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Design and Development of Biomimetic Quadruped Robot for Behavior Studies of Rats and Mice

Hiroyuki ISHII, Yuichi MASUDA, Syunsuke MIYAGISHIMA, Shogo FUMINO, *No member, IEEE*, Atsuo TAKANISHI, Cecilia LASCHI, Barbara MAZZOLAI, Virgilio MATTOLI, Paolo DARIO, *Member, IEEE*

Abstract—**This paper presents the design and development of a novel biomimetic quadruped robot for behavior studies of rats and mice. Many studies have been performed using these animals for the purpose of understanding human mind in psychology, pharmacology and brain science. In these fields, several experiments on social interactions have been performed using rats as basic studies of mental disorders or social learning. However, some researchers mention that the experiments on social interactions using animals are poorly-reproducible. Therefore, we consider that reproducibility of these experiments can be improved by using a robotic agent that interacts with an animal subject. Thus, we developed a small quadruped robot WR-2 (Waseda Rat No. 2) that behaves like a real rat. Proportion and DOF arrangement of WR-2 are designed based on those of a mature rat. This robot has four 3-DOF legs, a 2-DOF waist and a 1-DOF neck. A microcontroller and a wireless communication module are implemented on it. A battery is also implemented. Thus, it can walk, rear by limbs and groom its body.**

Key word: Biomimetics, Quadruped robot, Experiments with animals

I. Introduction

UNDERSTANDING human mind is one of the most important research issues. Animal experiments play a very important part for it. Many experiments with rats and mice have been performed in various research fields such as pharmacology, brain science, neuroscience and basic psychology [1]-[3]. In these fields, several experiments on social interactions have been performed as basic studies of mental disorders or social learning [4]-[6]. For instance, Ray performed two experiments to investigate whether a rat can imitate a motion of the other one[6]. Ray described that the rat might be able to imitate motions of the others [6]. However, some researchers mention lack of reproducibility in the experiments on social interactions using animals. We consider it's very difficult to improve reproducibility of the experiments on social interactions because the social interactions of animals are not reproducible naturally.

On the other hand, several quadruped robots have been developed. One of the most famous quadruped robots is AIBO [7]. This robot was developed for home entertainment. Big Dog and Little Dog are also well known. Big Dog was developed as a transport machine and Little Dog was developed for research on learning locomotion [8][9]. We then consider that reproducibility of the experiments on social interactions using animals can be increased by using a biomimetic quadruped robots as an agent that interacts with an animal subject. We developed two different quadruped robots [10][11]. The first one had four 2-DOF legs. The size and weight is almost equal to a mature rat [10]. However, this robot doesn't reproduce rat's social behavior such as rearing, sniffing or mounting. The second one had four 2-DOF legs, and a 1-DOF waist yaw joint [11]. However, this robot doesn't reproduce rat's social behavior either. Thus, we developed a new biomimetic quadruped robot that interacts with a rat.

We then designed a new quadruped robot WR-2 (Waseda Rat No. 2). WR-2 is designed to interact with a rat in a natural way. Thus, it should reproduce several social interactions such as chasing, sniffing, social grooming and mounting. The proportion and DOF arrangement of WR-2 are then designed based on those of a mature rat. This robot consists of four 3-DOF legs, a 2-DOF waist and a 1-DOF neck. It has a microcontroller, a wireless communication module and a battery. In this paper, we describe mechanical design, control system and specification of WR-2.

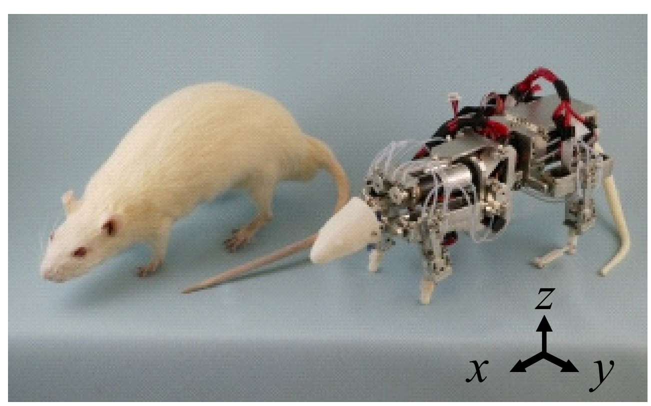


Fig. 1 Real rat (left) and WR-2 (right)

Hiroyuki ISHII is with Faculty of Science and Engineering, Waseda University, 2-2 Wakamatsu-cho, Shinjyuku-ku, Tokyo, 162-8480, Japan. (e-mail: h-ishii@takanishi.mech.waseda.ac.jp)

Yuichi MASUDA, Syunsuke MIYAGISHIMA and Shogo FUMINO are with Graduate School of Science and Engineering, Waseda University, 2-2 Wakamatsu-cho, Shinjyuku-ku Tokyo, 162-8480, Japan

Atsuo TAKANISHI1 is with Faculty of Science and Engineering, Waseda University, 2-2 Wakamatsu-cho, Shinjyuku-ku, Tokyo, 162-8480, Japan.

Cecilia LASCHI, Barbara MAZZOLAI, Virgilio MATTOLI and Paolo DARIO4 are with CRIM & ARTS Labs, Polo Sant'Anna Valdera, Scuola Superiore Sant'Anna, Viale Rinaldo Piaggio 34, 56025 Pontedera (Pisa) - Italy

II. Proportion and DOF Arrangement of Mature Rat

WR-2 is designed to interact with a rat in a natural way. Therefore, the body proportion and DOF arrangement of WR-2 should be same as those of a mature rat. In chapter II, we describe proportion and DOF arrangement of a mature rat.

A. Size and Proportion

The size and weight of a mature rat is as shown in table 1.

Table 1 Size and weight of a mature rat

Width	mm	50 - 120
Height	mm	70 - 150
Length	mm	200 - 350
Weight	g	300 - 1000

An x-ray picture of a mature rat and the proportion of each part, the upper and lower arm, the upper and lower limb and the neck to the spine are shown in figure 2. Comparing to other quadruped animals such as dogs or horses, the proportion of rat's spine to its arms and limbs are bigger. As shown in the figure, length of the lower limb is longer than that of the lower arm while those of the upper arm and the upper limb are almost same.

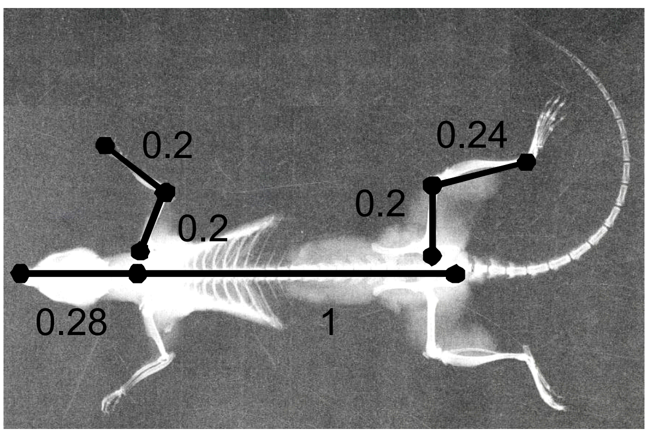
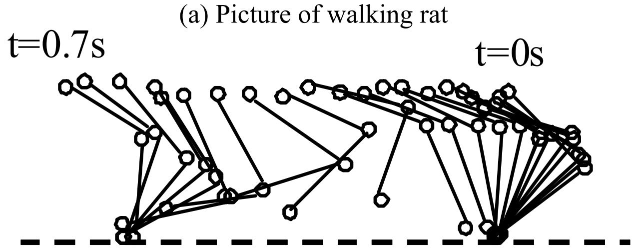


Fig. 2 X-ray picture of a rat and its body proportion

(a) Picture of walking rat



(b) Stick diagram of walking rat, drawn in ever 0.03 [ms]

Fig. 3 Motion analysis of rat

B. DOF arrangement

The DOF arrangement of a mature rat is experimentally obtained by a motion analysis. Walking motion of a rat is recorded by a video camera, and a stick diagram is obtained by visual analysis as shown in figure 3. We analyzed the motion of both the arms and limbs in not only x-z plane but also y-z plane. From the result of this analysis, we consider that each arm/ limb can be represented a 3-DOF manipulator, a roll and pitch at the shoulder/hip, a pitch at the elbow/knee. In addition, rats have a flexible spine, and they can bend their body when they rear by limbs or groom. We consider these motions can be represented a 2-DOF waist joint, a pitch and a yaw. Via this kind of motion and kinematical analysis, we consider that the muscle skeleton structure of the mature rat can be represented by the kinematic model as shown in figure 4.

III. Hardware Design

Hardware of WR-2 was designed based on the kinematic model as shown in figure 4 and studies in anatomy [12].

A. Arm

1) Design:

Each arm consists of 3 DOF, a roll and pitch at the shoulder and a pitch at the elbow. Proportion between the upper and the lower arm is determined based on the model as shown in figure 2.

As you can see in figure 3(a), the arms of rats are very small. Therefore, we consider that actuators should be implemented in the body, not in the arm.

2) Actuator:

Each joint is actuated by a DC motor with a rotary encoder. Specifications of the motors are shown in table 2.

Table 2 Specifications of the motors on WR-2

Joint	Power W	Encoder resolution deg/pulse
Shoulder/Hip roll	2.5	8.8×10^{-2}
Shoulder/Hip pitch	0.75	3.5×10^{-1}
Elbow/Knee pitch	0.75	3.5×10^{-1}

As shown in figure 5 (a), only the shoulder roll is directly driven by the DC motor. The shoulder pitch and the elbow pitch are driven by the DC motors via the wire and outer-tube connection mechanisms. The motors to drive these joint are implemented in the body. The problems of this kind of wire and outer-tube mechanisms are buckling of the tube and friction between the wire and the tube. To solve these problems, the outer-tubes are made from fluorine resin.

B. Limb

The design of each limb is almost same as that of the arm except for position of the motor to drive the knee pitch as shown in figure 5 (b).

C. Waist

The waist consists of 2-DOF joint, a yaw and pitch. Each axis is actuated by a servo motor for hobby use.

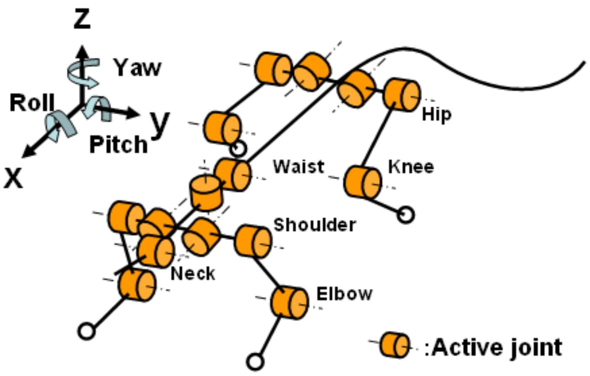
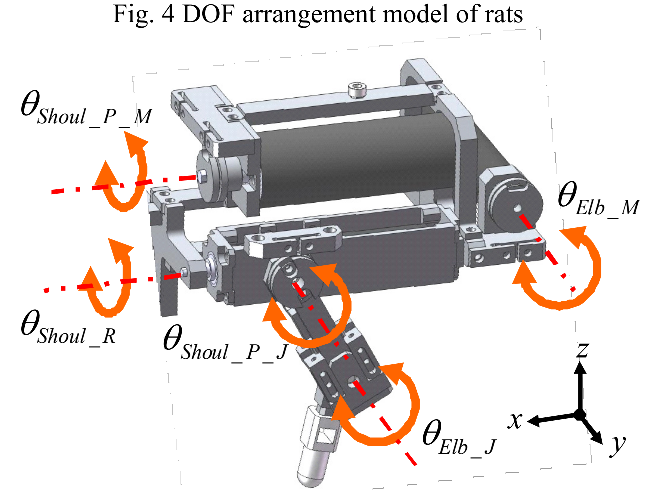
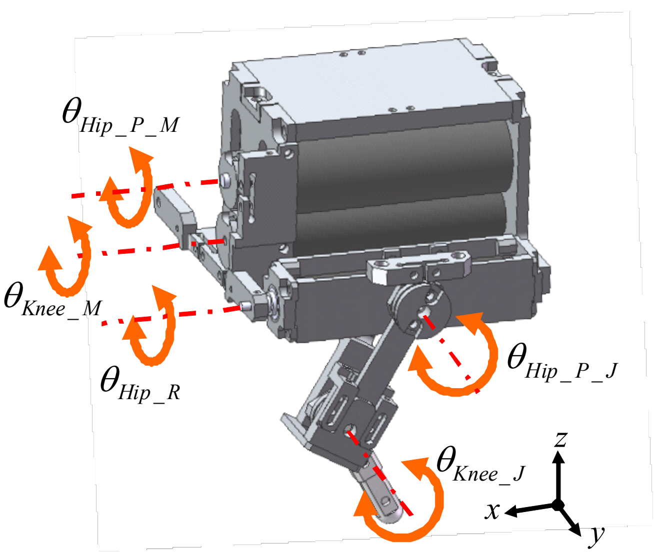


Fig. 4 DOF arrangement model of rats



(a) Left arm



(b) Left limb

Fig. 5 Mechanical design of arm and limb

IV. Control System

A microcontroller, wireless communication module are implemented in WR-2, and this robot is controlled by the PC via wireless connection.

A. Controller circuit

A controller circuit that is originally developed for WR-2 is implemented. A microcontroller, STM32F103ZE6T (STMicro electronics) and 6 motor drivers (each drives two motors) are implemented in it. All the motors, not only the DC motors but also the servo motors are connected with this circuit and controlled.

Some motion patterns are implemented in the microcontroller as time-line data of each joint angle. The microcontroller control the angle of each joint based on the pattern when it receives the instruction from the PC.

B. Control of DC motor

Angles of each DC motor are controlled with the position servo control. The microcontroller measures the angles of each motor and calculates instruction to the motor drivers (direction and duty ratio of PWM) every 1 [ms]. Signals (pulses) from the rotary encoders are counted using the external input interrupt functions. PWM pulses are generated using hardware timer modules of the microcontroller.

C. Walking pattern generator

Walking motion patterns are beforehand computed using the walking pattern generator as shown in figure 6. This generator was developed for WR-2 based on the theory of ZMP stability criterion [13][14]. Kinematic model with mass distribution as shown in figure 6 (b) is implemented in this generator. It computes time-line data of each joint angle based on the procedure as shown in figure 6 (a).

V. Specification

We performed some evaluation tests and obtained the performance data of WR-2 as shown in table 3.

Table 3 Performance data of WR-2

Dimension	mm	70 x 90 x 240
Weight	g	850
Walking speed	mm/s	15

VI. Conclusion and Future Work

We developed a biomimetic quadruped robot WR-2 for behavior studies of rats and mice. WR-2 is designed based on knowledge of rat's anatomy and the kinematic model that was experimentally obtained. WR-2 has four 3-DOF legs, a 2-DOF waist and a 1-DOF neck. Designs of each arm and limb are unique. Some joints are driven by the motors via the wire and outer-tube mechanism.

The shape of WR-2 is similar to that of a mature rat. However motion performance of WR-2 is lower than that of real one. We consider that WR-2's performance would be much better than the current result by tuning some mechanical parts such as tension of each wire. We will start to perform some experiments using WR-2 collaborating with the animal psychologists and the pharmacologists. In an experiment, we will put WR-2 and a real rat into a small box together. The social interactions between WR-2 and a rat are measured by the automatic experimental setup that was developed to measure behavior of a rat [15]. We consider that social interactions will be observed when WR-2 acts to the real rat.

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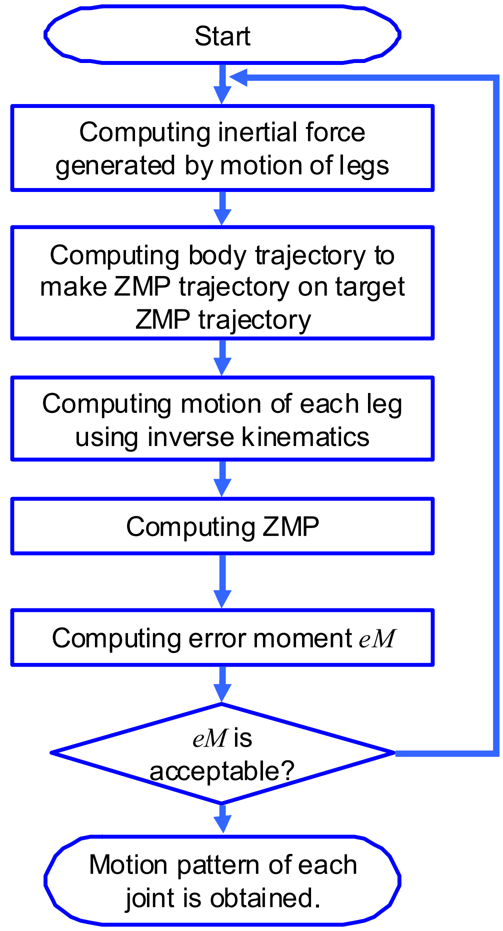
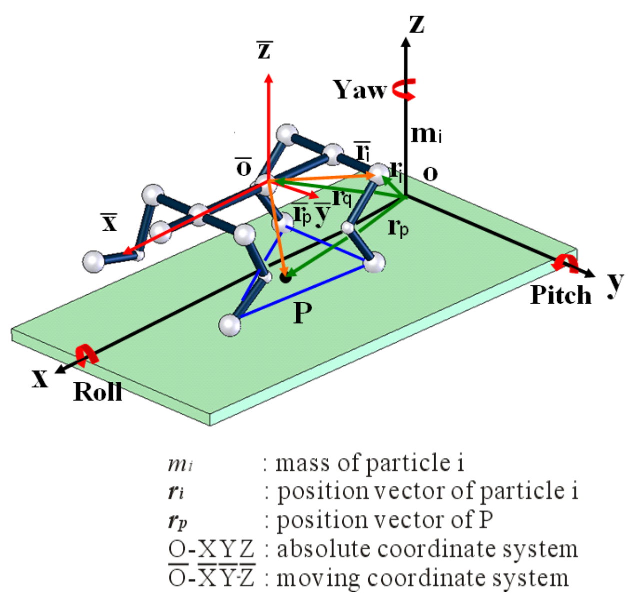


(a) Algorithm of computing walking pattern



(b) Kinematics model with mass distribution of WR-2

Fig. 6 dynamic walking pattern generator for WR-2