Small-size Humanoid Soccer Robot Design for FIRA HuroSot

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1. Introduction

Robot soccer games are used to encourage the researches on the robotics and artificial intelligence. FIRA (URL: http://www.fira.net) is an international robot soccer association to advance this research and hold some international competitions and congresses. There are many different leagues, such as SimuroSot, MiroSot, RoboSot, and HuroSot, in FIRA RoboWorld Cup. Each league is established for different research purposes. In the HuroSot league, many technology issues and scientific areas must be integrated to design a humanoid robot. The research technologies of mechanism design, electronic system, biped walking control, autonomous motion, direction judgment, kicking ball need to be applied on a humanoid robot (Chemori & Loria, 2004; Esfahani & Elahinia, 2007; Guan et al., 2006; Hemami et al., 2006; Hu et al., 2008; Haung et al., 2001; Miyazaki & Arimoto, 1980; Sugihara et al., 2002; Wong et al., 2005; Zhou & Jagannathan, 1996). This chapter introduces an autonomous humanoid robot, TWNHR-IV (**T**ai**w**a**n** **H**umanoid **R**obot-IV), which is able to play sports, such as soccer, basketball, weight lifting, and marathon. The robot is designed to be a vision-based autonomous humanoid robot for HuroSot League of FIRA Cup. TWNHR-IV joined FIRA Cup in 2007 and 2008. In FIRA 2007, TWNHR-IV won the first place in robot dash, penalty kick, obstacle run, and weight lifting; the second place in basketball and marathon. In FIRA 2008, TWNHR-IV won the first place in penalty kick, obstacle run, and weight lifting, the second place in robot dash and the third place in basketball. TWNHR-IV determines the environment via its sensors and executes the suitable motion by its artificial intelligent. In order to let TWNHR-IV have the environment perceptive ability, a vision sensor (a CMOS sensor), six distance sensors (six infrared sensors), a posture sensor (an accelerometer sensor) and a direction sensor (a digital compass) are equipped on the body of TWNHR-IV to obtain the information of the environment. Two processors are used to control the robot. The first one is a DSP for the high-level control purpose. The DSP receives and processes the image data from the CMOS sensor via a serial port. It is in charge of the high level artificial intelligent, such as navigation. The second one is NIOS II (an embedded soft-core processor) for the robot locomotion control. The second processor is used as a low-level controller to control the walking and other actions. TWNHR-IV is designed as a soccer player so that it can walk,

turn, and kick the ball autonomously. A control board with a FPGA chip and a 64 Mb flash memory are mainly utilized to control the robot. Many functions are implemented on this FPGA chip so that it can receive motion commands from DSP via a serial port and process the data obtained by infrared sensors, digital compass, and accelerometer. It is able to accomplish the different challenges of HuroSot, including Penalty Kick (PK), basketball, lift-and-carry, obstacle run, robot dash, weight lifting, and marathon autonomously and effectively.
The rest of this chapter is organized as follows: In Section 2, the mechanical system design of the robot TWNHR-IV is described. In Section 3, the electronic system including a vision system, a control core, and sensor systems are described. In Section 4, some simulation and experiments results of the proposed controller are described. Finally, some conclusions are made in Section 5.

2. Mechanical System Design

Mechanical system design is the first step of design a humanoid robot. Human body mechanism basically consists of 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 system design is to develop a robot that can imitate equivalent human motions. The degrees of freedom (DOFs) configuration of TWNHR-IV is presented in Figure 1. TWNHR-IV has 26 DOFs. In this chapter, the rotational direction of each joint is defined by using the inertial coordinate system fixed on the ground as shown in Figure 1 (Wong et al., 2008c).

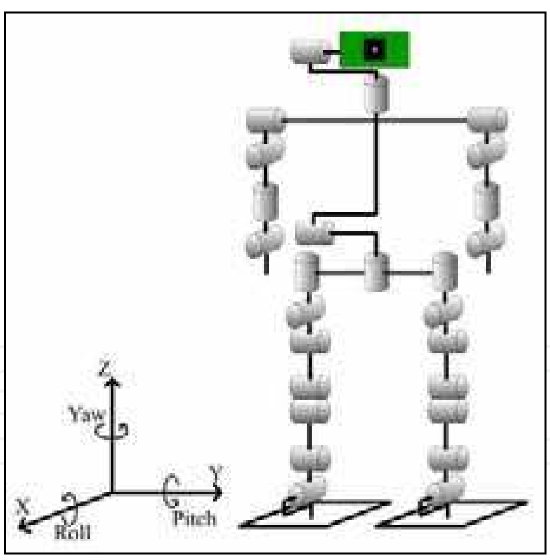


Fig. 1. DOFs configuration

A photograph and a 3D mechanical structure of the implemented robot are shown in Figure 2 The design concepts of TWNHR-IV are light weight and compact size. The height of TWNHR-IV is 43 cm and the weight is 3.4 kg with batteries. A human-machine interface is designed to manipulate the servo motors. The details of the mechanical structure of the head, arms, waist, trunk, and legs are described as follows.

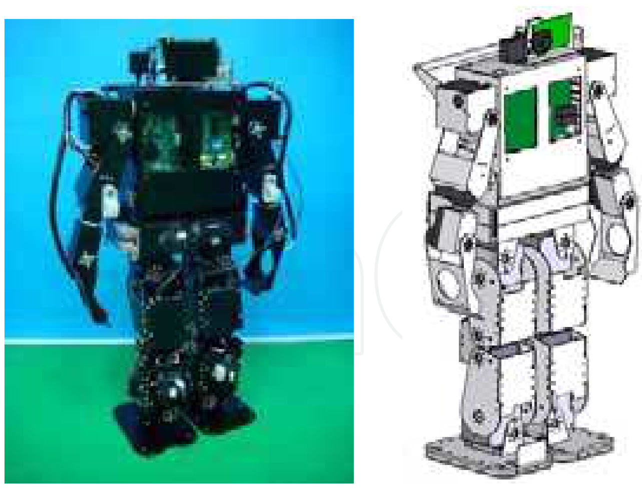


Fig. 2. Photograph and mechanical structure of TWNHR-IV

The head of TWNHR-IV has 2 DOFs. Figure 3 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 1 presents the head DOFs relation between human and TWNHR-IV.

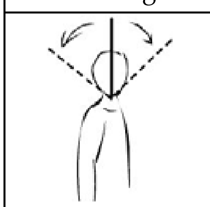
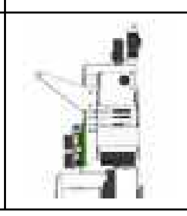
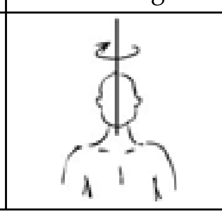
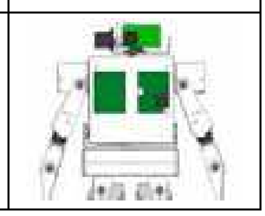
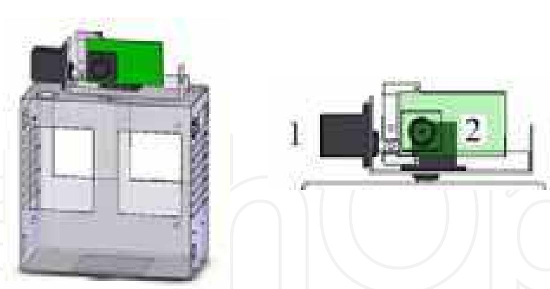
Human Figure	TWNHR-IV	Human Figure	TWNHR-IV
			

Table 1. The head DOFs relation between human and TWNHR-IV



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

Fig. 3. Head mechanism

The head of TWNHR-IV has 2 degrees of freedom. Figure 4 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 2 presents the specification of the joints for the waist and trunk.

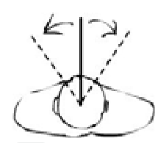
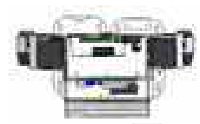
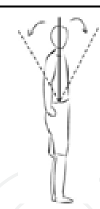
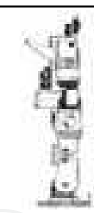
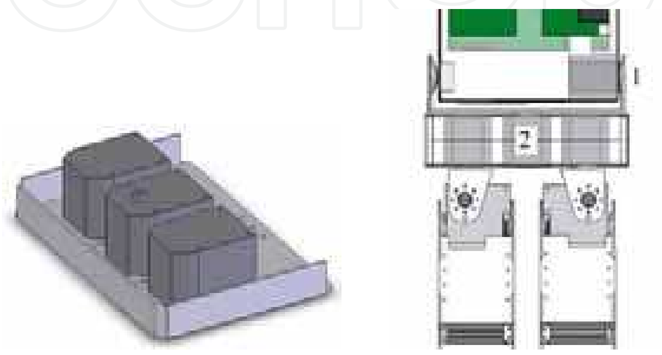
Human Figure	TWNHR-IV	Human Figure	TWNHR-IV
			

Table 2. The waist and trunk DOFs relation between human and TWNHR-IV



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

Fig. 4. Waist and trunk mechanism

Each arm of TWNHR-IV has 4 DOFs. Figure 5 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 3 presents the specification of the joints for each arm.

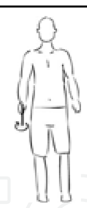
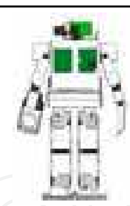
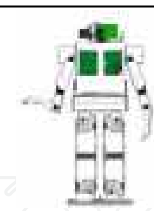
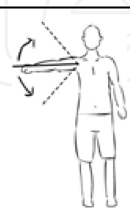
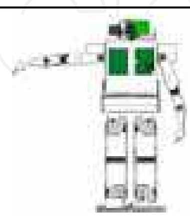
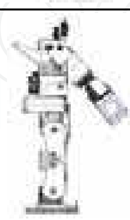
Human Figure	TWNHR-IV	Human Figure	TWNHR-IV
			
			

Table 3. The arms DOFs relation between human and TWNHR-IV

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

Fig. 5. Left arm mechanism

Each leg of TWNHR-IV has 7 Degrees of freedom. Figure 6 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 4 presents the specification of the joints for each leg.

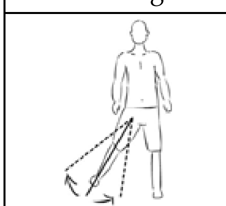
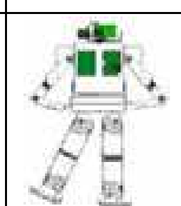
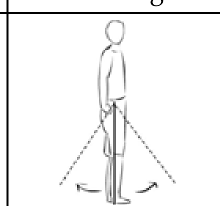
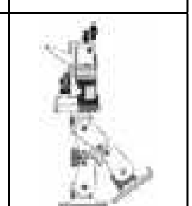
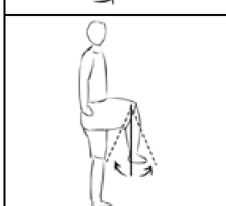
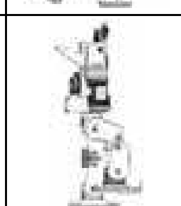
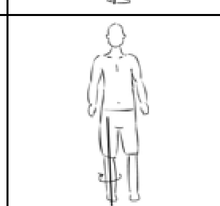
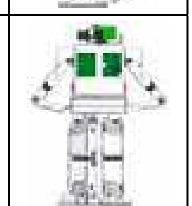
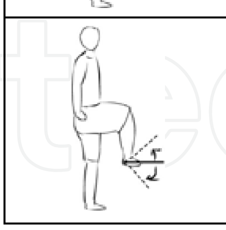
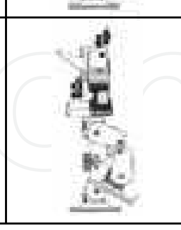
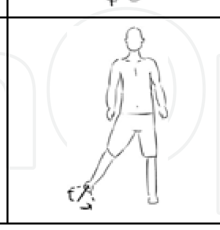
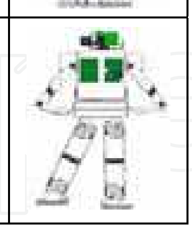
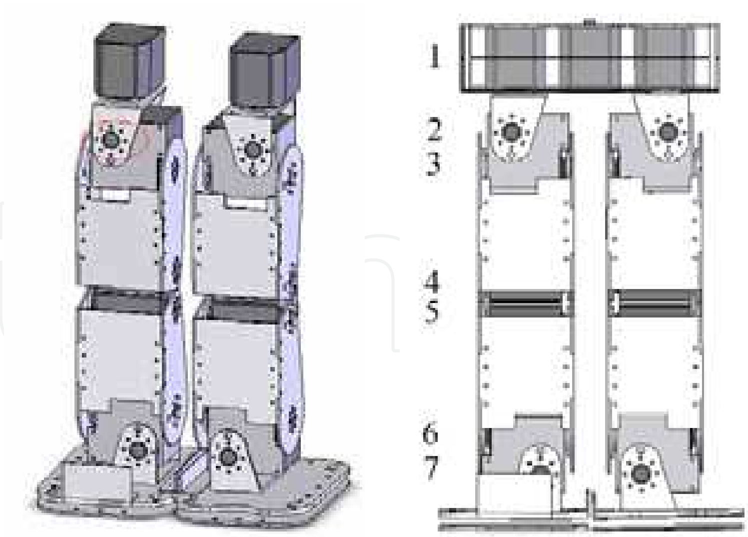
Human Figure	TWNHR-IV	Human Figure	TWNHR-IV
			
			
			

Table 4. The legs DOFs relation between human and TWNHR-IV



(a) 3D design (b) DOFs diagram

Fig. 6. Legs mechanism

The head of TWNHR-IV has 2 DOFs. The head is designed based on the concept that the head of the robot can accomplish the raw and pitch motion. The trunk of TWNHR-IV has 2 DOFs. The trunk is designed based on the concept that robot can walk to adjust the trunk motions to compensate for the robot's walk motion. Each arm of TWNHR-IV has 4 DOFs. 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. Each leg of TWNHR-IV has 7 DOFs. The legs are designed based on the concept that robot can accomplish the human walking motion. The specification is shown in Table 5.

Specification		
Height		43 cm
Weight		3.4 kg
Degree of Freedom & Motor Configuration		
	DOFs	Torque (kg/cm)
Head	2	1.7
Thunk	2	40.8
Legs	7(x2)	37.5
Arms	4(x2)	20
Total	26	

Table 5. Mechanism specification

3. Electronic System

The electronic system diagram is show in Figure 7, where NIOS II is a 32-bit embedded soft-core processor implement on a FPGA chip of a development board. TWNHR-IV is using the NIOS II development board to control all of the servo motors and communicate with sensors. The DSP processor μ'nsp decides motions and gives the NIOS II development board order commands to do such as walk forward, turn right and left. The motions through the RS-232 download to the NIOS II development board.

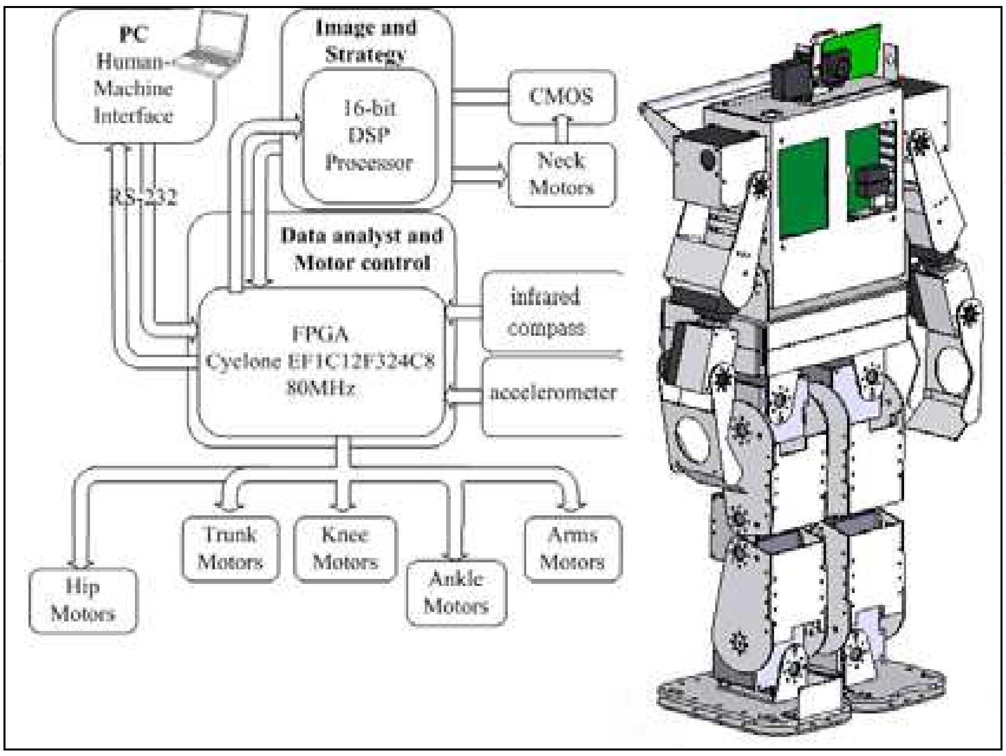


Fig. 7. System block diagram of the electronic system used for TWNHR-IV

3.1 Vision System

A 16-bits DSP processor named μ'nsp is used to receive and process the image data from the CMOS image sensor via the serial transmission. The CMOS sensor is mounted on the head of the robot so that the vision information of the field can be obtained. Two main electrical parts in the vision system of the robot are a CMOS sensor and a 16-bit DSP processor. The captured image data by the CMOS sensor is transmitted to the DSP processor via a serial port. Based on the given color and size of the object, the DSP processor can process the captured image data to determine the position of the object in this image. The noise of the environmental image can be eliminated by the DSP processor. It is shown an example of color image in Figure 8. In this image, two balls are detected. The cross marks in Figure 8 (b) denote center of each color region. Based on the extracted position information, an appropriate strategy is made and transmitted to the FPGA chip via a serial transmission.

(a) Picture from original image (b) Picture after processing the image

Fig. 8. Color detection from the input image.

3.2 Control Core

The NIOS II development board is used to process the data transmission and motion control. The motions of the robot are stored in the flash memory of NIOS II development board. The internal block diagram of NIOS II development is shown in Figure 9. There are several blocks in NIOS II, such as RS232 Transmission module, Receive module, Data Analysis module, Motion Execution module, Flash Access module, and Motor controller. These blocks are used to download and execute the motions, and these blocks are accomplished by the VHDL language. (Wong et al., 2008a)

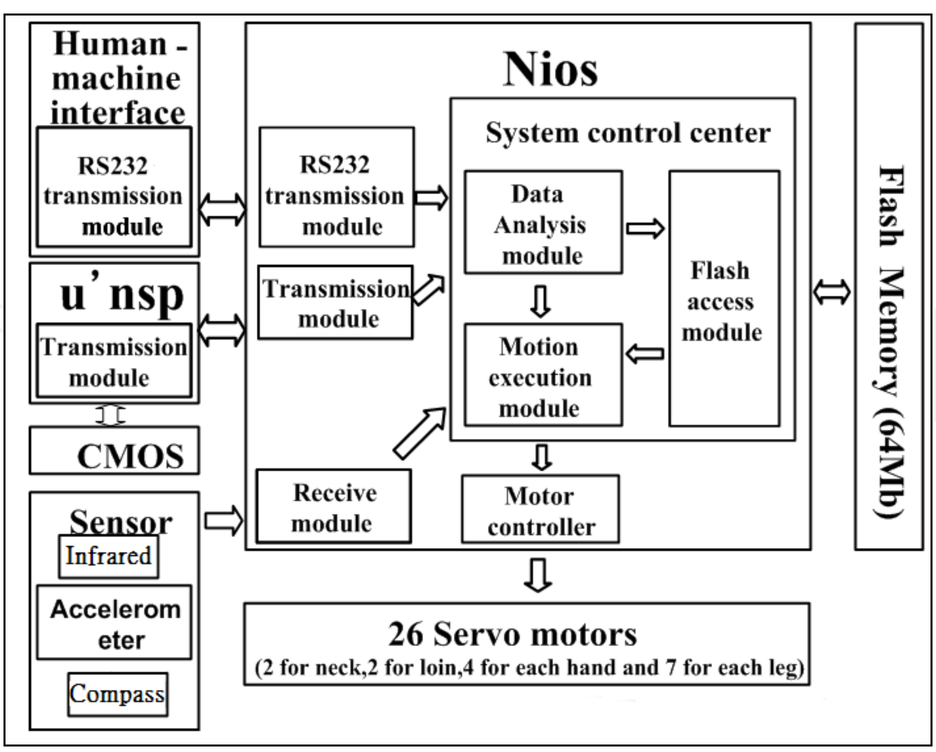


Fig. 9. The internal block diagram of NIOS II development

The motions of the robot are designed on a PC, and downloaded to the RS232 transmission module of the robot. Two different data will be sent to the RS232 transmission module, motion data and motion execution command. The Data analysis module analyzes the data from the RS232 transmission module. If the command is motion data, this data will be sent to the Flash access module and stored in the flash memory. If the command is motion execution, the Motion execution module will get the motion data from the flash memory and execute it. The diagram of flash access is shown in Figure 10.

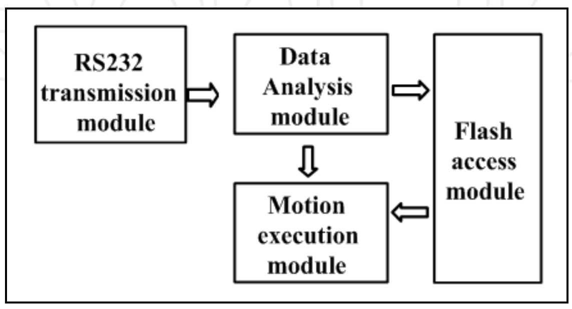


Fig. 10. The diagram of flash access

3.3 Sensors and Application

In order to let TWNHR-IV can go to an appointed place accurately, a digital compass is installed on the body of TWNHR-IV to determine the head direction of the robot. The indispensable magnetism information of the digital compass can provide the important direction information for the robot navigation. The digital compass picks the angle of the robot and the north geomagnetic pole. It can be used in the competition of robot dash, marathon, or others competition.

In order to let TWNHR-IV can avoid the obstacle, six infrared sensors are installed on the robot for detecting the distance between the obstacle and the robot. Two sensors are installed on the back of hands, two on the waist, and two on the legs. The distance information is sent to NIOS II decelopment board by RS232. The infrared is used in the competition of obstacle run, robot dash and weight lifting to avoid the obstacle on the field.

In order to measure the motion state of the robot. An accelerometer is utilized on the body of the robot for the balancing purpose. It provides important motion state information for robot balancing. The accelerometer can offer the indispensable acceleration information of the robot's motion. It is used to detect and examine the acceleration of the robot on the center of robot. This sensor can measure the speed of the earth's axis. The acceleration information is sent to the controller by a serial port. Then the robot can correct its actions by itself. The robot falling down can be detected by this accelerometer so that the robot can autonomously decide to stand up from the ground.

4. Experiments

4.1 Penalty Kick

The penalty kick is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to approach and kick a ball positioned somewhere in the ball area. The robot recognizes the ball by using the CMOS image sensor according to color. In the strategy design of penalty kick, a architecture of decision based on the finite-state

transition mechanism is proposed to solve varied situations in the competition. Figure 11 is the architectonic diagram of penalty kick strategy.
There are three states (Find ball, Track ball, and Shoot ball) in the strategy of penalty kick. According to the information of environment through the CMOS image sensor, the robot can decide what state is the next state, and decide the best behavioral motion via the relative location and distance between the ball and the robot. For example, when the robot can see the ball (Find ball state), then the next state is "Track ball state". But if the robot loses the ball in "Track ball state", the robot state will change to "Find ball state" to search the ball again. The behavioral motions of robot according to the relative location and distance between the ball and the robot are showed in Table 6 and Table 7.

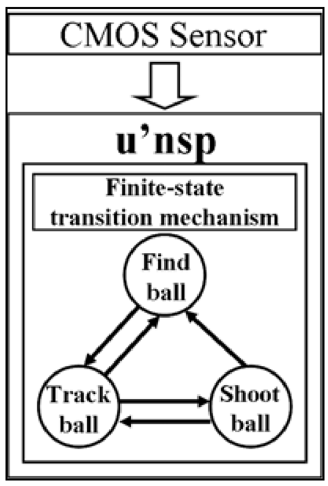


Fig. 11. Architectonic diagram of penalty kick strategy

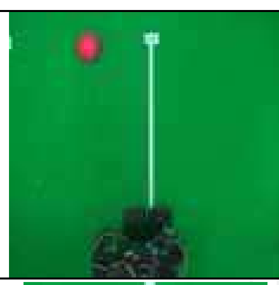
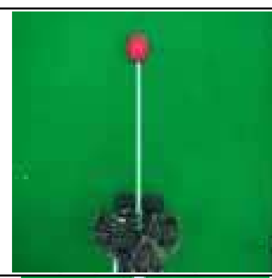
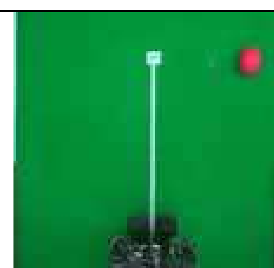
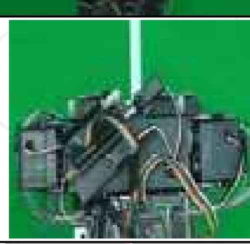
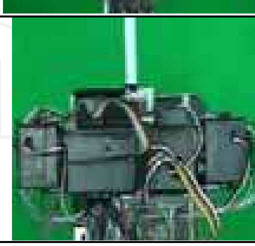
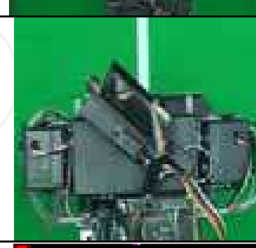
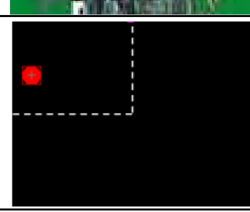
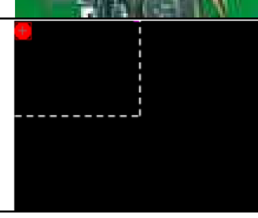
Relative location between the ball and the robot			
Angle of head in horizontal axis			
Image frame			
Behavioral motion	Slip left	Go straight	Slip right

Table 6. The behavioral motion of robot according the location between object and robot

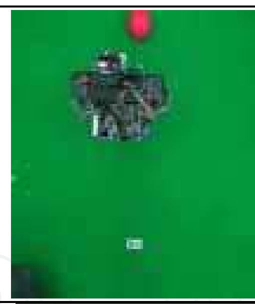
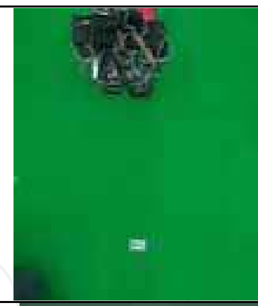
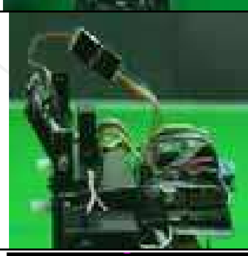
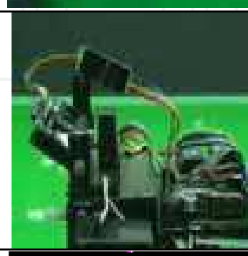
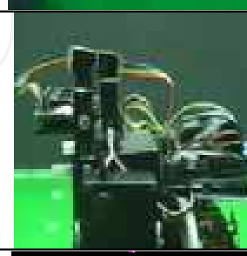
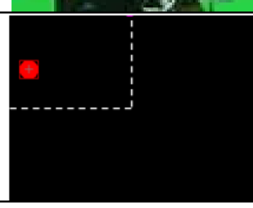
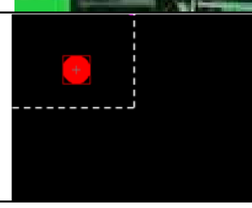
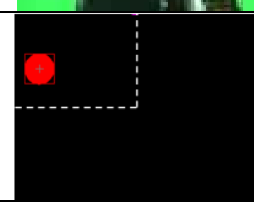
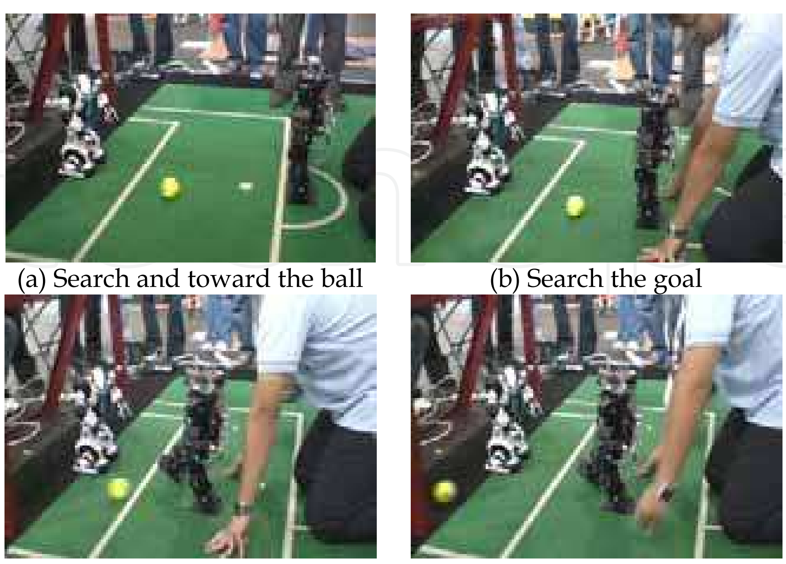
Distance between the ball and the robot			
Angle of head in vertical axis			
Image frame			
Behavioral motion	Go straigh	Go straigh small	Shoot ball

Table 7. The behavioral motion of robot according the distance between object and robot

Some pictures of TWNHR-IV playing the competition event: Penalty Kick (PK) are shown in Figure 12, where four pictures of TWNHR-IV are described: (a) Search and toward the ball, (b) Search the goal, (c) Kick the ball toward the goal, and (d) Goal. In this competition event, TWNHR-IV can use the CMOS sensor to track the ball and search the goal. The maximum effective distance of the CMOS sensor is 200 cm. When TWNHR-IV kicks the ball, the maximum shooting distance is 250 cm. (Wong et al., 2008b)



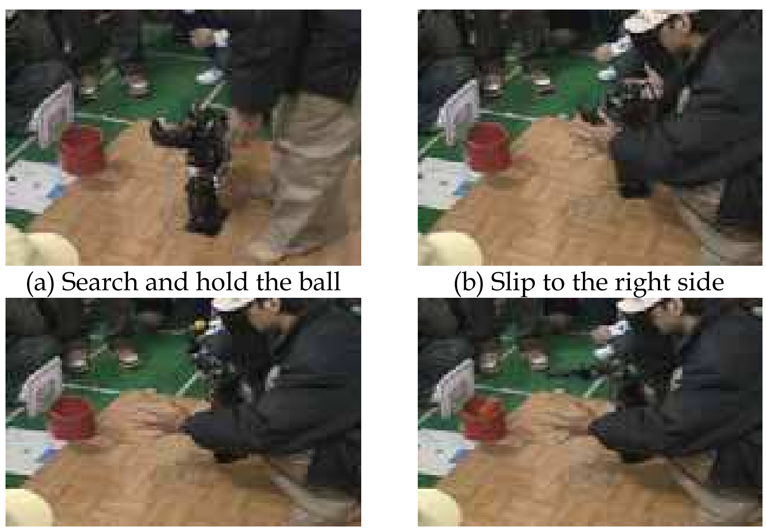
(a) Search and toward the ball (b) Search the goal

(c) Kick the ball toward the goal (d) Goal

Fig. 12. Photographs of TWNHR-IV for the penalty kick

4.2 Basketball

The basketball is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to throw the ball into a red basket. The robot stands in start point and then the robot need to move out of the start area. When the robot move out the start area, the robot could throw the ball into the basket. In the competition of basketball, the robot hold the ball and stay in the start area. When the robot move out the start area, the robot start to search the basket. The robot moves itself to face the baseket, and shoots the ball. Some pictures of TWNHR-IV playing the competition event: the basketball are shown in Figure 13, where we can see four pictures: (a) Search and hold the ball, (b) Slip to the right side, (c) Search the basket, and (d) Shoot. In this competition event, TWNHR-IV can use its arms to hold the ball and shoot the ball. The maximum shooting distance is 45cm.



(a) Search and hold the ball (b) Slip to the right side

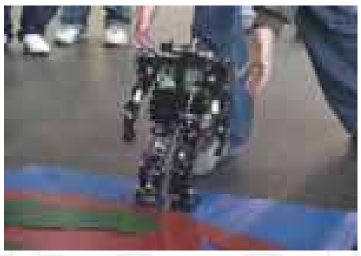
(c) Search the basket (d) Shoot

Fig. 13. Photographs of TWNHR-IV for the basketball

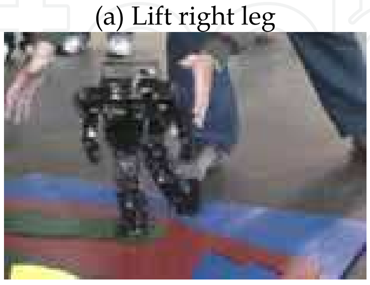
4.3 Lift-and-Carry

The lift-and-carry is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to carry some batteries and cross an uneven surface. There are four colors on the uneven surface, each color means different height of the field surface. The robot need to cross the field by passsing these color steps.

Some pictures of TWNHR-IV playing the competition event: the lift-and-carry are shown in Figure 14, where we can see four pictures: (a) Lift right leg, (b) Touch the stair by right leg, (c) Lift left leg, and (d) Touch the stair by left leg. In this competition event, TWNHR-IV can use the CMOS sensor to determine these stairs. The maximum crossing height is 2 cm, and the maximum crossing distance is 11 cm.


(a) Lift right leg


(b) Touch the stair by the right leg


(c) Lift left leg


(d) Touch the stair by the left leg

Fig. 14. Photographs of TWNHR-IV for the lift-and-carry

4.4 Obstacle Run

The obstacle run is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to avoid obstacles and arrive the goal area. In this competition, six infrared sensors are installed on the robot to detect the obstacle, as shown in Figure 15. The digital compass sensor is used to correct the head direction of the robot, when the obstacles are detected in safe range, the robot modify its head direction to the goal direction. (Wong et al., 2005; Wong et al., 2007a; Wong et al., 2007b)

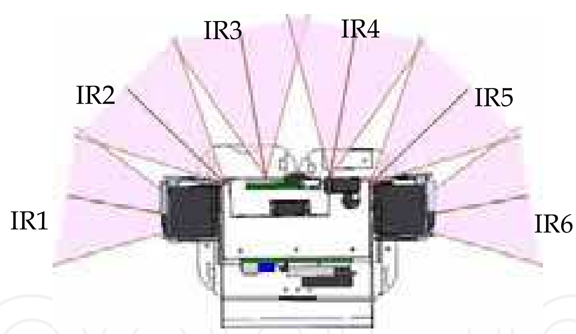


Fig. 15. Detectable range of six IR sensors

Some pictures of TWNHR-IV playing the competition event: the obstacle run are shown in Figure 16, where we can see two pictures: (a) Avoid obstacles, and (b) Move forward. In this competition event, TWNHR-IV can use the CMOS sensor and 6 infrared sensors to detect obstacles. Furthermore, TWNHR-IV can use the digital compass to determine its head direction. The maximum effective distance of the infrared sensor is 150 cm. The digital compass can determine 0 to 360 degree.

(a) Avoid obstacles (b) Walk forward

Fig. 16. Photographs of TWNHR-IV for the obstacle run

4.5 Robot Dash

The robot dash is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to go forward and backward as soon as possible. The digital compass sensor is used to correct the head direction. As shown in Figure 17, the robot direction is different to the goal direction that detected by a digital compass sensor, the correct motion is executed, that is shown in Table 8. There are three motions module when robot is walking forward. When the goal direction is on the right of the robot, the "Turn Left Forward" is executed, it is indicated that the turn left and forward are executed at the same time. When the goal direction is on the left of the robot, the "Turn Right Forward" is executed, it is indicated that turn left and forward are executed at the same time.. Normally, the "Forward" is executed. In that way, the robot does not waste time to stop and turn.

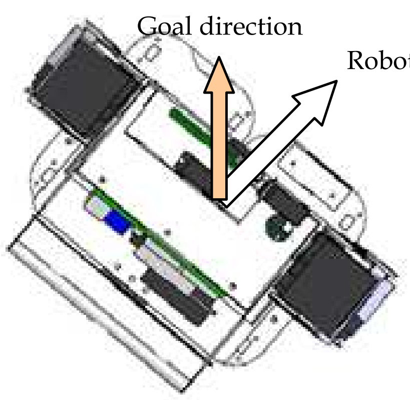


Fig. 17. Description of the relative angle of the goal direction and the robot direction

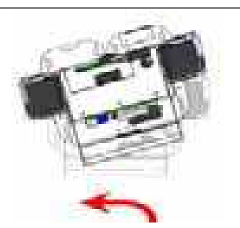
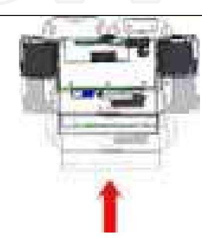
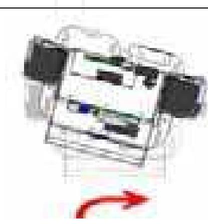
Turn Left Forward	Forward	Turn Right Forward
		

Table 8. Three motions mode

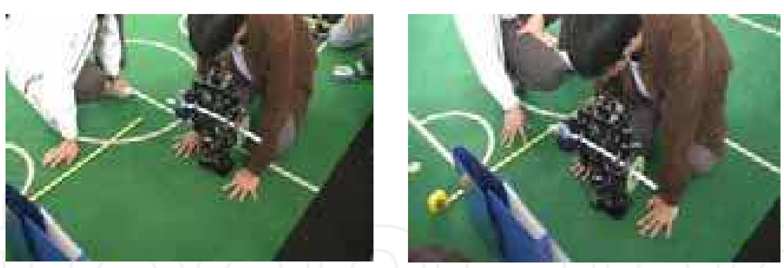
Some pictures of TWNHR-IV playing the competition event: the robot dash are shown in Figure 18, where we can see two pictures: (a) Walk forward, and (b) Walk backward. In this competition event, TWNHR-IV can use the 2 infrared sensors to detect the wall. If the infrared sensors detect the wall, TWNHR-IV will change the motion of walk forward to the motion of walk backward. The walking velocity of TWNHR-IV is 12 cm per second.

(a) Walk forward (b) Walk backward

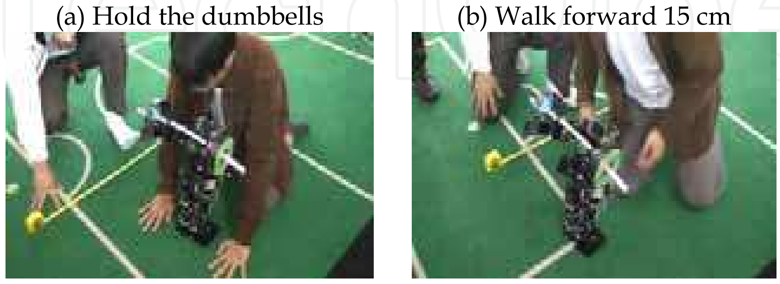
Fig. 18. Photographs of TWNHR-IV for the robot-dash

4.6 Weight Lifting

The weight lifting is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to go forward and lift the weight. The mechanism of TWNHR-IV is challenged in this competition, it also needs stable walking to complete.
Some pictures of TWNHR-IV playing the competition event: the weight lifting are shown in Figure 19, where we can see four pictures: (a) Hold the dumbbells, (b) Walk forward 15 cm, (c) Lift up the dumbbells, and (d) Walk forward 15 cm. In this competition event, TWNHR-IV can use infrared sensors to detect the wall. If the infrared sensors detect the wall, TWNHR-IV will lift up the discs and walk forward 15 cm. The maximum disc number lifted by TWNHR-IV is 43.



(a) Hold the dumbbells (b) Walk forward 15 cm



(c) Lift up the dumbbells (d) Walk forward 15 cm

Fig. 19. Photographs of TWNHR-IV for the weight lifting

4.7 Marathon

The marathon is one of competitions in HuroSot League of FIRA RoboWorld Cup. In the competition, the robot needs to track a visible line for a distance of 42.195 m (1/1000 of a human marathon distance) and finish it as quickly as possible. The robot recognizes the visible line by using the CMOS image sensor. From Figure 20, the image which we select is circumscribed by a white frame. (Wong et al., 2008d)

Every selected object is marked by a white fram. Through the CMOS image sensor, we can obtain the digital image data in the visible line. From Figure 20, P_{End} is the terminal point in the white frame and P_{Sta} is the starting point in the white frame. We transform the coordinate system from the white frame to the full image. The pixel of the full image are 120×160. According to the relation between the coordinate of the terminal point (P_{End}) and the coordinate of the starting point (P_{Sta}), we can obtain the trend of the visible line from one field to another field. The humanoid soccer robot decides the best appropriate strategy for the movement.

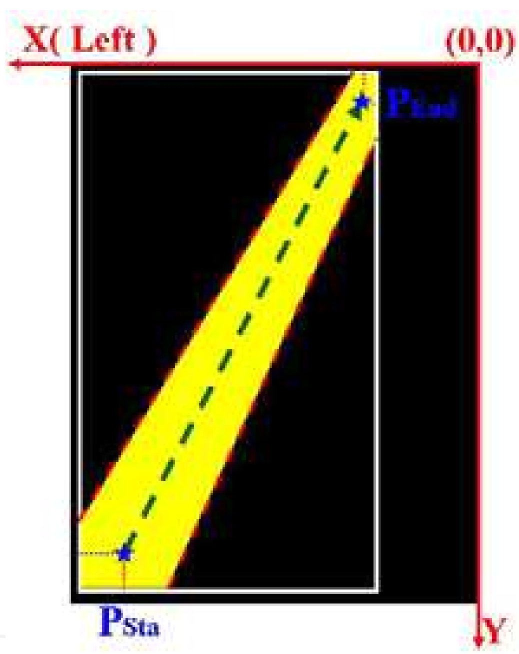


Fig. 20. Reference points of image information in the relative coordinate

Some pictures of TWNHR-IV playing the competition event: the marathon is shown in Figure 21, where we can see the TWNHR-IV follow the line. In this competition event, TWNHR-IV can use the CMOS sensor to follow the blue line and walk about 1 hour.

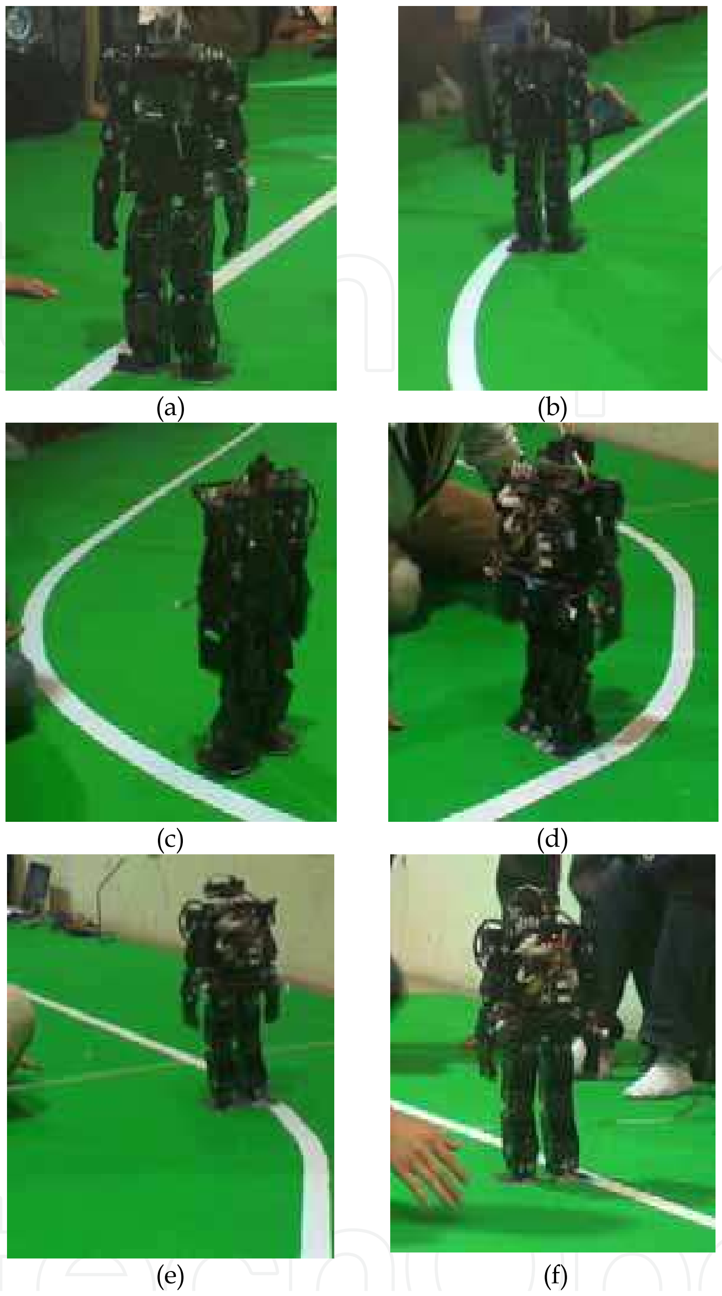


Fig. 21. A vision-based humanoid soccer robot can walk along the white line autonomously in the competition of marathon

5. Conclusions

A humanoid soccer robot named TWNHR-IV is presented. A mechanical structure is proposed to implement a humanoid robot with 26 degrees of freedom in this chapter. This robot has 2 degrees of freedom on the head, 2 degrees of freedom on the trunk, 4 degrees of freedom on each arm, and 7 degrees of freedom on each leg. A CMOS sensor, a digital compass, an accelerometer, and six infrared sensors are equipped on the body of TWNHR-IV to obtain the information of the environment. A CMOS sensor is installed on the head of the humanoid robot so that it can find the ball, track the line, and others image process. A digital compass is installed to detect the direction of the robot. An accelerometer is installed in the body of the humanoid robot so that it can detect the posture of robot. The implemented TWNHR-IV can autonomously detect objects, avoid obstacles, cross uneven surface, and walk to a destination. TWNHR-IV joined FIRA HuroSot 2007 and 2008, and won 7 times first place, 3 times second place, and one third place in different competitions. In the future, the localization ability is going to build in TWNHR-IV. Besides, fuzzy system and some evolutional algorithms such as GA and PSO will be considered to improve the speed of the motions and the movements.

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Robot Soccer
Edited by Vladan Papi

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The idea of using soccer game for promoting science and technology of artificial intelligence and robotics was presented in the early 90s of the last century. Researchers in many different scientific fields all over the world recognized this idea as an inspiring challenge. Robot soccer research is interdisciplinary, complex, demanding but most of all, fun and motivational. Obtained knowledge and results of research can easily be transferred and applied to numerous applications and projects dealing with relating fields such as robotics, electronics, mechanical engineering, artificial intelligence, etc. As a consequence, we are witnesses of rapid advancement in this field with numerous robot soccer competitions and a vast number of teams and team members. The best illustration is numbers from the RoboCup 2009 world championship held in Graz, Austria which gathered around 2300 participants in over 400 teams from 44 nations. Attendance numbers at various robot soccer events show that interest in robot soccer goes beyond the academic and R&D community. Several experts have been invited to present state of the art in this growing area. It was impossible to cover all aspects of the research in detail but through the chapters of this book, various topics were elaborated. Among them are hardware architecture and controllers, software design, sensor and information fusion, reasoning and control, development of more robust and intelligent robot soccer strategies, AI-based paradigms, robot communication and simulations as well as some other issues such as educational aspect. Some strict partition of chapter in this book hasn't been done because areas of research are overlapping and interweaving. However, it can be said that chapters at the beginning are more system-oriented with wider scope of presented research while later chapters generally deal with some more particular aspects of robot soccer.

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