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Mechanical Design of Small-Size Humanoid Robot TWNHR-3

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Abstract- **In this paper, a mechanical structure with 26 DOFs (degrees of freedom) is proposed so that an implemented small-size humanoid robot named TWNHR-3 is able to accomplish the man-like walking motion. The height and weight of the implemented robot is 46 cm and 3.1 kg, respectively. There are 2 DOFs on the head, 2 DOFs on the trunk, 4 DOFs on each arm, and 7 DOFs on each leg. Some basic walking experiments of TWNHR-3 are presented to illustrate that the proposed mechanical structure lets the robot move forward, turn, and slip effectively.**

I. INTRODUCTION

For the widely potential use, humanoid robot has been studied for decades by a lot of research groups. Researchers at Waseda University started the humanoid robot research since 1966, and they recently developed a biped humanoid robot WABIAN-2 [1]. It has lead to the realization of emotional walking that is expressed by the parameterization of body motion, walking experiments based on an online pattern generation using obtained visual and auditory information [2]. Honda Corporation developed the humanoid robot P2, P3, and Asimo. Asimo has 34 DOFs, 120 cm height, and 43 kg weight. The control method of Asimo is using ZMP to plan the pre-recorded joint trajectories and play them back with sensor-based compliant control [3, 4]. The Japanese National Institute of Advanced Industrial Science and Technology and Kawada Industries, Inc., have jointly developed HRP-2 and HRP-2P from 1998. HRP-2 that can walk, lie down and get up [5-7]. HRP-2 has 30 DOFs, 154 cm height, and 58 kg weight. Technical University of Munich developed the humanoid robot JOHNNIE for realization of dynamic 3-D walking and jogging motion. It has 17 DOFs, 180cm height, and 37 kg weight [8]. Sony Corporation also developed several compact size humanoid robots including SDR-3X, SDR-4X, and QRIO. QRIO has 38 DOFs, 58 cm height, and 7 kg weight [9]. The University of Tokyo developed H6 and H7. The robot has 35 DOFs, 137 cm height, and 55 kg weight. The two robots can walk up and down 25 cm high steps and can also recognize pre-entered human faces [10, 11]. Recently, Beijing Institute of Technology has developed a humanoid robot called BHR-02, and this robot can perform some complicated dynamic motion, such as Chinese "sword" Kungfu, based on human motion capture [12]. BHR-02 has 32 DOFs, 160 cm height, and 63 kg weight. Korea Advanced Institute of Science and Technology developed KHR-3 humanoid (HUBO) [13]. HUBO has 41 DOFs, 125 cm height, and 55 kg weight. Team Nimbro from University of Freiburg has developed humanoid robot Paul [14]. The robot has 24 DOFs, 60 cm height, and 2.9 kg weight. The robots with the Packet PC as the controller can play soccer.

Although the humanoid robot has been investigated for many years [15-17], there are still many issues to be studied. Hardware and software architectures, walking gait generation, and artificial intelligence are the main research field of humanoid robot. In this context, Intelligent Control Lab. of Tamkang University is developing a compact size humanoid robot called TWNHR-3 for research and development of humanoid robot performing application tasks. The objective of developing TWNHR-3 is to build a platform to investigate the walking gait generation and artificial intelligence. The work is focusing on the static and dynamic walking on even and uneven ground. In this paper, a mechanical structure for TWNHR-3 with 26 DOFs is described.

The rest of this paper is organized as follows: Section II describes the design concept of humanoid robot TWNHR-3, In Section III, a mechanical structure of TWNHR-3 is described. In Section IV, some experiment results are provided. Finally, some conclusions are made in Section V.

II. DESIGN CONCEPT

Mechanical design is the first step of design a humanoid robot. Human body mechanism basically comprises bones, joints, muscles and tendons. It is impossible to replace all of the muscular-skeletal system by current mechanical and electrical components. Therefore, the primary goal of the humanoid robot mechanical design is development of a robot that can imitate equivalent human motion.

Fig. 1 presents the DOF configuration of TWNHR-3. In this paper, the rotational direction of each joint is defined by using the inertial coordinate system fixed on the ground as shown in Fig.

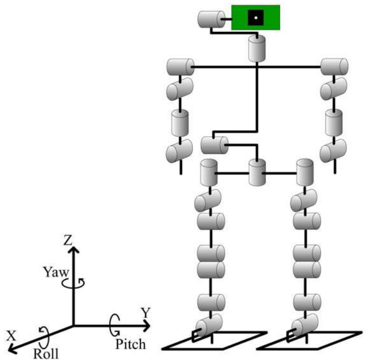


Fig. 1. DOF configuration.

III. MECHANISMS

The frameworks of TWNHR-3 are mainly fabricated from aluminum alloy 5052 in order to realize the concepts of light weight, wear-resisting, high stiffness and wide movable range. The main design concept of TWNHR-3 is light weight and compact size. The compact size robot has advantages such as the ease of maintenance and small construction costs. Each actuator system of the joint consists of a high torque and a gear. In this paper, the development of the head, arms, waist, trunk and legs is presented. The proposed robot has the mechanical with structural proportions similar to humans, achieving a human appearance. Fig. 2 is a photograph of TWNHR-3. The height of the robot is 46 cm and the weight is 3.1 kg with batteries. The rotating speed and rotating angle of each joint are designed based on the result of computer program. Fig. 3 shows the 3D solidwork design of TWNHR-3. A human-machine interface is designed to manipulate the servo motors. The details of each part are described as follows:

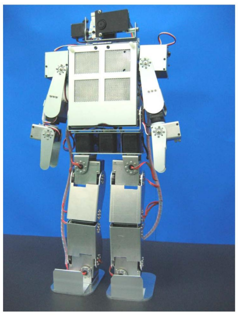
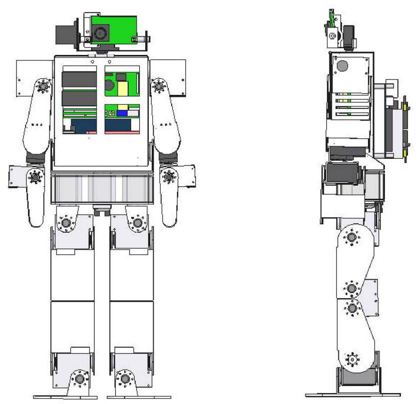
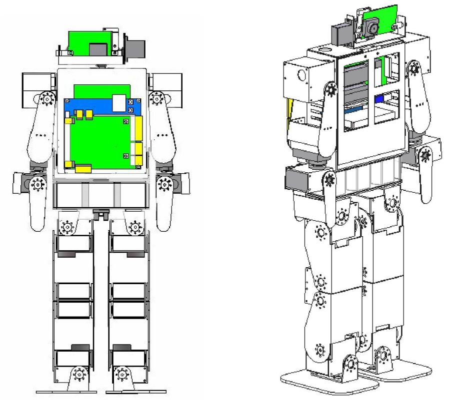


Fig. 2. Photo of TWNHR-3.



(a) Front view (b) Side view



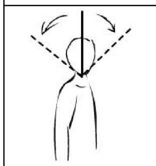
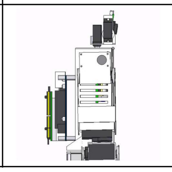
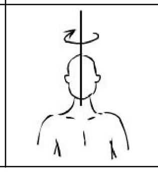
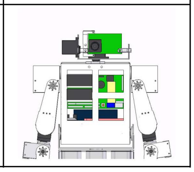
(c) Back view (d) Bird view

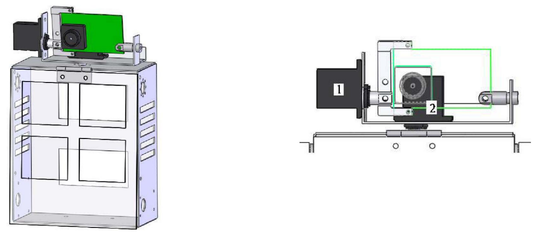
Fig. 3. Solidwork design of TWNHR-3.

A. Head

The head of TWNHR-3 has 2 DOFs. Fig.4 shows the 3D mechanism design of the head. The head is designed based on the concept that the head of the robot can accomplish the raw and pitch motion. Table I presents the head DOF relation between human and TWNHR-3.

Table I.
The head DOF relation between human and TWNHR-3.

Human figure	TWNHR-3	Human figure	TWNHR-3
			



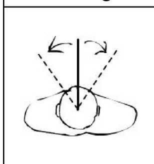
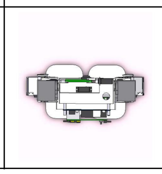
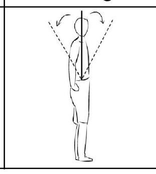
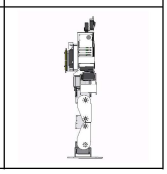
(a) Waist 3D design (b) DOFs diagram

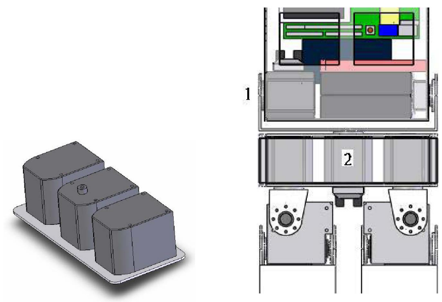
Fig. 4. Head mechanism.

B. Waist and Trunk

The head of TWNHR-3 has 2 DOFs. Fig. 5 shows the 3D mechanism design of the waist and trunk. The trunk is designed based on the concept that robot can walk and maintain its balance by using gyro to adjust the trunk motions to compensate for the robot's walk motion. Table II presents the specification of the joints for the waist and trunk.

Table II.
The waist and trunk DOF relation between human and TWNHR-3.

Human figure	TWNHR-3	Human figure	TWNHR-3
			



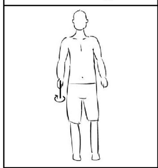
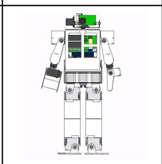
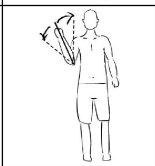
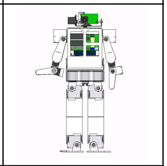
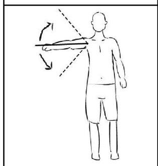
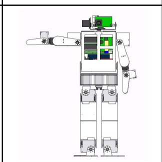
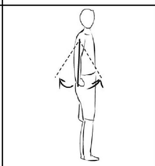
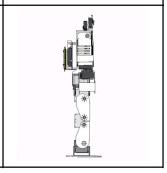
(a) Waist 3D design (b) DOFs diagram

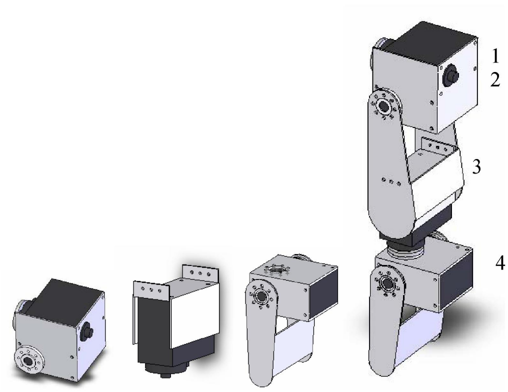
Fig. 5. Waist and trunk mechanism.

C. Arms

Each arm of TWNHR-3 has 4 DOFs. Fig. 6 shows the 3D mechanism design of the arms. The arms are designed based on the concept of size of the general human arms. The arms of the robot can hold an object such as a ball. Table III presents the specification of the joints for each arm.

Table III.
The arms DOF relation between human and TWNHR-3.

Human figure	TWNHR-3	Human figure	TWNHR-3
			
			

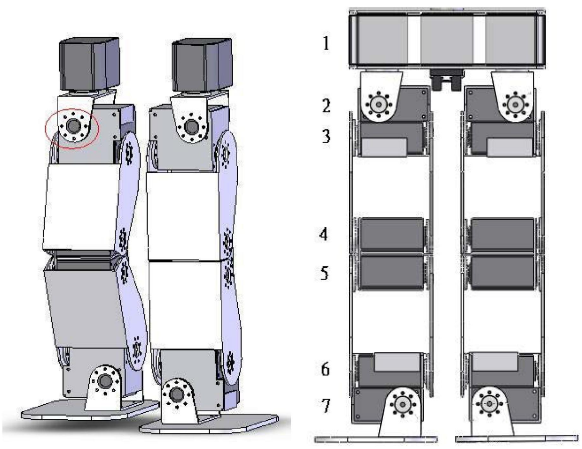


(a)Shoulder (b)Elbow (c)Wrist (d)Arm

Fig. 6. Left arm mechanism.

D. Legs

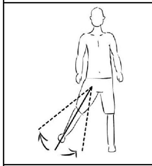
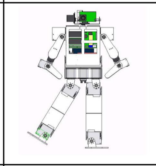
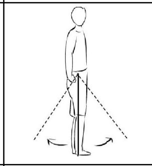
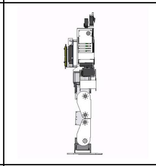
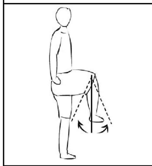
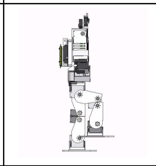
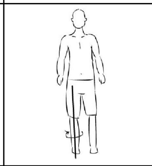
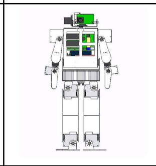
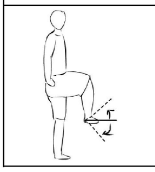
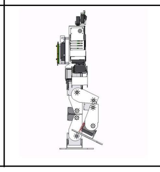
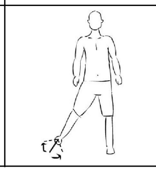
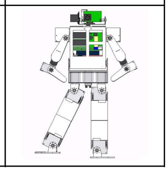
Each leg of TWNHR-3 has 7 DOFs. Fig. 7 shows the 3D mechanism design of the legs. The legs are designed based on the concept that robot can accomplish the human walking motion. Table IV presents the specification of the joints for each leg.



(a) 3D design (b) DOFs diagram

Fig. 7. Legs mechanism.

Table IV.
The legs DOF relation between human and TWNHR-3.

Human figure	TWNHR-3	Human figure	TWNHR-3
			
			
			

IV. EXPERIMENTS

In order to verify the effectiveness of the humanoid robot, three basic walking skills: straight walk, turn, and slip are carried out on a horizontal even plane and described as follows:

A. Straight walking

Fig. 8 shows the snapshots of straight walking TWNHR-3. The distance between every white line in the picture is 5cm. Every step of the straight walking is able to move forward 10 cm.

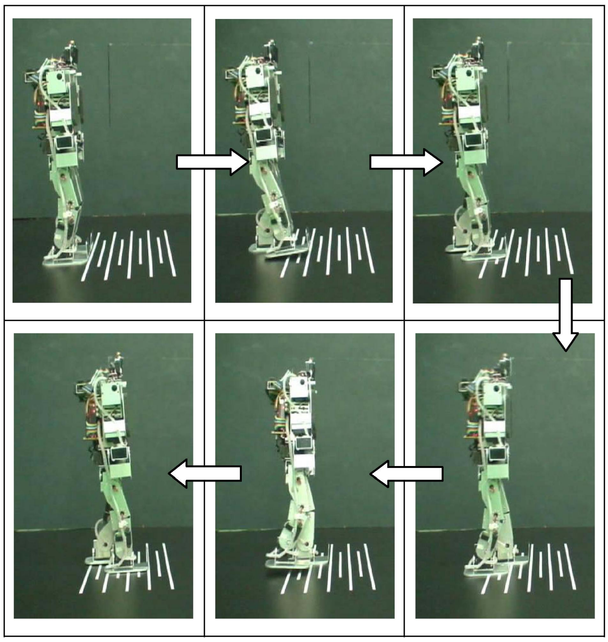


Fig.8. Straight walking.

B. Turn

Fig. 9 shows the snapshots of left turning TWNHR-3. The angle between every white line in the picture is 15 degrees. Each time of the robot turning is able to turn 30 degrees.

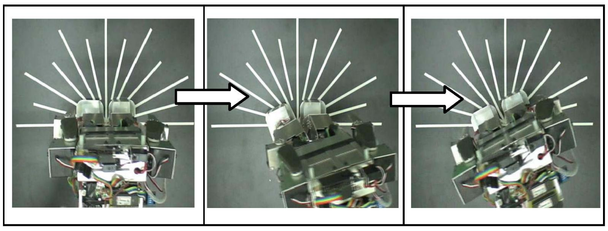


Fig. 9. 30 degrees left turning.

C. Slip

Fig. 10 shows the snapshots of right slipping TWNHR-3. The distance between every white line in the picture is 5cm. Every step of the slipping is able to slip 10 cm.

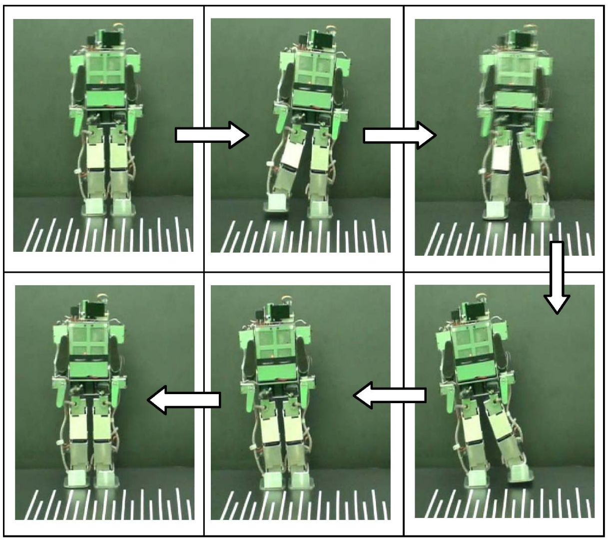


Fig. 10. Slipping to the right side.

V. CONCLUSIONS

A mechanical structure is proposed to implement a humanoid robot with 26 DOFs in this paper. This robot has 2 DOFs on the head, 2 DOFs on the trunk, 4 DOFs on each arm, and 7 DOFs on each leg. From the experiment results, we can see that the proposed mechanical structure can let the implemented robot move forward, turn, and slip effectively. One CMOS sensor is installed in TWNHR-3 so that it can be a vision-based soccer robot to autonomous find a ball and kick a ball. Moreover, TWNHR-3 wins champion of the humanoid league in Taiwan Cup 2006. In the future, force sensors will be installed in TWNHR-3 to study the biped walking control. More research on artificial intelligence will be carried on TWNHR-3 to make it to be an intelligent robot.

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