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Humanoid Robot System, HanSaRam-VII for RoboMarathon in HuroCup

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Abstract: This paper presents the recent development of small-sized humanoid robot, HSR (HanSaRam)-VII, which is developed to participate in HuroCup which is one of the game categories of FIRA (www.FIRA.net). As HuroCup is composed of seven kinds of competitions, humanoid robots participating in this league have to be capable of various tasks such as weight lifting, basketball, marathon, etc. HSR-VII is designed to have high degrees of freedom, distributed planner-reactor architecture using PDA and embedded computer. This distributed control architecture includes vision processing, navigation and on-line walking pattern generation algorithm. In addition, time-domain passivity control algorithm is introduced to guarantee the stable walking pattern generation. The performance of the system is demonstrated through the RoboMarathon.

1. INTRODUCTION

Humanoid robots have been developed to generate human-like motions. HUBO of KAIST (I.-W. Park *et al.* [2006]), Honda ASIMO (J. Chestnutt *et al.* [2005]), WABIAN series of Waseda University (O. Yu *et al.* [2006]), and HanSaRam (J.-H. Kim *et al.* [2004]) stand testimonial to the rapid progress and development in this area. Most of the humanoid robot researches are focusing on walking pattern generation. Current research on walking pattern generation is mainly based on the inverted pendulum model (Fumio Kanihiro *et al.* [2005]). From the predefined model, several stability maintenance algorithms such as impedance control (J.-H. Park [2001]), online (real-time) balance control during walking (S. Kajita *et al.* [2001]), time-domain passivity control (Y.-D. Kim *et al.* [2006] and Y.-D. Kim *et al.* [2007]) of the landing impact force and modifiable walking pattern generation algorithm (B.-J. Lee *et al.* [2007]) are presented.

Apart from the research topics related to walking algorithms, internal structures contain path planning and vision processing. In this aspect of research, QRIO is recently used to perform 2.5D grid map-based navigation (J. Gurmann *et al.* [2005]). This approach is also used for HRP in AIST (F. Kanehiro *et al.* [2005]).

The initial purpose of developing humanoid robots was to perform human-robot interaction in human environments. Thus, imitating human activities has been the main research topic of humanoid robots. FIRA was founded with this goal by Professor Jong-Hwan Kim at KAIST (B.-J. Lee *et al.* [2007]) and HuroCup has been added to the category of FIRA since 2007. HuroCup is composed of seven types of games including robot dash, penalty kick, obstacle run, lift and carry, marathon, weight lifting, and basketball in addition to soccer games. To perform these various tasks, humanoid robot has to have various abilities such as vision processing, navigation, path planning walking gate generation, etc. Furthermore, these functions have to be implemented for multi-purpose tasks in the sense of reusability in various competitions. Conventional humanoid robot systems are not appropriate in this aspect because of their limited design specifications for various tasks.

In this paper, multi-operational humanoid system, HSR-VII, is introduced for HuroCup. HSR-VII system has a distributed planner-reactor architecture using PDA and embedded-computer. In this architecture, vision processing, navigation and robust walking gate generation modules are implemented efficiently using two distributed computer systems. Overall system capabilities are tested through one of HuroCup games, RoboMarathon, with the research outcomes of robust walking pattern generation algorithm and vision processing scheme. HSR-VII was the first award winner of RoboMarathon at the 12th FIRA CUP USA 2007.

The reminder of this paper is organized as follow. Section 2 briefly summarizes competitions of HuroCup. Section 3 introduces the hardware design of HSR-VII. Section 4 describes the internal distributed planner-reactor architecture including walking pattern generation and vision system structure. Section 5 shows experimental conditions and snapshots of RoboMarathon in FIRA Cup 2007 to verify the performance of this system and concluding remarks follow in Section 6.

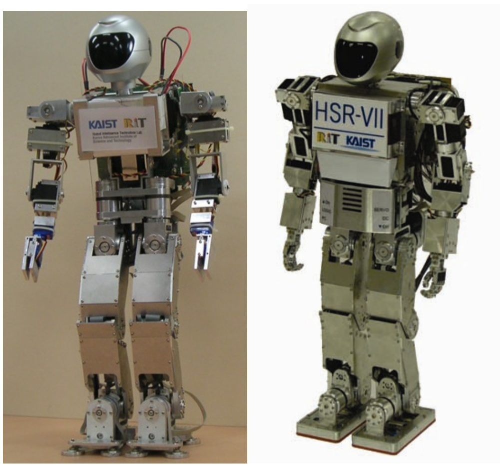
2. HUROCUP

HuroCup attempts to encourage research into the many areas of humanoid robotics, especially in the area of walking and balancing, complex motion planning, and human robot interaction. The HuroCup competition also emphasizes the development of flexible, robust, and versatile robots that can perform in many different domains. It consists of seven types of games including robot dash, penalty kick, obstacle run, lift and carry, marathon, weight lifting, and basket ball. In order to perform these various kinds of leagues, multi-purpose design of robot system is essential. Particularly, robust and easily modifiable walking pattern generation algorithm is needed for all category games.

3. SYSTEM DESCRIPTION OF HSR-VII

HanSaRam (HSR) is a humanoid robot that has continuously been undergoing redesign and development in the Robot Intelligence Technology (RIT) Lab, KAIST since 2000.

Compared with the HSR-VI (Fig.1(a)) (J.-K. Yoo *et al.* [2006]), which was originally designed for verifying walking algorithms, HSR-VII (Fig.1(b)) developed in 2006 has improved the structure of foot and the capability of arm to maintain its balance and grab a small object efficiently.



(a) HSR-VI (b) HSR-VII

Fig. 1. HanSaRam-VI and VII platform

Table 1. Principal specifications of HSR-VII

Dimensions	Height	528 [mm]
	Width	232 [mm]
Weight (battery included)		4.5 [kg]
D.O.F.	Head	2 DOFs
	Arm	2 Arms x 5 DOFs
	Hand	2 Hands x 1 DOF
	Waist	1 DOF
	Leg	2 Legs x 6 DOFs
	Total	27 DOFs
Maximum Walking Speed		120 [mm/s]

Table 1 shows the principal specifications of HSR-VII. HSR-VII consists of 13 DC motors in the lower body and 16 RC servo motors in the upper body for 27 degree of freedoms (DOF) in total. The purpose of using DC motors and harmonic drives in the lower body is to deliver sufficient power and accurate control. Using RC servo in the upper body reduces weight and enhances easier control.

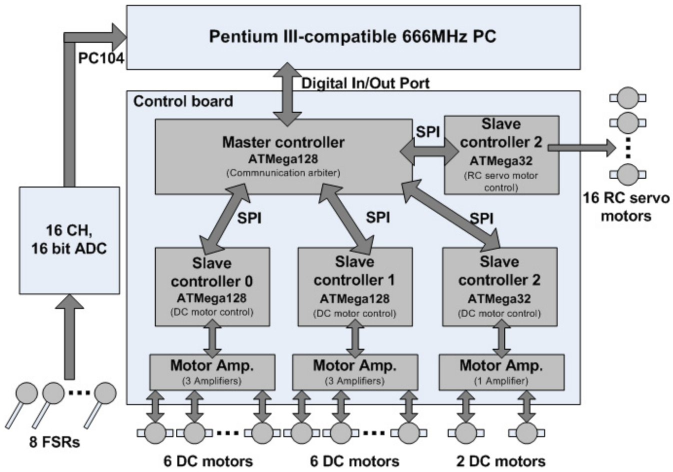


Fig.2 Control architecture of HanSaRam-VII

The control architecture and platform are shown in Fig. 2. Since one ATMega128 microcontroller can manipulate six DC motors, two ATMega128 micro-controllers are used for two legs, and one ATMega32 microcontroller is used for the waist motor. All the RC servo motors are controlled by one ATMega32 microcontroller and digitally converted FSR measurements are directly sent to the on-board PC through one ATMega128 master controller. Note that one DOF for five fingers is implemented by two servo motors.

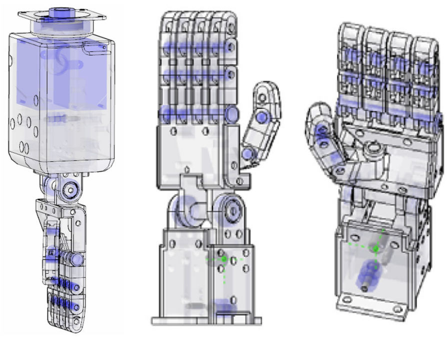


Fig. 3. Wire-driven hand module of HSR-VII

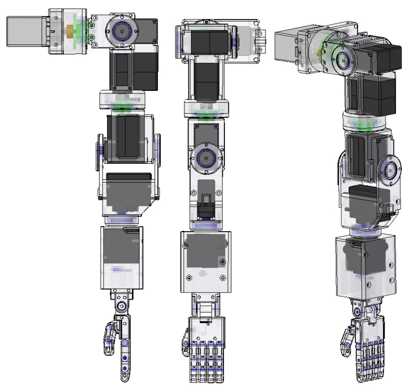


Fig. 4. Arm structure of HSR-VII

Hand structure of HSR-VII is known to be the smallest finger design at this time (Fig. 3). It enables to grab a small object and express hand gestures for human-robot interaction. Two servo motors are assigned to each hand to perform either grabbing or releasing. Since all five wires tightened to each finger are attached to one motor, it cannot control each finger. This extended structure of arms (Fig. 4) are essential for performing high level experiments of humanoids such as human-robot interaction and human-like motion generation.

4. DISTRIBUTED CONTROL ARCHITECTURE

A humanoid robot, HSR-VII, is composed of two components for the distributed planner-reactor layer (Fig. 5); one is an embedded computer, for reactor layer, which generates appropriate motion trajectories and the other is a PDA, for planner layer, which has a CMOS camera to capture and process image for localization and to perform path and motion planning. As the two layers of the architecture are implemented separately, perception of situation and motion trajectory generation can be performed in parallel (J.-K. Yoo *et al.* [2006]).

4.1. Planner Layer

Planner layer performs vision processing, and decision making for suitable path and motion to carry out a dedicated task. Vision processing module implemented in this system has the limitation of computing power because it has to be included in planner layer program in PDA. Though camera used in PDA has 640x460 resolution and 30fps abilities, 400MHz CPU-powered PDA limits capable algorithms for implementing the system. Due to this limitation, color-based object detection and simple self-localization algorithm based on the geometrical relationship of robot and objects on the ground are implemented in this system.

In this section, a scheme to estimate the depth information from a single captured image is described by using the following three useful traits of FIRA HuroCup playground:

1. The playground dimensions are predefined.

2. The border lines of the playground are perpendicular to each other.

3. All the elements on the ground such as the goal, ball and opponents exist just on the ground.

Fig.6 shows position estimation scheme used for this system, which correspond to the relationship between arbitrary point in captured image and real coordinate. The relational coordinates of feature points in the image are obtained through geometrical equations. The parameters required for calculating relational coordinates against the frontal direction of robot are the height (h), tilt angle (θ), angle of view of camera (Φ_x, Φ_y) and the size of image plane (S_x, S_y).

Using these information, relational perspective coordinates of any feature points in the image are calculated as follows:

$$\alpha = \theta_t - \frac{\Phi_y}{2}, \beta = 90 - \alpha \qquad (1)$$

$$\theta_x = \Phi_x \left(\frac{P_x}{S_x} - \frac{1}{2} \right), \ \theta_y = \Phi_y \left(1 - \frac{P_y}{S_y} \right) \qquad (2)$$

$$y_d = h \tan(\alpha + \theta_y), \ x_d = y_d \tan(\theta_x) \qquad (3)$$

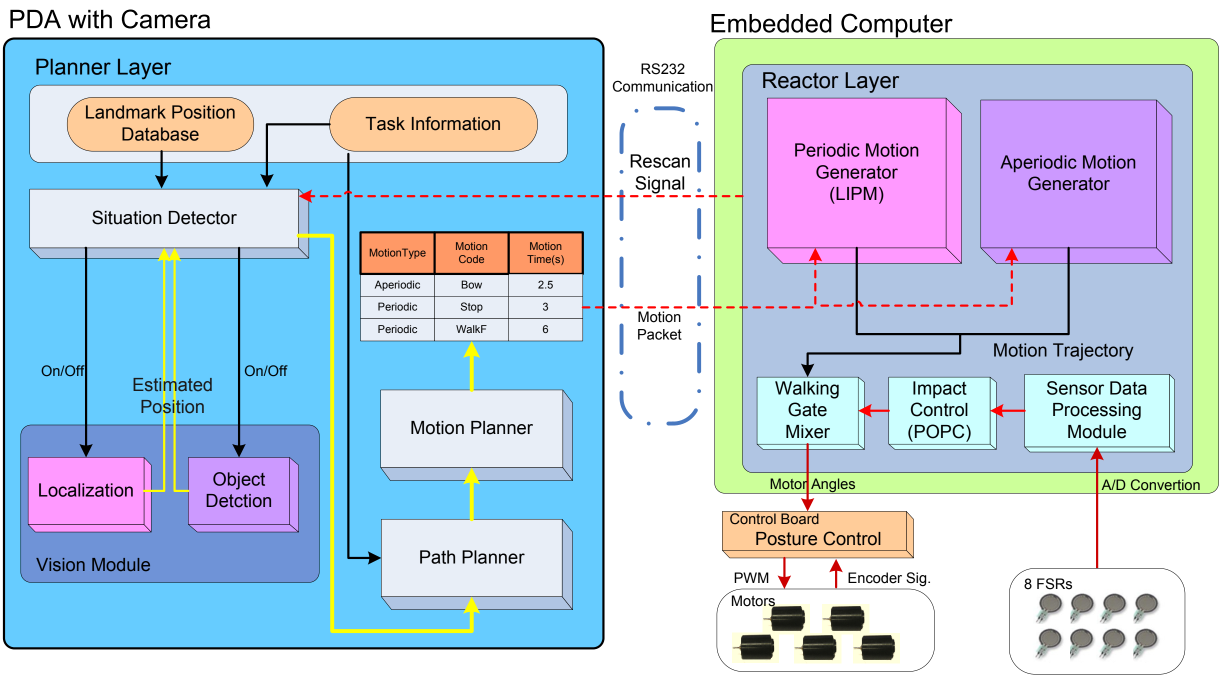


Fig. 5. Distributed control architecture for HSR-VII

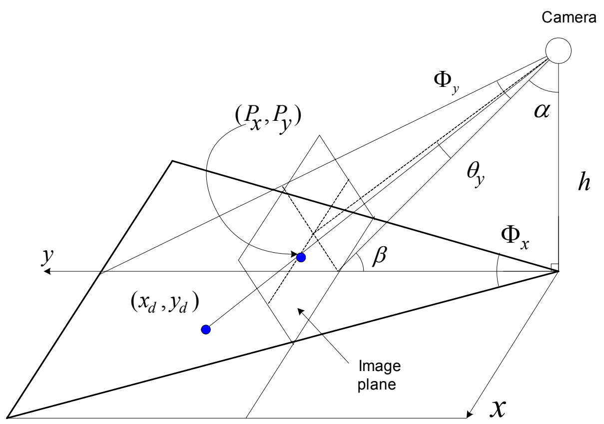


Fig. 6. Image plane and real coordinate

Where all angles are represented in degrees, (S_x, S_y) and (P_x, P_y) are measured in pixel units, and (P_x, P_y) is the coordinate of feature point on screen in pixel units. The useful features in the image are ball, goal, and the border lines of the playground. The former two features are detected by RGB detection module and their positions are assumed by the centroid of points over the threshold.

The situation detector, which is implemented in the planner layer, decides current situation by using the relative location of the robot, ground borders, and objects according to task and landmark information. Subsequently, appropriate paths are generated in path planner and one of them is eventually selected as the best one by the distance. In order to follow the suggested path, motion planner generates the process of motions to perform, and transfer them using RS232 protocol one by one to reactor layer. It also selects one of vision modules to use according to the detected situation. Situational decision making is performed according to finite state machine (FSM), which can be easily modifiable through programming.

4.2. Reactor Layer

The on-board Pentium-III compatible PC, running RT-Linux, calculates the periodic motion pattern in real time. Four FSR sensors are attached on each foot to measure the landing impact force and the ground reaction force even the foot hits the ground in non-perpendicular direction. If there is no compensation technique to the original planned periodic motions, the robot's foot may get a big landing impact force from the ground in a very short time and the stability of the robot cannot be guaranteed.

According to the motion-type code in motion packet in Fig. 5, one of motion generator is chosen and generates the corresponding motion. Periodic motion generator produces periodic motion trajectories such as walking, turning and changing walking direction and speed according to the inverted pendulum model. Aperiodic motion generator outputs pre-programmed motion trajectories that are provided by using a simulator.

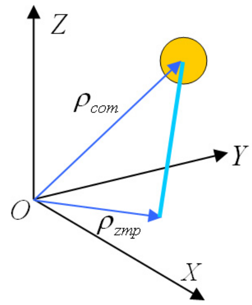


Fig. 7. 3D-inverted pendulum model

3D linear inverted pendulum model (LIPM) can be summarized in the following. COM and ZMP (Fig. 7) represent the center of mass and the zero moment point, respectively. The dynamic equation of ZMP criterion can be described as follows:

$$M = (\rho_{com} - \rho_{zmp}) \times m(\ddot{\rho}_{com} + g) + n = \begin{bmatrix} 0 \\ 0 \\ * \end{bmatrix} \quad (4)$$

where M is the moment around the ZMP and m is the mass of the pendulum. If the angular momentum of robot is assumed to be kept as zero during walking, the moment around the COM, n, can be ignored for the simplicity of modelling. x_{com} and y_{com} are expressed as follows:

$$(z_{com} - z_{zmp})\ddot{x}_{com} - (x_{com} - x_{zmp})(\ddot{z}_{com} + g) = 0 \quad (5)$$

$$(z_{com} - z_{zmp})\ddot{y}_{com} - (y_{com} - y_{zmp})(\ddot{z}_{com} + g) = 0 \quad (6)$$

Under the assumption of massless telescopic leg, height of COM can be simplified to a constant. Then, (5) and (6) can be simplified as

$$\dot{x}_{com} = \frac{g}{Z_c} x_{com} = \omega^2 x_{com} \quad (7)$$

$$\dot{y}_{com} = \frac{g}{Z_c} y_{com} = \omega^2 y_{com} \quad (8)$$

where ω is $\sqrt{g / Z_c}$.

Above two equations, (7) and (8), are independent. Therefore, using these equations, dynamics calculation of humanoid robot can be performed with relatively low computational burden (S. Kajita *et al.* [2001]).

The posture control module in reactor layer controls motors according to the motion trajectory. POPC-based impact control module compensates its posture according to the FSR sensor data so as to control the contact force and reaction force from the ground and maintain the posture (Y.-D. Kim *et al.* [2006]).

Compliance control uses a time domain passivity approach, which calculates the energy based on the landing force and foot position in order to stabilize on-line periodic motions. The time-domain passivity compliance control system consists of both passivity controller (PC) and passivity observer (PO), which regulates and checks the input and output energy flow between the robot's foot and the ground. If the PO can predict the next status of the system, the PC can modify the desired walking path to make the system passive. In other words, the passivity controller changes the initial planned periodic motions in real-time to achieve the stable landing of HSR-VII. Significantly, the passivity compliance controller guarantees a stable periodic motion without even having to know any system model information whatsoever.

Fig. 8 shows the data flow structure of reactor layer located in embedded computer. In this layer, dynamics, inverse kinematics and POPC-based impact control related calculations are performed in every 5ms using RT-Linux kernel thread. Data communication between user and kernel level is connected through shared memory and RT-FIFO structure.

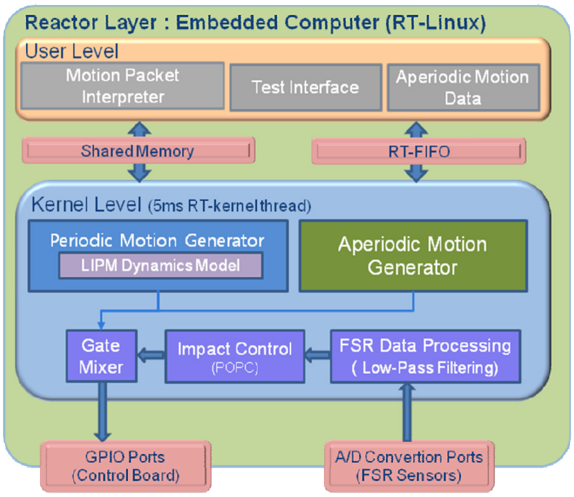


Fig. 8. Reactor controller architecture

5. EXPERIMENTAL RESULTS

In order to verify the performance of whole system of HSR-VII, one of HuroCup leagues, RoboMarathon was used. RoboMarathon is the most appropriate one among the HuroCup leagues to show its ability for walking, decision making, vision processing and robustness against changing environment.

5.1. Specification of RoboMarathon

Similar to the human marathon run, the HuroCup RoboMarathon aims to test the robustness and endurance of humanoid robots. The task is for the robot to track a visible line for a distance of 42.195m (1/1000 of a human marathon distance) as quickly as possible. Below three rules are essential among various rules of the league (J. Baltes [2007]):

a. The race commences with a staggered start of 3 minute intervals.

b. If the distance between the smaller and the faster robot is less than 50cm, then the referee will instruct the handler of the slower robot to remove his or her robot.

c. The human handlers are not allowed to interfere in any way with other robots, the referee, or other human handlers.

5.2. RoboMarathon Competition

According to above rules, HSR-VII took a part in RoboMarathon league of HuroCup. For detecting line of marathon playground, color-based object detection module was used. By detecting far and near coordinate of line point, HSR-VII estimated the curvature of line and changes its direction of walking using planner and reactor architecture components described in Section 4.

Fig. 9 shows the snapshots of broadcasting movie clip which was aired by EBS (Educational Broadcasting Channel in the Republic of Korea).

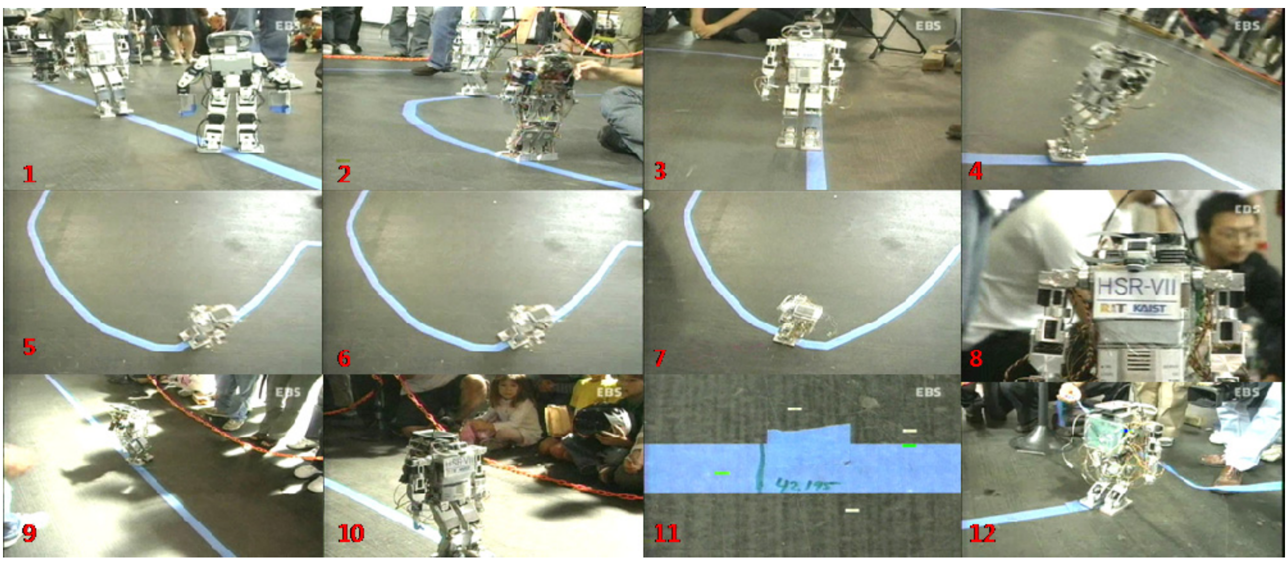


Fig. 9. Snapshots of broadcasting movie clip of HSR-VII's RoboMarathon

Fig. 9(1) and (2) shows chasing situation of Marathon. If the distance between two robot is less than 50 cm, the slower preceding robot has to be removed from track not to avoid the faster one. From Fig. 9(4) to (7), HSR-VII shows its ability to trace line though its curvature is almost 90 degrees. Furthermore, Fig. 9(9) shows its robust vision system(J.-K. Yoo *et al.* [2006]) could perform its line-finding function successfully.

At last, Fig. 9(11) and (12) shows HSR-VII finished RoboMarathon as the first winner of the first RoboMarathon at the 12th FIRA CUP USA 2007. The number of competitors was 18, and the final record of HSR-VII was 33 minutes and 22 seconds for 42.195m.

6. CONCLUSION

This paper presented the system of recently developed small-sized humanoid robot, HSR-VII. It was developed to participate in HuroCup, which is one of the game categories of FIRA. Due to the seven kinds of leagues in HuroCup, easily modularizable planner-reactor architecture was used. Planner layer was implemented in PDA with head mounted camera including decision making, vision processing and motion/path planner. Reactor layer was implemented in embedded computer including walking pattern generation module, POPC-based impact control module and posture control module. 3D-LIPM was briefly summarized, and the performance of the whole system was verified through RoboMarathon in HuroCup.

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