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Obstacle Avoidance Design for Humanoid Robot Based on Four Infrared Sensors

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Abstract

A behavior strategy of humanoid robot for obstacle avoidance based on four infrared sensors is proposed and implemented on an autonomous humanoid robot. A mechanical structure with 26 degrees of freedom is design so that an implemented small-size humanoid robot named TWNHR-III is able to accomplish five walking motions. Three walking experiments are presented to illustrate that the proposed biped structure lets TWNHR-III can move forward, turn, and slip. One electronic compass and four infrared sensors are mounted on TWNHR-III to obtain the head direction of the robot and detect obstacles, respectively. Based on the obtained information from these sensors, a decision tree method is proposed to decide one behavior from five movements: walk forward, turn right and left, and slip right and left. Two MATLAB simulations and one real experiment are presented to illustrate that the robot can avoid obstacles autonomously and go to the destination effectively.

Key Words: Humanoid Robot, Autonomous Mobile Robot, Obstacle Avoidance, Decision Tree

1. Introduction

Although the robot has been investigated for many years, there are still many issues to be studied, especially in the humanoid robots [1–4]. Hardware and software architectures, walking gait generation, and artificial intelligence are the main research fields of humanoid robots. Robot soccer games are used to encourage the researches on robotics and artificial intelligence (AI). Two international robot soccer associations, RoboCup [5] and FIRA [6], advance this research and hold the international competitions and the international symposiums. Robot soccer games are two teams constituted by several soccer robots to play soccer games under some size restrictions and rules. In the FIRA Cup event, several main categories are organized: the **Mi**cro-**ro**bot **So**ccer **t**ournament (MiroSot), the **Simu**lated **ro**bot **So**ccer **t**ournament (SimuroSot), the **Robo**t **So**ccer **t**ournament (RoboSot), and the **Hu**manoid **ro**bot **So**ccer **t**ournament (HuroSot). In the HuroSot category, the humanoid robot has to detect all information from the game field and decides its strategy by itself. There are many robots in the match field, so the robot must have the ability to avoid the collision with other robots and walk to an appropriate destination. Thus obstacle run is a competition category in the HuroSot league of FIRA Cup. The main idea of this competition category is used to test the ability of obstacle avoidance of the robot. In general, vision sensors, ultrasonic sensors, and infrared sensors are usually used to detect obstacles in the soccer game [7–11].

In this paper, a mechanical structure with 26 degrees of freedom is design so that an implemented small-size humanoid robot named TWNHR-III (TaiWaN Humanoid Robot-III) is able to accomplish five walking motions: walk forward, turn right and left, and slip right and left. One digital electronic compass and four infrared

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sensors are installed on TWNHR-III. Based on the information obtained from these sensors, a decision tree method is proposed to determine one behavior from these five movements in each decision so that TWNHR-III can avoid obstacles and go to a destination effectively.

The rest of this paper is organized as follows: In Section 2, the system architecture of TWNHR-III is described. In Section 3, a decision tree method for obstacle avoidance is proposed and two simulation results and one practical test on TWNHR-III are described. In Section 4, some conclusions are made.

2. System Architecture of TWNHR-III

The system architecture of TWNHR-III is described in this section. The height of TWNHR-III is 46 cm and the weight is 3.1 kg with batteries. The frameworks of TWNHR-III are mainly fabricated from aluminum alloy 5052 in order to realize the concepts of light weight, wear-resisting, high stiffness, and wide movable range. Each actuator system of the joint consists of a high torque and a gear. The rotating speed and rotating angle of each joint are designed based on the result of computer program. The mechanical structure and electronic structure of TWNHR-III are described as follows:

2.1 Mechanical Structure

Mechanical structure design is the first step in the humanoid robot design. The degrees of freedom (DOFs) configuration for TWNHR-III is described in Figure 1, where 26 degrees of freedom are implemented and the rotational direction of each joint is defined by using the inertial coordinate system fixed on the ground. There are 2 degrees of freedom on the neck, 2 degrees of freedom on the waist and trunk, 8 degrees of freedom on the arm, and 14 degrees of freedom on the two legs. A photograph and some mechanical views of TWNHR-III are respectively described in Figure 2 and Figure 3.

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 electronic components. Therefore, the primary goal of the humanoid robot mechanical design is to let the implemented robot can imitate equivalent human motion. A mechanical structure is designed and implemented so that the implemented humanoid robot can find the ball, walk forward, turn right and left, and slip right and left. The details of the development of the head, waist and trunk, arms, and legs are described as follows:

2.1.1 Head

The 3D mechanism design and DOFs diagram of the head are described in Figure 4, where the head of TWNHR-III has 2 degrees of freedom and each degree is

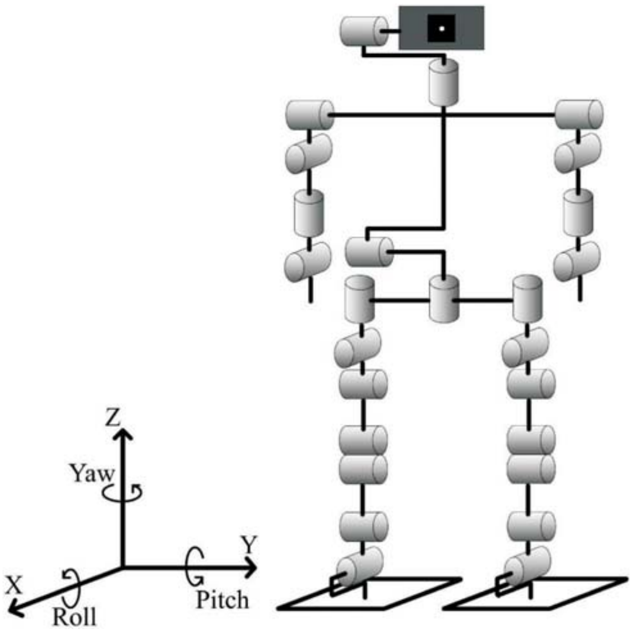


Figure 1. DOF configuration of TWNHR-III.

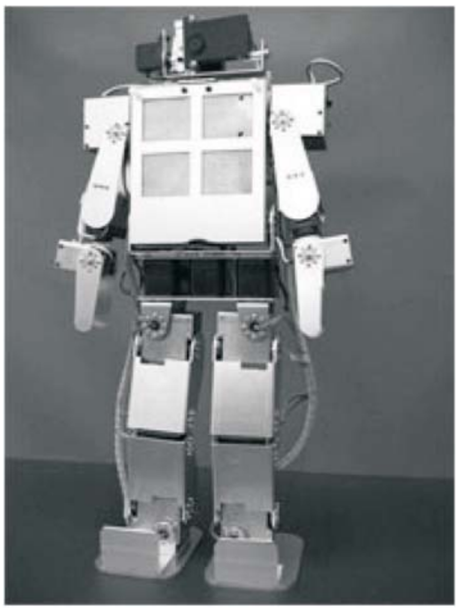


Figure 2. Photograph of TWNHR-III.

described by the number in (b). The raw and pitch motions are implemented on the head so that it can turn right-and-left and up-and-down. Some corresponding behaviors between human and TWNHR-III in the joints of head are described in Table 1.

2.1.2 Waist and Trunk

The 3D mechanism design and DOFs diagram of the waist and trunk are described in Figure 5, where each waist and trunk of TWNHR-III has 2 degrees of freedom and each degree is described by the number in (b). The waist and trunk are designed based on the concept that robot can adjust the trunk motions to compensate for the robot's walk motion. Some corresponding behaviors between human and TWNHR-III in the joints of waist and trunk are described in Table 2.

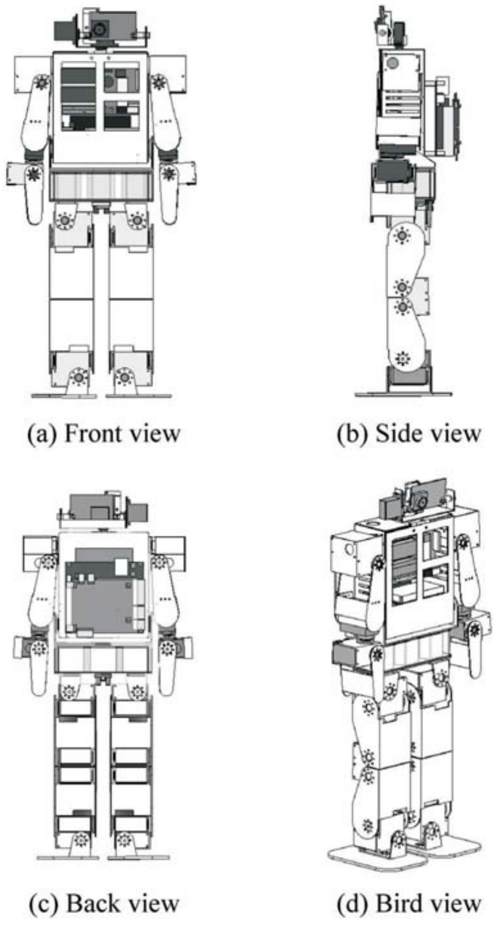


Figure 3. Views of TWNHR-III from 3D mechanism design.

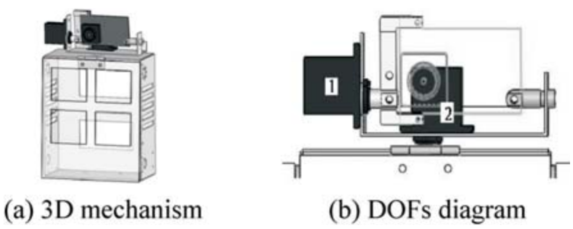
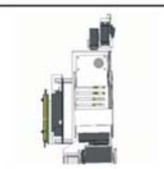
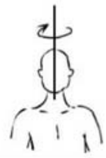
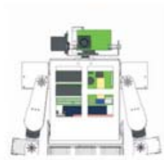


Figure 4. Head mechanism of TWNHR-III.

2.1.3 Arms

The 3D mechanism design of the arms are described in Figure 6, where each arm of TWNHR-III has 4 degrees of freedom. The arms of the robot are designed

Table 1. Corresponding behaviors between human and TWNHR-III in the joints of head

	Human	TWNHR-III
(a)		
(b)		

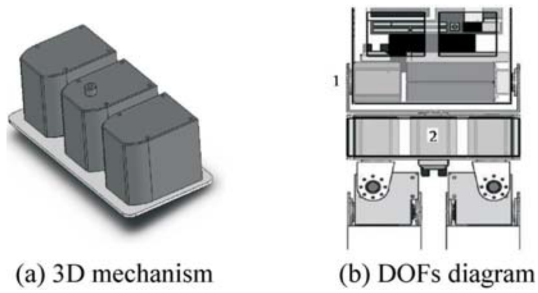


Figure 5. Waist and trunk mechanism of TWNHR-III.

Table 2. Corresponding behaviors between human and TWNHR-III in the joints of waist and trunk

	Human	TWNHR-III
(a)		
(b)		

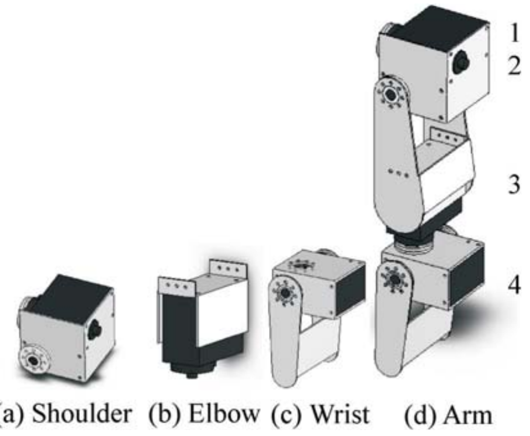


Figure 6. Left arm mechanism of TWNHR-III.

based on some behaviors of human's arms. For example, its arm can hold an object such as a ball. Some corresponding behaviors between human and TWNHR-III in the joints of arms are described in Table 3.

2.1.4 Legs

In order to realize the normal walking motion of human, 7 degrees of freedom are adopted to implement the joints of one leg. Leg is take great part weight of whole body, due to the knee joint. In order to improve the robust of the leg, two motors are designed and implemented in one knee joint. The 3D mechanism design and DOFs diagram of the legs are described in Figure 7, where each leg of TWNHR-III has 7 degrees of freedom and each degree is described by the number in (b). The legs are designed based on the concept that robot can accomplish the human walking motion. Some corresponding behaviors between human and TWNHR-III in the joints of legs are described in Table 4.

Table 3. Corresponding behaviors between human and TWNHR-III in the joints of arms

	Human	TWNHR-III
(a)		
(b)		
(c)		
(d)		

2.2. Electronic Structure

In the electronic structure design for TWNHR-III, the system block diagram is described in Figure 8, where 26 servomotors with high torques are used as the actuators of the robot. In order to build a fully autonomous vision-based humanoid robot, a 16-bit DSP processor with a CMOS sensor is chosen to process the vision image of environment. The image of the field is captured by the CMOS sensor and the position information of the ball and goals is processed and extracted by the DSP processor. One electronic compass and four infrared sensors are mounted on TWNHR-III to obtain the head direction of the robot and detect obstacles, respectively. The installed positions and their detectable ranges of these four infrared sensors are described in Figure 9 and Figure 10, respectively. The electronic compass is mounted on the body to detect the head direction of the robot and the goal direction, respectively. The relative angle of goal direction and robot direction is shown in Figure 11. In the circuit design, the SoPC (System on a Programmable Chip) concept is applied and implemented on a FPGA chip to reduce the complexity of circuit design. The implemented FPGA chip can process the data obtained from the sensors and generate desired pulses to control

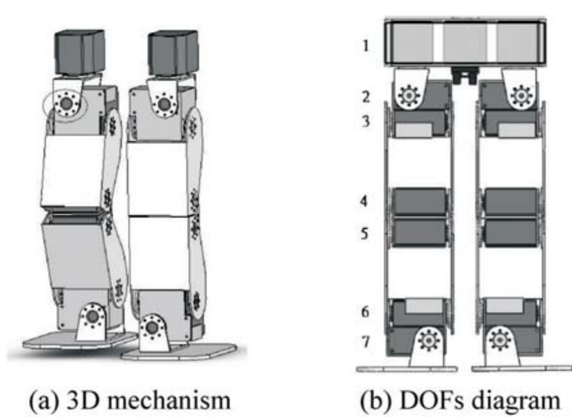


Figure 7. Legs mechanism of TWNHR-III.

Table 4. Corresponding behaviors between human and TWNHR-III in the joints of legs

	Human	TWNHR-III
(a)		
(b)		
(c)		
(d)		
(e)		
(f)		

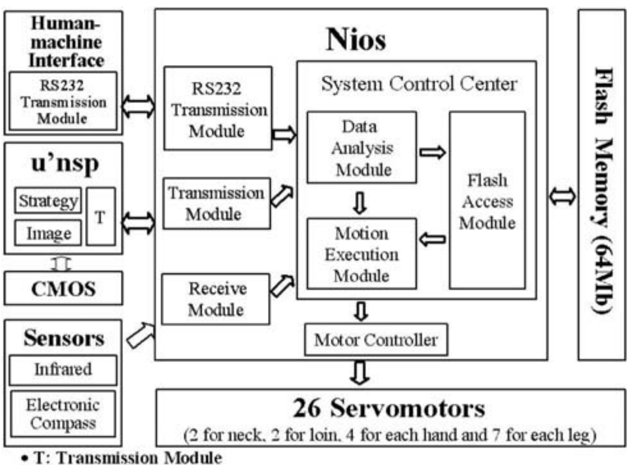


Figure 8. System block diagram of TWNHR-III in the electronic system design.

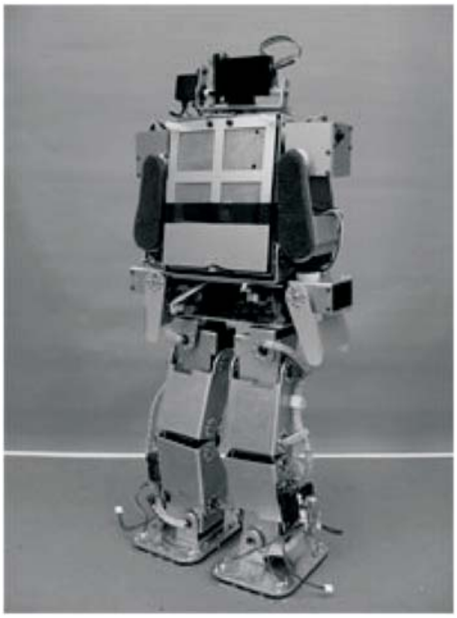


Figure 9. Installed positions of four infrared sensors on TWNHR-III.

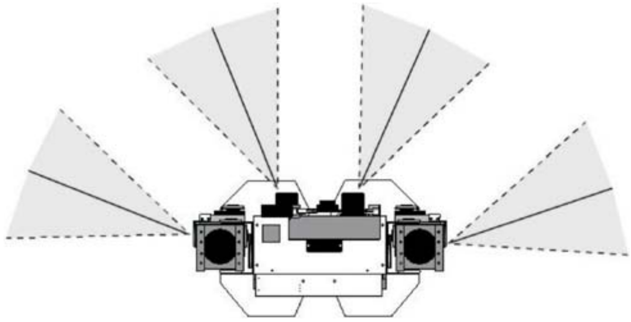


Figure 10. Detectable ranges of four infrared sensors.

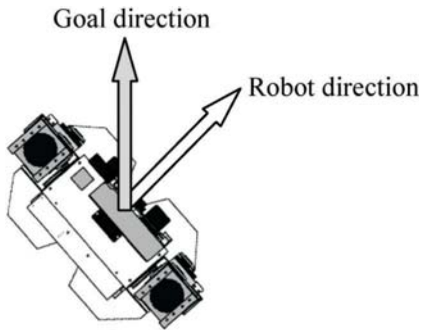


Figure 11. Description of the relative angle of the goal direction and the robot direction obtained by the electronic compass.

the angles of servomotors. Many functions are implemented on the FPGA chip to process the data and control the robot so that the weight of the robot is reduced.

2.3. Walking Experiments

A mechanical structure with 26 degrees of freedom is design so that TWNHR-III is able to accomplish five walking motions: walk forward, turn right and left, and slip right and left. Its control method is based on the try and error method. In order to verify the effectiveness of the implemented humanoid robot, three basic walking skills: straight walk, turn, and slip are carried out on a horizontal even plane and described as follows:

2.3.1 Straight Walk

Some snapshots of straight walking of TWNHR-III are shown in Figure 12, where the distance between every white line is 5 cm. Every step of the straight walking is able to move forward 10 cm.

2.3.2 Turn

Some snapshots of left turning of TWNHR-III are shown in Figure 13, where the angle between every white line is 15 degrees. Each time of the robot turning is able to turn 30 degrees.

2.3.3 Slip

Some snapshots of right slipping of TWNHR-III are shown in Figure 14, where the distance between every white line is 5 cm. Every step of the robot slipping is able to slip 10 cm.

From these experiment results, we can see that the proposed mechanical structure can let TWNHR-III move forward, turn, and slip effectively.

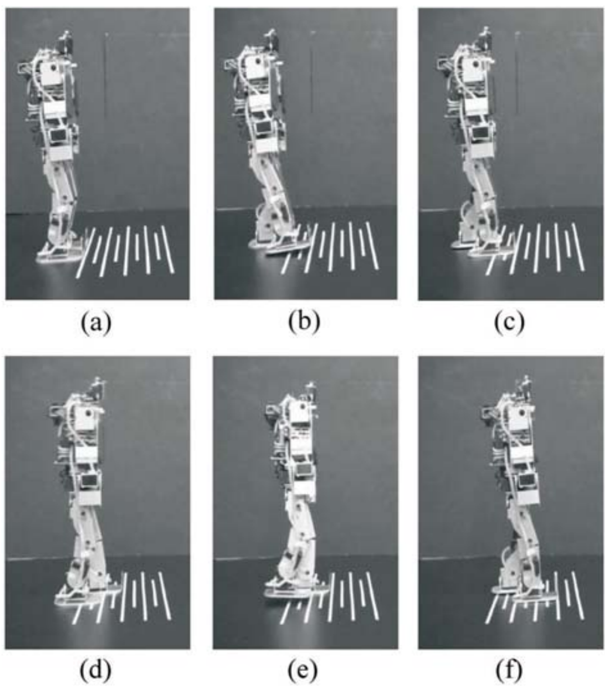


Figure 12. Straight walking of TWNHR-III.

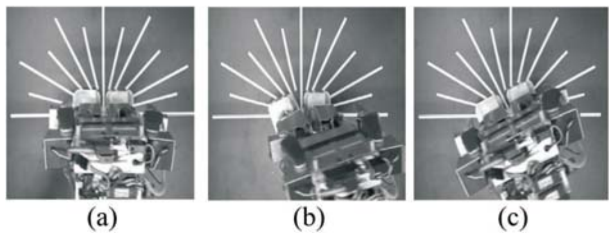


Figure 13. 30 degrees left turning of TWNHR-III.

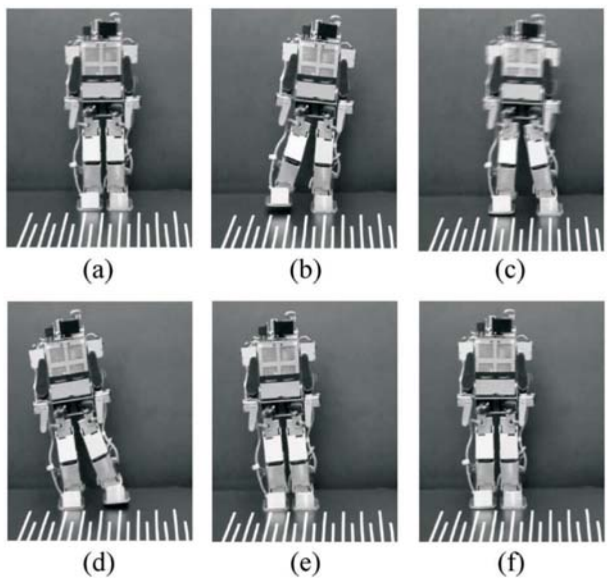


Figure 14. Slipping to the right side of TWNHR-III.

3. Obstacle Avoidance

3.1 Decision Tree Method

Obstacle run is a competition category in the HuroSot league of FIRA Cup. As shown in Figure 15, there is a finish line marked on one side of the playing field. This side of the playing field is called the finish side. The opposite side of the playing field is called the start side. The two other sides are called side lines. A robot has crossed the finish line when the robot crosses the finish plane and touches the ground in the end zone. During the obstacle run competition, the robot does not allow to touch any obstacles. The robot has to detect obstacles and the di-

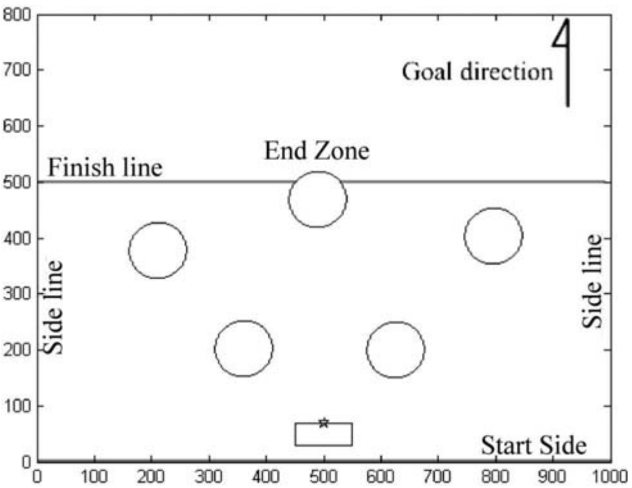


Figure 15. Diagram of the obstacle run competition.

rection of the goal line. A decision tree method based on four infrared sensors is proposed and described in Figure 16. The behavior output of the decision tree is the robot's five basic motions including go forward, 30 degree right turn, 30 degree left turn, slip right, and slip left. Sixteen behavior situations and their corresponding movements are described in Table 5. The strategy will check the relative behavior from the decision tree before the robot move. In order to let the robot walk toward the goal direction, the robot will adjust the robot direction to face the goal direction based on the electronic compass information when the robot is in the safe situation (B16 situation).

3.2 Simulation and Experiment Results

In order to illustrate the proposed method can successfully avoid obstacles and go to the destination, two MATLAB simulations and one real experiment are presented. Figure 17 and Figure 18 illustrate the obstacle avoidance ability of the robot by MATLAB simulation results. In Figure 17, there is one obstacle on the robot's way to the goal line. When the robot detects the obstacle, the "slip right" behavior is made by the proposed decision tree method to avoid the obstacle based on the detected behavior situation B10. The robot keeps slipping to the right side, until there is no obstacle in front of the robot. When the detected behavior situation is changed from B10 to B16, the "move to goal line" behavior is made to let the robot walk toward the goal line. In Figure 18, there are two obstacles on the robot's way to the goal line. The robot also chooses the behavior from the proposed behavior strategy. At the location of "Safe point", the robot is already in the safe situation. Therefore, the detected behavior situation is B16 to let the robot walk toward the goal line. As the robot moving forward, it detects the other obstacle. The "slip left" behavior is made

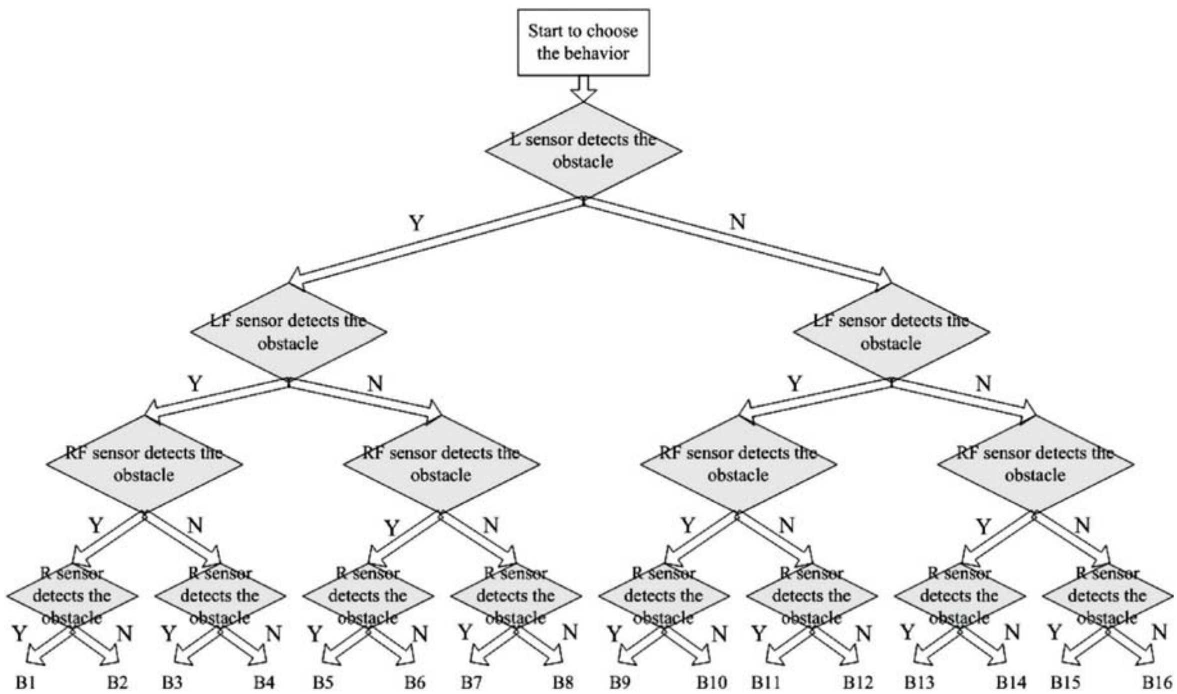
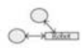
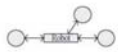
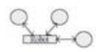
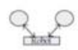


Figure 16. Decision tree of the proposed obstacle avoidance strategy.

Table 5. The behavior table of the decision tree

Behavior Situation	Sensor Situation	Obstacle Situation	Decided Movement
B1			Turn left
B2			Slip right
B3			Turn right
B4			Slip right
B5			Turn left
B6			Turn left
B7			Go straight
B8			Slip right
B9			Slip left
B10			Slip right
B11			Turn right
B12			Slip right
B13			Slip left
B14			Slip left
B15			Slip left
B16			Move to Goal line

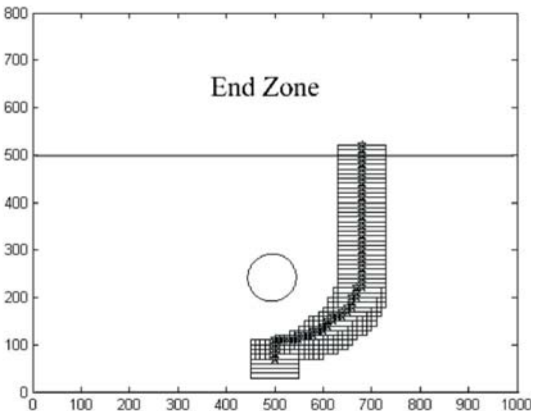


Figure 17. Simulation result of the robot avoids one obstacle.

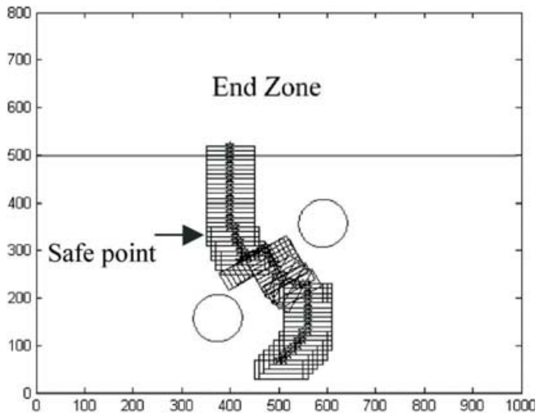


Figure 18. Simulation result of the robot avoids two obstacles.

to avoid this obstacle based on the detected behavior situation B9. The detected behavior situation will change to B16 when the robot is away from this obstacle. The computer simulation results in Figure 17 and Figure 18 illustrate that the robot can effectively avoid obstacles and successfully arrive the goal line based on the proposed decision tree method.

In the practical test, the proposed decision tree method implemented on the TWNHR-III in a real test ground is discussed. Six sequential image stills of TWNHR-III for a real experiment of obstacle avoidance are shown in Figure 19, where two obstacles are on the robot's way to the goal line. Once TWNHR-III detects the obstacle via the infrared sensors, the robot will do an appropriate behavior to avoid obstacles. We can see that TWNHR-III can successfully avoid two obstacles by the proposed decision tree method.

5. Conclusion

The soccer robot needs to play a soccer game autonomously. Playing soccer game is a good test platform to verify the ability of the designed and implemented robot. There are many robots in the match field, so the soccer robot must have the ability to avoid the collision with other robots and move to an appropriate destination. Thus the obstacle run is a competition category in the HuroSot league of FIRA Cup. Some basic walking experiments of TWNHR-III have been presented to illustrate that the proposed mechanical structure with 26 degrees of freedom can let TWNHR-III move forward, turn, and slip. Based on the obtained information from one compass and four infrared sensors installed on TWNHR-III, a decision tree method is proposed. Two MATLAB simulation results and one practical test on TWNHR-III have been presented to illustrate that the proposed decision tree method can let the robot effectively avoid obstacles and successfully go to the destination. One CMOS sensor is installed on TWNHR-III so that it can be a vision-based soccer robot to autonomously find a ball and kick a ball. Moreover, TWNHR-III won champion of the humanoid league in Taiwan Cup 2006. In the future, TWNHR-III will be used to investigate the walking gait and artificial intelligence. For example, some force sensors will be installed on TWNHR-III to study the biped walking control on even or uneven ground. More research on artificial intelligence will be carried on TWNHR-III to make it to be an intelligent robot.

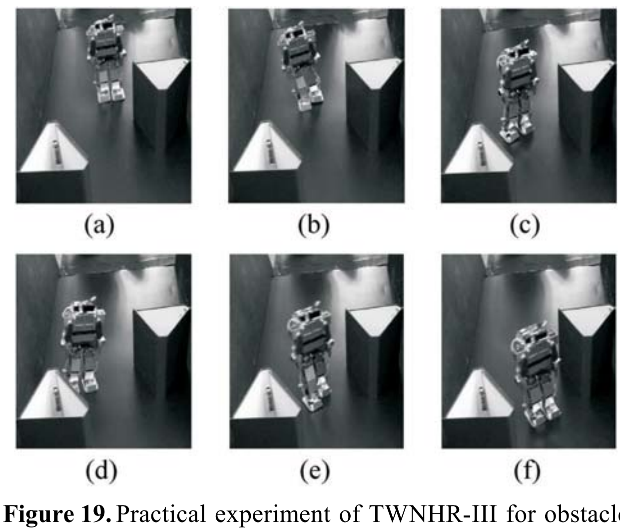


Figure 19. Practical experiment of TWNHR-III for obstacle avoidance.

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