Robotics in Education: Plastic Bottle Based Robots for Understanding Morph-Functionality

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***Abstract*— in this paper, we introduce our robot package for educational use. The main characteristics are the followings: robots are built by connecting plastic bottles and RC servo motors with glues so that technical skills such as machining are not required for students; three types of robot controllers, such as manual controller, autonomous controller, bio-signal interface controller, are provided so that students can experience autonomous robots and bio-signal interface techniques. Thus, this package provides opportunities to design both robot structure and control architecture and, moreover, to experience new engineering technologies. So far, we have conducted robot education courses for undergraduates and graduates three times. The first course purposed to teach students morpho-functionality, which is a concept of embodied artificial intelligence. As results, all the students have designed locomotive robots and understood "morpho-functionality." In the second and third courses, students have experienced to control locomotive robots with bio-signal interface techniques. Thus, we have shown that this educational package provide variety of robot techniques and, depending on course hour and students target, we can modify course programs.**

I. Introduction

RECENTLY, robotics entries into educational field. The most remarkable work is LEGO mind Storm [1, 2]. The LEGO is based on a toy so that it is easy to assemble robots such as vehicle and also easy to implement behaviors by provided easy-use controller such as graphical user interface. Therefore, this robot is used in education such as "Roberta project" in Germany. On the contrary, there is another type of robot - RC-servo motor based humanoids [3]. In educational course, this robot is assembled with manual script by students, and, then, students implement behaviors with c programming or graphical interface. After taking this course, the students enable the robots to perform quasi-static action such as locomotion and gymnastics. Thus, this robot course provides knowledge of control architecture.

In our research, we also focus on robotics for educational use. Especially, we purpose to give students opportunities to use their creativity on both designing both robot structure and implementing controller. Therefore, we propose plastic bottle based robots for robot structure because of economized machining time, easy assembling, and easy morphology modifying, and three types of robot controllers: remote controller, autonomous controller, and bio-signal interface controller, for experience to use and build new robot techniques.

In this paper, we, firstly, introduce our educational robot setup. Then, we report several results in educational course we have conducted. Finally, we conclude this paper.

II. Set Up of Educational Robot Package

Our educational robot package consists of three course programs: making electronic circuit, building plastic bottle based robot, and implementing control architecture (C programming). Depending on course hour and target, we can apply different combination of these programs. For example, all three course programs require 6 to 8 hours and only one course program require 1 to 2 hours.

"Making Electronic circuit" course program provides students soldering experience and circuit design knowledge of microchip, LED, sensor, and motor. "Building plastic bottle based robot" course program enables students to construct plastic bottle based robots such as arm robot as shown in fig.1 by connecting plastic bottles and RC servo motors with hot glue. "Implementing control architecture" course program provides two unique controllers: autonomous robot controller and bio-signal interface controller. Autonomous robot controller consists of motor command and sensor data acquisition so that it lets students learn concept of sensory motor coordination [8]. Students can modify not only control parameters in sample source code but also whole control architecture if they want. Bio-signal interface controller uses electromyographic (EMG) signals, which are the extracellular field potentials produced by muscles. With this controller, students are able to control robots as if they use their muscles. Moreover, we also explain the principle of this technique in the course. Addition to it, manual controller is used for demonstration of robots built in "building plastic bottle based robots" course.

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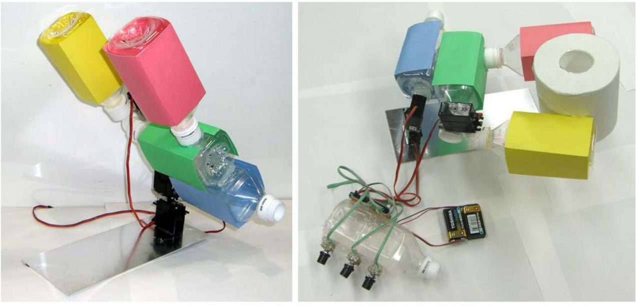


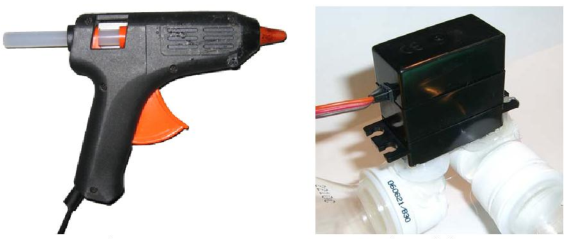
Fig.1 An instance of Plastic bottle robots

A. *Robot Structure: Plastic Bottle Based Robots*

In our robot structure, plastic bottles (fig2b) are used as body parts, RC-servo motors (fig2a) as actuated joints, and connected with hot glue (fig3). The advantages of the structure are economizing machining time, easy-assembling, easy-modifying. It is sure that preciseness is less than metal materials, however, its structure has enough strength to realize desired behaviors and, moreover, we considered not to let students feel technical difficulties so that it is better robot structure than metal ones for educational purpose.

(a) RC-Servo Motor (b) Plastic bottle

Fig.2 Components of Robot Structure



(a) Hot glue gun (b) A joint

Fig.3 Example of assembling

B. *Controller type I: Autonomous Robot Controller*

Autonomous Robot controller as shown in fig.4 is built for microchip H8/3664 CPU16MHz (table I) and capable to control three RC-servo motors (fig.5 and table II), to read two light sensors (fig.6 and table III). As for sensors, we can also use different types of sensors and, for example, we made touch sensor to measure contact information as shown in fig.7, by ourselves. Thus, we also provide sensor building opportunities.

As for implementation of autonomous robot controller, sample source codes (C programming) are provided together with this controller as listed in table IV. (These sample source codes are unloaded from a computer to a microchip through serial port.) For example, the source code contains oscillation algorithm for RC servo motors: motor axis moves to two different angle positions alternately at a certain cycle. There are some comments in the source code so that students could modify crucial control parameters easily, such as the angle positions and the cycle as control parameters. Moreover, we provide sample source codes of sensory-motor action, which function reading values of light detect sensor and determining angle of motors. The source codes also contain comments at crucial control parameters.

Basically, these source codes work without any modification so that students choose to modify either source codes or robot structure in order to design robot behaviors with our autonomous controller.

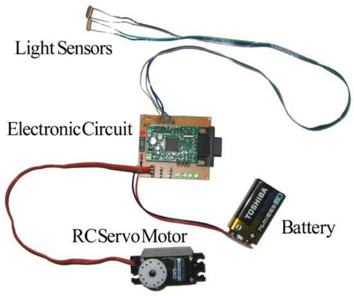


Fig.4 Basic Robot Controller system

Table I

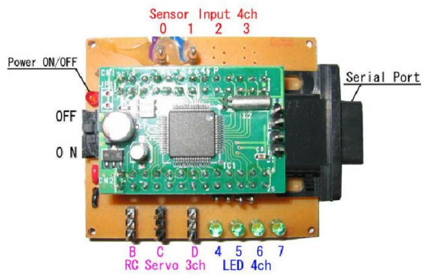
Microchip H8/3664(16MHz)

Function	Use for Edutainment
Communication	RS232
RC Servo Control	3ch
Sensor Input	4ch
LED	4ch
Battery	9V

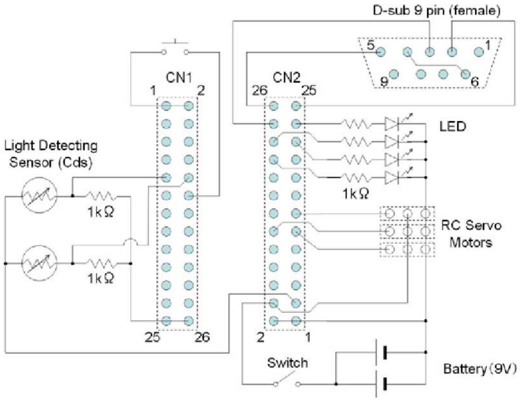
Table II

Spec. of RC Servo Motor

Standard RC Servo Motor GWS S03T/2B			
Spec.		Torque	Speed
	6.0V	8.0kg-cm	0.27sec/60°
Weight	46 g		
Size	39.5 × 20.0 × 39.6mm		



(a) Appearance of Electronic circuit



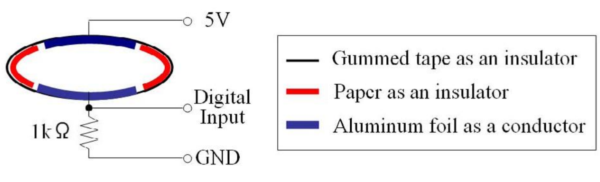
(b) Circuit design
Fig.5 Electronic circuit as Controller

Fig.6 Light detect sensor

Table III
Light detect Sensor (Cds sensor)

	Cds Sensor Resistance [Ω]	Analog output [V]	AD Converter 8bit (0-255)
Bright Light	0 – 400	0.00 – 1.45	0 – 74
Indoor	400 – 1000	1.45 – 2.50	74 – 128
Gloomy	1k – 5k	2.50 – 4.20	128 – 214
Dark	5k - ∞	4.20 – 5.00	214 – 255

(a) touch sensor



(b) Concept figure of touch sensor
Fig.7 Light detect sensor

Table IV
Contents of sample codes

	Contents
Sample code 1	Oscillation algorithm of RC servo motors
Sample code 2	Sensor values reading algorithm
Sample code 3	Combination of the above

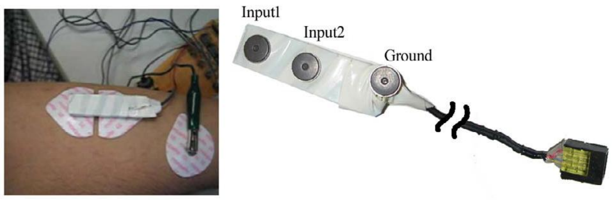
Table V
Configuration of remote controller

Volume	AD Output [V]	8 bit (0-255)	RC servo
Left	0.0	0	Left
Center	2.5	127	Center
Right	5.0	255	Right

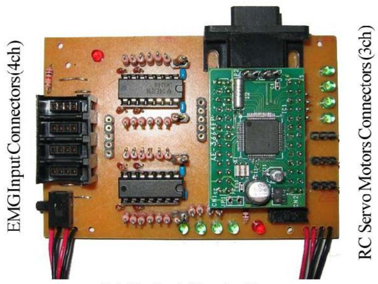
C. Controller type II: Bio-signal Interface Controller

We also provide bio-signal interface controller as one of our robot package. Practically, we use EMG signal as one of human bio-signal, which is electrical potential when human move its muscle. We use EMG sensors and electronic circuits, which function full wave rectifier and RC low pass filter as shown in fig 8, built by ourselves. The EMG sensor is a differential amplifier and its amplification rate is set to 80000 and the full wave rectifiers and RC low pass filters (table VI) are installed for the simplification of information processing on EMG signals because EMG signal contains much information as shown in fig.9a. Thus, the bio-signal interface controller can extract only stress value of muscle in fig.9b, the value signal is smoothed in fig.9c, and is fed into A/D converter of the microchip in order to determine angle of RC servo motors.

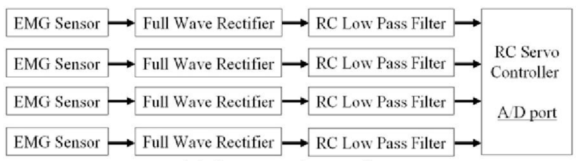
In short, we implemented bio-signal information processing on electronic circuits. Therefore, it is easy to use and experience bio-signal techniques for students. Moreover, it helps them to understand the techniques on both engineering aspect and biology aspect.



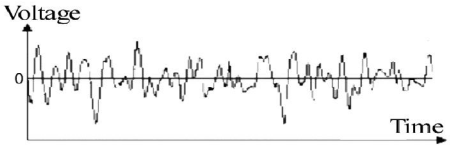
(a) EMG Sensors (left: installation of EMG sensor, right, EMG sensor)



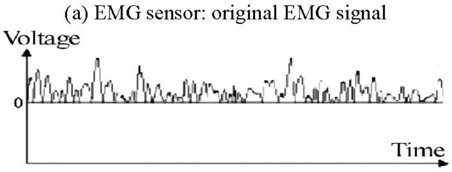
(b) Robot Controller
(Full wave rectifier, RC low pass filter, RC servo controller)



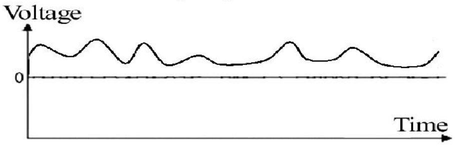
(c) Conceptual procedure
Fig.8 EMG RC-Servo Controller



(a) EMG sensor: original EMG signal



(b) Full wave rectifier: acquiring absolute values of EMG signal



(c) RC low pass filter: smoothing the signal

Fig.9 Signal Process in EMG Controller

Table VI
Spec. of EMG controller

Function	Contents
EMG sensors 4ch (Differential amplifier)	Amplification rate: 80000 Range of Voltage output: 0.2V～2.4V Shown in fig.10(a)
Full wave rectifier	Shown in fig.10(b)
RC Low pass filter	R=180[kΩ], C=0.1[μF], Cut-off freq.: 8.8[Hz] Shown in fig.10(c)

D. Controller type III: RC Servo Manual Controller

Manual controller is made for helping tool when students design plastic bottle based robots. This controller is made as the followings: three potentiometers are connected to AD converter input port and the angles of the potentiometers are mapped on angles of three RC servo motors, respectively. Then, students control angles of RC servomotors manually.

Fig.10 Remote controller

III. The First Edutainment Course: Designing Passive Dynamics Locomotors

The first edutainment course is organized for 20 students in master course at engineering department and aimed at teaching importance of morphology. The main characteristic is that students could build their own robot structure and implement its behaviors as described the above.

In the edutainment course, students purposed to design locomotive robots with one or two motors. So, we provided autonomous robot controllers (controller type I) and instructed the sample source codes, which contains oscillation generation algorithm and sensor reading algorithm. In the first course, we did not limit material of robot structure. Therefore, students could use not only plastic bottles but also cardboards.

A. Introduction of designing locomotive robots

In the field of bipedal locomotion, there are two main streams: One is conventional bipedal robots, which achieve walking with high-speed information process and many high-drive motors [5, 9]. These robots realize variety of behaviors, however, requires large energy; another is represented with passive dynamic walker, which is well-designed for walking - straight legs and curved feet connecting at passive hip joints and latch knee joints [4,6]. This robot achieves walking only on an incline. However, the robot walks without any motors and sensors so that it consumes less energy than conventional robots. This is because the robot exploits gravity to locomotion energy through morphology. Furthermore, the walking style of the walker is similar to human walking.

The main factor of difference between two main streams could be considered as "exploitation of its own dynamics" and the exploitation is generated by passive components in robot structure. Therefore, our purpose is to explore more passive components such as material properties and mechanical structures in order to design natural locomotion.

Thus, the main concept of this course is to understand importance of "embodiment" so that robots can be designed with one or two RC servo motors and find out morphology, which exploits its own dynamics with any materials and shapes such as carton, plastic bottles, and other plastic products. Addition to it, sensory motor system should also be designed for the purpose of understanding robust behaviors.

B. Contest: 1 meter race

Students are allowed to use only one or two RC servo-motors and implement autonomous control program freely to design robots. Then, all the robots compete with 1 meter race (fig.11 left). This purpose is for understanding morphological function [8], which represents efficiency for locomotion as passive dynamic walkers.

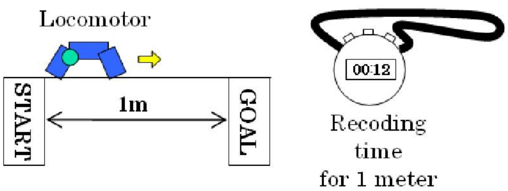


Fig.11 Regulation of 1 meter race

C. Results: Locomotive Robots Designed by Students

Fig.12 and Table VII shows results of 1 meter race: representative locomotive robots and all the recoding time. There are two gaits of locomotion gait: kicking-ground, and falling over types. The kicking ground (KG) type moves forward by kicking the ground with a rear leg (fig.14). In short, driving forward force is generated with the kicking motion. The falling over (FO) type moves forward by falling over after the motor lifts up its fore leg (fig.15). In short, the FO type changes its body shape and, then, exploits gravity to fall over to forward as a part of pattern of inversed pendulum model.

Table VI lists the time when the designed robot traveled 1 meter forward. These best KG type and FO type reached 1 meter at approximately 10 seconds. Thus, this edutainment course is conducted and we acquired the robots, which represented morphological function [7]. Moreover, the best robots are mostly plastic bottle based robots (fig.13).

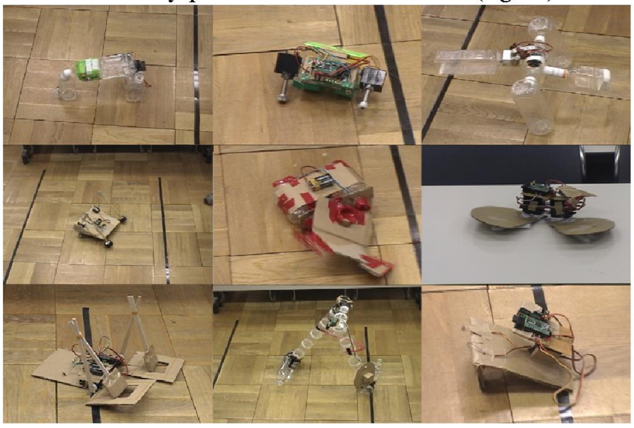


Fig.12 Representative Locomotors design by students

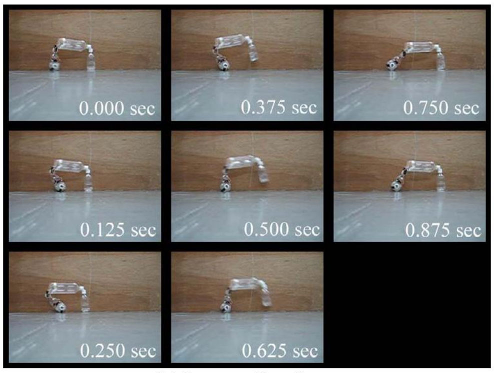
(a) KG type (b) FO type

Fig.13 Best Locomotors (plastic bottle based robots)

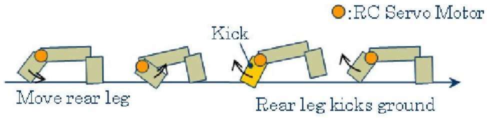
TABLE VII

Ranking of of locomotive robots design by students in the first course

Ranking	Time for 1 meter	Locomotion Type
1	7.4 sec	Kicking Ground
2	8.1 sec	Falling Over (fig13b)
3	11.0 sec	Kicking Ground (fig13a)
4	90 sec	Falling Over
5 - 20	More than 5 min / No goal	Others

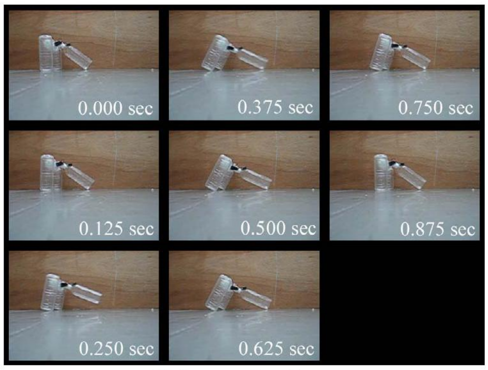


(a) Locomotion Scene

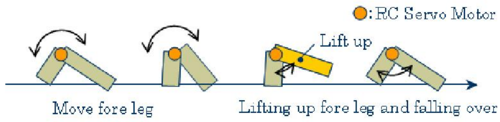


(b) Qualitative analysis of gait

Fig.14 KG type



(b) Locomotion Scene



(b) Qualitative analysis of gait

Fig.15 FO type

IV. The Second and Third Edutainment Course: Controlling Robots By Bio-Signals

The second and third edutainment courses are organized for totally ten students (undergraduates and graduates) at engineering department and aimed at teaching bio-signal techniques. So, we applied bio-signal robot controller (controller II). Other setting is the same as the first edutainment course.

A. Contest: Going Up to Steps

We set a goal as robots go up steps as shown in fig.16. This is because that we provide both remote controller and EMG controller, which control robots manually. In this course, we allow students to use unlimited numbers of RC servo-motors and controllers. Also, there is no restriction on robot structure as the first course.

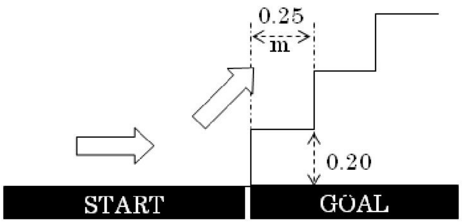
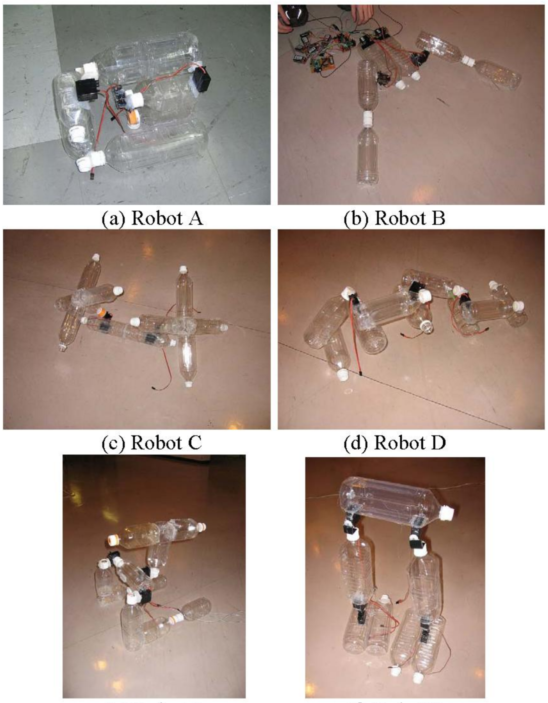


Fig.16 Competition Regulation

B. *Results: Locomotive Robots Designed by Students*

Locomotive robots designed by students as shown in fig.17. The best robot is Robot A and its behavior is shown in fig.18. This robot eventually achieved going up three steps. Otherwise, robot D and robot F could go up only one step at 0.10 m height. However, these results are not generated with EMG control but manual control. This is because EMG generates continuous movement so that it was difficult to control static movement for going up steps. However, the movement looked natural.



(a) Robot A (b) Robot B

(c) Robot C (d) Robot D

(e) Robot E (f) Robot F

Fig.17 Locomotors design by students in the second edutainment course

TABLE VIII
Ranking of locomotive robots design by students in the second course

Rank	Contents
1	Robot A went up three steps (0.2m).
2	Robot F could not go up normal but short steps (0.03m).
3-	Robot B, C, D, and E could go up only one short step (0.03m). Because the structural size require more depth at steps.

Students in the second course implemented source codes but students in the third course used bio-signal interface. The difference influenced its course hour (Table IX).

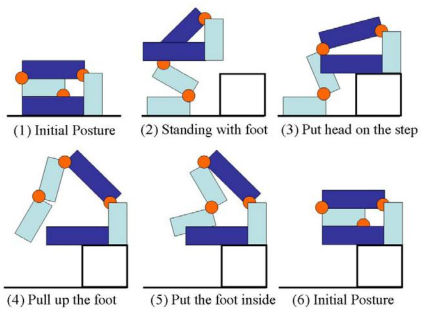


Fig.18 Conceptual figure of the best robot's movement

TABLE IX
History of our robot education course

	Students' Task			Participants	Duration
	A	B	C		
1st	No	Yes	Yes:1	20 Graduates	5 hours
2nd	No	Yes	Yes:2	7 Undergraduates	6 hours
3rd	No	Yes	No:2	3 Undergraduates	2 hours
Info.	A: making electronic circuit, B: building plastic bottle based robot, C: implementing control architecture (1: autonomous, 2: bio-signal)				

V. Conclusion

In this paper, we introduced our robot package for educational use. With this package, students can design both morphology and controller: robot structure is constructed with plastic bottles and RC servo-motors so that it is easy to build; three types of controllers such as autonomous robot controller, bio-signal interface controller, and manual controller are presented. In robot education courses, students built locomotive robots with autonomous robot controller and we have confirmed morph-functionality among those robots. With bio-signal interface controller, students have practically experienced bio-signal technologies. Thus, we can modify course programs depending on students' targets and course hour. Therefore, we concluded this robot package is helpful that students experience engineering technologies.

References

[1] H. Lund and L. Pagliarin, "Edutainment Robotics,: Applying Modern AI Techniques." In Proceedings of International Conference on Autonomous Minirobots for Research and Edutainment, 2001.

[2] C. Paul, V. Hafner and J. C. Bongard, "Teaching New Artificial Intelligence using Constructionist Edutainment Robots", Workshop on Edutainment Robots, 2000.

[3] KONDI KAGAKU CO., LTD, http://www.kondo-robot.com/html/Info_En.html

[4] S. Collins, A. Ruina, "A bipedal walking robot with efficient and human-like gait," In Proc. IEEE International Conference on Robotics and Automation, 2005.

[5] M. Hirose, Y. Haikawa, T. Takenaka, K. Hirai, "Development of Humanoid Robot ASIMO," Proc. Int. Conference on Intelligent Robots and System, 2001.

[6] T. McGeer, "Passive dynamic walking," Int. J. Robotics Research, 9(2) pp.62–82, 1990.

[7] C. Paul, "Morphology and computation," Proc. of Int. Conf. on the Simulation of Adaptive Behaviour, 2004.

[8] R. Pfeifer, C. Scheier. Understanding Intelligence. MIT Press, 1999.

[9] M.aH. Raibert, Legged robot that balance, 1986.