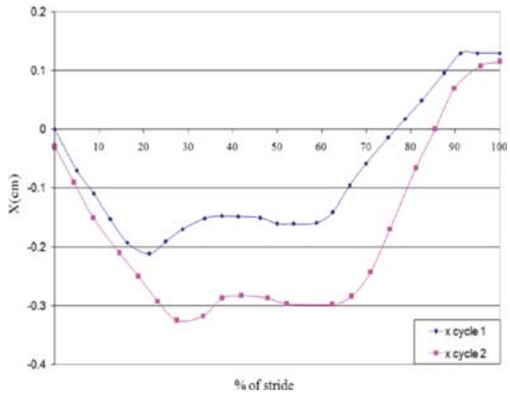

Figure 15: Horizontal displacement (X) versus % of stride.

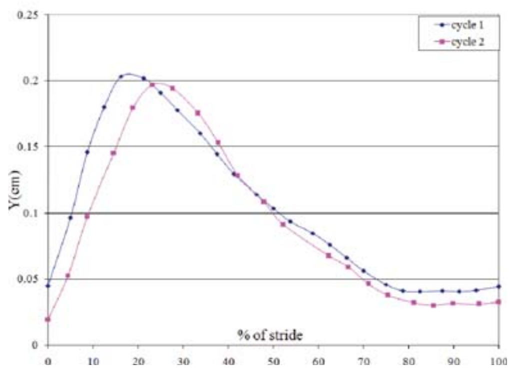

Figure 16: Vertical displacement (Y) versus % of stride.

3 SIMULATION METHOD

After extracting data relating to the position of spider's legs in terms of time, the data are used for simulation of spider's walking. At first equivalent linkage mechanism of spider's legs was created, and geometrical characteristics of the linkages were obtained. Then, the data obtained in the previous section (position of defined points on spider's legs in relation to time) were used as input to the mechanism; by implementation of trigonometric equations between linkages and numerical derivation, angle, angular velocity, and angular acceleration of linkages will be obtained.

Finally, a model of this mechanism in SIMULINK environment will be developed in order to simulate the spider's walking and extracting data which is necessary for selection and control of actuators in a legged robot.

The modeling process consists of four stages as follows:

1. Development of an equivalent linkage model of spider's leg.
2. Using values of position in relation to time as input to model.
3. Extracting of angle, angular velocity and angular acceleration from the model for simulation of spider's walking in SIMULINK environment.
4. Simulating the model of spider's legs in SIMULINK to produce necessary data for selection and control of actuators.

3.1 Generation of linkage model

At this stage with reference to spider's legs, two linkage models, equivalent to those of spider were produced. The dimension of linkages for these models was measured from two joints on each spider's legs that can be seen in Table 1.

3.2 Inputs to the model

After primary modeling in the previous stage, the data obtained from data acquisition and image processing stage were given as input to the model. The input parameters were coordinates of the defined points with respect to spider's center of mass in relation to time. By using these inputs, the model will mimic spider's legs moving path and kinematic parameters (angle, angular velocity and angular acceleration) with respect to the linkages.

3.3 Output parameters

In this section, the angle of each linkage was obtained by using trigonometric equations with respect to the horizontal axes (see eqns (1)–(3) and Fig. 17). Then by using the numerical derivative, angular velocity of linkages was obtained (see eqn (4)).

Based on the nature of derivation, existence of some noise and uncertain data was undeniable. In order to reduce this noise, it was necessary to pass the final data through a Low Pass Filter (LPF). Continuing the same algorithm, by derivation of angular velocity quantities, angular acceleration quantities were obtained. These quantities are shown in Figs. 18–20.

$$\tan\beta = \frac{y_3 - y_2}{x_3 - x_2} \tag{1}$$

$$\tan\alpha = \frac{y_2 - y_1}{x_2 - x_1} \tag{2}$$

$$\theta = 180 - \alpha - \beta \tag{3}$$

$$\dot{\theta}(t_0) = \frac{1}{2\Delta t}[-3\theta(t_0) + 4\theta(t_0 + \Delta t) - \theta(t_0 + 2\Delta t)], \quad \Delta t = 0.0333 \tag{4}$$

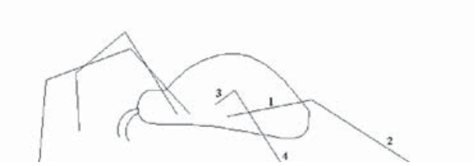

Table 1: Dimension of linkages.

L (cm)	Number of links
0.618	1
1.618	2
0.364	3
1.11	4

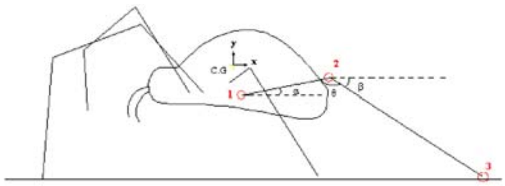

Figure 17: Angle of link 1 with respect to horizontal axes (x).

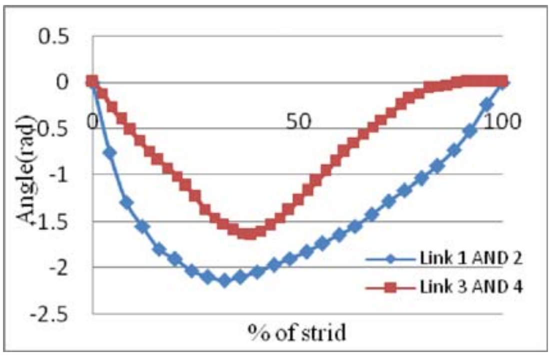

Figure 18: Angle between linkages versus % of stride.

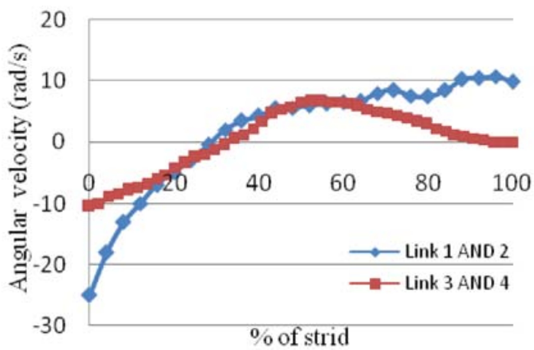

Figure 19: Angular velocity versus % of stride.

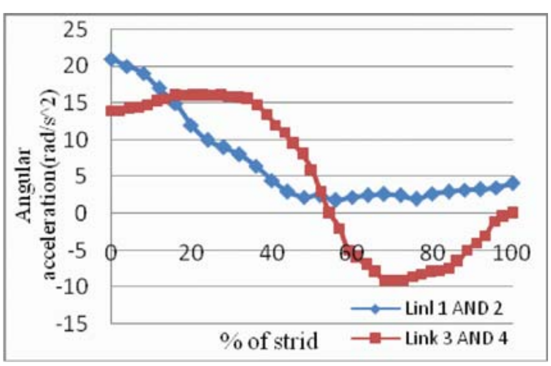

Figure 20: Angular acceleration versus % of stride.

3.4 Simulation

After acquiring the values for parameters such as angle, angular velocity, and angular acceleration of each link with respect to others, a linkage model for the spider's legs in SIMULINK environment was created (Fig. 21). Then, the values for the above parameters were given to the model. As a result, simulation of spider's walking was carried out and traversed path of spider's legs was mimicked.

Figures 22 and 23 show the traverse path through which the linkage model of the spider's legs in SIMULINK environment had passed.

By simulating this model and by giving mechanical properties of linkages such as mass and moment of inertia to the model, values of torque in joints (required for the aforementioned path) were obtained.

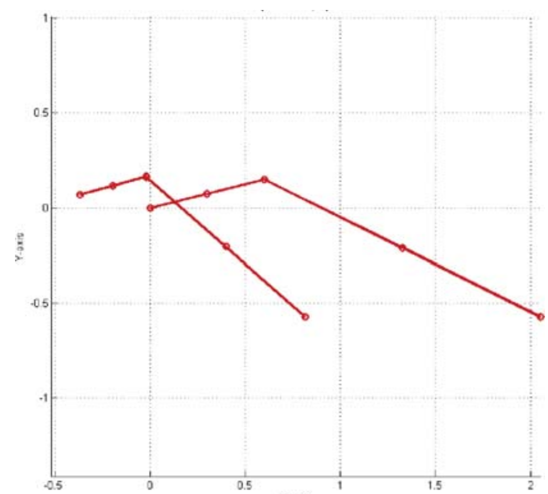

Figure 21: Model of spider's legs in SIMULINK.

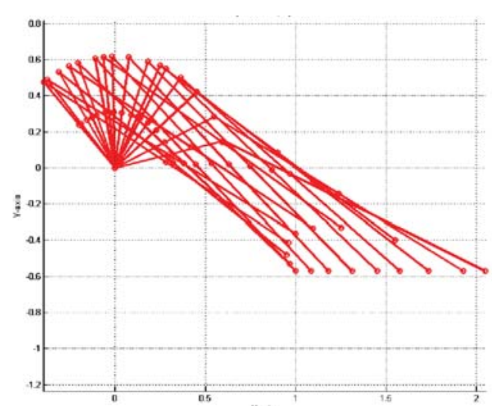

Figure 22: Traversed path of rear leg.

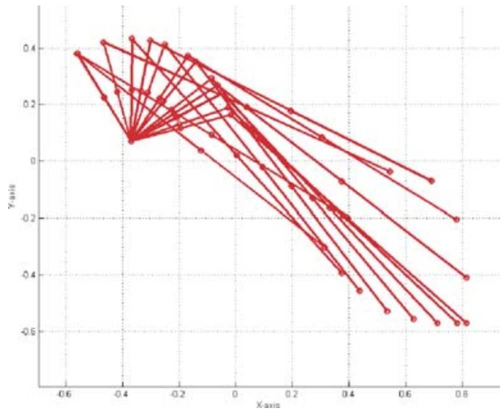

Figure 23: Traversed path of front leg.

4 CONCLUSION

Using image processing techniques the positions of defined points on the spider's legs with respect to its center of mass were determined. Then, by using these data as input to equivalent linkage model of spider's leg and utilizing trigonometric equations, angle between linkages were determined. By applying numerical derivation to these angles, quantities for angular velocity and angular acceleration were obtained. Finally a linkage model in SIMULINK was developed. After giving kinematic parameters (angle, angular velocity and angular acceleration) for linkages and their mechanical properties such as moment of inertia and mass to the model, simulation of spider's walking as a legged robot was carried out. This simulated robot could traverse the path similar to the behavior of a spider's legs, hence, mimic spider's walking. By using joint sensors in SIMULINK, values of torque in joints required for producing the traverse path of spider's legs were obtained. As result, by choosing the best actuators in the equivalent linkage model of spider's legs, and designing proper controllers for these actuators, spider's walking has been accurately mimicked. The obtained data, with regards to spider's capability in moving over complex and uneven surfaces, have been very useful and can help us to optimize controller's efficiency which is used in articulated or legged robot.

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