Tsinghua Hephaestus 2007 TeenSize Team Description

Mingguo Zhao, Zongying Shi
Yu Liu, Dizhi Zhou, Hao Dong, Zhibin Liu, Xuemin Su

Tsinghua University, Department of Automation, Beijing, China

{mgzhao | szy}@mail.tsinghua.edu.cn
{liuyu | zhoudz04 | donghao00 | liu-zb04 | suxm06}@mails.tsinghua.edu.cn
http://www.au.tsinghua.edu.cn/robotlab/

Abstract. This document describes the specifications and functions of the humanoid robot THHRP-2, which is developed by team Tsinghua Hephaestus as a platform for research in bipedal locomotion, robot vision, self-localization and multi-robot cooperation. The robot will also be used to participate in TeenSize League of RoboCup 2007 Atlanta.

1 Introduction

The Tsinghua Hephaestus Humanoid Robot Project (THHRP) was established at Dept. of Automation, Tsinghua University, China, in July 2006. Before that, we had three years' research experience in Sony Aibo, mainly in robot vision, localization and multi-robot cooperation. We participated in RoboCup 2006 Four Legged League and got the fifth place in the Technical Challenges. For the humanoid robot project now, we focus our research interests in mechanisms of humanoid robot, bipedal locomotion, robot vision, self-localization and multi-robot cooperation.

THHRP-2 is constructed with strong servo motors and new skeleton types made up of carbon fiber. It is developed as a research platform and will be used to form the Tsinghua Hephaestus TeenSize humanoid soccer team. This year we are going to enter the international RoboCup competitions for the first time and show our research achievements to the whole world.

This document describes the specifications and functions of THHRP-2, as well as the research we are carrying on. It is organized as follows. In Section 2 we introduce the mechanical and electrical design of the robot. Sections 3 and 4 describe the robot vision and localization respectively. The gait planning and control method is described in Section 5, and the software architecture is shown in Section 6. Finally we conclude the document in Section 7.

2 The Robot

2.1 Mechanical Design

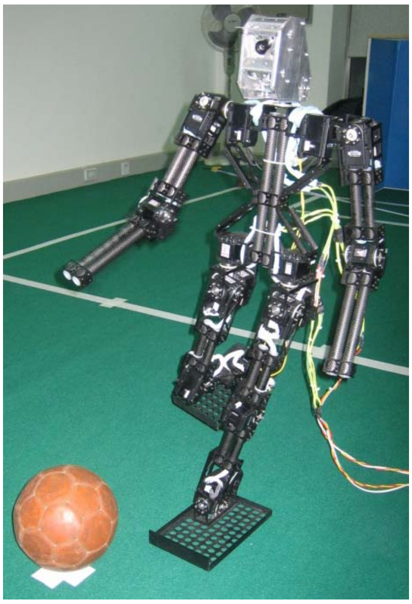

Fig. 2-1. THHRP-2 robot

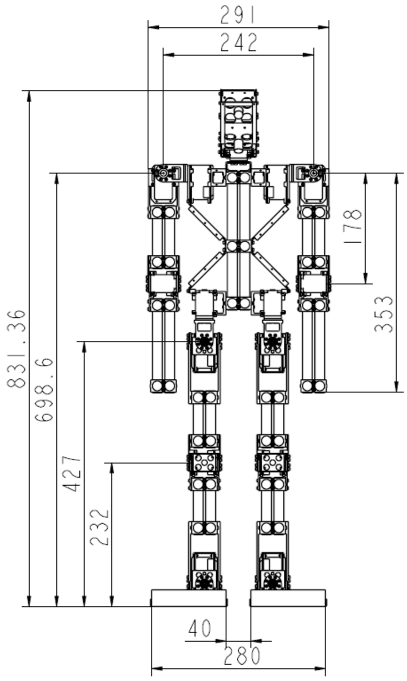

Fig. 2-2. Dimensions of THHRP-2

Fig. 2-1 shows our newly developed THHRP-2 kicking the ball. The robot is 830mm high and has a weight of 5.5Kg including batteries. It is driven by 19 actuators: 6 in each leg, 3 in each arm, and 1 in the head. Same as our KidSize robot THHRP-1, the hip and ankle joints of THHRP-2 are also orthogonal. The actuators are Robotis RX-64, which has a maximum torque of 64Kgcm and weighs 116g. Fig. 2-2 shows the detailed dimensions of THHRP-2.

In the design procedure of THHRP-2, we did some research in material and skeleton type, and finally designed carbon fiber tubes as main skeleton parts for the connections of adjacent joints. The robot benefits from this design concept in two points. First, carbon fiber tubes are much lighter than aluminum parts while maintaining the strong stability, which offers a big advantage for robot bipedal locomotion. Second, in this design prototype we can easily modify the robot size by adjusting the lengths of the tubes. Now we are anxious to see the performance of THHRP-2 in the RoboCup soccer games.

Configuration of DoFs and specifications of the servo motors are shown below.

Table 2-1. DoFs of THHRP-2

Joint	DoF	Angle Range
Head	Yaw×1	$-150^o \sim +150^o$
Shoulder	Pitch×2	$-120^o \sim +180^o$
	Roll×2	$0^o \sim +200^o$
Elbow	Pitch×2	$0^o \sim +150^o$
Hip	Pitch×2	$-90^o \sim +90^o$
	Roll×2	$-60^o \sim +90^o$
	Yaw×2	$-20^o \sim +30^o$
Knee	Pitch×2	$-150^o \sim 0^o$
Ankle	Pitch×2	$-90^o \sim +90^o$
	Roll×2	$-85^o \sim +85^o$
Total	19 actuators (Robotis RX64)	

Table 2-2. Specifications of servo motors of THHRP-2

Type	Robotis RX-64
Size [mm×mm×mm]	61.1×40.2×41
Torque [Kgcm]	64 (18V)
Speed [sec / 60deg]	0.162
Weight [g]	116
Voltage [V]	18
Operation current [A]	1.2 (Max)
Operation angle range [deg]	300/ Endless turn
Communication speed [bps]	1Mbps
Manufacturer	Robotis

2.2 Electrical Design

For THHRP-2, we use one PC 104 as the main controller, connected with all motors and sensors of the robot by three USB ports and three COM ports, as shown in Fig. 2-3. Specifically, two Logitech QuickCam Pro 4000 CCD cameras are chosen to be the vision sensor and are located in the robot head. One dual-axis acceleration sensor and three gyro sensors are located in the trunk. Buttons and LEDs, located on the back, are set to control and indicate the robot state, and their signals are processed by the MCU communicated with the main controller via a RS-485 Bus. The servo motors of upper body and lower body are connected in series on a RS-485 Bus respectively. Specifications of the electrical system are shown in Table 2-3.

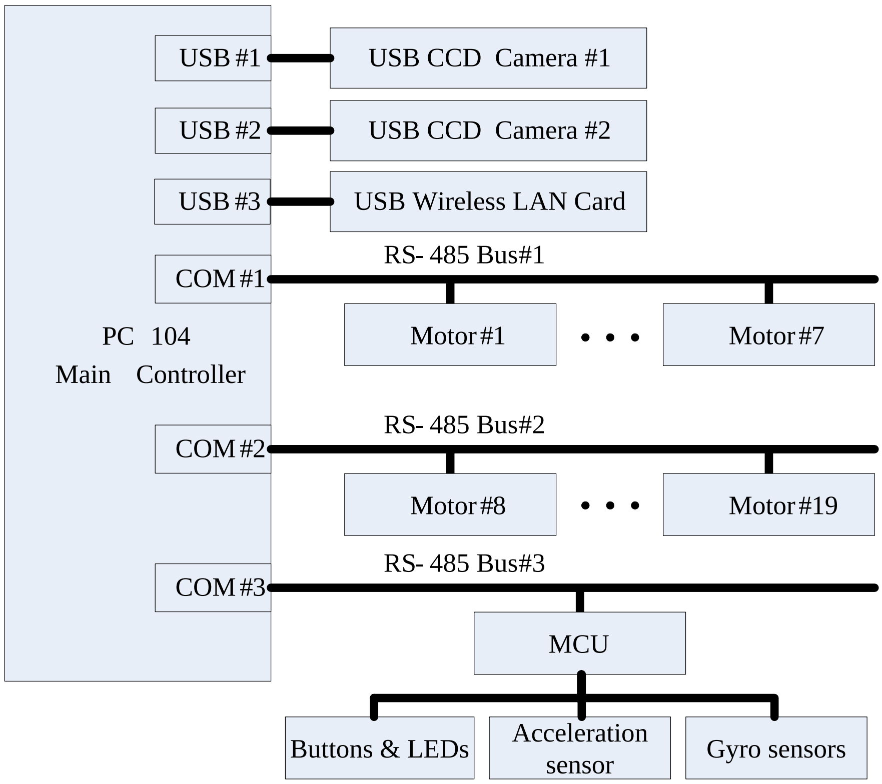

Fig. 2-3. The electrical system architecture of THHRP-2

Table 2-3. Specifications of the electrical system of THHRP-2

	THHRP-2
CPU	GeodeLX 800 (500 MHz)
RAM	256MB
ROM	1GB
OS	Redhat Linux
Interface	USB2.0 ×4 UART ×4 RGB display output interface ×1 LAN ×2
Sensor	USB CCD Camera ×2 Acceleration Sensor (dual axis) ×1 Gyro Sensor ×3 Buttons & LEDs
Application	Image processing Localization processing Behavior control Motion control Wireless communication

3 Vision

The result of image processing provides most percentage of the environmental information, which is necessary for robot localization and behavior control. As the field of Humanoid League is set up in order that object classes of interest can be characterized by distinct colors, color segmentation is firstly implemented to take advantage of the information of colors. The following object recognition process is based on the result of color segmentation. However, not the whole image is used to retrieve features for object recognition, but the image is scanned along a grid, thus to save computational expense.

3.1 Vision Sensor

For THHRP-2, two cameras are used, one is configured pointing to the ground in order to cover the nearer area, and the other is configured horizontally, covering area far away. Thus the head of the robot has only one yaw DoF. Each Logitech Pro 4000 camera is connected to the main controller via a USB cable. And image series of a resolution of 320×240 can be provided in real time by up to 25 frames per second.

3.2 Color Segmentation

We implemented a fast method of color segmentation based on a color look-up table. First, images of objects, such as goal, ball, beacon and etc, are captured and stored. Then the pixels in the images are manually labeled as what color it belongs to. And the color look-up table is generated simultaneously with the labeling process. Since it is necessary that the look-up table covers the whole color space (YUV), which consists of 256×256×256 pixels, the storage size of the look-up table could be huge. Thus, in order that the size of the table is acceptable, the table is compressed using run length code.

3.3 Object Recognition

Object recognition is based on the result of the color segmentation, but not all pixels in an image are checked. Features for recognition are retrieved from a horizontally aligned grid, as is shown in Fig. 3-1 (c). First, the pose of the camera is calculated according to the pose of the robot, and a horizon line in the image is calculated. Then the grid is constructed based on the horizon line, to which the grid lines are perpendicular and in parallel. Density of grid lines is higher in the area near the horizon line, whereas the grid lines are coarser in the rest of the image. Each grid line is scanned pixel by pixel from top to bottom and from left to right respectively. During the scanning each pixel is classified using the color look-up table. Features, a characteristic series of colors or a pattern of colors, are used for object recognition, e.g., a sequence of some orange pixels is an indication of a ball. Fig. 3-1 (d) shows the recognized ball, goal and beacon in the image.

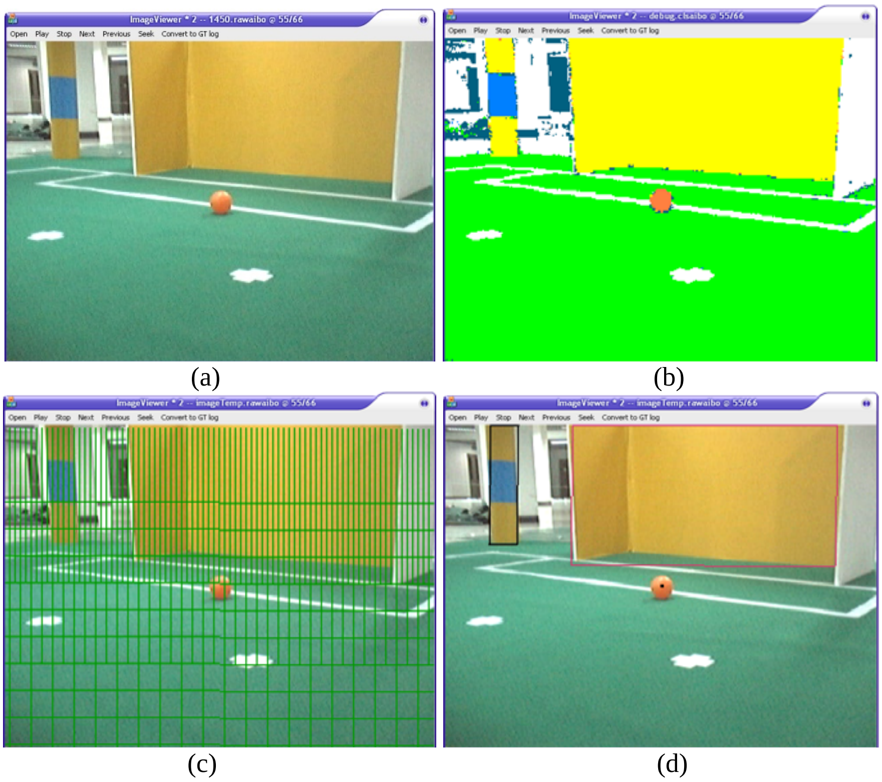

Fig. 3-1. (a) Original image captured by the camera; (b) Result of the color segmentation; (c) Grid-lines; (d) Result of object recognition.

3.4 Research on Color Invariance to Lighting Intensity

The approach of color segmentation above is static and global, thus not adaptive to variation of lighting conditions. When lighting condition of the game field changes, the result of color segmentation may not remain consistent. In order to solve the problem, we developed a method of color space transformation, through which images captured under different lighting intensity maintain color invariance, as shown in Fig. 3-2.

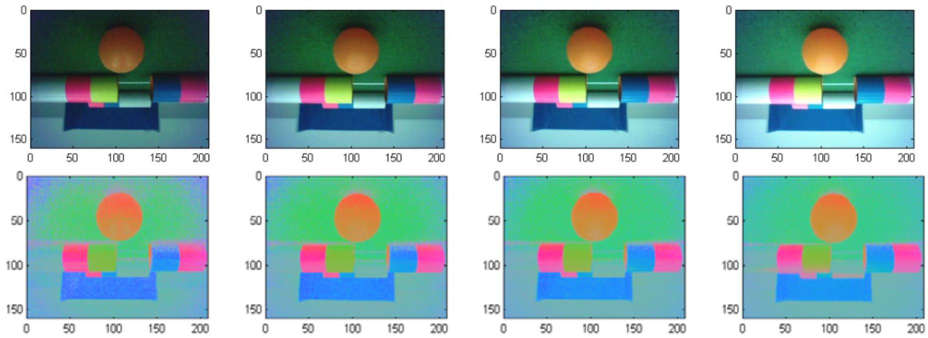

Fig. 3-2. Transformation of images under different lighting intensity

4 Localization

As mentioned before, our robot is developed as a research platform for mobile robot localization and object tracking. Table 4-1 outlines the results of our research works, which provide strong support for the competitive robot soccer games. In this section, only the algorithms of self localization and ball tracking are introduced.

Table 4-1. Issues of our research

Achieved Issues	Ongoing Issues
• Individual robot self localization • Active localization • Individual ball localizing and tracking	• Inter-detecting based multi-robot cooperative localization • Multi-robot cooperative localization using co-detected moving object • Collaborative ball localizing and tracking

4.1 Self localization of Individual robot

The localization problem in RoboCup domain is a typical map based global localization problem. In our earlier works [1,2,3,4], we investigated the performance of different existing localization methods such as EKF, MCL, Multiple Hypotheses Localization (MHL) and Adaptive MCL (A-MCL), etc. And, in [4], we proposed a negative-information integrated multiple hypotheses localization method, which had been applied to our 4-legged robots team with success. In order to achieve further improvement in robustness, we developed Clustered Dual-MCL (CDMCL) for individual self locator of our humanoid robots. It is a combination of Clustered-MCL [5] and Dual-MCL [6]. This method is able to keep better sample diversity than regular MCL so that multiple pose hypotheses can be properly tracked throughout an extended period of time, until all of them are distinguished by later observations.

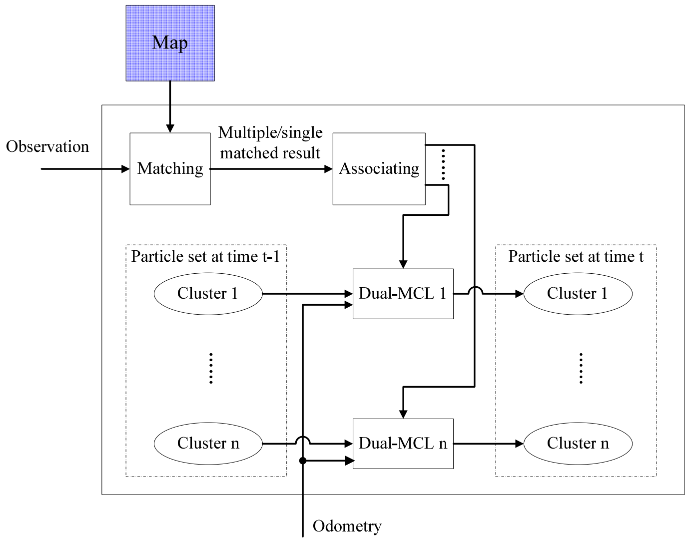

Fig. 4-1. One iteration of CDMCL

As shown in Fig. 4-1, CDMCL is executed as follows:

1) All particles are classified into different clusters according to their spatial similarity and all clusters are independently tracked using particle filters.

2) The detected features received from image processor are matched to the map of field and single or multiple probable matching results are obtained.

3) Each cluster is associated with a matching result, under the concept of nearest neighbor filter.

4) Each cluster is updated following the way of Dual-MCL with the associated matching result used in measurement update phase. Since two complimentary ways of generating samples are integrated, it is able to compensate the inaccuracy of motion model and solve the kidnapped robot problem effectively.

Then proceed to the next step, a potential field assisted active localization method [7] is applied to enable the robot to actively enhance the efficiency of localization and decrease the uncertainty of estimated robot position.

4.2 Ball Localizing and Tracking

Ball state estimation is a typical dynamic object tracking problem. We utilize particle filtering with sensor resetting [8, 9] for ball state representation and tracking, and adopt a novel Q-Hull K-means clustering algorithm (QHK-means) to extract probable ball locations from the particle set and output final estimation result.

In filtering process, each particle represents a possible ball position and velocity, which are calculated in the robot-centric coordination system. The update routine is done in two phases: the prediction step and the measurement update step. The former step is done at each iteration, while the latter is carried out only if a ball is seen.

QHK-means clustering algorithm involves four steps:

1) The neighborhood region of each particle is determined using Q-Hull algorithm [10], under the constraint of a given upper bound in distance.
2) All modes of the probabilistic distribution are found by picking out the particles whose weights are highest in their neighborhood regions.
3) K-means clustering algorithm is called to classify all of the particles into different clusters.
4) The sum-weight of particles in each cluster is calculated, and the cluster with the largest sum-weight is picked out. The weighted average of the particles in the chosen cluster is computed and outputted as the final estimation result.

QHK-means is able to generate arbitrary number of clusters and avoid converging to sub-optimal clustering results.

5 Gait Planning & Control

THHRP-2 has two kinds of locomotion pattern: omnidirectional walking and special actions such as kicking and getup. Special actions are described using key frames, which can be edited very fast by our software tool *HumanoidRobotControl*. Omnidirectional walking means the robot can walk in every direction with variable step length. Fig. 5-1 shows the control method for regular walking. Elementary gaits corresponding to different walking patterns, such as walking forward and backward, turning left and right and so on, are saved in a database. The behavior module determines the target position and orientation according to the results of localization and the sensor measurements, and then constructs an action series which consists of the elementary gaits to realize omnidirectional walking.

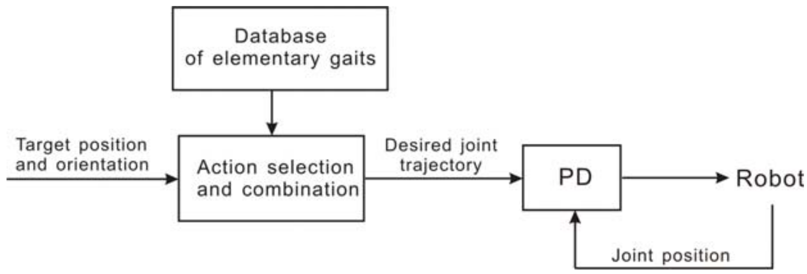

Fig. 5-1 Configuration of walking control

The feasible gait for biped robots must meet two basic conditions: stability and adaptability to the ground. Here we take the classical ZMP in the field of biped robot control as the stability criterion [11]. ZMP is a point on the ground where the total moment generated due to gravity and inertia equals to zero [12]. The ZMP criterion states that ZMP must be inside the convex hull of the support area to ensure the stability of the foot-ground contact. In fact, the ZMP criterion means the support foot should contact the ground with the whole sole to retain stable posture in the single support phase. And the minimum distance from ZMP to the boundary of the convex hull is called stability margin. The adaptability to ground is ensured by constraining the trajectory of the swing foot. We adopt a ZMP based parametric method to plan gait which approximates joint trajectories by cubic spline functions connected at knots, so the gait can be described completely by several key postures.

After setting gait parameters, such as step length, step period and the interval for single support phase, we adopt the following method to plan regular gaits [13]:

(1) Design the trajectory of the swing foot based on cubic spline interpolation to ensure the adaptability to ground, that is the swing foot should be lifted up in time and contact ground at the destination point, conquering the unevenness of ground and the backlash and flexibility of the robot itself.

(2) Determine the corresponding hip trajectory based on cubic spline interpolation by optimizing the hip knots and obtain gait. Considering the uncertainty of the robot, such as backlash, flexibility and the tracking errors of joints, we can determine a lower bound of the gait stability margin, which can be ensured by adjusting the hip knots. If trajectories of hip and swing foot in Cartesian space are known, then the corresponding trajectories of each joint can be obtained by solving inverse kinematics, and the ZMP trajectory can be calculated by recursive Newton-Euler method. The feasible set of hip knots is defined by the range of joint angle. By searching in this set we can find the hip knots, whose corresponding hip trajectory make the stability margin maximum and larger than the lower limit, and meanwhile we obtain the optimized gait.

The forward walking speed of THHRP-2 is 25cm/s. Other walking patterns can be obtained using similar methods. Currently, we are working on online gait generation which should make the robot locomotion more adaptable.

Postures of THHRP-2 at regular time intervals of a complete walking period and kicking action are shown in Fig. 5-2 and Fig. 5-3 respectively.

Fig. 5-2 Key frames of THHRP-2 at regular time intervals of a complete walking period

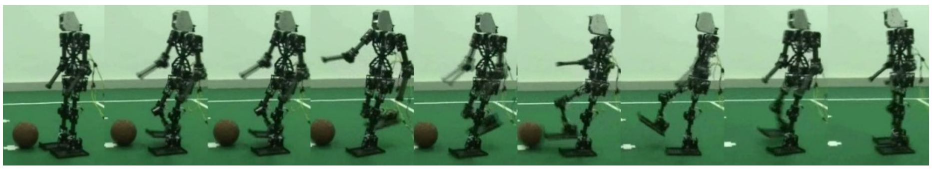

Fig. 5-3 Key frames of THHRP-2 at regular time intervals of a complete kicking action

6 Software Architecture

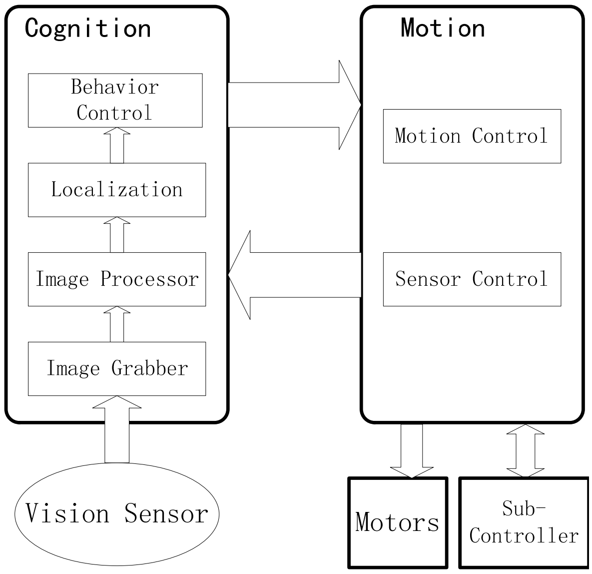

Fig. 6-1. Software Architecture

6.1 Processes

The software architecture consists of two processes, Cognition and Motion. The two processes runs in parallel and interchange data through a message queue. Cognition is responsible for information perception, self-localization and behavior decision, while Motion is responsible of gait planning and motor controlling.

6.2 Modules

Each process is divided into modules according to functionality. And modules are arranged so that they are independent to each other. Module configurations and data flows are shown in Fig. 6-1.

Image Grabber: grabs images from the vision sensor and generates related information of the image and the pose of the camera.

Image Processor: processes the incoming images grabbed by Image Grabber, and yield information needed for Localization and Behavior Control.

Localization: implements the localization algorithm, manages position information of robots and the ball, as to be used by Behavior Control.

Behavior Control: controls the game process and makes behavior decisions.

Motion Control: manages all the actuators of the robot, and controls locomotion or any other action of the robot according to the requests from Cognition.

Sensor Control: manages other sensors, and interacts with the Sub-Controller.

7 Conclusion

Our TeenSize robot THHRP-2 is a self-autonomous humanoid robot, with 2 cameras, 1 dual-axis acceleration sensor, 3 gyro sensors, 1 WLAN card and 19 actuators integrated on body, controlled with a PC 104 computer system. In this paper we present the specifications and functions of THHRP-2, as well as some related works on vision, localization and gait planning. At the moment, bipedal walking as well as kicking actions can be executed on THHRP-2, and further strategies about TeenSize soccer games will be accomplished soon.

This year, we are going to participate in the worldwide RoboCup competitions for the first time. It will be a good opportunity for us to learn and we are anxious for that.

Team Members

Currently, our team Tsinghua Hephaestus consists of the following members.
Team leader: Dr. Mingguo Zhao
Staff: Dr. Zongying Shi
Students: Yu Liu, Dizhi Zhou, Hao Dong, Zhibin Liu, Xuemin Su

References

[1] Mingguo Zhao, Yixin Cai, et al., "Self-Localization in RoboCup Four-Legged Robot League". In *China Intelligence Automation Conference* (CIAC'05), 2005.

[2] Yixin Cai, "Research on Robot Localization in RoboCup Four Legged League". Master Thesis, China: Tsinghua University. 2006.

[3] Yixin Cai, Mingguo Zhao, Zongying Shi, Wenli Xu, "An Experimental Comparison of Localization Methods in RoboCup Four-legged League". *Robot*, 2006. *accepted*.

[4] Yixin Cai, Mingguo Zhao, Zongying Shi, Wenli Xu, "Improved Multiple Hypotheses Localization using Negative Information". *Journal of Tsinghua University (Science and Technology)*, 2007. *submitted*.

[5] A. Milstein, J.N. Sanchez, E.T. Williamson, "Robust Global Localization Using Clustered Particle Filtering". In *Proc. of AAAI*, 2002.

[6] Thrun S, Fox D, Burgard W, et al., "Robust Monte Carlo Localization for Mobile Robots". *Artificial Intelligence*, 2001, 128 (1): 99-141.

[7] Zhibin Liu, Zongying Shi, Mingguo Zhao, Wenli Xu, "Environment Potential Field Assisted Active Localization for Mobile Robot". *Control and Decision*, 2006. *submitted*.

[8] S. Lenser and M. Veloso, "Sensor resetting localization for poorly modeled mobile robots", In *Proc. of the IEEE International Conference on Robotics and Automation (ICRA)*, 2002.

[9] T. Röfer, H.D. Burkhard, T. Laue, et al., "GermanTeam Robocup 2005", *Tech. rep.*, 2005. Available online: http://www.germanteam.org/GT2005.pdf

[10] Barber, C. B., D.P. Dobkin, and H.T. Huhdanpaa, "The Quickhull Algorithm for Convex Hulls," *ACM Transactions on Mathematical Software*, Vol. 22, No. 4, Dec. 1996, p. 469-483.

[11] M. Vukobratovic, A. A. Frank. "On the stability of biped locomotion". *IEEE Trans. on Biomedical Engineering*, 1970, 17(1): 25–36.

[12] A. Takanishi, M. Ishida. “The realization of dynamic walking by the biped WL-10RD” *Proc. of Int. Conf. on Advanced Robotics*. 1985. 459–466.
[13] Z. Y. Shi. “Research on Gait Planning and Decentralized Robust Tracking Control of Biped Robots”. Ph.D. Thesis, China: Tsinghua University, 2005.