Pneumatic Musculoskeletal Infant Robots

Kenichi Narioka, Ryuma Niiyama, Yoichiro Ishii, and Koh Hosoda

***Abstract*— The basis of human motor skills and cognitive abilities is acquired during its infancy. The mechanism of the development, however, is as yet a big mystery. Our goal is to clarify the role of embodiment, especially of the musculoskeletal system, in the early stage of the development through robot experiments in the real world. In this paper, we describe the design concept of infant-sized musculoskeletal robots driven by McKibben pneumatic artificial muscles. We show some examples that demonstrate the musculoskeletal infant robot can be a good platform to investigate motion development.**

I. Introduction

The basis of human motor skills and cognitive abilities of are developmentally acquired during its infancy. Due to the complexity of the human body and difficulties in measurement, the mechanisms of human development are still a big mystery. Cognitive developmental robotics [1] is an approach to understand human development using artificial agents, in practice, computer simulations and robots. Through observations of the development of an agent, we might improve our models and derive a new understanding of development. In addition, the developmental models would assist to enhance cognitive and physical abilities of robots.

Infant development involves a huge variety of interactions with the environment via the body. The properties of the body play a great role in such interaction; the musculoskeletal structure especially greatly affects the infant's movement. To investigate the role of the musculoskeletal body in human development based on the methodology of cognitive developmental robotics, it requires the introduction of a musculoskeletal structure in the robot.

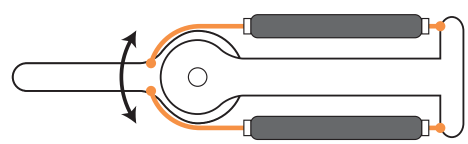
Recently, numerical simulations of infants including a musculoskeletal structure and a neural system have been developed [2]. However, the characteristics of the soft body were ignored, and its environment was also simplified. Since it is difficult to simulate soft materials with complex form in a realistic environment precisely, physical models are useful in such a study. In previous studies using physical robots, the robot had no musculoskeletal structure, the weight and size of the robot were far from that of an infant [3], or deal only with social interactions [4]. In addition to the properties of the body, one of the necessary conditions of the robot is its ability to move around in the environment without any trouble such as mechanical damage or heat problems.

In this paper, we present musculoskeletal infant robots for human developmental studies. We employ a pneumatic musculoskeletal system [5], [6] based on the structure of the human body. We describe the design of two types of musculoskeletal robots corresponding to infants of different age in months. The pneumatic actuator used in the system avoids the problem of mechanical damage and excessive heat in long-term experiments in the real world. The musculoskeletal infant robot is expected to help in understanding the role of embodiment in human development.

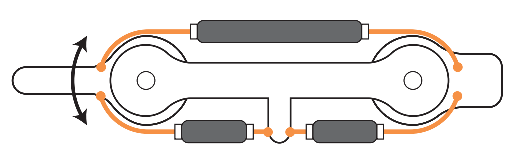
II. Pneumatic musculoskeletal system

A. Musculoskeletal structure

The model of the artificial musculoskeletal structure is shown in Fig.1. Not only the joint angle but also the stiffness of a joint can be easily controlled with agonistic and antagonistic mono-articular muscles as shown in Fig.1 (a). A bi-articular muscle, which works over two joints can be implemented as shown in Fig.1 (b). A bi-articular muscle is one of the characteristic structures of human musculoskeletal system and is supposed to play a role in coordinating relevant muscles, so it may have a great effect on motor development.



(a) mono-articular muscles



(b) mono-articular muscles and bi-articular muscle

Fig. 1. Musculoskeletal structure

B. McKibben pneumatic muscle

We use McKibben pneumatic muscles as actuators that compose the artificial musculoskeletal system. A McKibben pneumatic muscle, which basically consists of an inner

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rubber tube and an outer nylon sleeve, contracts when compressed air is supplied to the inner tube. The maximum contraction ratio is around 25% while the ratio is adjusted by its inner pressure. The stiffness of a pneumatic muscle is also changed according to the inner pressure. We made pneumatic muscles with various lengths, a part of which is shown in Fig.2. The length of the two upper and the two lower pneumatic muscles is 60 mm and 200 mm, respectively. The inner pressure of the upper muscle of each pair is around 0.5 MPa so that their length becomes shortened. Edges of some pneumatic muscles are connected to steel wires, which are guided by metal parts, so that the directions of the tensions of the muscles are easily modulated.

Fig. 2. McKibben pneumatic muscles

The features of pneumatic muscles offer the following benefits to a robot with a pneumatic musculoskeletal system:

- Mechanical softness and backdrivability allow movement involving hard physical contact with the environment
- High power-weight ratio contributes to good mobility
- Reduced heat problems compared to that of electric motors allow the robot to move for longer periods

It is difficult to carry out long term experiments of motor development using existing architectures with electric motors. By contrast, the advantages of the pneumatic musculoskeletal system outlined above can be quite useful for such an experiment.

C. System overview

The pneumatic and electrical system we implemented is shown in Fig.3. There are two types of solenoid valves. The air solenoid valve (a) (S070, SMC Corporation) is a two position valve consisting of two valves, for supplying and exhausting air, are used for one pneumatic muscle as shown ont the left side of Fig.3. Valve (a) is quite small and lightweight but its effective cross-section area is small so that its air flow limit is low. On the other hand, the air solenoid valve (b) (SYJ3320, SMC Corporation) is a three position valve so that one valve is used for one pneumatic muscle as shown on the right side of Fig.3. Valve (b) is relatively large and heavy but its air flow limit is high.

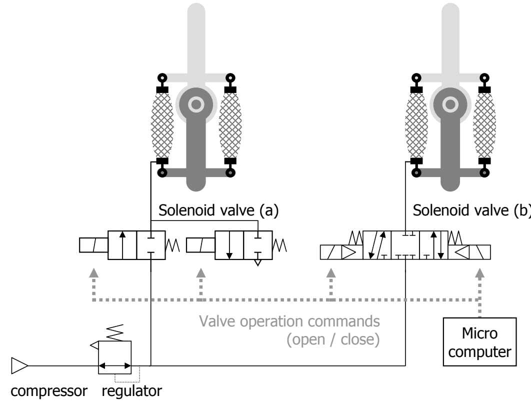


Fig. 3. Pneumatic and electric system

III. Musculoskeletal infant prototypes

A. Pneuborn-7II

The overview and the basic specification of a pneumatic musculoskeletal infant robot named “Pneuborn-7II” are shown in Fig.4 and Table I, respectively. The body size corresponds to that of a seven-month-old infant and the target tasks of the robot are basic locomotion such as rolling over and crawling, which are acquired at the age of around seven months. The skeletal structure, muscle alignment, and range of motion are designed on the basis of functional anatomy, biomechanics, and observation of real human babies. The robot is autonomous and contains a micro controller, air solenoid valves, battery, air source (CO_2 cartridge bottle). If it is required to move for long hours, air can be supplied by an external air compressor.

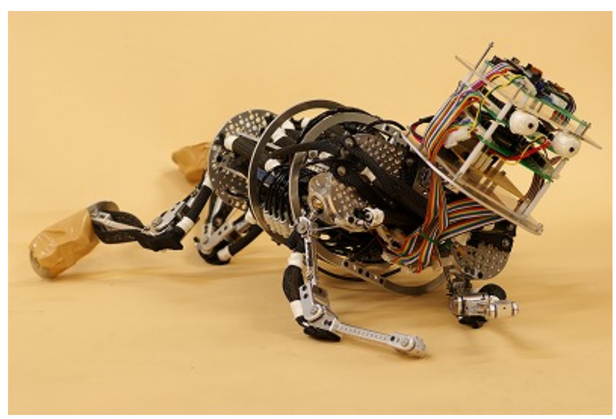


Fig. 4. Musculoskeletal infant robot Pneuborn-7II

The skeletal system of the robot is shown in Fig.5. Ball and socket joints are used as shoulder and hip joints. These joints are attached to the trunk with certain angles, referring to the anatomical structure of a human infant. A spinal structure is implemented by three pitch and three yaw joints so that the trunk of the robot can rotate, flex, and extend as shown in Fig.6. At present there are 19 pneumatic muscles, which drive shoulder, hip, knee, neck, and trunk joints as shown

TABLE I

SPEC OF PNEUBORN-7II

Height	0.8 m
Weight	5.44 kg
DoF	Total 26 ： Arm 5×2 (Shoulder 3, Elbow 1, Wrist 1) Leg 5×2 (Hip 3, Knee 1, Ankle 1) Neck 2, Trunk 4
Muscle	Total 19 : Arm 3×2 (Shoulder's flexion, extension, adduction) Leg 5×2 (Hip's flexion, extension, abduction Knee's flexion, extension) Neck, Trunk 3 (Trunk's rotation, Spine's extension)
Controller	H8-3069 (Renesas Technology Corporation)
Air valve	(a) S070 (SMC Corporation) ×10 (b) SYJ3320 (SMC Corporation) ×9
Air source	CO_2 cartridge / external air compressor

in Table I. The other joints are passive joints. A bi-articular muscle is implemented over the hip joint and the knee joint, corresponding to a human hamstring.

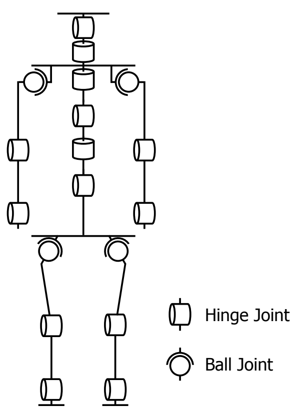


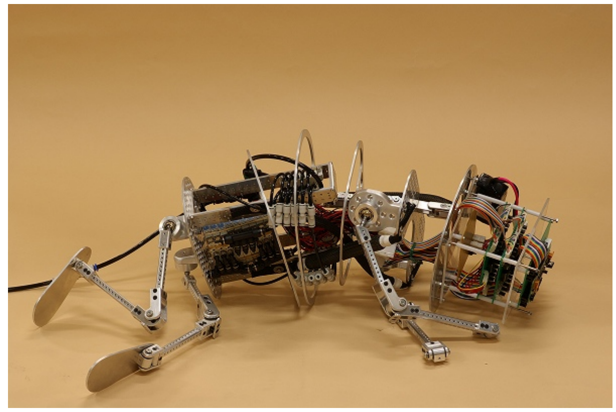
Fig. 5. DoF of Pneuborn-7II

The first challenge for this robot is to acquire locomotion behaviors such as crawling. We are now trying to apply the architecture of locomotion learning with CPG and Powell's method [8].

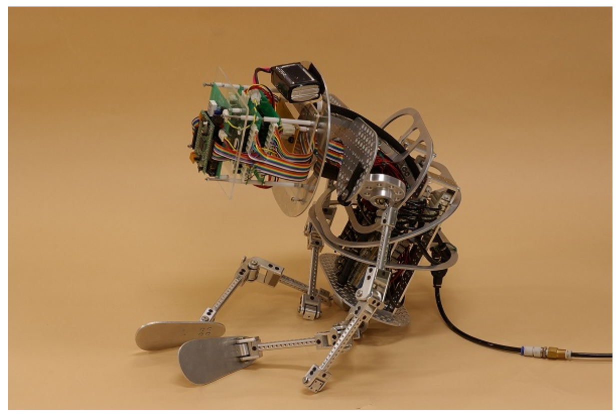
B. Pneuborn-13

We built up another infant robot named "Pneuborn-13". The overview and the specification of the robot are shown in Fig.7 and Table II, respectively. Although the basic structure of this robot is the same as Pneuborn-7II, the design concept is somewhat different. The target of investigation of Pneuborn-13 is development of bipedal walking. Accordingly 18 pneumatic muscles are concentrated at the ankle, knee, and hip joints.

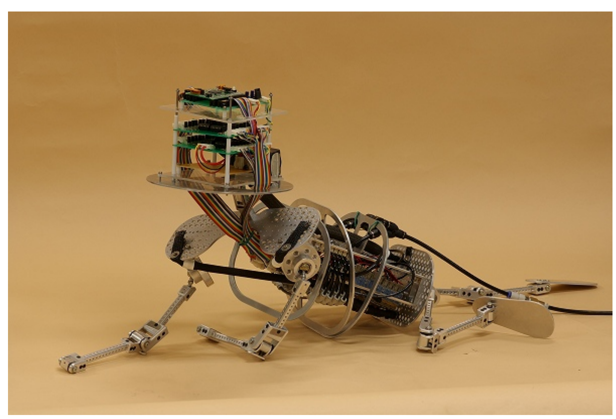
The weight and height of the body correspond to that of a 13-month-old infant. The robot is autonomous as Pneuborn-7II and contains a controller, air valves, battery, air source



(a) axial rotation



(b) flexion



(c) extension

Fig. 6. Motion of trunk

(CO_2 cartridge bottle). Only valve (a) is used in this robot. Although the skeletal system of Pneuborn-13 as shown in Fig.8 is almost the same as Pneuborn-7II, there is no spinal joint.

Pneuborn-13 can keep a standing posture and make stepping motions. Using this robot, we are trying to clarify the role of the musculoskeletal structure in the emergence of bipedal walking.

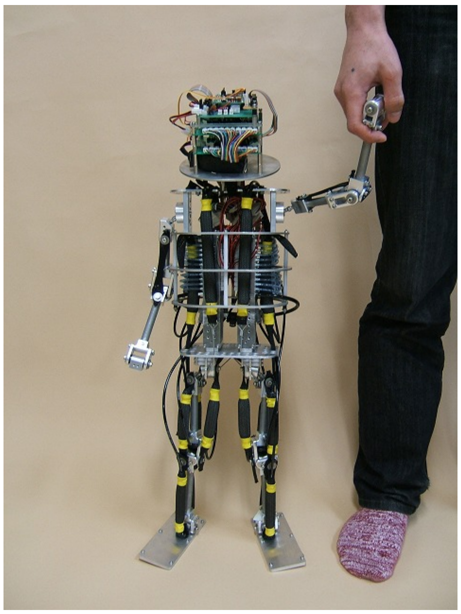


Fig. 7. Musculoskeletal infant robot Pneuborn-13

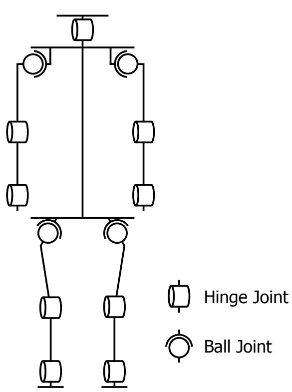


Fig. 8. DoF of Pneuborn-13

IV. Discussion

We have described the design concept of infant robots with a pneumatic musculoskeletal system. Two prototypes, Pneuborn-7II and Pneuborn-13, have been introduced. Since these robots have humanlike musculoskeletal structure, they can serve us a platform to understand the role of the body structure in motor development of an infant.

TABLE II
SPEC OF PNEUBORN-13

Height	0.75 m
Weight	3.9 kg
DoF	Total 21 DoF : Arm 5×2 (Shoulder 3, Elbow 1, Wrist 1) Leg 5×2 (Hip 3, Knee 1, Ankle 1) Neck 1
Muscle	Total 18 : Leg 9×2 Hip : flexion, extension, adduction, abduction external rotation Knee : flexion, extension Ankle : flexion, extension
Controller	H8-3069 (Renesas Technology Corporation)
Air valve	S070 (SMC Corporation)
Air source	CO_2 cartridge / external air compressor

One of the features of the robots is the ability to move around for an extended period, in contact with the environment. In fact, we have carried out a pilot study to verify that the infant robots can move around for at least several hours without breakdown and overheating.

We plan to conduct some experiments of motor development using these infant robots. The target tasks of Pneuborn-7II are locomotion such as rolling over and crawling while that of Pneuborn-13 is bipedal walking. Our goal is to clarify the relationship between motor development and embodiment, especially concerning the musculoskeletal system.

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