

Design And Synthesis of Eight-Legged Spider Mechanism

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Abstract— Less than half the world's landmass is accessible to existing wheeled and tracked vehicles. But people and animals using their legs can go almost anywhere. We aim to develop a new type of rough-terrain robots that capture the mobility, autonomy, and speed of living creatures. Such robots will travel in outdoor terrain that is too steep, rutted, rocky, wet, muddy, and snowy for conventional wheeled vehicles. They will travel in cities as well as in our homes, doing chores and providing care, where steps, stairways, and household clutter limit the utility of wheeled vehicles. Robots meeting these goals will have various sensors, sophisticated computing and power systems, advanced actuators, and dynamic controls. It is marvelous that creatures can go over rough terrain at remarkably higher speeds than practically possible with wheeled vehicles

Key words - Walking Robot, Biologically Inspired Robot, Mechanism Analysis, Leg Mechanism

INTRODUCTION

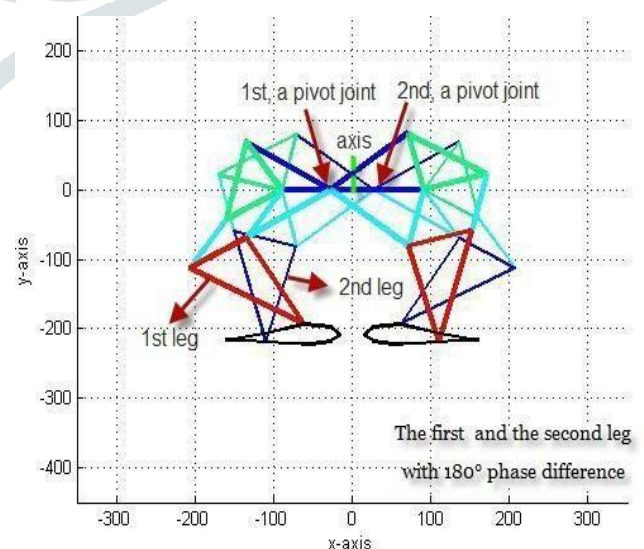
Multi-legged robots have been studied extensively for efficient walking on surface[1-6]. However, existent methods use servo motors for each leg, which makes the robot heavy by weight and slow in speed. Hence, it is the best that the body stability is improved by more than six light-weighted legs and less number of motors. It does not mean that the number of legs is equal to the one of motors. Even if the number of motor is reduced, the forward, backward, left, and right motions of the robot should be easy in a possible way. 'Land' in this research means the environment such as marsh place or sand surface. Therefore, the first research subject is to make the body drive satisfied the above all conditions based on Jansen mechanism[7]. Through the mimicry of biological behaviors, that is, the number of suitable joints is decided. Then, it is designed so that the robot mechanism is well operated on water and land, and behaviors autonomously. As well for the purpose of its optimal walking, the relative length ratio among legs is analyzed. By the proposed leg's length, the legs of crab robot is manufactured in H/W. Next, eyes and ears that animals keep for sensory organs are imitated by means of electronic sensors and are used as sensory tools. In other words, the biologically inspired robot grasps surrounding environment and chooses suitable action through fusion of sensor information. Second research subject is on implementation of a remote controlled non-autonomous robot based on RF or blue-tooth type communication. From outside, the non-autonomous robot is

controlled by the user from a PC or a cell phone who sees the external environment through the equipped camera on the robot.

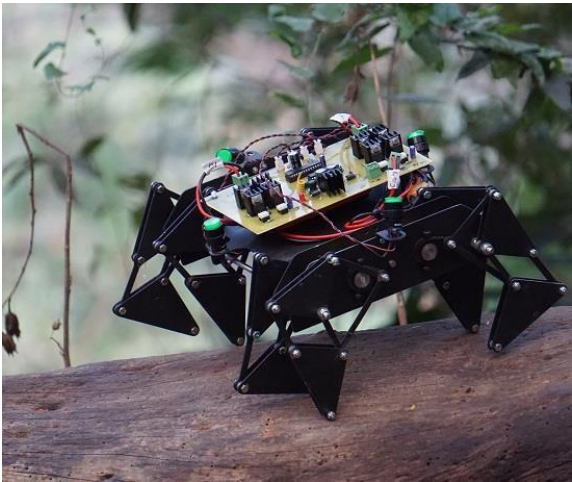
I. WALKING ROBOT MOTON

In this section, the movement of a crab robot is described. The proposed crab robot uses two dual-axis DC motors with bevel gears. Structurally, the foot-point of one leg contacts on the ground and another does not contact on the ground. Figure 1.(a) is the simulation of the proposed crab robot legs. The thick line indicates the first leg and the thin line indicates the second leg. Figure 1. (b) shows the actual structure of the proposed robot. Circle markers in Figure 1. (b) represent the rotation axis of the first(left circle marker) and the second(right circle marker) leg with a 180° phase difference. An arrow markers indicate the foot-point of the robot.

In general, a biped robot walks while its body is up and down. In contrast, Theo Jansen's mechanism maintains natural gait keeping the body without moving up and down. In other words, it moves smoothly like a wheel-type robot. For these reason, the image of camera vision equipped to the crab robot is stable and clean without shaking. The rotation direction of the crab robot, depends on the drive of two dual-axis DC motor. The crab robot moves forward and backward freely, since the radius of its rotation is very small.



(a) The simulation of two leg phases



(b) Prototype of the robot model

Figure 1. Simulation and robot model

II. KINEMATIC ANALYSIS OF THE TWELVE-BAR

Figure 2 shows the twelve-bar linkage of crab robot in a X-

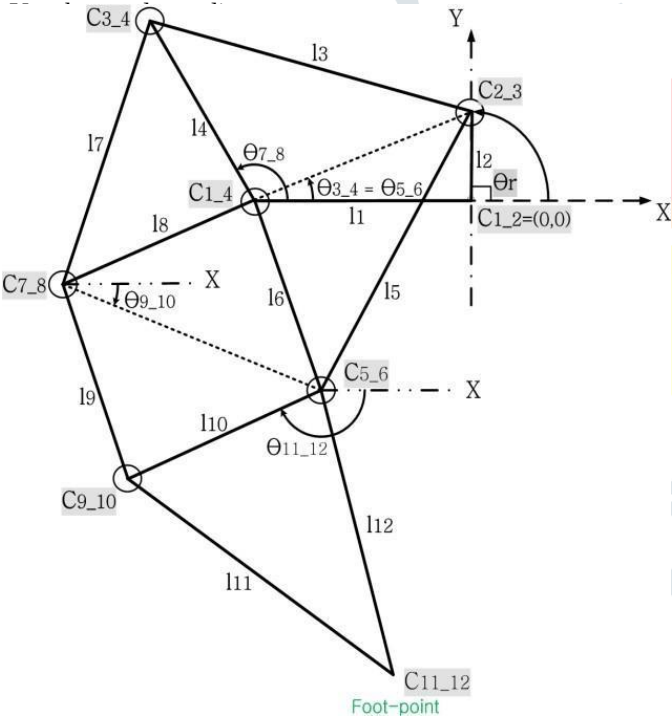


Figure 2. Twelve-bar linkage structure of a crab robot (the left side)

For design of a crab robot, the length of twelve-bar linkages is shown in Table 1.

Table 1. Link lengths of robot

link number	l ₁	l ₂	l ₃	l ₄	l ₅	l ₆
	l ₇	l ₈	l ₉	l ₁₀	l ₁₁	l ₁₂
link	90	28	128	83	128	83
length[mm]	83	115	83	83	83	166

As illustrated in Figure 1, suppose kinematic analysis on such conditions. In Figure 2, C and l are the node and length of the bar link, respectively. C_{2_3} of the link l₂ is shifted from 0° to θ_r . When C_{2_3} is coaxial with y-axis, θ_r is 90°. θ_r is the rotation of the motor.

The order of analysis is as follow:
C_{1_2},C_{1_4}, and C_{2_3} are easily taken from the coordinate.

- ① Node C_{3_4}is obtained from C_{1_4} and C_{2_3}
- ② Node C_{7_8}is obtained from C_{1_4} and C_{2_3}
- ③ Node C_{5_6}is obtained from C_{1_4} and C_{2_3}
- ④ Node C_{9_10}is obtained from C_{7_8} and C_{5_6}
- ⑤ Node C_{11_12}is obtained from C_{5_6} and C_{9_10}

The node that should find in the robot leg structure is the above five nodes. Fundamentally, the linkage structure of the crab robot is based on a four-bar linkage mechanism[8]. The node connected to two circles can be obtained using a tangential equation. In order to find the location of foot-point C_{11_12}, five θ_i for each node in X-Y coordinates is needed. According to the intersection between the two circles, robot joint θ_i is given by the following equation.

$$\theta_i = \text{Atan2} (C_{2y}-C_{1y}, C_{2x}-C_{1x})$$
$$i = 3_4, 5_6, 7_8, 9_10, 11_12$$

C_{1x}, C_{1y}, C_{2x}, and C_{2y} in (1), correspond to the second and third column in Table 2. Table 2 shows the linkage of robot legs.

$$\text{Atan2} (y, x) = \theta_i = \tan^{-1} \left(\frac{y}{x} \right), \quad (-\pi < \theta_i \leq \pi)$$

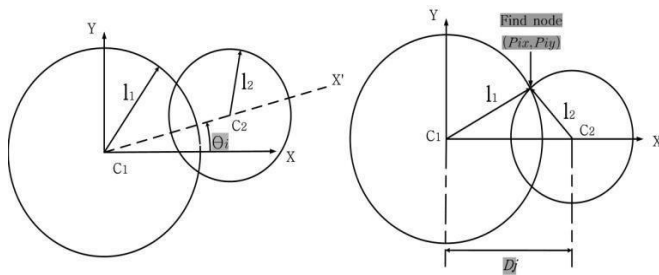
Table 2. Pivot point (node of robot joints) of two circles and radius(robot link length)

Find nodes	C ₁ (C _{1x} , C _{1y})	C ₂ (C _{2x} , C _{2y})	l ₁ radius of circle	l ₂ radius of circle
① C _{3_4}	C _{1_4}	C _{2_3}	l ₄	l ₃
② C _{7_8}	C _{1_4}	C _{3_4}	l ₈	l ₇
③ C _{5_6}	C _{1_4}	C _{2_3}	l ₆	l ₅
④ C _{9_10}	C _{7_8}	C _{5_6}	l ₉	l ₁₀
⑤ C _{11_12}	C _{5_6}	C _{9_10}	l ₁₂	l ₁₁

The radius of the circle in figure 3 is the length of the bar(l₁,...,l₁₂). In Figure 3(b) the distance between the center of the two circles is D_j . Using the tangential equation to two circles. D_j is given, where i values are node values defined earlier.

As in (3), C_{1x} , C_{1y} , C_{2x} , and C_{2y} in table 2 correspond to the second and third columns.

$$D_j = \sqrt{(C_{2x} - C_{1x})^2 + (C_{2y} - C_{1y})^2}, \quad j = 1, 2, i \quad (3)$$



(a) X-coordinate of the two circles and X' with θ_i (b) Radiuses of two horizontal circles

Figure 3. C, X-Y coordinate system of two circles

To find the nodes of the robot legs, (2) and (3) are employed, where P_{iy} of $P_i (P_{ix}, P_{iy})$ are X-Y coordinate axis, respectively. i is previously defined in (1). Using trigonometric functions (4) is used to find two circles. From the horizontal line of two circles, P_{iy} has $\pm$ two solution. For upward and downward tendency of the link, two solutions exist.

$$P_{ix} = \frac{D_j^2 + l_1^2 - l_2^2}{2 D_j}, \quad P_{iy} = \pm \sqrt{l_1^2 - (P_{ix})^2} \quad (4)$$

(4) is taken in the nodes of two horizontal circles in figure 3.(b). The coordinate (X_n, Y_n) for C_n is given (5).

$$\begin{aligned} X_n &= \cos\theta \times P_{ix} - \sin\theta \times P_{iy} + C_{1x} \\ Y_n &= \sin\theta \times P_{ix} + \cos\theta \times P_{iy} + C_{1y} \\ \text{Where } n &= 1, 2, 1, 4, 2, 3, i. \end{aligned} \quad (5)$$

To find a foot-point, each nodes are given using (1)-(5). The

coordinates of each node is represented using (6).

$$\begin{aligned} C_n &= (X_n, Y_n) \\ C_{1,2} &= (X_{1,2}, Y_{1,2}) \\ C_{1,4} &= (X_{1,4}, Y_{1,4}) \\ C_{2,3} &= (X_{2,3}, Y_{2,3}) \\ C_{3,4} &= (X_{3,4}, Y_{3,4}) \\ C_{3+2k, 4+2K} &= (X_{3+2k, 4+2K}, Y_{3+2k, 4+2K}) \quad k = 1, 2, 3, 4 \\ C_{11,12} &= (X_{11,12}, Y_{11,12}) \end{aligned} \quad (6)$$

Next, we describe the process to find the foot-point of a crab robot. $C_{1,2}$ to the X-Y rectangular coordinates with a bevel gear on the motor shaft is the center point, where $C_{1,2} = (0, 0)$. $C_{1,4}$ is the node of a fixed link. In Figure 2, l_1 bar links are represented by a single linkage bar. $C_{1,2}$ and $C_{1,4}$ are fixed by a horizontal bar $X_{1,4}$ and $Y_{1,4}$ are the fixed points in the leg joint of a crab robot. The coordinate is located in the second quadrant and represented by the following equation.

$$\begin{aligned} C_{1,4} &= (X_{1,4}, Y_{1,4}) \\ X_{1,4} &= -l_1 \sin\theta \\ Y_{1,4} &= l_1 \cos\theta \end{aligned} \quad (7)$$

$C_{2,3}$ is the node that transfers dynamic energies.

$$\begin{aligned} C_{2,3} &= (X_{2,3}, Y_{2,3}) \\ X_{2,3} &= l_2 \cos\theta \\ Y_{2,3} &= l_2 \sin\theta \end{aligned} \quad (8)$$

And $C_{2,3} = (X_{2,3}, Y_{2,3})$ is given by the following equation. To find the foot-point of a crab legs, five nodes should be obtained. To find the $C_{3,4}$, $C_{1,4}$, the intersection of $C_{2,3}$ are used. First, $\theta_{3,4}$ is obtained as in Figure 3(a). By the previous process, $C_{3,4} = (X_{3,4}, Y_{3,4})$ is given by the following equations.

$$\begin{aligned} \theta_{3,4} &= \text{Atan2}(C_{2,3y} - C_{1,4y}, C_{2,3x} - C_{1,4x}) \\ d_{3,4} &= \sqrt{(C_{2,3x} - C_{1,4x})^2 + (C_{2,3y} - C_{1,4y})^2} \\ P_{3,4x} &= \frac{d_{3,4}^2 + l_3^2 - l_4^2}{2 d_{3,4}}, \quad P_{3,4y} = \pm \sqrt{l_3^2 - (P_{3,4x})^2} \end{aligned} \quad (9)$$

$$X_{3,4} = \cos\theta \times P_{3,4x} - \sin\theta \times P_{3,4y} + C_{1,4x}$$

$$Y_{3,4} = \sin\theta \times P_{3,4x} + \cos\theta \times P_{3,4y} + C_{1,4y}$$

Referring to table 1. the 2nd, 3rd, and 4th of nodes are given by equation (1)-(5). Foot-point $C_{11,12}$, which is the last 5th node, is given by the following equation.

$$\begin{aligned} \theta_{11,12} &= \text{Atan2}(C_{9,10y} - C_{5,6y}, C_{9,10x} - C_{5,6x}) \\ d_{11,12} &= \sqrt{(C_{9,10x} - C_{5,6x})^2 + (C_{9,10y} - C_{5,6y})^2} \\ P_{11,12x} &= \frac{d_{11,12}^2 + l_{11}^2 - l_{12}^2}{2 d_{11,12}}, \quad P_{11,12y} = \pm \sqrt{l_{11}^2 - (P_{11,12x})^2} \end{aligned} \quad (10)$$

$$X_{11,12} = \cos\theta \times P_{11,12x} - \sin\theta \times P_{11,12y} + C_{5,6x}$$

$$Y_{11,12} = \sin\theta \times P_{11,12x} + \cos\theta \times P_{11,12y} + C_{5,6y}$$

To find the coordinate points of foot-point when the link with $C_{2,3}$ is located at 0° , each θ_i for each node are in table 3. Finally, Foot-point the $C_{11,12}(X,Y)$ can be obtained. When the rotation axis is 0° , each node is located as in Table 4.

Table 3. θ_i for each node when the link with $C_{2,3}$ is located at 0°

Node	$C_{3,4}$	$C_{5,6}$	$C_{7,8}$	$C_{9,10}$	$C_{11,12}$
θ_i [deg]	0°	0°	76.93°	-46.15°	164.63°

Table 4. Location of each node when the link with C2_3 is located 0°

Node	C1_2	C1_4	C2_3	C3_4	C5_6	C7_8	C9_10	C11_12
(X,Y)	0	-90	28	-71	-71	-170	-151	-109
[mm]	0	0	0	80	80	21	-58	-219

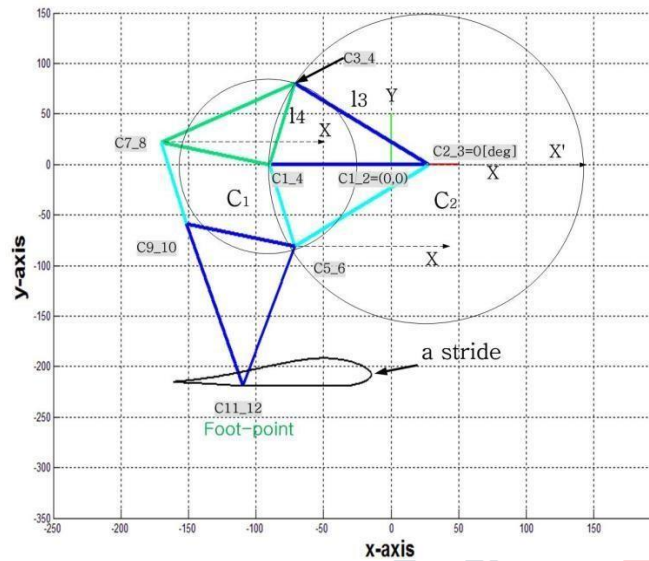


Figure 4, Location of each node when θ_r rotates from 0° to 360°

Figure 5. shows the X-Y position of each nodes when θ_r rotates from 0° to 360°. In addition, the stride of left leg is shown. In figure 6 and 5, the X and Y values of the foot- point C11_12 are shown, respectively.

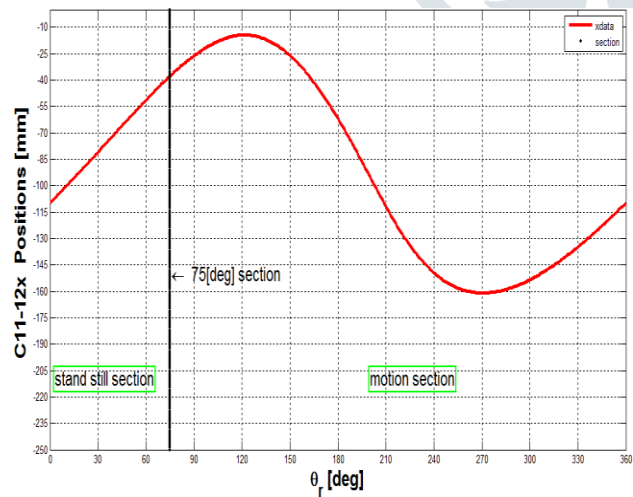


Figure 5. When θ_r rotates from 0° to 360°

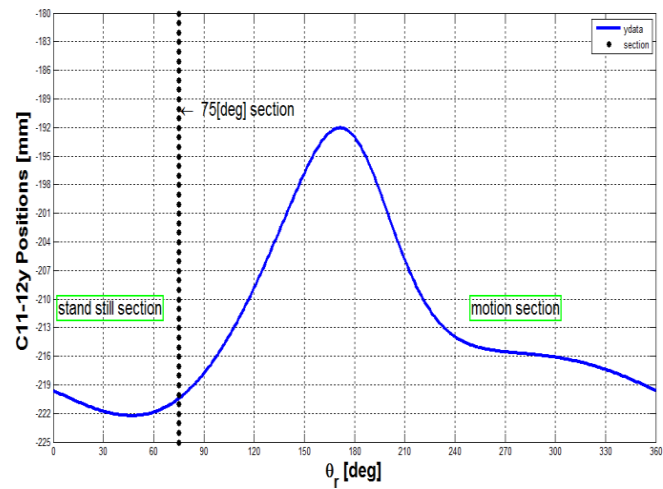


Figure 6. When θ_r rotates from 0° to 360°

III. CONCLUSIONS

This paper presents the crab robot implemented in H/W based on Jansen mechanism, and its kinematic analysis. It is expected that the proposed biologically inspired robot is applicable to solve many engineered problems, since it is able to walk on land. Besides, it has great availability, since the proposed biologically inspired robot is seen and controlled from a PC or a cell phone, even other PCs on internet. Conclusively, the proposed biologically inspired robot walks autonomously on shore and marsh place and provides visionary information to external users. If the robot is lighter in weight with high efficiency battery, it can be more used in various place by various usage such as search, intelligence, watch, special material scattering, since it can be controlled from outside. Further research is on implementation of biologically inspired robot migrates to the location designated from the user by the help of GPS. Then it carries a programmed mission out and comes back to the position that programmer inputs through a GPS position receiver.

ACKNOWLEDGEMENT

This work was supported (National Robotics Research Center for Robot Intelligence Technology, Kyungnam University) by Ministry of Knowledge Economy under Human Resources Development Program for Convergence Robot Specialists.

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