Mechanical Design of Small-Size Humanoid Robot: HIWIN MAN

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A structure design and a mechanical design of a humanoid robot named HIWIN MAN are described in this paper. This humanoid robot with 23 DOFs (degrees of freedom) is designed so that it is able to accomplish some human-like motions. The height and the weight of HIWIN MAN are 59 cm and 4.5 kg, respectively. There are 2 DOFs on the head, 4 DOFs on each arm, 1 DOF on the waist, and 6 DOFs on each leg. In the structure design of HIWIN MAN, the design concept, actuators model and frameworks are described. In the mechanical design of HIWIN MAN, the 3D design and the mechanism dimension of the head, waist, arms, and legs are described. Finally, three basic walking experiments of HIWIN MAN are presented to illustrate that the proposed mechanical structure is able to let HIWIN MAN walk forward, turn, and slip effectively.

1. INTRODUCTION

In the past, humanoid robots have been studied for decades by a lot of research groups. Researchers at Waseda University started the humanoid robot research since 1966, and they developed a biped humanoid robot WABIAN-2R[1]. The WABIAN-2R is developed to imitate the human motion. The walking experiments are based on an online pattern generation obtained by the visual and auditory information.[2] Honda Corporation developed humanoid robots named Asimo. The newest Asimo has 34 DOFs, 130 cm height, and 54 kg weight. The control method of Asimo is using the zero moment point to plan the pre-recorded joint trajectories and play them back with sensor-based compliant control.[3] Sony Corporation also developed several compact size humanoid robots named QRIO. QRIO has 38 DOFs, 58 cm height, and 7.3 kg weight.[4] The Japanese National Institute of Advanced Industrial Science and Technology and Kawada Industries, Inc., have jointly developed HRP-2 from 1998. HRP-2 can walk, lie down, get up, open a door and through a door.[5] HRP-2 has 30 DOFs, 154 cm height, and 58 kg weight. Beijing Institute of Technology also developed a humanoid robot called BHR-03, and this robot is characterized by its light weight construction.[6] BHR-02 has 32 DOFs, 160 cm height, and 63 kg weight. Korea Advanced Institute of Science and Technology developed KHR-3 humanoid (HUBO).[7] HUBO has 41 DOFs, 125 cm height, and 55 kg weight.

Although the robot has been investigated for many years, it still has many issues to be studied, especially in the humanoid robot area.[14-16] In this paper, a small-size humanoid robot called HIWIN MAN is developed. The objective of developing HIWIN MAN is to build a platform to investigate the walking gait generation and other artificial intelligence. The work is focusing on the static and dynamic walking on even and uneven ground. In this paper, a mechanical structure for HIWIN MAN with 23 DOFs is described. The rest of this paper is organized as follows: Section 2 is the structure design of HIWIN MAN. Section 3 is the mechanical design of HIWIN MAN. In Section 4, some experiment results are provided. Finally, some conclusions are made in Section 5.

2. Structure Design

The main design purposes are lightweight and robust so that HIWIN MAN can sustain the high speed movement. The actuators of the HIWIN MAN are fabricated from ROBOTIS. Three actuators are adopted on HIWIN MAN. These actuators specifications are shown in Table 1. The upper and lower bodies of HIWIN MAN are shown in Fig.1 and Fig.2, respectively. In the implementation of the head and arms of HIWIN MAN, Ax-18a and Rx-28 actuators are used to reduce the weight of the upper body. In the implementation of the waist, trunk and legs of HIWIN MAN, Rx-28 and Rx-64 actuators with a higher torque are used to let the robot have a higher power.

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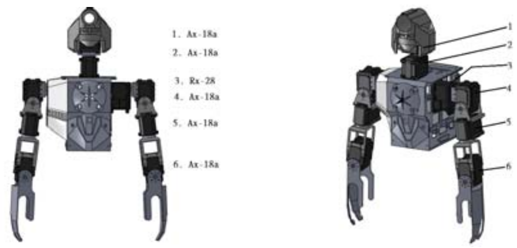
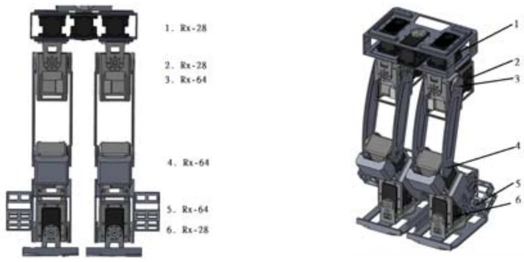
Table 1. The specifications of the actuators used for HIWIN MAN.

Actuator	Weight	Torque	Speed
Ax-18a	55g	18 kg·cm	0.119 sec/60°
Rx-28	72g	37.7 kg·cm	0.126 sec/60°
Rx-64	125g	64 kg·cm	0.162 sec/60°



(a) Front view (d) Bird view

Fig.1. Upper body of HIWIN MAN.



(a) Front view (d) Bird view

Fig.2. Lower body of HIWIN MAN.

The 3D Solidworks design and the photograph of HIWIN MAN are shown in Fig.3 and Fig.4, respectively. It has 23 DOFs and the height of the robot is 59 cm and the weight is 4.5 kg with batteries. The Solidworks software is used to do the stress and weight analysis of HIWIN MAN and check the collision of mechanism. These simulation and check procedure can speed up the design of HIWIN MAN and ensure the mechanism stress. The stress analysis of HIWIN MAN part is shown in Fig. 5. Use the stress analysis to choose the material of the alloy for HIWIN MAN. The frameworks of HIWIN MAN are mainly fabricated from aluminum alloy 5052, alloy 6061, and alloy 7072. The complex materials will realize the concepts of light weight, high stiffness and wide movable range.

(a) Front view (b) Side view (c) Back view (d) Bird view

Fig. 3. Solidworks design of HIWIN MAN.

Fig. 4. Photo of HIWIN MAN.

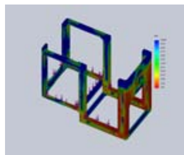


Fig. 5. Stress analysis of the HIWIN MAN part.

3. Mechanical Design

The DOFs diagram of the HIWIN MAN is shown in Fig. 6. It has 23 DOFs and 2 DOFs on the head, 1 DOF in the waist, 4 DOFs on each arm, and 6 DOFs on each leg. In this section, the developments of the head, arms, waist, trunk and legs are presented as follow:

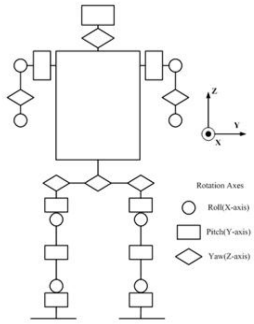
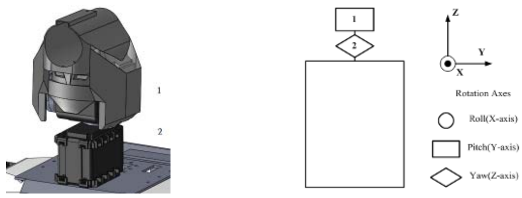


Fig. 6. DOFs diagram of HIWIN MAN.

3.1. Head

The mechanical design of head is to increase the view of the webcam on the HIWIN MAN. There are 2 DOFs to increase two dimension of the webcam. The 3D mechanism design and the DOFs diagram of the head is shown in Fig.6. The design purpose of the head mechanism is the robot can accomplish the pitch and yaw motion. These 2 DOFs can increase the visible range of HIWIN MAN. The head mechanism dimension of HIWIN MAN is shown in Fig. 7. The head mechanism have some protection design on the head. This protection design concept is lightweight and merge into the mechanism frameworks.



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

Fig. 6. Head mechanism.

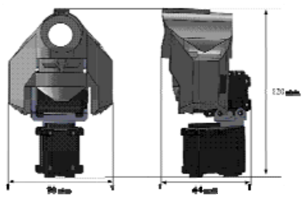
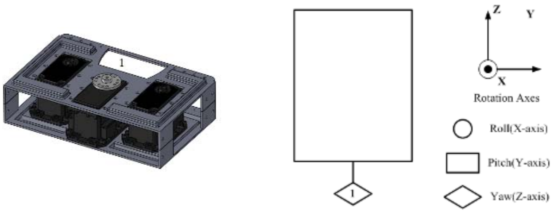


Fig.7. Head mechanism dimension

3.2 Waist

The mechanical design of the waist is for the fall down. There is 1 DOF in the waist. The 3D mechanism design and the DOF diagram of the waist are shown in Fig. 8. The actuator of the waist is in the middle of the three actuators. The design purpose of the waist mechanism is the robot can accomplish the yaw motion. This DOF can provide the HIWIN MAN turn the body over to the front side or back side to stand up. This DOF can also provide the waist turn to increase the ambit of the arms and the head. The waist mechanism dimension of HIWIN MAN is shown in Fig. 9. In order to realize light weight, high stiffness design concept in the waist. HIWIN MAN combines one of the leg DOF with the waist. Because these three DOFs all use Rx-28 actuator. The waist mechanism can design as a cube only use two simple mechanism. The waist structure is the center of gravity in the HIWIN MAN. Since this waist mechanism is the highest stiffness and the center of gravity, the HIWIN MAN can move as high speed motion.



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

Fig. 8. Waist mechanism.

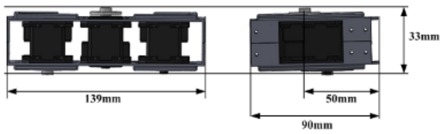
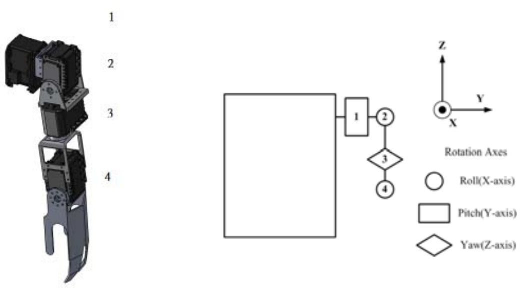


Fig. 9. Waist mechanism dimension of HIWIN MAN.

3.3 Arms

The mechanical design of the arms is for manipulation the object. There are 4 DOFs in each arm. The 3D mechanism design and the DOFs diagram of the arms are shown in Fig. 10. The design purpose of the arms mechanism is the robot can hold the objects such as a ping pong ball or hold a stick with compact disks. The arms are designed based on the concept of size of the general human arms. These DOFs can provide HIWIN MAN to hold on objects. The arms mechanism dimension of HIWIN MAN is shown in Fig. 11. In order to realize light weight, high stiffness design concept in the arms. HIWIN MAN combines one of the arm DOF with the body. Therefore the first DOF of the arms is inside the body. This is contributive for the robot balance when robot is walking. The hand is a special design for HIWIN MAN. This design can provide the arms of HIWIN MAN for manipulation the object.



(a) Left arm 3D design (b) Left arm DOF diagram

Fig. 10. Left arm mechanism.

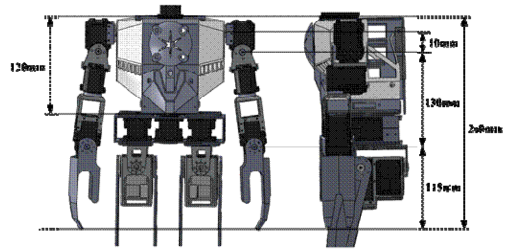
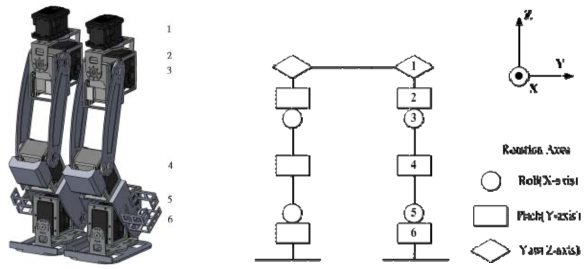


Fig. 11. Arms mechanism dimension of HIWIN MAN.

3.3 Legs

The mechanical design of the legs are for imitate the human walking motion. There are 6 DOFs in each leg. The 3D mechanism design and DOF diagram of the legs are shown in Fig. 12. The design purpose of the legs mechanism is the robot can accomplish the human walking motion. This design can provide the legs of HIWIN MAN for imitate the human walking motion. The legs mechanism dimension of HIWIN MAN is shown in Fig. 13. In order to realize light weight, high stiffness design concept in the legs. HIWIN MAN use alloy 7072 to combine 2 DOFs as a cube in the hip and ankle. Therefore the first DOF of the legs is inside the waist. This is contributive for the robot balance when robot is walking. The battery box is beside the ankle of HIWIN MAN. This design can lower the center of gravity of HIWIN MAN.



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

Fig. 12. Legs mechanism.

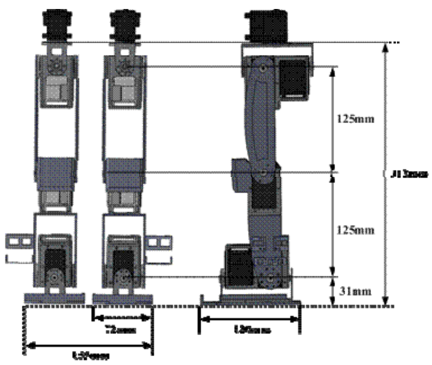


Fig. 13. Arms mechanism dimension of HIWIN MAN.

4. Experiments

In order to verify the performance of the implemented humanoid robot, three basic walking motions: straight walking, turning, and sideway slipping are carried out on a horizontal even plane and described as follows:

4.1 Straight Walking

The snapshots of straight walking for HIWIN MAN are shown in Fig. 14. The distance between every line in the picture is 5cm. Every cycle of the straight walking is able to walk forward 15 cm. And the time of each cycle is 1 sec. Compare with the result of TWNHR-IV[9], the straight walking performance of the HIWIN MAN is improved 15 cm per second.

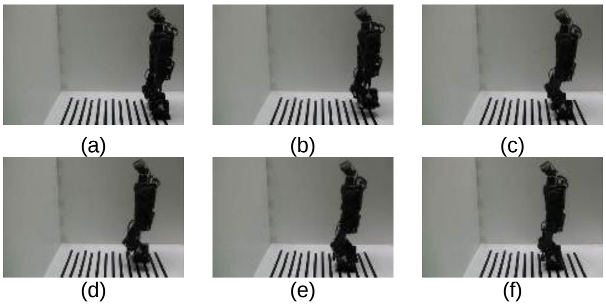


Fig.14. Straight walking.

4.2 Turning

The snapshots of right turning for HIWIN MAN are shown in Fig. 15. The angle between every line in the picture is 10 degrees. Each time of the robot turning is able to turn 20 degrees. And the time of each cycle is 1 sec. Compare with the result of TWNHR-IV [9], the turning performance of the HIWIN MAN is accurate than the TWNHR-IV.

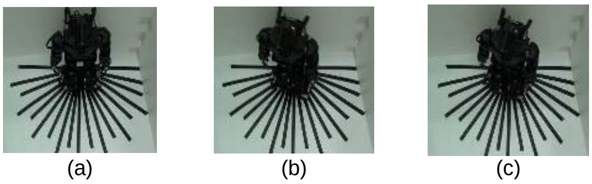


Fig. 15. 20 degrees right turning.

3.3 Sideway slip

The snapshots of sideway slip to the right for HIWIN MAN are shown in Fig. 16. The distance between every line in the picture is 5 cm. The robot is able to sideway slip 5 cm in each step. And the time of each step is less than 1 sec. Compare with the result of TWNHR-IV[9], the performance of the HIWIN MAN is better than the TWNHR-IV.

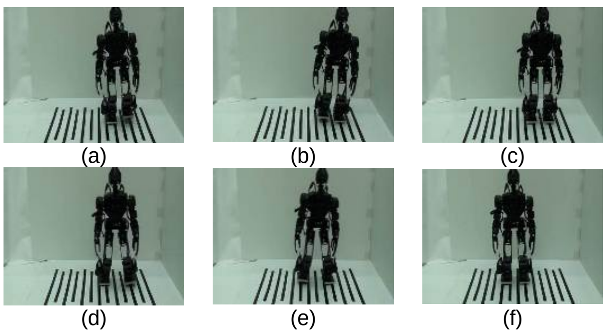


Fig. 16. Sideway slip to the right side.

5. CONCLUSION

A mechanical structure with 23 DOFs is proposed to implement a humanoid robot in this paper. This robot has 2 DOFs on the head, 1 DOF on the waist and trunk, 4 DOFs on each arm, and 6 DOFs on each leg. From the experimental results, we can see that the proposed mechanical structure can let the implemented robot walk forward, turn, and slip effectively. One webcam is installed on HIWIN MAN so that it can be a vision-based soccer robot to find a ball and kick a ball autonomously. Some artificial intelligence can be carried on HIWIN MAN to make it to be an intelligent robot. HIWIN MAN had been used to attend the “2011 FIRA HuroCup Competition” and won the Champion. It illustrates that the proposed method can let HIWIN MAN have a good performance.

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