Hexapod Leg Coordination using Simple Geometrical Tripod-Gait and Inverse Kinematics Approach

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***Abstract*—The coordination of legs movement is an important capability in any multi-legged robots motion. The required timing for legs coordination depends on the number of legs and servos, as well as the complexity of the chosen algorithm. This paper proposed the use of tripod-gait movement algorithm for a hexapod which is defined by simple geometrical and inverse kinematics approach. The hexapod has 3 servos in each leg or 18 servos in total that should be able to produce several motions including moving forward, backward, turn left and turn right as fast as possible. Experimental results showed that the proposed method worked well for hexapod legs coordination. Furthermore, this simple approach can move the hexapod two times faster than the ordinary inverse kinematics method.**

***Keywords*—hexapod; legs coordination algorithm; six-legged robot; inverse kinematics, tripod gait.**

I. Introduction

In multi-legged robots, legs coordination plays a vital role in defining the robots movement. Generally, multi-legged robots move according to the preplanned gait [1], although some more advanced methods such as the petri-net control [2], neural network control [3], adaptive gait using genetic algorithm [4], and combination of artificial intelligence control methods [5] have been proposed. The most common method for six-legged robot legs coordination is the tripod gait [6], [7], in which the robot moves its three legs at a time, producing fast movement that is comparable to the movement of a faster but rather difficult to be stabilized two-legged robots. Here, hexapod or six-legged robot is chosen due to its high stability, even when one of its leg is missing [4], [8].

To define the motion of a six-legged robot, a method to map the desired legs positions to each servo's angular position is required. The angle of each servo is calculated by considering the mechanical design and dimensions of the robot, which is known as the inverse kinematics control. This approach has been widely studied and modified recently, such as the use of quadratic programming for inverse kinematics control [9] and its modified method which is called the differential kinematics [10]. An obvious advantage of using the conventional inverse kinematics control is its simplicity and general applicability. However, for a hexapod with six legs and multi-servos in each leg, calculating each servo's angle for every single leg position using inverse kinematics will result in an obvious timely movement. Meanwhile, in many applications, it is desired that the robot can move as fast as possible.

In this paper, hexapod leg coordination using simple geometrical tripod-gaits for moving forward, backward, turn left and turn right is proposed. Inverse kinematics calculation is done before implementing the control algorithm to the robot, so that the robot can move faster. The performance of this simple approach in terms of time is compared with the conventional inverse kinematics approach, where the calculation is directly implemented to the robot as part of the control algorithm.

This paper is organized as follows. The next section describes the hardware of the developed hexapod that is used in this study, including the positions of servos in each leg as well as the servos' dimensions and movements. Then, section 3 described about the proposed method, e.g. the hexapod legs coordination using tripod gait and simple geometrical approach. In this section, the sequences of the proposed tripod gait movements are described. The inverse kinematics calculations are explained in section 4, whereas the experimental results and discussion to analyze the performance of the proposed method is elaborated in section 5. Section 6 concludes the findings from this study.

II. The Hexapod

The utilized hexapod for the entire experiments in this paper is developed in the Department of Computer Science, Bogor Agricultural University [11]. The dimension of the hexapod is 40cm x 30cm x 27cm. Its main components consist of an MSR01 robot body, 12 HS645MG servos, 6 HS225BB servos, an Arduino Uno microcontroller and a smart peripheral controller (SPC) as the servo controller. The robot has six legs as shown in Fig. 1, where each leg has 3 servos namely the coxa, femur and tibia (Fig. 2).

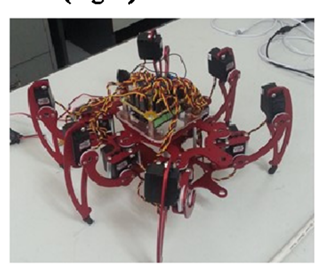

Fig. 1. The developed hexapod

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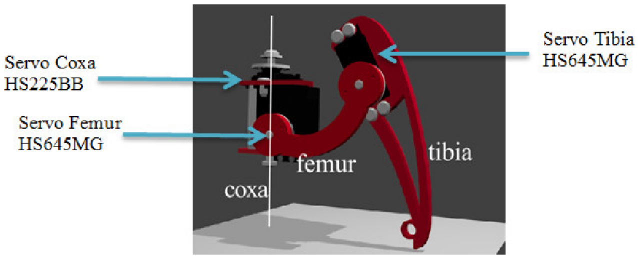

Fig. 2. The servo positions in each hexapod leg

The dimensions and movement range of each joints and its corresponding servo is presented in Table 1.

TABLE I. DIMENSIONS AND MOVEMENT OF EACH SERVO

Servo	Length (mm)	Minimum angle	Maximum angle
Coxa	15	-90°	90°
Femur	80	-90°	90°
Tibia	130	0°	90°

III. HEXAPOD LEGS COORDINATION USING TRIPOD GAIT AND SIMPLE GEOMETRICAL APPROACH

Each leg movement in hexapod consists of 4 cyclic states, namely: power, lift, swing and contact. Power is the state when the leg position is very stable, just above the surface. Lift is the state when the servos above femur and tibia rotate counter-clockwise so that the leg is lifted along the *z*-axis. Swing is the state when the coxa servo rotates over the *z*-axis, whereas contact is the state when the leg returns from the swing state with $z = 0$. The four states will be repeated during movement.

To move forward, three hexapod legs will move forward while the other three legs remain on their positions. Then, after finishing the first cyclic step, the other three legs will start moving forward. This movement is called a tripod gait, as illustrated in Fig. 3. Table 2 shows the simple geometrical positions of each leg state during forward movement.

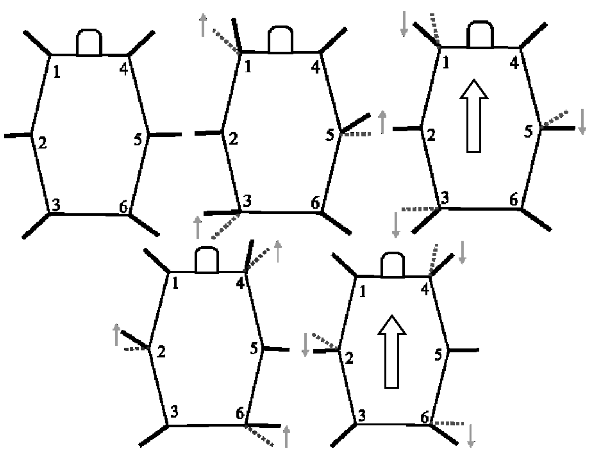

Fig. 3. The sequence of tripod-gait: forward movement

TABLE II. THE GEOMETRICAL POSITIONS OF EACH LEG FOR FORWARD MOVEMENT

State	Position (mm)		
	x	*y*	*z*
Lift	0	0	30
Swing	0	65	30
Contact	0	65	0
Power	0	0	0

The legs coordination for backward movement is similar to the forward movement, but the distance replacement in the *y*-axis is -65 mm rather than 65 mm, therefore, the hexapod body will move backwards. The tripod-gait algorithm for backward movement is shown in Fig. 4, whereas its corresponding geometrical positions are listed in Table 3.

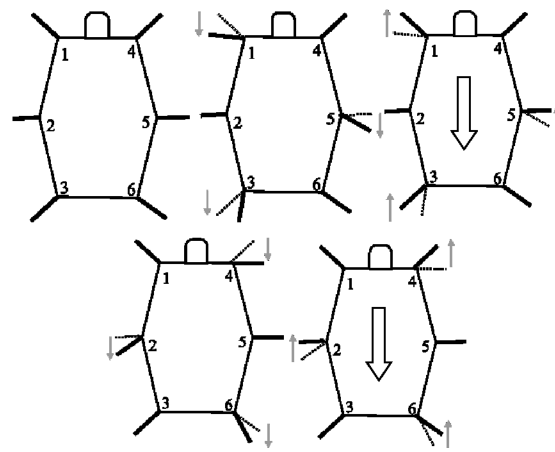

Fig. 4. The sequence of tripod-gait: backward movement

TABLE III. THE GEOMETRICAL POSITIONS OF EACH LEG FOR BACKWARD MOVEMENT

State	Position (mm)		
	x	*y*	*z*
Lift	0	0	30
Swing	0	-65	30
Contact	0	-65	0
Power	0	0	0

The turning movements, both left turn and right turn, the tripod gait sequences are quite different. For turning to the right, The 1st and 3rd legs move forward by 30 mm but the 5th leg moves backward by -30 mm. On the contrary, in the next step, the 4th and 6th legs move backward by -30mm, while the 2nd leg move forward by 30mm. This geometrical positions will cause the hexapod to turn to the right by 45°. The tripod-gait algorithm for turn right movement is shown in Fig. 5.

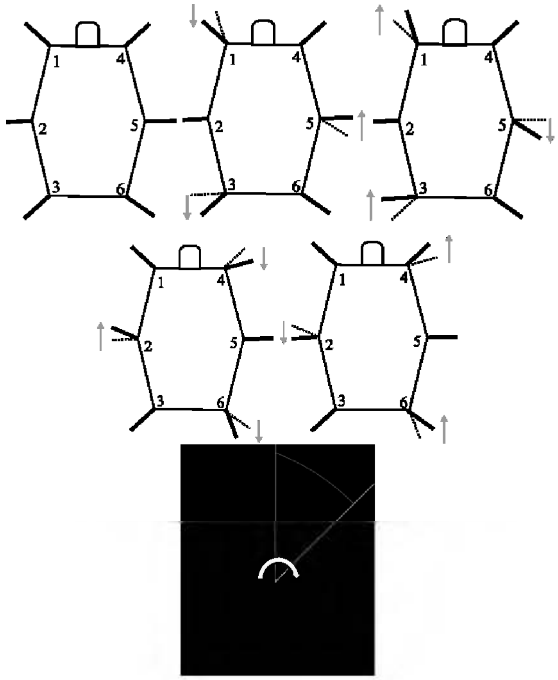

Fig. 5. The sequence of tripod-gait: turn right movement

For turning to the left, the 1st and 3rd legs move backward by -30mm and the 5th leg moves forward by 30 mm. Then, in the second stage, the 4th and 6th legs move forward by 30mm, while the 2nd leg moves backwards by -30 mm. Therefore, the hexapod will turn 45° to the left as shown in Fig. 6. The geometrical positions for each leg for turning to the right and left are shown in detail in Table 4.

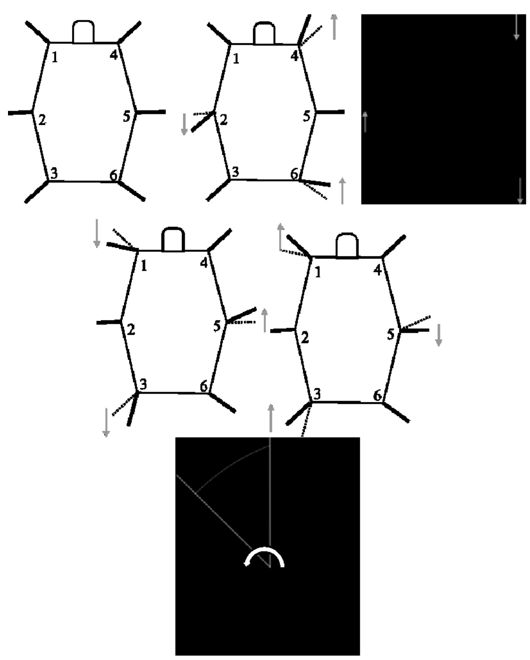

Fig. 6. The sequence of tripod-gait: turn left movement

TABLE IV. THE GEOMETRICAL POSITIONS OF EACH LEG FOR TURN RIGHT AND LEFT MOVEMENTS

State	Position (mm) for Turn Right / Turn Left		
	x	*y*	*z*
1st and 4th legs			
Lift	0 / 0	0 / 0	30
Swing	30 /-30	30 / -30	30
Contact	30 / -30	30 / -30	0
Power	0 /-30	0 / 0	0
2nd and 5th legs			
Lift	0 / 0	0 / 0	30
Swing	-30 / 30	-30 / 30	30
Contact	-30 / 30	-30 /30	0
Power	-30 / 30	0 / 0	0
3rd and 6th legs			
Lift	0 / 0	0 / 0	30
Swing	30 / -30	30 / -30	30
Contact	30 / -30	30 / -30	0
Power	30 / 30	0 / 0	0

IV. INVERSE KINEMATICS CALCULATION

Inverse kinematics are used to calculate the angular values on each servo (θ_1, θ_2 and θ_3) based on the given x, y, and z position information as shown in Fig. 7 and Fig. 8. The angular value for coxa or servo 1, θ_1, is calculated as follows:

$$\theta_1 = \tan^{-1}\left(\frac{y}{x}\right) \tag{1}$$

To calculate the angular values of tibia or servo 2 and femur or servo 3, θ_2 and θ_3, preliminary calculation for angles A_1, A_2 and A_3 are necessary as depicted in Fig. 8. These angles are calculated as follows:

$$A_1 = \tan^{-1}\left(\frac{L}{Z_o}\right) \tag{2}$$

$$A_2 = \cos^{-1}\left(\frac{{a_3}^2 - L^2 - {a_2}^2}{-2a_2L}\right) \tag{3}$$

$$A_3 = \cos^{-1}\left(\frac{L^2 - {a_3}^2 - {a_2}^2}{-2\,a_3a_2}\right) \tag{4}$$

where a_1 is the distance from hexapod body to coxa rotating-axis, a_2 is the distance between coxa rotating-axis and tibia rotating-axis and a_3 is the distance between tibia rotating-axis and the end-effector position (x, y, z).

Z_o is the distance from the surface to the lower limit of the robot body which can be expressed as:

$$Z_o = 78 - z \tag{5}$$

with z is the position of the end-effector in the z-axis.

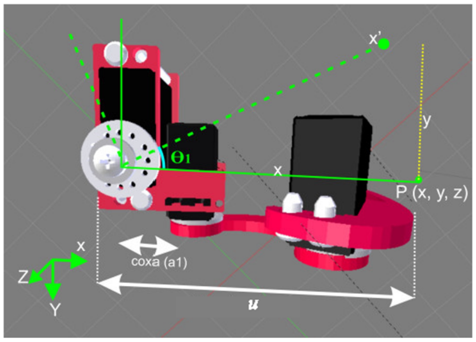

Fig. 7. Hexapod leg geometry: top view

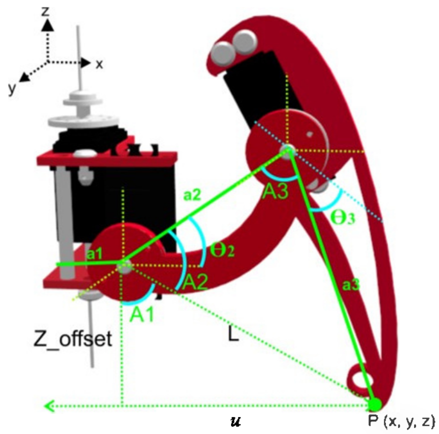

Fig. 8. Hexapod leg geometry: front view

L is the length of the hexapod leg that can be expressed as:

$$L = \sqrt{(u - coxa)^2 + y^2} \qquad (6)$$

with *u* is the distance from the base coordinate to the end-effector, *coxa* is the width of the coxa servo and *y* is the position of the end-effector in the *y*-axis.

From Fig.8, θ_2 and θ_3 can be obtained as follows:

$$\theta_2 = 90 - (A_1 + A_2) \qquad (7)$$

$$\theta_3 = 90 - A_3 \qquad (8)$$

The servo angle should be normalized prior to the implementation since the angular range of the servo is 0 to 180 whereas the calculated geometrical angle range is -90 to 90 degrees. Furthermore, the initial angle for servo 2 is 54.85° whereas the initial angle of servo 3 is 41.33°.

V. Experimental Results and Discussion

To compare the timely performance of the proposed simple tripod-gait and geometrical approach with the conventional inverse kinematics approach, the algorithm is implemented in two ways:

1. Proposed method: the hexapod legs are directly controlled by using the final results of the inverse kinematics calculation using the exact values obtained from the simple tripod-gait and geometrical positions.
2. Conventional inverse kinematics method: the hexapod legs are controlled using the desired end-effector positions, integrating the inverse kinematics algorithm in the controller program.

TABLE V. Comparison of The Proposed Method and The Conventional Inverse Kinematics Method

Movement	Displacement		Required time (s)	
	(mm)	(°)	Proposed method	Conventional method
Forward	130	0	2.05	4.29
Backward	50	0	2.23	4.30
Turn left	0	45	3.42	5.44
Turn right	0	45	3.28	5.42

The execution times for the first and second methods are compared in Table 5. It can be observed that the computational time of the proposed method is twice times faster than the conventional method. These results are obtained since the need for inverse kinematics calculations in the conventional method is diminished in the proposed method. However, the hexapod movement in this proposed method is less flexible because it is based on some predetermined positions of end-effectors. This proposed method is suitable to be implemented in many applications that require fast hexapod movement with less complexity both on the working environment of the robot and on the type of robot movement. It is recommended that this proposed method is implemented in the hexapod as one of the options among two or more switching controllers, where the other controller(s) may be made more sophisticated and flexible to overcome the uncertainty of the hexapod working environment.

VI. Conclusion

The tripod-gait movements defined by simple geometrical and inverse kinematics approach are proposed for the controller of a hexapod robot. Experimental results and evaluations have shown that the proposed method worked well for an 18-servos hexapod in producing several basic motions including moving forward, backward, turning left and turning right. It is revealed that this simple approach can move the hexapod twice times faster than the conventional inverse kinematics algorithm. Due to its fast but rigid movement, it is recommended that this proposed method is implemented in the hexapod as one of the options among two or more switching controllers, where this controller is applied when the hexapod is required to move fast in a smooth working environment.

References

[1] A. Skaburskyte, M. Luneckas, T. Luneckas, J. Kriaucіunas, and D. Udris, "Hexapod robot gait stability investigation," in 2016 IEEE 4th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE), 2016, pp. 1–4.

[2] Z. Guangtao, Z. Haojun, W. Jinsong, and L. Tiemin, "Petri-net-based coordination motion control for legged robot," in Systems, Man and Cybernetics, 2003. IEEE International Conference on, 2003, vol. 1, pp. 581–586 vol.1.

[3] H. Cruse, C. Bartling, G. Cymbalyuk, J. Dean, and M. Dreifert, "A neural net controller for a six-legged walking system," in From Perception to Action Conference, 1994., Proceedings, 1994, pp. 55–65.

[4] A. Manglik, K. Gupta, and S. Bhanot, "Adaptive gait generation for hexapod robot using Genetic Algorithm," in 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), 2016, pp. 1–6.

[5] P. Kutilek, S. Viteckova, J. Hejda, V. Krivanek, R. Doskocil, and A. Stefek, "Control of hexapod with static-stable walking using artificial intelligence," in 2016 17th International Conference on Mechatronics - Mechatronika (ME), 2016, pp. 1–6.

[6] M. Liu, M. Li, and J. Pang, "Fault-tolerant gait implementation of hexapod robot based on finite state automata," in 2017 29th Chinese Control And Decision Conference (CCDC), 2017, pp. 6800–6805.

[7] Y. Go, X. Yin, and A. Bowling, "Navigability of multi-legged robots," IEEE/ASME Trans. Mechatronics, vol. 11, no. 1, pp. 1–8, Feb. 2006.

[8] M. Gorner and G. Hirzinger, "Analysis and evaluation of the stability of a biologically inspired, Leg loss tolerant gait for six- and eight-legged walking robots," in 2010 IEEE International Conference on Robotics and Automation, 2010, pp. 4728–4735.

[9] D. Khudher and R. Powell, "Quadratic programming for inverse kinematics control of a hexapod robot with inequality constraints," in 2016 International Conference on Robotics: Current Trends and Future Challenges (RCTFC), 2016, pp. 1–5.

[10] G. Hoang, J. H. Min, G. M. Lee, B. H. Jun, H. K. Kim, and S. B. Kim, "Omni-directional walking control for a six-legged robot using differential kinematics algorithm," in 2014 14th International Conference on Control, Automation and Systems (ICCAS 2014), 2014, pp. 1163–1168.

[11] Wulandari, K. Priandana, and A. Buono, "Implementation of Inverse Kinematics for the Coordination Control of Six Legged Robot," in Proceedings of The International Seminar on Sciences (ISS) 2013, 2013, pp. 215–218.

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