Optimal Walking Trajectory for a Quadruped Robot Using Genetic-Fuzzy Algorithm

Jung-Shik Kong*, Bo-Hee Lee** and Jin-Geol Kim***

* Department of Industrial Automation , Inha University, Yong-Hyun Dong, Nam Ku, Inchon, Korea
(Tel : 82-32-860-7384; Fax : 82-32-863-4386 ; E-mail:tempus@dreamwiz.com)
**School of Electrical Engineering , Semyung University, Shin-Wal Dong, Chechon, Korea
(Tel : 82-43-649-1305; Fax : 82-43-644-6966 ; E-mail:bhlee@semyung.ac.kr)
***School of Electrical Engineering, Inha University, Yong-Hyun Dong, Nam Ku, Inchon, Korea
(Tel : 82-32-860-7384; Fax : 82-32-863-4386 ; E-mail:john@inha.ac.kr)

Abstract: This paper presents optimal walking trajectory generation for a quadruped robot with genetic-fuzzy algorithm. In order to move a quadruped robot smoothly, both generations of optimal leg trajectory and free walking are required. Generally, making free walking is difficult to realize for a quadruped robot, because the patterned trajectory may interfere in the free walking. In this paper, we suggest the generation method for the leg trajectory satisfied with free walking pattern so as to avoid obstacle and walk smoothly. We generate via points of leg with respect to body motion, and then we use the genetic-fuzzy algorithm to search for the optimal via velocity and acceleration information of legs. All these methods are verified with PC simulation program, and implemented to SERO-V robot.

Keywords: quadruped robot, genetic-fuzzy algorithm, avoid obstacle, optimal leg trajectory, free walking

1. INTRODUCTION

The concerns for the human-interactive robots, especially in the field of entertainments, have been increasing rapidly. They give people some pleasure and aids to the disabled person with moving indoors or outdoors under uneven terrain and obstacles like stairway, projection and so on. In order to overcome these restrictions, it is required to design the leg type of human-interactive robots with vision system, which can recognize the uneven terrain and obstacles. Besides, they also should have the autonomous characteristic based on AI technology, voice management technology, motor control technology and microprocessor application technology etc. Recently, these concepts have been implemented to such as Honda's ASIMO[1], Sony's AIBO[2-3], Fujitsu's HOAP-1[4] and so on. These robots contain the walking capability, interaction with human in the restricted fields, and obstacle avoidance using stereovision system.

Important issues of a quadruped robot are the recognition ability for environment and free walking ability. To recognize external environment, ability that recognizes obstacles and moves uneven terrain is needed[5,6]. Also to walk freely, robot must have ability that can changes body movement state to via points of leg. Research for path generation of the body is developed continuously. But relationship from leg trajectory to body path generation can't be expressed clearly, and also optimal leg trajectory of a quadruped robot can't be defined clearly. Therefore to guarantee free walking ability of a quadruped, optimal body path generation and smooth leg motion generation are needed simultaneously.

In this paper, we propose fuzzy-genetic algorithm to be able to maintain free walking ability and to produce optimal leg trajectory. Once a robot receives body movement information, it generates leg trajectory to be corresponded this information. To make the smooth leg trajectory, the robot determines optimal via point with fuzzy algorithm. At this time, the fuzzy algorithm uses genetic algorithm to make the rule-base that can generate optimal via velocity and acceleration. From generation via position from body movement and determination via velocity and acceleration from genetic-fuzzy algorithm, the robot can generate optimal leg trajectory.

2. QUADRUPED ROBOT CONFIGURATION

2.1 System Configuration

We designed a quadruped robot, called SERO-V, which has 14 joints and a main controller. Each of joints is actuated by RC-motor and a main controller is an Atmega103 8-bit microprocessor from ATMEL. When the main controller communicates with a PC simulator, they send some recognition signal and then receive each angle data of quadruped robot each other. The RC-motor is position controllable motor and ranges from the area of –90 degree to 90 degree, and the main controller send RC-motor position data. Fig 1 shows the configuration of SERO-V.

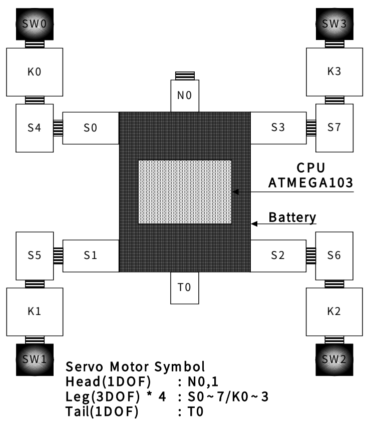
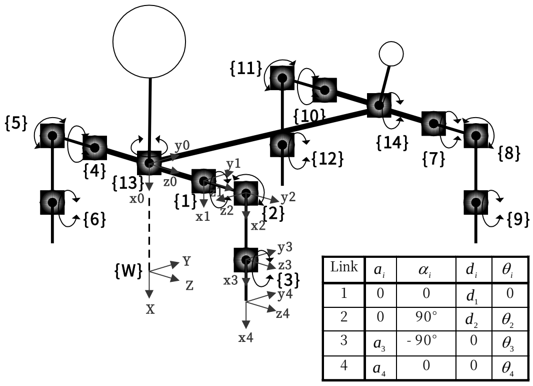


Fig. 1. Total configuration of SERO V

2.2 Body and legs analysis

Our robot has the total 14 motors including 3 joints each leg and, one at head and one at tail. For the part of leg, two of the 3 motors are used as the shoulder joint to realize walking action, and the other performs a knee joint to make a robot stable walking. The Fig. 2 represents the coordinate system of SERO-V.



Link	a_i	α_i	d_i	θ_i
1	0	0	d_1	0
2	0	90°	d_2	θ_2
3	a_3	- 90°	0	θ_3
4	a_4	0	0	θ_4

Fig. 2. Coordinate system of SERO IV

Because robot legs have the symmetry structure, we tried to do kinematics analysis only a front-left leg, and the others can be expanded easily. The inverse kinematics of a front-left leg is as follows.

$$\theta_2 = \sin^{-1}\left(\frac{-\beta \pm \sqrt{\beta^2 - \alpha\gamma}}{\alpha}\right) \tag{1}$$

$$\alpha = p_x^2 + p_y^2 \qquad \beta = a_4 p_y s_4 \qquad \gamma = a_4^2 s_4^2 - p_x^2 \tag{2}$$

$$\theta_3 = \sin^{-1}\left(\frac{2ka_3}{p_x^2 + p_y^2 - a_4^2 + a_3^2 + (p_z - d_1 - d_2)^2}\right) \tag{3}$$

$$\theta_4 = \cos^{-1}\left(\frac{p_x^2 + p_y^2 - a_4^2 + a_3^2 + (p_z - d_1 - d_2)^2}{2a_3 a_4} - \frac{a_3}{a_4}\right) \tag{4}$$

Where, P_x, P_y, P_z, a_3, a_4, d_1 and d_2 are the position vectors of the end points and link parameters, θ_2 is the shoulder's pitch joint, θ_3 is the shoulder's yaw joint, and θ_4 is the knee joint, respectively. Inverse kinematics of the others leg can be derived by only changing the base coordinate.

3. FREE WALKING ALGORITHM

3.1 Genetic algorithm

Generally speaking, a genetic algorithm is used in searching optimal result, it has good performance searching optimal solution[7-9]. It can find the optimal solution without solving any differential equation for the dynamic system. Genetic algorithm makes new generation with the series string data represented the regeneration, crossover and mutation, which parameters are shown in Table 1. In addition to, genetic algorithm is used at fuzzy rule-base. All of the parameters such as a crossover rate and mutation rate are determined by many experiments. Where, θ, $\dot{\theta}$, $\ddot{\theta}$ are angle, angular velocity and angular acceleration of each leg joint, and fitness function is derived from the minimization of movement of each leg joint, and the string number of genetic algorithm is represented by via points count and each axis. The Fig. 3 shows the fitness trends according to the generation times, which the number of generation times is determined by experiments. The Fig.4 is a flowchart of the trajectory generation based on genetic algorithm.

Table 1 Parameters of GA

Parameter	Value	Parameter	Value
Generation No.	250	Population No.	100
Crossover Rate	0.7	Mutation Rate	0.2
String No.	240		
Fitness function	$\frac{1}{\sum(\dot{\theta}_{i+1} - \dot{\theta}_i)^2 + \sum(\ddot{\theta}_{i+1} - \ddot{\theta}_i)^2}$		

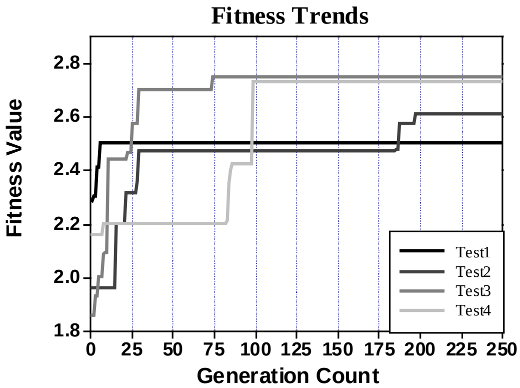


Fig.3. Fitness trends of front-left leg

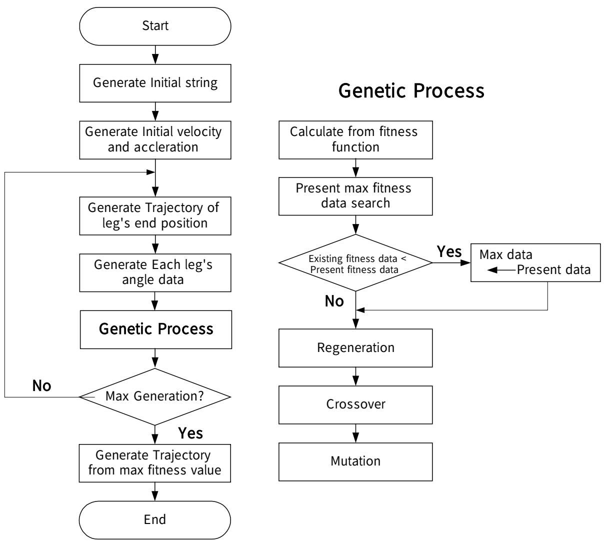


Fig. 4. Flowchart of genetic algorithm

3.2 Fuzzy algorithm

Because via points are the key issue to determine robot action patterns, the leg via points of a quadruped robot are important element to move smoothly. If the robot walks at pre-defined terrain, utilization of predefined trajectory should be very effective, but if it is required to walk around all terrain, pre-determined leg trajectory can't be valid anymore. This is why the fuzzy algorithm is needed. Fuzzy algorithm is optimal solution finding algorithm that imitates human's action pattern. Fuzzy algorithm can find the optimal solution quickly with robustness[10].

We propose the fuzzy algorithm that determines the optimal via points. To get the points, a robot collects the body propulsion data such as relative distance and relative orientation. These data are converted into fuzzy data using Fig.5 and Fig.6 membership function. After processing the fuzzification, rule base generates the velocity and acceleration of via points with the corporation of genetic algorithm. And interference engine that has 91 if-then-else-logics with the related to 7 walking distance and 13 walking angle data uses this rule base. From interference engine, fuzzy conclusion data are generated, and these data are converted velocity and acceleration of via points by defuzzification. At this time, we use the defuzzification process using Center Of Area method.

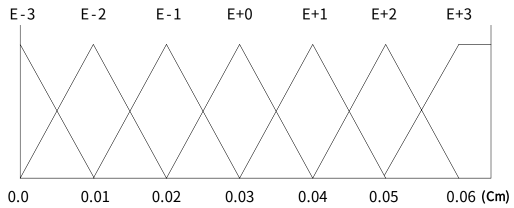


Fig. 5. Membership function for body distance

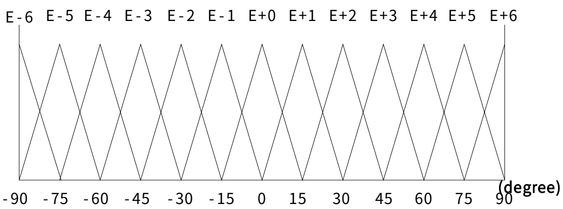


Fig. 6. Membership function of body orientation

3.3 Walking Pattern Generation

The procedure of making the walking pattern can be divided into three parts. First, we construct the rule base table using a genetic algorithm. The Fig. 7 shows the simulator GUI that makes via points, induced rule base to use fuzzy algorithm, and accompanied by genetic algorithm.

After the making rule base, a robot generates via points from its external movable data that are consisted of the walking distance and angle data. They have to be converted into via points of legs because the body and leg trajectories are coupled each other directly.

Also we have to generate the leg's pattern. The motion of legs should be restricted. Unless legs motion is restricted, the motion of legs increases infinitely. Fig. 8 is leg movement flow each times. Because at least three legs of a quadruped robot have to remain on the surface to maintain stable walking, the determination of legs movement according to period of time is important. At each time, via points are determined by the method of the Fig. 8., the number means end points of leg each times. Table 2 is via points with respect to walking distance and angle, l is desired moving distance, θ is desired direction, and sub script means the number of body propulsion with respect to time. The legs are moved a half distance of body propulsion, touched down on the surface, and propelled the body other a half distance. In this time two legs are propelled the body, one leg is swing, and one leg is on the surface to satisfy the stability and free motion. The procedure of walking is repeated from phase1 to phase8.

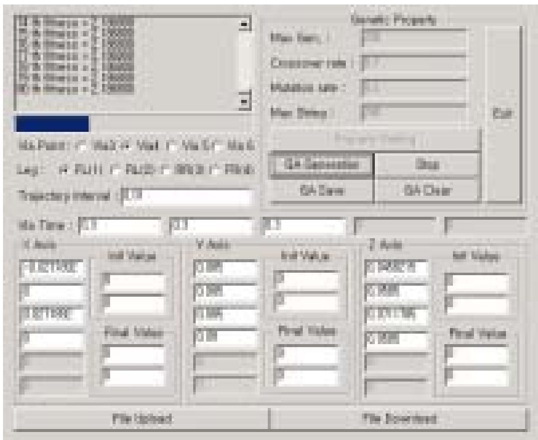


Fig. 7. GUI of genetic algorithm

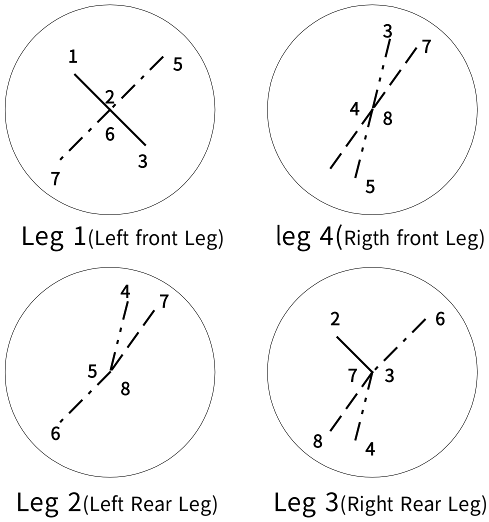


Fig. 8. Plain view of legs according to walking .

Table 2. legs via points w.r.t. direction and orientation of body

	Leg1			Leg4		
	x	y	Z	x	y	z
1	$l_1\cos\theta_1$	0	$l_1\sin\theta_1$	$-l_0\cos\theta_0$	0	$-l_0\sin\theta_0$
2	0	0	0	0	-0.05	0
3	$-l_1\cos\theta_1$	0	$-l_1\sin\theta_1$	$l_2\cos\theta_2$	0	$l_2\sin\theta_2$
4	0	-0.05	0	0	0	0
5	$l_3\cos\theta_3$	0	$l_3\sin\theta_3$	$-l_1\cos\theta_1$	0	$-l_1\sin\theta_1$
6	0	0	0	0	-0.05	0
7	$-l_3\cos\theta_3$	0	$-l_3\sin\theta_3$	$l_4\cos\theta_4$	0	$l_4\sin\theta_4$
8	0	-0.05	0	0	0	0

If external data are converted successfully, robot must determine velocity and acceleration of each via point. Because the realization of smooth walking can reduce impact of robot, smooth walking of robot is an important factor.

Fuzzy algorithm is a kind of fitting algorithm. From fuzzy algorithm, a quadruped robot creates optimal velocity and acceleration. In order to determinate velocity and acceleration, we have to determine the fuzzification data of the external moving data that are organized with distance and angle. These data are converted from the fuzzified input, and the fuzzified data are compared with internal inference engine and determine the fuzzy conclusion, and finally this fuzzy conclusion is converted crisp data by defuzzification. From these processes, a robot can create optimal via point.

4.SIMULATION RESULT

All of the algorithms are developed with Visual C++ in PC environment. We design a PC based commander for the algorithm as shown in Fig. 9.

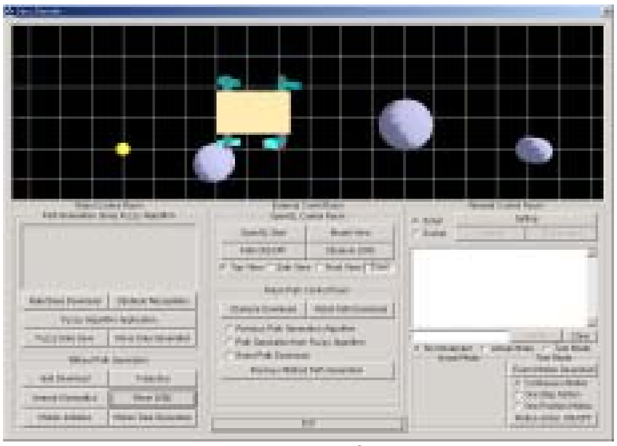


Fig. 9. Simulator GUI for our robot

In Fig. 9., upper block of figure shows the plain view of walking with obstacle information (sphere shape) and rightmost of lower blocks is an actual robot commander via serial channel. Using this block, we can send a robot actual angles that can move free walking. Middle block represents 3D control unit, which we can investigate the movement of robot with OpenGL engine, and confirm the validity of the desired robot operation. The leftmost part deals with kinematics and leg trajectory generation of robot after giving the parameters for the robot. We can use the optimal walking trajectory after verifying the given information from the above simulator.

All of the sequences to get the walking trajectory are as follows. First the simulator gets some obstacle information, and calculates the available motion data that contain distance and angle data of body that a robot wants to walk. Finally these data are converted via point data of legs by fuzzy algorithm.

If we don't use genetic-fuzzy algorithm, it is difficult to create motions of various direction and distance, and not to use this algorithm, velocity and acceleration may be almost determined '0'. We suppose that velocity and acceleration of via point are both '0', when we don't use this algorithm. Fig. 10. shows the full trajectory position comparison and The Fig. 11 reveals the comparison of the full step trajectory acceleration of each axis between using genetic-fuzzy algorithm and not using algorithm. During 11.6 second of total walking time, the robot meets 20 times of body propulsion

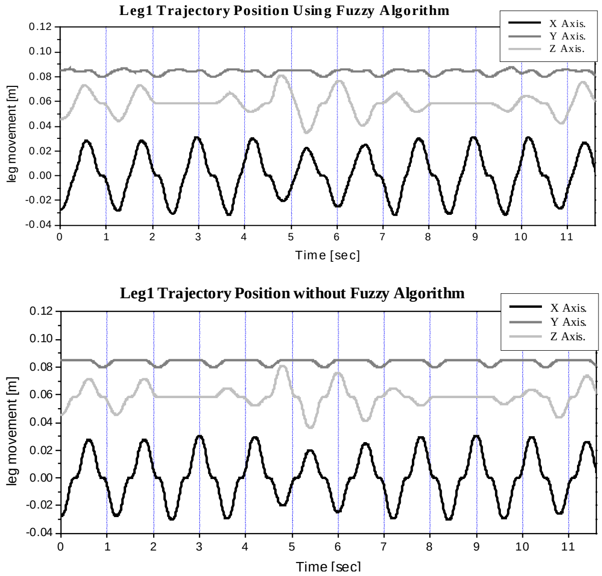


Fig 10. Position comparison of leg1

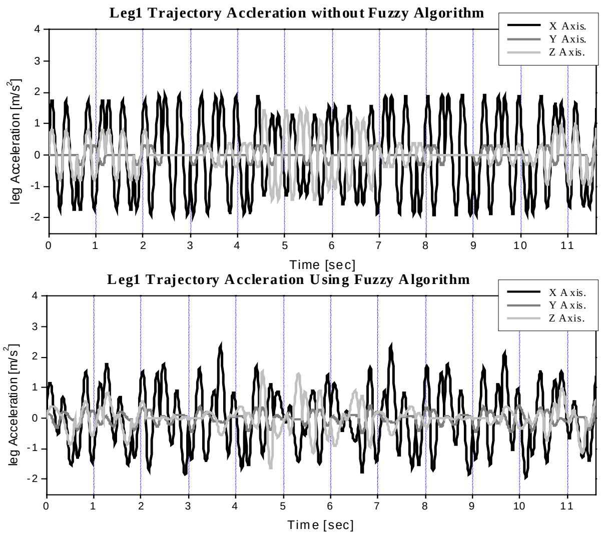


Fig 11. Acceleration comparison of leg1

In Fig. 12, the deviation rates of acceleration are reduced wide when we apply genetic-fuzzy algorithm, and the value of the root's mean sum of acceleration is reduced about 25%. The Fig. 11 shows angular acceleration comparison between using algorithm and not using algorithm.

We investigate the improvement of acceleration of joints after or before using algorithm. The sum of acceleration of shoulder's pitch joint(θ_2) is reduced about 25%, and shoulder's yaw joint(θ_3) is improved about 28%. The acceleration data of knee joint(θ_4) is improved about 6%. Angular acceleration reduction means that robot moves smoothly. As a result, joints of robot have the less impact after applying algorithm.

The Fig. 13 is motion snapshot of 3D data. We suppose uneven terrain, and a robot has already some recognized obstacle information and path generation, so it can move into the direction to avoid obstacle.

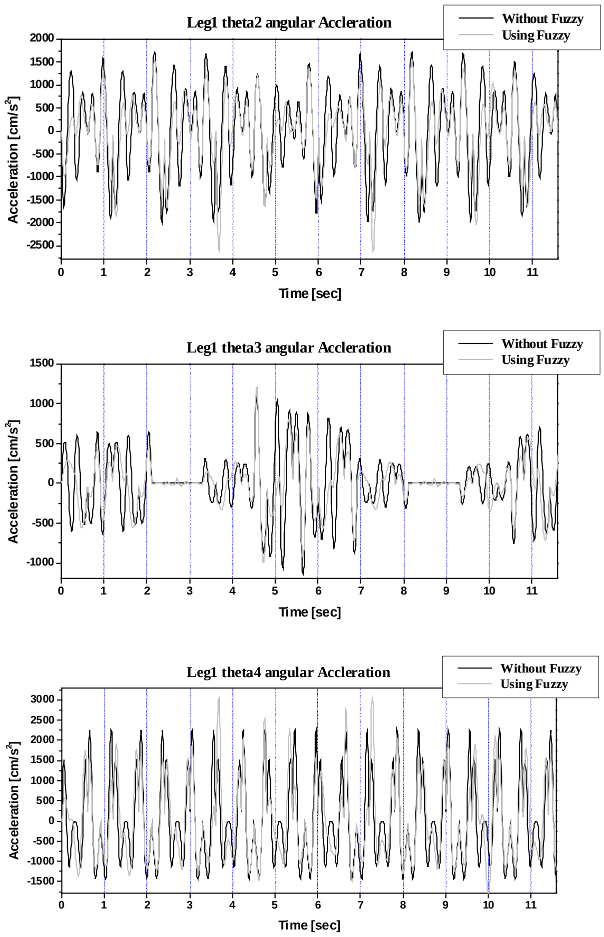


Fig. 12. Joint angular acceleration leg 1

5. CONCLUSION

When we design the mobile robot, the most important thing is how to move toward target point considering external environment. Especially, in designing a quadruped robot, it has a difficulty that the body drive trajectory can't be related with its leg's trajectory directly. Therefore we need the relation algorithm between its trajectories. Other important point for designing a robot is to realize the smooth motion generation of legs, which is essential to implement the stable walking.

In this paper, we suggest genetic-fuzzy algorithm to solve those problems. We propose the generation method for leg trajectory based on rule-base data from genetic algorithm. By using fuzzy rule-base, we can construct the whole of fuzzy algorithm. After the external movement data comes in, the fuzzy algorithm creates optimal via points that can be considered the uneven terrain walking. Once we have via points, optimal leg trajectory can be created using trajectory planning. The suggested method is verified with our robot SERO-V.

In the future, we will implement vision system and various sensors to obtain the real data from external environment, so we can realize more accurate motions and approach the human interactive behavior between human and robot.

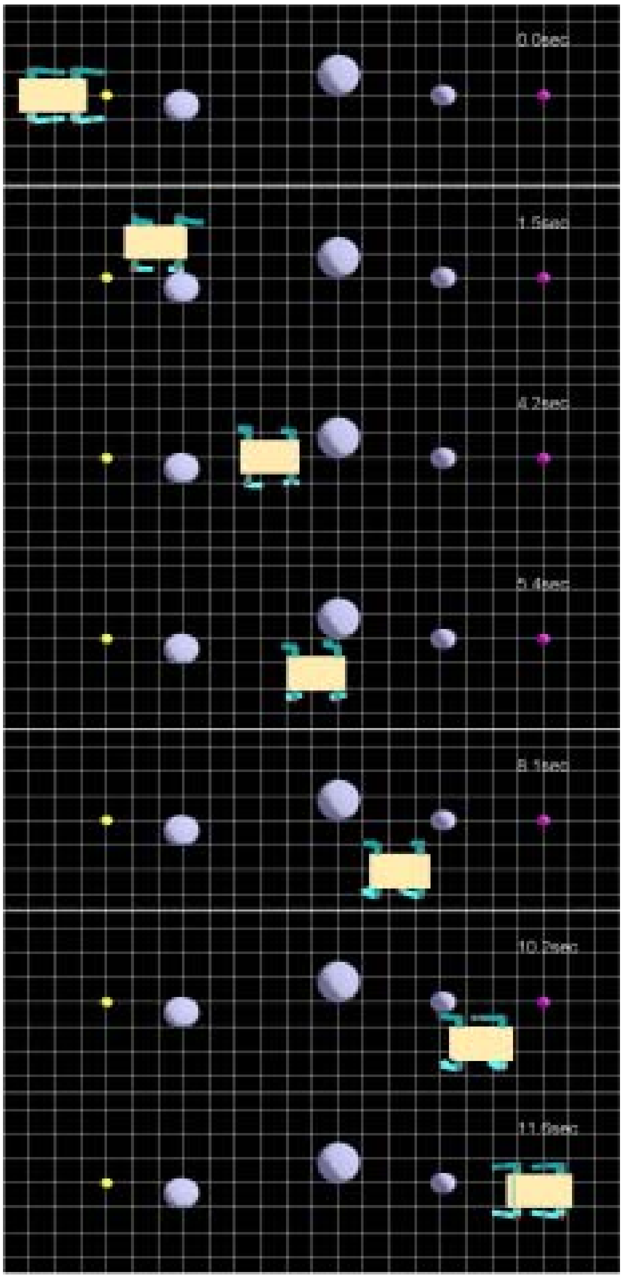


Fig. 13. Simulation snapshot of 3D walking sequence

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