

# Quadrupedal Gait Generation Based on Human Feeling for Animal Type Robot

Hidekazu Suzuki and Hitoshi Nishi

*Tokyo Polytechnic University & Fukui National College of Technology  
Japan*

## 1. Introduction

Animals have for long been recognized as being a positive force in healing processes (Baun et al., 1984). In recent years, animal-assisted therapy (AAT), which makes use of the healing effects of animals has attracted attention (Fine, 2006). Examples of the expected results of this type of therapy are buffering actions for stress, improvement of sociability and shortening of the medical treatment period through mental healing. Thus, the introduction of AAT is being considered in hospitals and health facilities. However, it is difficult to employ AAT in such facilities because of the risks of the spread of infection from animals to patients and the necessity of proper animal training.

Robot-assisted therapy (RAT), in which robots resembling animals are used instead of real animals, is important for patient safety (Shibata et al., 2005). Pet robots resembling various animals, such as the dog robot "AIBO", seal robot "Paro", etc., are used in this type of therapy. Banks et al. reported no difference between the effectiveness of a living dog and an AIBO robotic dog in reducing loneliness (Banks et al., 2008). Shibata et al. applied a mental commit robot, Paro, to RAT, and they verified that the interaction with Paro has psychological, physiological and social effects on people (Shibata et al., 2004; Wada et al., 2005). In these applications, it is important that the robot imitates the motions of living animal, especially essential motions, such as walking, running, etc.

However, it is difficult for the robot to walk and run like an animal because it is affected by various types of dynamic noise in the real world, in contrast to the ideal world. In recent years, many researchers have studied gait generation methods for various types of robots (Estremera & Santos, 2005; Kimura et al., 2005). A legged robot in the real world will have n-DOF (degrees of freedom) for movement, and it is difficult to solve the optimization problem in n-dimensional continuous state/action space to generate an adequate gait (Kimura et al., 2001). Therefore, evolutionary approaches, such as use of fuzzy logic, genetic algorithms, neural networks, or various hybrid systems, are employed for gait learning and parameter optimization (Inada & Ishii, 2003; Son et al., 2002). For example, Chernova et al. generated fast forward gaits using an evolutionary approach for quadruped robots (Chernova & Velosa, 2004). However, these gait generation methods for legged robots did not evaluate the degree to which the robot's movement approximated that of a living animal, because they were not designed for enhancement of the effects of RAT.

In the present study, therefore, we attempted to generate an animal gait for a quadrupedal robot using a genetic algorithm and gait patterns based on zoological characteristics (Suzuki et al., 2007). Moreover, a questionnaire study was performed to determine an adequate mix of several combinations of gait velocity and duty ratio for generated gait, and thus a more natural animal-like gait for the AIBO was chosen based on subjective human feelings from among the various gaits. Furthermore, parameters of each leg were adjusted again through an additional optimization on the ground.

## 2. Concept of Gait Generation

In this research, we used AIBO (ERS-7 M2, Sony), which is a well-known quadrupedal pet robot, as shown in Fig. 1. AIBO has 15 joints (head and legs), 3 DOF (degrees of freedom) at each leg, and 31 sensors. We can construct an application to control AIBO using OPEN-R SDK, a cross-development environment based on the C++ language provided by Sony.

Usually, when generating a gait for a robot, we often construct a robot model on the basis of dynamics. However, the dynamics of AIBO change in a complex manner depending on the situation in a real environment, and therefore strict modeling is difficult. Moreover, it may be even more difficult to define subjective human feelings for animals based on a model. Therefore, we generated a gait for AIBO on the basis of that of living animal and subjective human feelings.



Fig. 1. AIBO (ERS-7 M2 : Sony)

We attribute animal gait to that which achieves efficient propulsion. Moreover, both mono-leg propulsion and coordinated movement of each leg realize an efficient gait. Hence, we attempted to generate the orbit of a mono-leg, based on an animal's orbit, which can achieve efficient propulsion in the real world.

Figure 2 shows the normal gait of a walking dog. In this figure, (a) represents the dog's leg that is in contact with the ground and (d) represents the leg shape, which kicks out. Further, the start and end shapes of the leg are decided as shown in Fig. 3. However, the intermediary orbit in the real world is unknown. Therefore, we utilized a genetic algorithm (GA) (Michalewicz, 1994; Goldberg, 1989; Goldberg, 2002) to optimize the intermediary orbit of AIBO's leg.

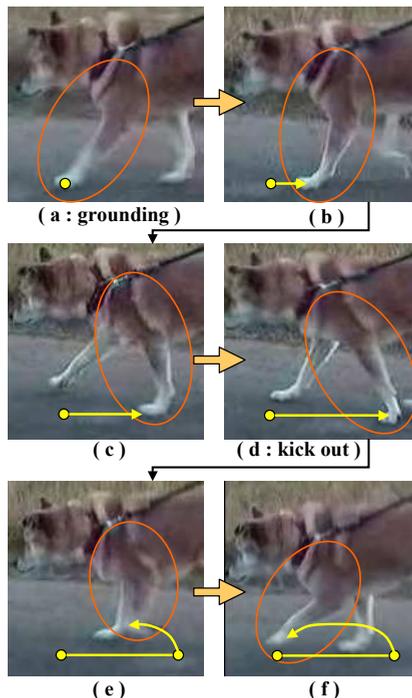


Fig. 2. Normal gait of a dog

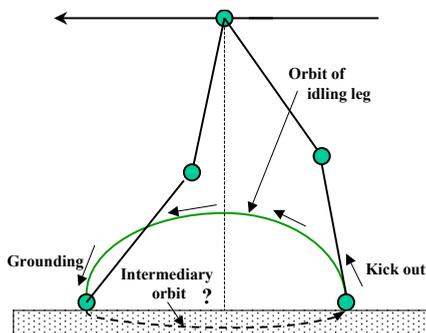


Fig. 3. Start and end shapes of the leg

### 3. Orbit Generation for AIBO's Leg

A genetic algorithm is an example of an AI program (Back, 1996) and is well known as a parallel search and optimization process that mimics natural selection and evolution. In the GA process, the search for a solution to a given problem is performed using a population of individuals as binary strings, which represent the potential solutions to that problem. The

GA is viewed as an optimization method as the iterative process of evolution toward better search solutions is equivalent to the process of optimizing the fitness function. The term “parallel,” which is used in “parallel search” above, is related to the implicit parallelism of GA and has been explained previously by Goldberg (Goldberg, 1989; Goldberg, 2002). This concept means that even though the GA processes only  $s$  individuals in the population in each generation, we can obtain useful processing of around  $s^3$  schemata in parallel without any special bookkeeping or memory requirements.

Figure 4 shows the genes of the GA employed in the present search, which has three parameters ( $\theta_1, \theta_2, r$ ). Here, by studying the moving image of a dog's gait, we noted that there is a turning point that changes the velocity of the leg in front and behind. It appears that the function of the leg changes from providing support to driving. The three parameters ( $\theta_1, \theta_2, r$ ) represent the leg shape at this turning point, as shown in Fig. 5, and  $T_g$  is the grounding time [ms]. Hence, the intermediary orbit is uniquely decided by the parameters ( $\theta_1, \theta_2, r$ ). Briefly, the problem of generating a high propulsive orbit for AIBO's leg is changed to the problem of optimizing the parameters ( $\theta_1, \theta_2, r$ ).

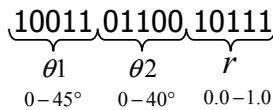


Fig. 4. Genes of GA

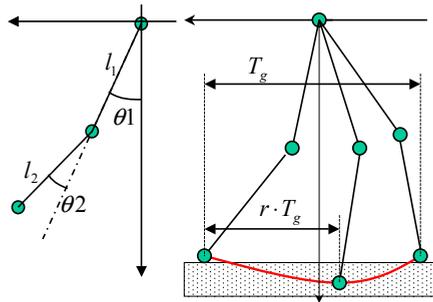


Fig. 5.  $\theta_1, \theta_2, r$  and  $T_g$

The GA process is shown in Fig. 6. A population comprising a set of  $s$  individuals is used by the GA process to search for the target orbit in the real world. As the elitist model of the GA is adopted, the best sorted individual in the  $N$ -th population, designated as a vector  $\phi_1^N$  and possibly representing the leg's orbit, which can realize efficient propulsion in the real world is selected to survive. Let us denote the components of  $\phi_1^N$  expressing the orbit of the  $l$ -th individual in the  $N$ -th generation by  $\theta_1^N, \theta_2^N, \text{ and } r_1^N$ .

In this study, we prepared a board attached with a free wheel, as shown in Fig. 7, to evaluate the propulsion caused by mono-leg motion in the real environment. Moreover, we adopted the measured advance distance of the evaluation board as the fitness value of the

GA search. In this evaluation system, AIBO moves the mono-leg only for one cycle based on the orbit represented by each individual of the population.

The obtained fitness values  $E_1^N(\phi_1^N), E_2^N(\phi_2^N), \dots, E_s^N(\phi_s^N)$  are sorted. Based on the ranking and a selection rate to die, the weakest individuals in terms of poor fitness values are replaced by newly created individuals. In creating the new individuals, random selection and random crossover are first performed. In this process, paired mates and two-point crossover are used. Next, a random bit-by-bit mutation (exchange of 1 by 0 or vice versa) is performed on the individuals obtained after the crossover. This ends the  $N$ -th generation and the population obtained after these operations constitute the population at the starting point of the  $(N+1)$ -th generation. The preceding steps are then repeated with the individuals in population  $N+1$  to evolve the population toward the solution.

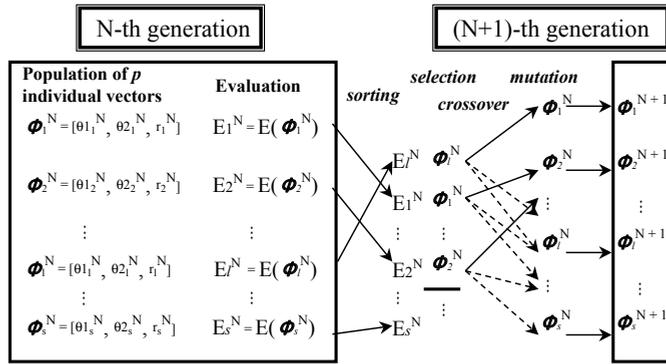


Fig. 6. Elitist model searching of a GA

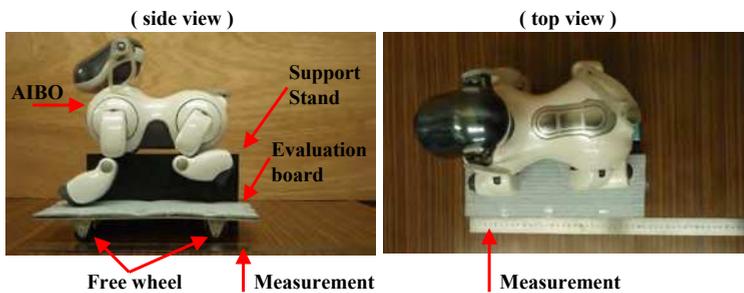


Fig. 7. Measurement method

In this experiment, we prepared three normal orbits, as shown in Fig. 8, using two-link inverse kinematics to compare the fitness value of the orbit optimized by the above GA process. Figure 9 shows the result of this experiment. Further, the orbit approximating an animal's gait and optimized by the GA shows a high evaluation value, i.e., a high propulsive

force. In this GA process, the population size, selection rate, and mutation rate are 10 individuals, 0.5, and 0.3, respectively.

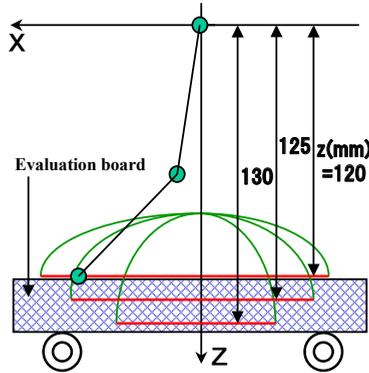


Fig. 8. Comparison orbits

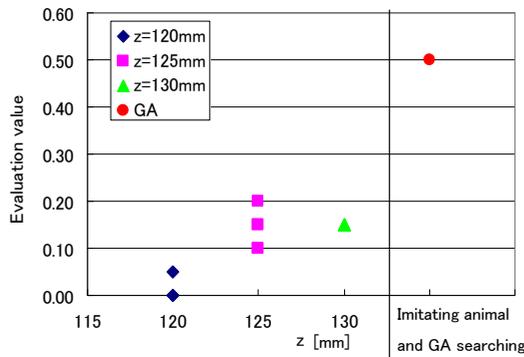


Fig. 9. Experimental result of GA

#### 4. Quadrupedal Gait Based on Human Feeling

As described in the previous section, we constructed the orbit of the mono-leg that can provide efficient propulsive force by approximating an animal's gait and optimizing GA. Next, we addressed the coordination between each leg, which can realize an efficient gait. The gaits of various animals have already been studied and analyzed in the field of zoology. Moreover, Alexander et al. classified quadrupedal gait on the basis of energy cost, as shown in Fig. 10 (Alexander et al., 1980). In this figure, the numbers near each leg represent the phase difference based on the left forefoot;  $d$  is the duty ratio and it refers to the grounding ratio. In this classification, the phase difference between a dog's walking gait and running gait correspond to that between the "Walk" and "Trot" gaits shown in Figs. 10(a) and (b), respectively. We generated the quadrupedal gait of AIBO using both the above-mentioned optimum orbit of mono-leg and "Walk" gait to generate an animal-like walking gait.

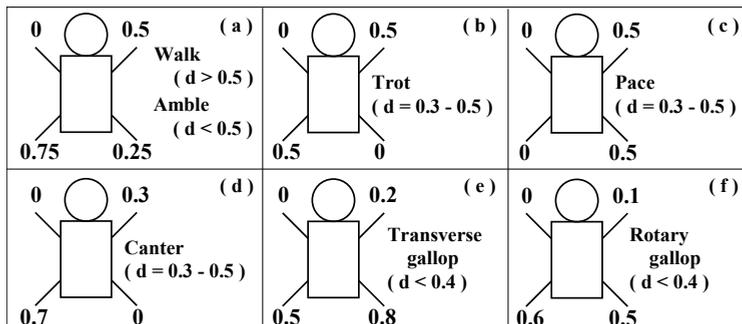


Fig. 10. Classification of quadrupedal gaits

		Duty ratio ( grounding ratio)				
		0.51	0.56	0.63	0.69	0.75
$T_{all}$ [ms]	200	58	54	38	67	36
	600	78	78	72	57	57
	1000	79	78	80	59	69
	1400	74	62	69	65	58
	1800	62	67	49	51	49

Table 1. Questionnaire related to subjective human feeling

In the “Walk” gait, the duty ratio generally decreases from 0.75 to 0.50 depending on the increment in the gait velocity. However, it is difficult to select an adequate mix of gait velocity and its duty ratio to cause a human observer to perceive an animal-like gait, because of the variable sensitivity of humans. Hence, we prepared a questionnaire study regarding several combinations of the gait velocity and duty ratio to determine an adequate mix. The results of the questionnaire study for 30 participants are shown in Table 1. In this table,  $T_{all}$  indicates the time period at motion cycle of mono-leg and includes the grounding time, which corresponds to  $T_g$  in Fig. 5 and is calculated as  $T_{all} \times (duty\ ratio)$ , and idling motion. This questionnaire study presented the participants with the moving image, the combined duty ratio of the 25 patterns, and  $T_{all}$ . Further, the participants assigned points from 1 (poor) to 5 (good, meaning the gait resembled that of a living animal) according to their subjective feelings regarding each moving image. Figures 11-13 show the results for duty ratios of 0.51, 0.63, and 0.75, respectively, for each value of  $T_{all}$ . Table 2 and Fig. 14 show the median of the polling number that seems to be the average subjective human feelings regarding the animal gaits.

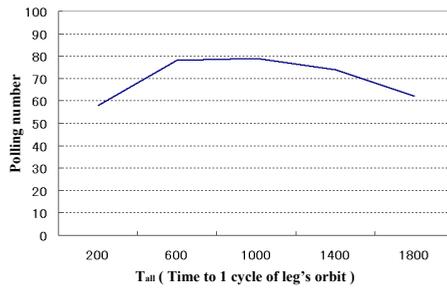


Fig. 11. Questionnaire data of duty ratio 0.51

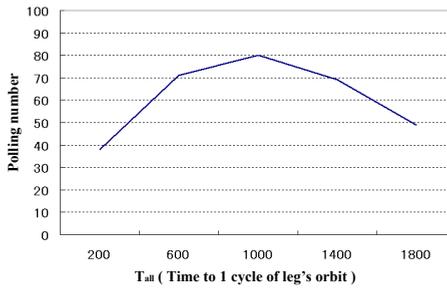


Fig. 12. Questionnaire data of duty ratio 0.63

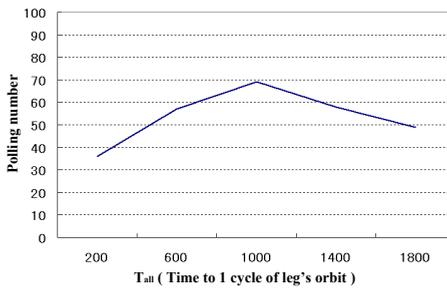


Fig. 13. Questionnaire data of duty ratio 0.75

	Duty ratio ( grounding ratio)				
	0.51	0.56	0.63	0.69	0.75
Median of gait cycle [ms]	996	995	1020	1031	1038

Table 2. Median data of polling number

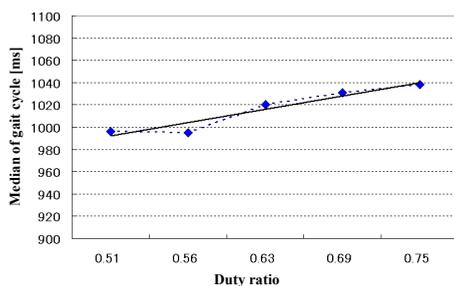


Fig. 14. Median of each duty ratio

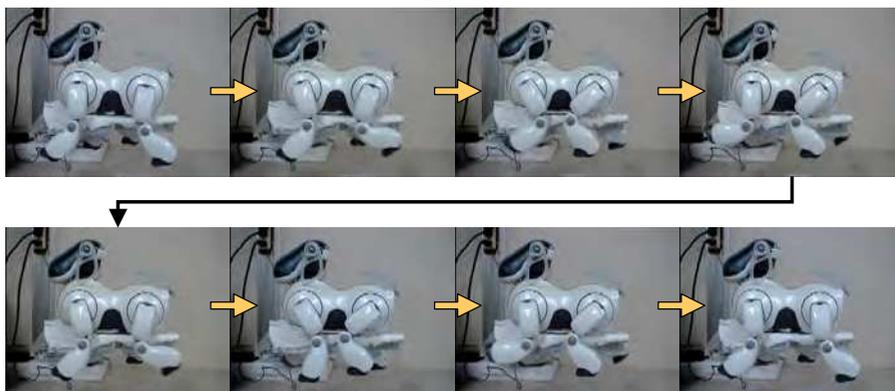


Fig. 15. Quadrupedal gait of AIBO based on animal gait



Fig. 16. Motion verification at conference

Figure 15 shows one of the animal gaits generated by the orbit of the mono-leg optimized by the GA, and an adequate mix of gait velocity and duty ratio based on subjective human feelings. In this gait,  $T_{all}$  is 1020 [ms] and the duty ratio is 0.63. Further, we have presented AIBO's gait generated by the above method at an international conference to verify the degree to which it approximates the natural gait of a living animal based on subjective human feelings (Fig. 16); we have confirmed that many viewers feel that this AIBO gait is fairly similar to that of a living animal.

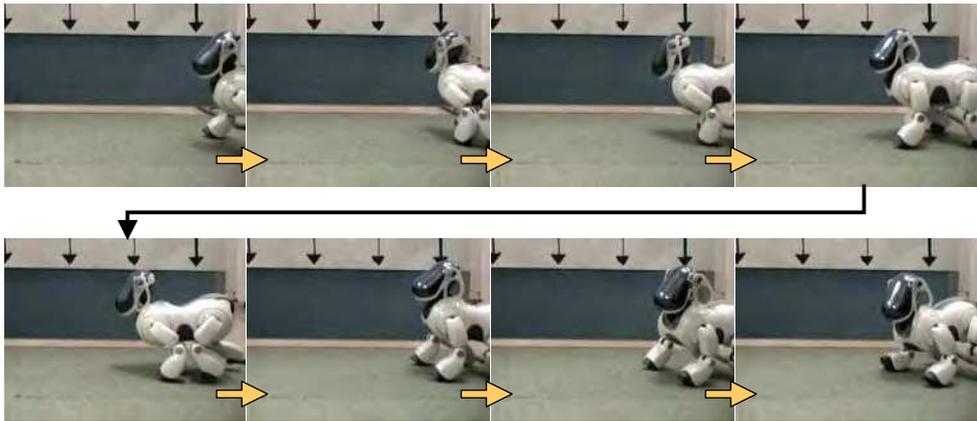


Fig. 17. Walking on ground

## 5. Modification for Dynamical Interference

We performed further experiment using the generated gait (Fig. 15) to check the adaptability to interaction with ground like that shown in Fig. 17. AIBO walked forward unsteadily, and the motion did not resemble the gait of a living animal. It seems that the generated gait cannot adapt to the dynamical interference by ground reaction.

So, we tried the additional optimization for generated gait to correct minor deviation of angle and timing for each joint. In this optimization experiment, the parameters ( $\theta_1$ ,  $\theta_2$ ) of each joint generated by above-mentioned process are modified slightly in the range of  $\pm 8^\circ$  by GA. In the optimizing process, the walking distance at 5 cycles of gait is adopted as the evaluation value of the GA. Figure 18 shows the gaits of each generation in this experiment. In the first half of the optimization, AIBO walked unsteadily and diagonally. However, at the 10-th generation, AIBO walked straight ahead stably and its gait resembled that of a living dog as well as the result of previous experiment (Fig. 15).

## 6. Conclusion

We proposed a method for generation of an animal gait for a quadrupedal robot. This method optimizes the orbit of the mono-leg using a GA based on the propulsive force and realizes the coordination of each leg on the basis of subjective human feelings. Moreover, we modified the generated gait by additional GA optimization to adapt to the dynamical interference by ground reaction.

We checked that AIBO walks straight ahead by proposed method, however, we also checked the centroid fluctuation at leg switching. It seems that the gait evaluation used for GA reproduction should include stability performance. In a future study, we intend to improve the evaluation method of optimization by including a body balance parameter.

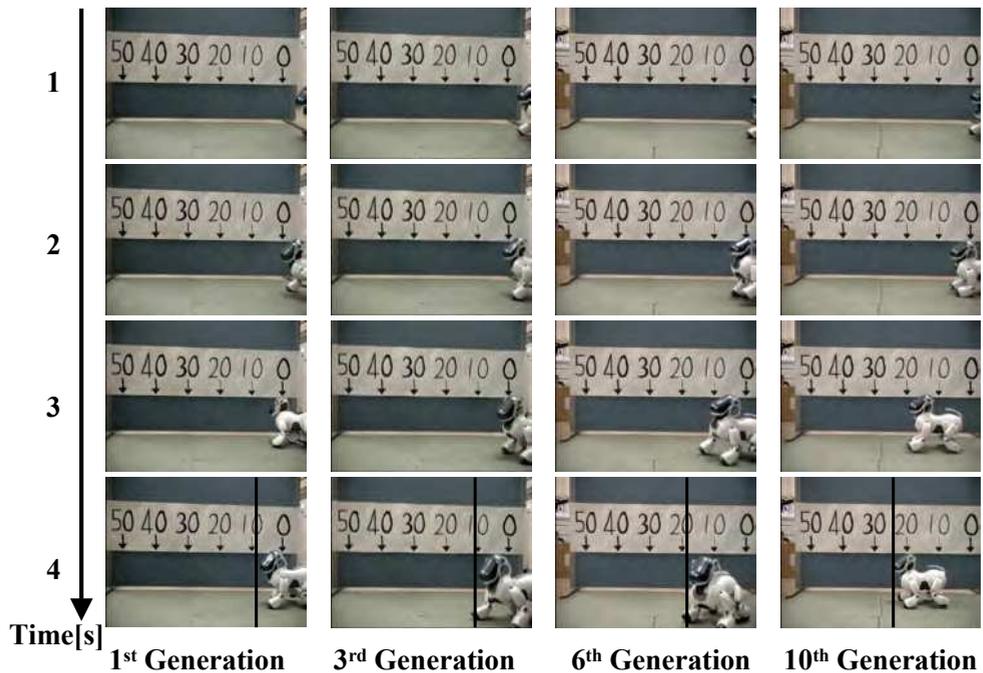
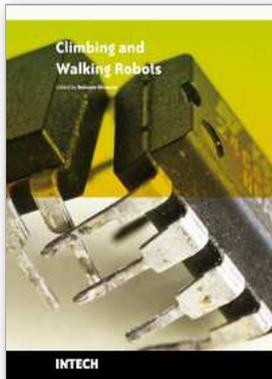


Fig. 18. Gait at each generations

## 7. References

- Alexander, R. McN.; Jayes, A. S. & Ker, R. F. (1980). Estimation of energy cost for quadrupedal running gaits, *Journal of Zoology*, vol. 190, pp. 155-192.
- Back, T. (1996). *Evolutionary Algorithms in Theory and Practice*, Oxford University Press, ISBN-9780195099713, Oxford.
- Banks, M. R.; Willoughby, L. M & Banks, W. A. (2008). Animal-Assisted Therapy and Loneliness in Nursing Homes: Use of Robotic versus Living Dogs, *Journal of the American Medical Directors Association*, Vol. 9, No. 3, pp. 173-177.
- Baun, M. M.; Bergstrom, N.; Langston, N. & Thoma, L. (1984). Physiological Effects of Human/Companion Animal Bonding, *Nursing Research*, Vol. 33, No. 3, pp. 126-129.
- Chernova, S. & Velosa, M. (2004). An Evolutionary Approach to Gait Learning for Four-Legged Robots, *Proceedings of the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2562-2567.
- Estremera, J. & Santos, P. G. (2005). GENERATING Continuous Free Crab Gaits for Quadruped Robots on Irregular Terrain, *IEEE Transactions on Robotics*, Vol. 21, No. 6, pp. 1067-1076.
- Fine, A. H. (2006). *Handbook on Animal-assisted Therapy: Theoretical Foundations and Guidelines for Practice*, Academic Press, ISBN-9780123694843, California.

- Goldberg, D. E. (1989). *Genetic Algorithms in Search, Optimization, and Machine Learning*, Addison-Wesley, ISBN-9780201157673, Boston.
- Goldberg, D. E. (2002). *The Design of Innovation: Lessons from and for Competent Genetic Algorithms*, Springer, ISBN-9781402070983, New York.
- Inada, H. & Ishii, K. (2003). Behavior Generation of Bipedal Robot Using Central Pattern Generator (CPG) -1st Report: CPG Parameters Searching Method by Genetic Algorithm, *Proceedings of the 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2179-2184.
- Kimura, H.; Yamashita, T. & Kobayashi, S. (2001). Reinforcement Learning of Walking Behavior for a Four-legged Robot, *40th IEEE Conference on Decision and Control*, pp. 411-416.
- Kimura, H.; Fukuoka, Y. & Katabuti, H. (2005). Mechanical Design of a Quadruped "Tekken3&4" and Navigation System Using Laser Range Sensor, *Proceedings of International Symposium on Robotics*.
- Michalewicz, Z. (1994). *Genetic Algorithms + Data Structures = Evolution Programs*, Springer-Verlag, ISBN-3540580905, New York.
- Shibata, T.; Wada, K.; Saito, T & Tanie, K. (2005). Human Interactive Robot for Psychological Enrichment and Therapy, *Proceedings of the Symposium on Robot Companions: Hard Problems and Open Challenges in Robot-Human Interaction*, pp. 98-109.
- Shibata, T.; Mitsui, T.; Wada, K. & Touda, A. (2001). Mental Commit Robot and its Application to Therapy of Children, *2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics Proceedings*, pp. 1053-1058.
- Son, Y.; Kamano, T.; Yasuno, T.; Suzuki, T. & Harada, H. (2002). Target Tracking Control of Quadrupedal Robot Using CPG Network Tuned by Genetic Algorithm, *Proceedings of 2002 International Symposium on Advanced Control of Industrial Processes, TA2D-4*, pp. 661-666.
- Suzuki, H.; Nishi, H.; Aburadani, A. & Inoue, S. (2007). Animal Gait Generation for Quadrupedal Robot, *Proceedings of Second International Conference on Innovative Computing, Information and Control*, CD-ROM, No. A03-02.
- Wada, K.; Shibata, T.; Saito, T. & Tanie, K. (2004). Effects of Robot-Assisted Activity for Elderly People and Nurses at a Day Service Center, *Proceedings of the IEEE*, Vol. 92, No. 11, pp. 1780-1788.



## **Climbing and Walking Robots**

Edited by Behnam Miripour

ISBN 978-953-307-030-8

Hard cover, 508 pages

**Publisher** InTech

**Published online** 01, March, 2010

**Published in print edition** March, 2010

Nowadays robotics is one of the most dynamic fields of scientific researches. The shift of robotics researches from manufacturing to services applications is clear. During the last decades interest in studying climbing and walking robots has been increased. This increasing interest has been in many areas that most important ones of them are: mechanics, electronics, medical engineering, cybernetics, controls, and computers. Today's climbing and walking robots are a combination of manipulative, perceptive, communicative, and cognitive abilities and they are capable of performing many tasks in industrial and non-industrial environments. Surveillance, planetary exploration, emergency rescue operations, reconnaissance, petrochemical applications, construction, entertainment, personal services, intervention in severe environments, transportation, medical and etc are some applications from a very diverse application fields of climbing and walking robots. By great progress in this area of robotics it is anticipated that next generation climbing and walking robots will enhance lives and will change the way the human works, thinks and makes decisions. This book presents the state of the art achievements, recent developments, applications and future challenges of climbing and walking robots. These are presented in 24 chapters by authors throughout the world. The book serves as a reference especially for the researchers who are interested in mobile robots. It also is useful for industrial engineers and graduate students in advanced study.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Hidekazu Suzuki and Hitoshi Nishi (2010). Quadrupedal Gait Generation Based on Human Feeling for Animal Type Robot, Climbing and Walking Robots, Behnam Miripour (Ed.), ISBN: 978-953-307-030-8, InTech, Available from: <http://www.intechopen.com/books/climbing-and-walking-robots/quadrupedal-gait-generation-based-on-human-feeling-for-animal-type-robot>

**INTECH**  
open science | open minds

### **InTech Europe**

University Campus STeP Ri  
Slavka Krautzeka 83/A  
51000 Rijeka, Croatia  
Phone: +385 (51) 770 447  
Fax: +385 (51) 686 166

### **InTech China**

Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821



© 2010 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](#), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.