Autonomous Humanoid Soccer Robot : Taiwan 101 V1

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Abstract

Robot soccer games are very interesting research topics. Among different matches of robot soccer games, the humanoid robot category is a very challenging problem. In addition to stabilize complicated motion planning of biped walking, the humanoid robot must be capable of environment sensing and decision-making in autonomous manner. The Taiwan 101 V1 is a middle size humanoid robot with 3.6 Kg in weight and 63 cm in height. This robot is constructed as an 18 degree-of-freedom (DOF) mechanical structure. There are 6 DOF constructed for each leg; and 3 DOF constructed for each upper limb. Therefore, the Taiwan 101 V1 is capable of walking, turning, side shifting, and step climbing. At the same time, the PDA acts as the supervisory controller of the humanoid robot to deal with the image capture and recognition, decision-making, and motion planning. Finally, the Taiwan 101 V1 was constructed in laboratory in 2006, and it granted the fourth place of the HuroSot category in FIRA 2006 [8].

Keywords: *humanoid robots; autonomous robots; and soccer robots.*

1 Introduction

Recently, robot soccer games are widely discussed in universities all over the world. Typically, robot soccer game is an interdisciplinary research topic. In general, the technologies of mechanical design, electrical driving, and soft-computing based intelligent sensing, reasoning and control are all included to finish the soccer robot games. Typically, the movements of robots are categorized as wheeled and legged. Among different types of driving mechanisms, the developments of biped walking robots are more challenging than the others. There are several events held for demonstrating autonomous skills of humanoid robots, such as annual events of FIRA (Federation of International Robot-soccer Association) [8] and RoboCup [11].

From the viewpoint of the game rule, the FIRA humanoid robot game (HuroSot) is more focused on the skill representations. Foe example, the humanoid robots must be capable of stepping onto uneven terrane with carrying different weights autonomously in FIRA 2006 event. At the same time, the humanoid robots have to cross the path with randomly placed obstacles. Therefore, the sensors and intelligent controller must be developed as well for the autonomous soccer robots.

In this paper, several humanoid robot related papers are surveyed. QRIO [2] is a famous humanoid robot that was created by Sony Co. The control architecture of QRIO used the distributed control architecture with multiple satellite DSPs (Digital Signal Processor) and a main central processing unit, where the satellite DSP processor deals with the sounds, foot sole force sensors, etc.

In addition, the HanSaRam-VI [5] humanoid robot is designed as a 25 DOFs with 52 cm in height and 4.6 kg in weight. Especially, the control system of HanSaRam-VI is constructed using a hybrid architecture that consists of an embedded PC and a PDA. The PDA is responsible of capturing CMOS web camera, localization, object detection, and motion planning. The embedded PC is responsible of motion generator. Such a robot is capable of executing kick motions in the robot soccer game.

HRP-2 [4] is a large size humanoid robot, and its control architecture is also developed based on a distributed architecture that substitutes conventional centralized control architectures. Such control architecture provided scalable computing power at low energy. In addition, the reliability of the controller is also improved by replacing fragile analog signal wires with digital network and redundant routes.

ARMAR [3] is a wheeled humanoid robot, and it performs a modular and distributed control architecture to achieve natural interaction and mobile manipulation task goals. Their architecture was organized as a three-level hierarchy with task planning, coordination, and execution.

YABIRO [1] is a small size biped humanoid robot that consists of 14 DOFs, and it is controlled using a real time control architecture. The distributed tasks are categorized as control, actuation, and sensing. In addition, the CAN bus is used to establish real-time communications in their work.

In this paper, we introduce a PDA based autonomous humanoid robot, named Taiwan 101 V1.

The Taiwan 101 V1 is a middle size humanoid robot with 3.6 Kg in weight and 63 cm in height. This robot is constructed as an 18 degree-of-freedom (DOF) mechanical structure. There are 6 DOF constructed for each leg; and 3 DOF constructed for each upper limb. Therefore, the Taiwan 101 V1 is capable of walking, turning, side shifting, and step climbing.

At the same time, the PDA is selected as the supervisory controller of the humanoid robot to deal with the image capture and recognition, sensor data collection, decision-making, and motion planning. In addition, a programmable System-on-Chip (PSoC) [7] based gait synchronization controller is further developed to coordinate and synchronize the joint angles of the humanoid robots. The trained gait patterns are stored in the EEPROM of the gait synchronization controller, and these gait patterns are combined to present the desired motions. The Taiwan 101 V1 was constructed in laboratory in 2006, and it granted the fourth place of the HuroSot category in FIRA 2006 [8].

Finally, this paper is organized as follows. Section II introduces the humanoid robot design of Taiwan 101 V1; section III describes the gait synchronization controller; section IV proposed the supervisory control of the humanoid robot; section V illustrates the experiments; finally, the conclusions and future works are presented in section VI.

2 Mechanical Design of Taiwan 101 V1

The Taiwan 101 V1 is a middle size humanoid robot, and it is configured with 18 degree-of-freedom (DOF), and the robot is 63 cm in height and 3.6 Kg in weight. The robot body is designed to meet the middle size specification of HurSot category in FIRA 2006. The conceptual kinematic model is shown in Fig. 1. There are three DOFs on each upper extremity and six DOFs on each leg.

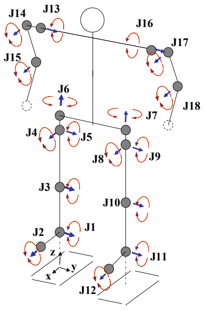

Figure 1: Conceptual kinematic model of Taiwan 101 V1.

The conceptual model is further realized using the Pro/E software. Fig. 2 shows the 3D CAD model of the mechanical design of Taiwan 101 V1. The joints of Taiwan 101 V1 are constructed using conventional RC servo motors (type: KRS-4014HV ICS Red Version [10]) so that the torques of motors are sufficient to drive the robot body. There are totally 106 parts to assemble the humanoid robot. Consequently, the Taiwan 101 V1 is assembled as shown in Fig. 3. Especially, the diagonal cross based 2D joint design is used in the ankle and hip joints so that these joints behave similar motion to humans. Fig. 4 shows the photo of the diagonal cross based joint design at the ankle joint.

Figure 2: 3D mechanical design of Taiwan 101 V1.

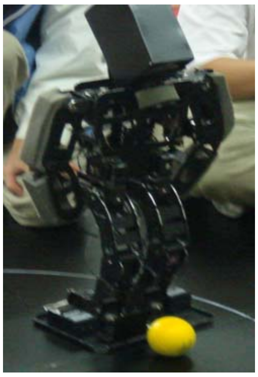

Figure 3: Photo of Taiwan 101 V1.

Figure 4: Diagonal cross based joint design.

3 Gait Synchronization Controller

The gait training and control function is desired to train the gait motions of the biped humanoid robots, and the trained gait motions are further used to control the biped humanoid robots. To achieve gait training and control purposes, the gait training program and the gait synchronization controller are developed in this paper. They are elaborated as follows:

3.1 Gait Training Program

In this paper, the Taiwan 101 V1 does not include any force/ torque sensor on it. Therefore, the Taiwan 101 V1 is not capable of walking in a dynamic manner. Instead, we use the pre-trained gait data to form the desired motions. To train the biped humanoid robot, a PC based gait training program is developed using the Microsoft Visual C++ in laboratory. This program is responsible of accepting user's commands to adjust joint angles of the humanoid type robot, as shown in Fig. 5. In summary, the gait training program consists of the following functions:

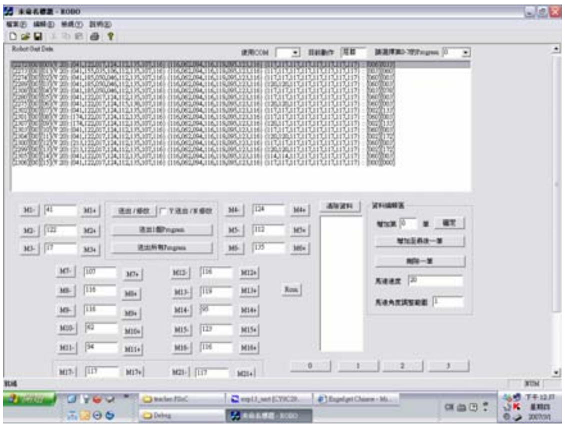

Figure 5: In-lab developed gait training program.

1. This program provides RS 232 serial communication interface to download gait patterns to the PSoC based gait synchronizer.
2. This program controls the joint angles of the humanoid robot in real-time (max: 24 joints).
3. This program records the gait training data in the Microsoft Access Database. The gait training data is further categorized as the gait programs, gait sequences and motor angles, and they are illustrated as follows:
    a. Gait program: It represents a single gait motion, such as flat walking, turning, side shifting, step climbing, etc. In addition, a program is composed of several sequences (max: 24 sequences).
    b. Gait sequence: It represents the sub-sequence of a gait program segment. Note that the time interval of the sequence is also defined. Especially, the motion of all joint motors can be synchronized at each gait sequence.
    c. Motor angles: Each gait sequence consists of the angles of all motors on the robot.

3.2 Gait Synchronizing Controller

The gait synchronization controller is responsible of receiving individual motion commands in the training stage and receiving entire gait training data before standalone operations. The gait synchronization controller is also developed based on PSoC. For the training stage, this module receives the individual motion commands and then controls the angles of corresponding motors via serial communications. For the standalone operation stage, this module receives the entire gait training data and then stores in the corresponding memory addresses of the EEPROM for the invocations of the supervisory controller, i.e., PDA (Acer n50 [6]). The control architecture of gait synchronizing PSoC module is shown in Fig. 6. The photos of PSoC based gait synchronization controller and the embedded PC are shown in Fig. 7. In addition, the linear and parabolic interpolation approaches are implemented for the gait synchronizing module. There are several important features for the interpolation approaches:

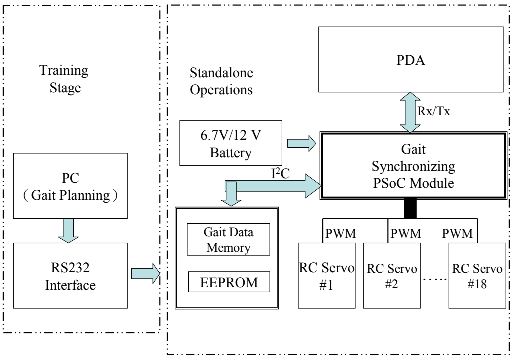

Figure 6: Architecture of gait synchronizing module.

Figure 7: Photo of gait synchronization controller.

a. The linear and parabolic interpolation approaches are capable of smoothing motor motions so that the stability of motions can be improved.
b. The linear and parabolic interpolation approaches can reduce the amounts of training sequences.
c. The general RC servo motors do not support velocity control capability. Since the time interval of each sequence is defined for the linear and parabolic interpolation functions, the angular velocity control of motors can be easily desired.

At the same time, all joint motors can be also synchronized at each sequence.

4 Supervisory Control

The supervisory controller of the Taiwan 101 V1 is implemented to deal with the image capture and recognition and the motion planning. These tasks are designed according to the competition categories. Table I shows the summary of tasks desired for different types of competitions.

Table I: Task summary of different competitions

Category	Image Recognition	Motion Planning
Robot Dash	Recognizing the target marker position and borderline of the ground	Adjusting the robot motion (forward, backward, turning, side-shifting) to reach the goal and to walk back
Penalty Kicks	Recognizing the ball, goal border, and goal keeper	Adjusting the robot motion (forward, turning, side-shifting, kicking ball) to reach the ball and kick
Obstacle Run	Recognizing the obstacles on the pathway	Adjusting the robot motion (forward, backward, turning, side-shifting) to pass obstacles on pathway
Lift-and-Carry	Recognizing color transitions of different step levels	Adjusting the robot motion (forward, turning, side-shifting, up-stair, down-stair) to pass uneven terrain

Based on the summary table of Table I, the tasks of image recognition and motion planning can be defined properly. In this work, the compact flash interfaced COMS web camera (with type FlyCAM-CF, LiveView Co. Ltd. [9]) is selected as the image capture device. The PDA, web camera, and the lens are combined as the head of the Taiwan 101 V1, as shown in Fig. 8. In this manner, the field of view includes the necessary filed of play of four competition categories.

Figure 8: Picture of image capture camera and PDA.

Basically, the image recognition techniques may use the threshold of color representations. In this work, the YUV representations are used to increase the robustness of color identifications. In addition, to increase the efficiency of recognition, the sampling of pixels is done according to the sizes of interested objects. Fig. 9 shows the picture of recognizing the red color. Note that the red points indicated in this picture are the color representations that satisfy the threshold condition of the red color. Such a threshold condition must be rejustified according to the light condition of the field of play. Finally, the center of gravity of the interested color pixels is calculated as the image location of the interested object. Such image location information can be further used to plan the motions.

The task of motion planning is executed according to the sensing of objects such as the image locations of the interested objects. The interested objects are summarized as shown in Table I. The motion planning module is responsible of executing different types of skills and mission according to different scenarios. To complete a desired skill and mission, the pre-trained gait motions of forward walking, backward walking, turning, side-shifting, kicking ball, up-stair, down-stair, and so on are dynamically combined. Fig. 10 shows the architecture of the supervisory controller. Initially, the scenario is selected according to competition category. Subsequently, the image recognition module is executed to get the image locations of interested objects. The rule based motion planning are further executed according to the selected scenarios. The rule based motion planning cooperating with the image locations of interested objects to infer and plan the motions. Finally, the motion commands are sent out to the gait synchronization controller.

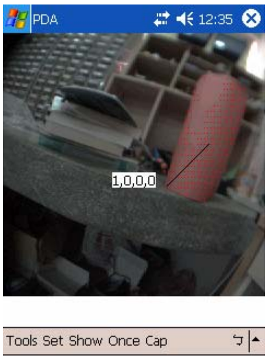

Figure 9: Picture of recognizing the red color.

The motion planning of four competition categories is developed for the Taiwan 101 V1 to participate the events of FIRA 2006. Among different competition categories, the Taiwan 101 V1 performed better performance in the penalty kick and lift-and-carry categories. The Taiwan 101 V1 poorly behaved in the robot dash and obstacle run categories due to the unique image sensing approach. In general, the electrical compass and infrared sensor modules are used to detect the robot orientations and the obstacle distances. However, these sensors are not added on the Taiwan 101 V1. Therefore, it is very difficult to detect the obstacle distance and robot orientation by using the CMOS web camera merely.

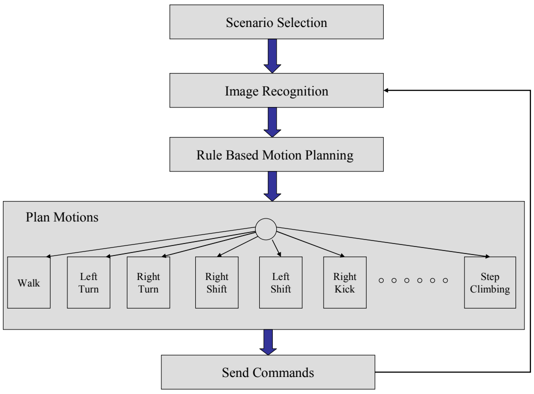

Figure 10: Architecture of supervisory controller.

In this section, the successful part of the penalty kick (PK) is introduced. We focus the discussions on the rule based motion planning. In Fig. 11, the rule based motion planning of kicking ball without goal keeper is indicated. In this case, the reaching goal position of the ball is defined as the center of goal. Initially, the robot recognizes the ball position. Then, the robot turns itself from direction A to direction B. And, the robot moves toward a position that is behind the ball position roughly. Theoretically, this position is called the subgoal (position B), and it is determined by the opposite direction of the ball and the center of goal with a specified offset. However, due to limited field of view of the camera and the single camera capture architecture, it is difficult to precisely define accurate subgoal position practically. Therefore, the robot just roughly moves toward to the subgoal with small offset. In this work, 5-10 cm offset distance can be reached experimentally. When the robot moves around the subgoal, the robot tries to move itself so that the ball and the center of goal are in front of the robot. At this moment, the robot is very close to the theoretical subgoal. Subsequently, the robot shifts left or right so that the ball is in front of one foot. Finally, the robot moves itself to reach the ball and then kick the ball.

The other situation is designed for the case with the goal keeper, as shown in Fig. 12. This case is similar to the previous case; however, the reaching goal position of the ball is not defined by the center of goal. Instead, we define the reaching goal position by the goal boundary and the goal keeper locations. Practically, the reaching goal position is selected as larger space of the goal keeper and any of the goal boundary location. As similar to the previous case, the robot moves to the initial subgoal position (position B). When the robot reaches the initial subgoal position, it determines a better reaching goal position. Then, the robot shifts itself to a new subgoal that is possible to kick the ball to the reaching goal position. Subsequently, similar procedures are done to complete the penalty kick competition.

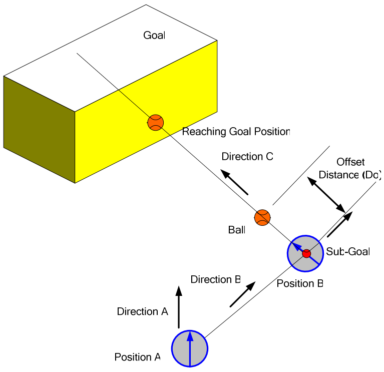

Figure 11: Kicking without goal keeper condition.

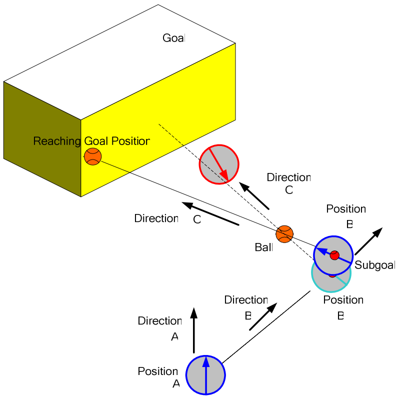

Figure 12: Kicking with goal keeper condition.

5 Experiments

5.1 Gait Training

In this subsection, the gait training pattern of individual motion is introduced. The individual gait training patterns are further combined dynamically to complete a desired competition scenario. The typical gait patterns includes the forward walking, backward walking, turning, side-shifting, kicking ball, up-stair, and down-stair. Due to limited pages of this paper, we just show the experiment of kicking ball in this paper. Fig. 13 shows the video segments of kicking ball using the right foot.

5.2 Motion Planning and Execution

In this subsection, the motion planning and execution for a competition scenario is discussed. We use the video segments of PK game to demonstrate the rule based motion planning performance. These video segments are captured from the FIRA 2006, as shown in Fig. 14. The motion planning of the robot is described as follows:

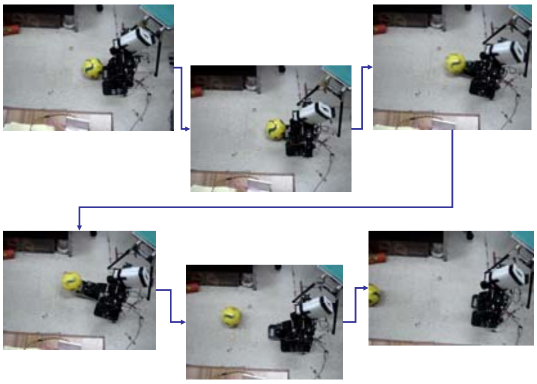

Figure 13: Video segments of kicking ball.

1. The robot stands at the initial position (part a).
2. The robot walks toward the subgoal (part b).
3. The robot justifies it orientation by right side shifting (part c).
4. The robot shifts itself to the right-hand-side again (part d).
5. The robot walks toward the subgoal again (part e).
6. The robot shifts itself to the right-hand-side to reach the subgoal (part f).
7. The robot shifts itself to the right-hand-side again so that the right foot is possible to kick the ball (part g).
8. The robot walks forward to the subgoal to reach the kicking position (part h).
9. The robot kicks the ball, and finally the ball reaches the ball (part i).

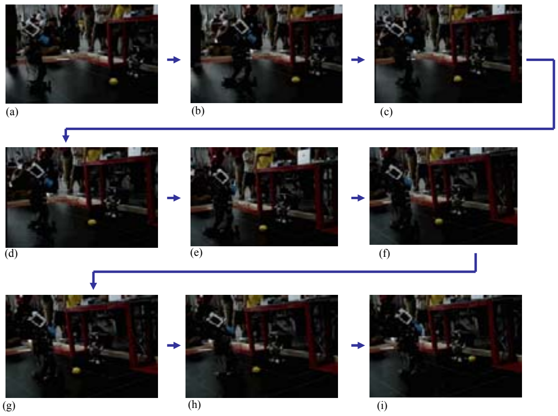

Figure 14: Video segments of PK game in FIRA 2006.

6 Conclusions

This paper presents the development of a middle size humanoid robot. This robot is designed for the FIRA HuroSot game category in 2006. The designs and implementations of the mechanical structures and control modules are introduced. In addition, the PDA based supervisory controller is also discussed in terms of the image capture and recognition and the rule based motion planning. A real robot named Taiwan 101 V1 is implemented to validate the proposed control architecture of this paper. Finally, the Taiwan 101 V1 granted the fourth place of the HuroSot category in FIRA 2006. In the future, the infrared, compass and FSR pressure sole sensor modules are planned to integrate on the current controller to perform more complete solution for the humanoid soccer robot games.

Acknowledgements

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