Mechanical Design And Control System Configuration of a Humanoid Robot

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Abstract–This paper presents the research work on a small size humanoid robot: RoboSapien. The objective of this project is to build a platform for the study of dynamic walking and the artificial intelligence tools. In all, the robot has 17 degrees of freedom and each joint is driven by a DC servo motor. Two DSPs are utilized in the control system. In this paper, the mechanical design, control system configuration and experimental results are presented.

Keywords Humanoid robot; mechanical design; dynamic walking; control system configuration.

1 Introduction

Very little of the world is accessible by wheeled robots. Biped robots can adapt easily to various types of grounds especially those unknown environment. Biped robots can be used to explore inaccessible or hazardous locations and provide services in the places that are dangerous or not reachable for human beings. Waseda University had started the biped robot research in 1966 and have developed and investigated the Biped robot WABIAN. A 2-D biped robot SpringFlamingo and 3-D biped robot M2 have been designed and developed by the MIT Leg Laboratory.

Many humanoid robots have been developed [1], [2], [3], [4] and even several companies have commercialized humanoid robots. Many researchers are concentrating on algorithms of humanoid robot control [5-21]. Hardware development, walking gait generation and artificial intelligence are the main research areas related to the humanoid robot.

RoboSapien (Fig. 1) is a fully autonomous humanoid robot designed and built in the Mechatronics and Automation laboratory of National University of Singapore. Through the design of RoboSapien, this project aims to build a platform to investigate the walking gait generation and relevant intelligent control. The work focuses on static and dynamic walking on flat and uneven grounds, and climbing stairs.

This paper is organized as follows. Section 2 describes the mechanical design and specifications of RoboSapien. The electrical components are introduced in section 3. Section 4 presents the control system configuration. Experimental results are provided in Section 5, and finally Section 6 concludes the paper.

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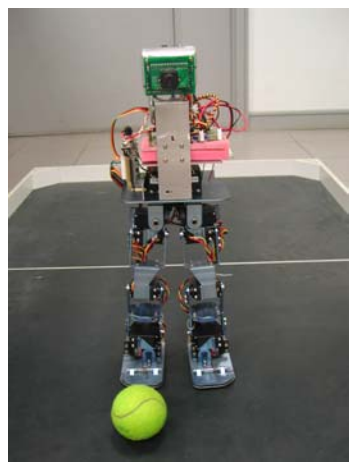

Fig. 1. RoboSapien

2 Mechanical Design

Fig. 2 shows the joint configuration of RoboSapien. RoboSapien has 6 DOF on each leg: three on the hip, one on the knee and two on the ankle. The design and mechanical structure of the legs are shown in Fig. 3 and 4. Two additional DOF on the toe are designed following the structure of the human toe. However, there are no actuators on those DOF. Springs control the joints passively (Fig. 5).

Standard DC servo motors (Hitec motors) are used as actuators. Normal DC servo motor has only one shaft. A new cover with shaft (Fig. 6) is designed to substitute the original cover, so that the motor has

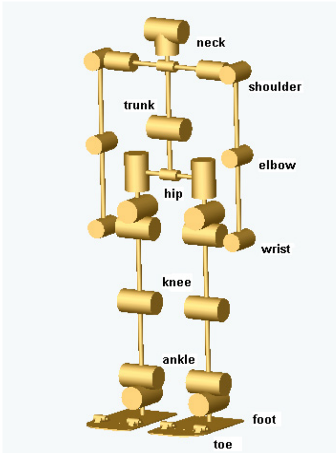

Fig. 2. Joint configuration of RoboSapien

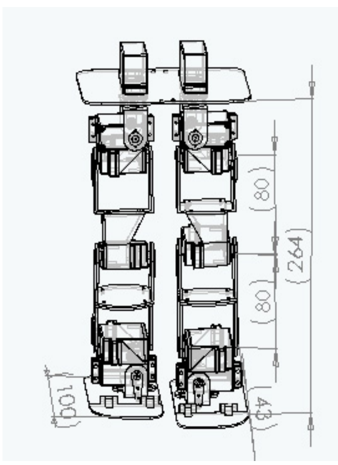

Fig. 3. Lower body mechanical design of RoboSapien

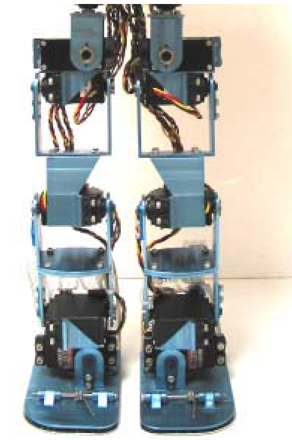

Fig. 4. Mechanical structure of legs

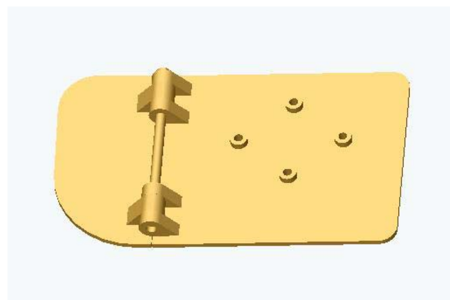

Fig. 5. The foot design

shafts on both sides. This helps to improve the stability of the actuator.

Table I lists the specifications of the lower body of RoboSapien.

TABLE I
SPECIFICATIONS OF ROBOSAPIEN

	length	mass
Trunk	0.14	0.8 kg
Thigh	0.08	0.3 kg
Shank	0.08	0.2 kg
Foot	0.043	0.1 kg

3 ELECTRICAL COMPONENTS AND SENSORS

3.1 Actuator

Modified DC servo motors are utilized as the actuators. The DC servo motor has a built-in PID controller. The specifications of this motor is listed in Table II.

3.2 Force sensor

Eight flexible force sensors (Fig. 7) are used on the biped robot's feet to detect the ground reaction force. Four sensors are fixed on the four corners of each sole. A simple amplification circuit is used to drive the sensor.

3.3 Tilt sensor and accelerometer

A tilt sensor (Fig. 8) is fixed on the upper body of RoboSapien. This tilt sensor has two axes. These axes is used to detect the tilt angles in the sagittal and lateral planes. However, when the body undergoes acceleration, the angle measured by the tilt sensor is not the same as the actual tilt angle. An accelerometer can be utilized to compensate this error.

3.4 Digital compass

For navigation of the robot, a digital compass (Fig. 9) is fixed on RoboSapien. Direction information is very important to realize certain tasks. The digital compass can provide an approximate direction information and navigate the robot to accomplish the

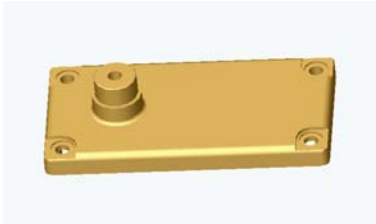

Fig. 6. New cover with shaft

TABLE II
SPECIFICATIONS OF ACTUATORS

Motor data	value
operating speed	0.13sec/60 degrees at no load
Stall torque	13kg.cm
Dimensions	39.4 x 20 x 37.8mm
Weight	56g

Fig. 7. Flexible force sensor

Fig. 8. Tilt sensor

assigned tasks. The compass has an accuracy of 2^o and a resolution of 1^o. The compass communicates with the DSP boards via PWM signals. The working of the digital compass depends on the magnetic field of the earth. The compass should be placed away from any electromagnetic components such as motors.

3.5 Video camera

With the help of a video camera (Fig. 10) the robot can track a specified object. Driven by two servo motors, the camera can turn about the horizontal and vertical axes. It has a built in processor to process the image and determine the position information of the object in front of the robot. The position information of the object is sent to the controller through the serial port.

3.6 IR sensor

An Infra Red sensor fixed on the robot body can detect obstacles even under poor lighting conditions. When the robot walks, the IR sensor rotates (120^o) the vertical axis, to detect obstacles in the path of the robot.

4 CONTROL SYSTEM CONFIGURATION

The control system structure of RoboSapien is shown in Fig. 11. The system is divided into two parts: a high level control part and a walking control part. Digital Signal Processors (DSP) Motorola 56F805 and 56F807 are used as the controllers. The two DSPs communicate through Serial Peripheral Interface (SPI). The high level control DSP receives the video camera signals via serial port. The camera provides the position information of an object within a specified color range. The DSP reads the IR sensor's signal to obtain the obstacle's distance and position information. The DSP also receives the output from the digital compass. The compass provides the direction information. In accordance with the the information from the sensors, the DSP makes decisions and commands the low level DSP for walking control. The DSP for high level control is also used to control the DC sevo motors to drive the camera and IR sensor.

The walking control DSP is used as a low level controller to control walking and other actions, like kicking a ball. The lower level DSP receives commands from the higher level DSP. Signals from tilt sensor and eight force sensors are sent to the lower level DSP via A/D ports. Based on the sensor information and higher level commands the walking motion and other actions are generated. The lower level DSP controls the DC servo motors on the legs with appropriate PWM signals. After the desired positions are generated by the walking control algorithm, the position information is sent to the DC servo motors.

5 EXPERIMENTATION AND ANALYSIS

Walking on flat ground and climbing stairs are simulated in the Yobotics [22] simulation platform. In the simulation, a 12 DOF biped robot (Fig. 12) is built to simulate RoboSapien.

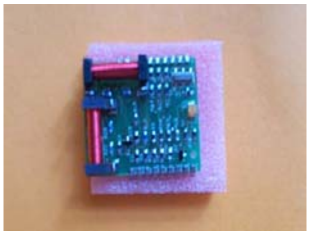

Fig. 9. Digital compass

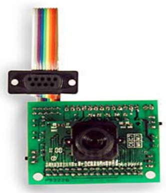

Fig. 10. Video camera

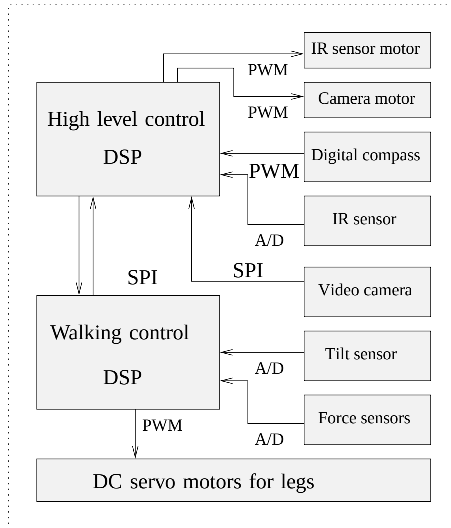

Fig. 11. Control system configuration

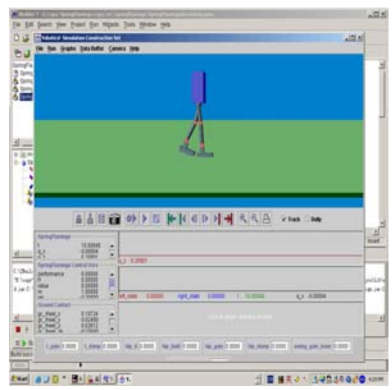

Fig. 12. The simulation model

5.1 Walking on flat ground

The simulation result of dynamic walking gait with a step size of 11.5 centimeters and speed of 1 step/sec for flat ground is shown in Fig. 13. In this gait generation algorithm, the desired velocity and step length can be specified. The vertical velocity of the body can be tuned to reduce the ground impact. As shown in Fig. 14, the vertical velocity is set to zero and the hip trajectory is along the x direction at the end of one step. The hip, knee and ankle joint profiles are shown in Fig. 14, 15, 16 respectively.

5.2 Climbing up stairs

Fig. 17 shows the simulation result of dynamic walking gait with a step size of 11.5 centimeters at a speed of 1 step per second for climbing stairs. The swing foot can avoid the obstacle by setting appropriate parameters to the cubic polynomial trajectory. The hip, knee and ankle joints profiles are shown in Fig. 18, 19, 20, respectively.

6 Conclusion

This paper has addressed the development of a humanoid robot RoboSapien. This fully autonomous humanoid robot is small in size and is light weight. Various compact sensors are equipped on the robot. Force and tilt sensors are used in the walking control. Digital compass, IR sensor and video camera are used to gather the environment information and navigate the robot while in motion. Yobotics is used to simulate the dynamic walking of RoboSapien on flat ground and stairs. Simulation results are presented in this paper.

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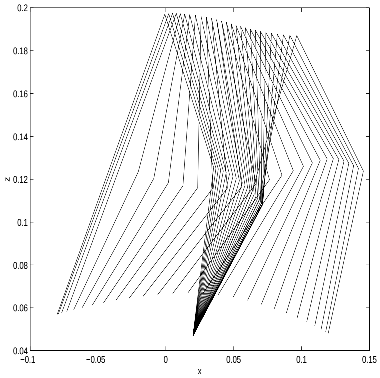

Fig. 13. Walking gait for flat ground

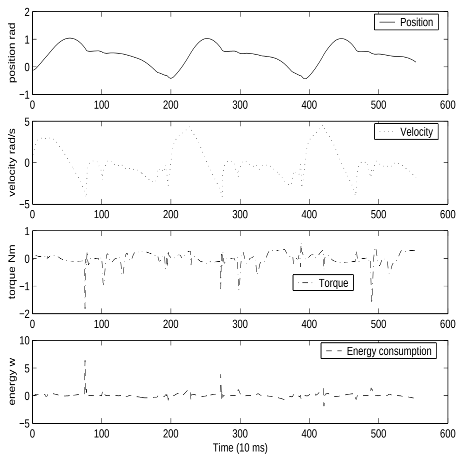

Fig. 14. Simulation result of hip joint on flat ground

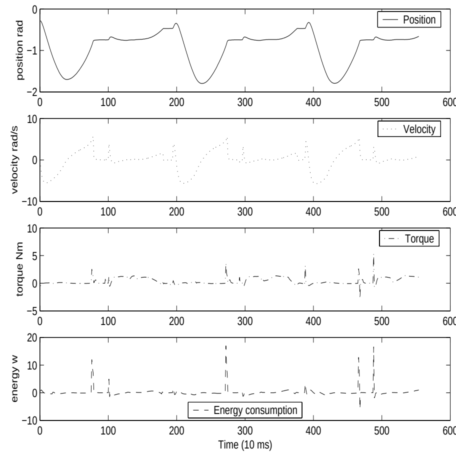

Fig. 15. Simulation result of knee joint on flat ground

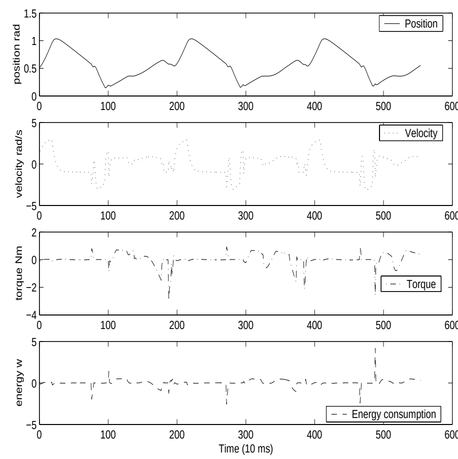

Fig. 16. Simulation result of ankle joint on flat ground

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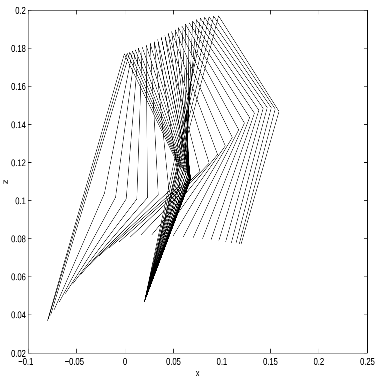

Fig. 17. Walking gait for stairs

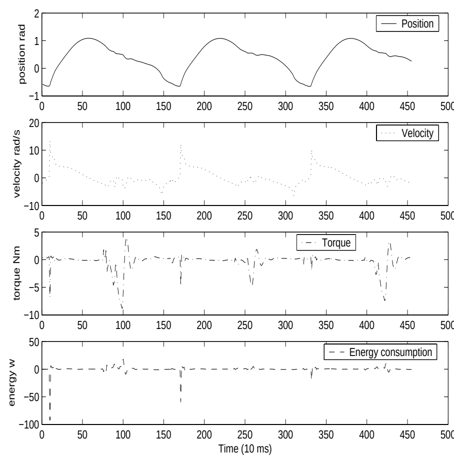

Fig. 18. Simulation result of hip joint climbing stairs

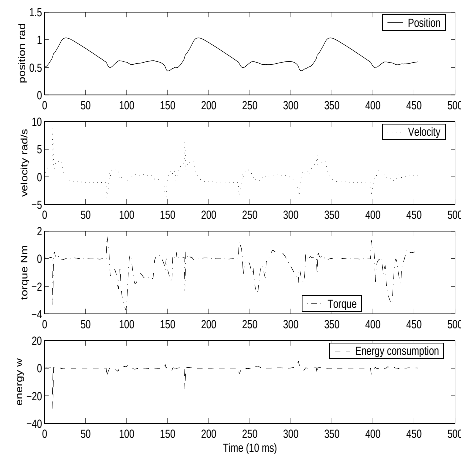

Fig. 20. Simulation result of ankle joint climbing stairs

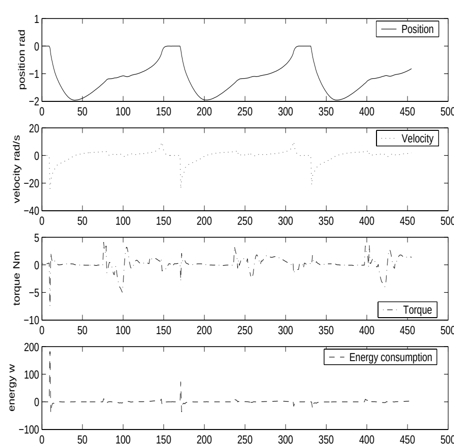

Fig. 19. Simulation result of knee joint climbing stairs