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Petri-net-based implementations for FIRA weightlifting and sprint games with a humanoid robot

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ABSTRACT

In this paper, the Petri net-based wireless sensor node architecture (PN-WSNA) is used to control a humanoid robot to play weightlifting and sprint games in the FIRA HuroCup league. With the PN-WSNA approach, the control scenario and decision-making for playing weightlifting and sprint games can be modeled as a PN-WSNA model. The PN-WSNA inference engine is further used to interpret and execute the PN-WSNA model according to the sensor information from visual perception. Therefore, the implementation of playing weightlifting and sprint games is achieved in terms of the PN-WSNA model instead of native code. To verify the PN-WSNA-based implementation approach, an autonomous humanoid robot equipped with a camera and a single-board computer is used for experiments, where the camera is responsible for grabbing image frames; the single-board computer is responsible for visual localization; and the PN-WSNA models the execution and locomotion command generation. Finally, several PN-WSNA models for playing weightlifting and sprint games are proposed and the experimental results are demonstrated and discussed to validate the feasibility of applying the proposed PN-WSNA-based implementation approach.

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1. Introduction

Participating in autonomous robot competitions is an important way to acquire education in robotics. Participants may learn not only hands-on skills and technologies but also novel intelligent control approaches for robotics. The Federation of International Robot-soccer Association (FIRA) HuroCup League [1] is an important organization that defines a number of challenging sport-related skills for autonomous humanoid robots. Current FIRA HuroCup matches are sprinting, penalty kicking, obstacle racing, lifting and carrying, weightlifting, marathon, wall-climbing and basketball. With the above-mentioned matches, humanoid robots have to use cameras to detect image features, such as lines, objects, markers, obstacles, etc., and then make decisions. As a consequence, the autonomous humanoid must be capable of image processing and recognition, localizing image patterns [2], decision making for navigation [3] and locomotion [4] to perform the tasks specified in the FIRA HuroCup league.

Research into humanoid robots for performing autonomous tasks in competitions has been getting more popular in recent years. Vadakkepat et al. [5] presented humanoid robot research into processing architecture, gait generation and vision systems in their laboratory. Those humanoid robots have been successfully participating in various robotic soccer competitions. Haddadin et al. [6] proposed the idea of a kicking motion with elasticity for humanoid robots to meet the safety and performance concerns in human–robot soccer games.

Zagal et al. [7] presented the techniques of self-modeling approaches for humanoid soccer robots. Calderon et al. [8] identified the generation of human-like soccer primitives from human data for operating humanoid robots. Cherubini et al. [9] proposed policy gradient learning for a humanoid soccer robot. Finally, Friedmann et al. [10] presented adequate motion simulation and collision detection for playing soccer games with humanoid robots.

On the other hand, the implementation of humanoid robot control system is important in executing tasks. Programming with a high-level language, such as the C language, is a conventional way to realize autonomous navigation and task execution for robots. Although programming with a native high-level language is convenient for autonomous robot developers, such kinds of high-level programming code are hard to maintain. As a consequence, several popular commercial solutions for robot programming have been proposed, such as LabVIEW from National Instruments [11] and Simulink from MathWorks [12]. With these solutions, the developers do not need to deal with complicated programming efforts from coding huge high-level programs. Instead, they can realize their system in terms of model-based implementation approaches that are capable of proposing fast and reliable robotic solutions.

The Petri net-based wireless sensor node architecture (PN-WSNA) [13] is a model-based implementation approach that can

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be used to develop autonomous sensing and decision functions for intelligent control systems. The PN-WSNA is a high level Petri net (PN), and PNs [14] are usually used to model discrete event dynamic systems (DEDSs) with concurrent and asynchronous characteristics. Practically, the behaviors of autonomous robots can be characterized as DEDSs, where the decision is made according to a change of sensor status.

Therefore, a number of Petri-net-based approaches have been proposed to model and realize autonomous robot control systems. For example, Costelha et al. [15] used Petri nets as solutions for the modeling, analysis and execution of robotic tasks. Zhang et al. [16] presented an agent oriented hierarchical Petri net to deal with environment perception, information fusion, path-planning and autonomous driving for autonomous robots. You et al. [17] presented a household mobile robot, and a Petri net was used to develop event-driven dual-driving-wheel synchronization control models. Huang [18] proposed an action selection strategy for soccer robots based on a Petri net.

Usually, a conventional PN cannot deal with sensor and actuation interfaces. As a consequence, they are hardly used for task execution. However, the PN-WSNA provides additional interfaces and functions for sensor data collection and inference, intra-communication and device actuation. Hence, the PN-WSNA can be applied directly to deal with real control problems.

To verify the proposed PN-WSNA-based modeling approach, PN-WSNA models for executing the tasks in the HuroCup league for weightlifting [19] and sprint games are discussed in this paper with a small size humanoid robot, named HuroEvolution-JR. The rest of this paper is organized as follows: Section 2 introduces HuroEvolution-JR and PN-WSNA; Section 3 describes the PN-WSNA models and experiments for the weightlifting games; Section 4 elaborates the PN-WSNA models and experiments for the sprint games; finally, Section 5 summarizes the conclusions and future work.

2. Introduction of HuroEvolution-JR and PN-WSNA

2.1. Mechanical design of HuroEvolution-JR

The HuroEvoluation-JR is a humanoid robot, especially developed for the FIRA kid-size competition. The HuroEvoluation-JR is configured with 22 degrees of freedom (DOF), where 12 DOFs are arranged in two legs; 8 DOFs are arranged in two arms; and 2 DOFs realize the pan-and-tilt motions on the neck joint for driving the head camera. Commercial RC servos [20] are used for driving the joint motions of the HuroEvoluation-JR. The height and weight of HuroEvoluation-JR are 45 cm and 2.8 kg, respectively. Fig. 1(a) shows a photograph of HuroEvoluation-JR and Fig. 1(b) illustrates its mechanical design structure. It is noted that a newly designed humanoid robot was used in this paper as compared to the authors' previous work [19].

In this paper, the skills for playing weightlifting and sprint games are proposed. Weight-lifting needs two arms to hold a weight-bar. Therefore, a set of passive grippers was produced to hold a weight-bar, as shown in Fig. 2(a). A dimension tolerance for the bar slot was designed to handle image recognition uncertainties. Fig. 2(b) shows the situations of holding a weight-bar. The weight-bar is composed of a lifting bar with a diameter between 8 and 15 mm and a number of weights applied at its two ends. The weights used in the weightlifting competition were standard 5 1/4-inch CDs or DVDs.

According to the FIRA weightlifting game, three key motions are identified, as shown in Fig. 2(c). The first key motion is to firmly hold the weight-bar. In practice, the proposed passive gripper contains a bar slot, and it is desired to enter the section below the weight-bar so that the weight bar slides into the bar slot of the passive gripper. Then, two RX-28 RC servos located on two wrist joints performed slight spin motions to tightly lock the weight-bar to avoid movement of the weight-bar during lifting and walking. The second key motion is to hold the weight-bar below the neck. The third key motion is to hold the weight-bar above the neck; however, the height difference of the weight-bar between the second and the third key motions must be greater than 15 cm.

2.2. Control systems of HuroEvolution-JR

The control system of the HuroEvolution-JR is composed of a single-board computer (Pico-820 [21]), a web camera (Philips SPC900NC [22]) and a locomotion controller (Robotis CM-5 [20]), as shown in Fig. 3. The single-board computer is responsible for executing the visual localization subsystem and several PN-WSNA model programs. The visual localization subsystem is used to calculate the floor coordinates of image targets of interest, such as balls, lines, weight-bars, etc. The details of the visual localization equations can be referred to in [23]. Also, the PN-WSNA model program contains a PN-WSNA model inference engine, which is responsible for executing the PN-WSNA models in real-time. The details of the PN-WSNA model program can be referred to in [13]. The locomotion controller is responsible for generating the motions of hands and legs to achieve various motions in competitions, and will be described later.

2.3. Visual localization

In this paper, the weightlifting and sprint games are discussed. First, the image targets for the weightlifting game are discussed; these are the image centroid of the weight-bar (P_{bar}), the lateral offset of the beacon marker image centroid (X_{offset}) and the angle of the weight-bar (θ_{bar}) and the angle (θ_{line}) and minimum distance ($Dist_{line}$) of the intermediate or final lines, as shown in Figs. 4 and 5. Note that (R_x, R_y) and (L_{ripx}, L_{ripy}) are presentations in the robot coordinate system (i.e., $X_{rob} - Y_{rob}$) and camera coordinate system (i.e., $X_{cam} - Y_{cam}$), respectively; θ_{mp} is the angle of the pan motor of the camera. These parameters can be obtained from the camera orientation and height, the camera pixel coordinates of the image targets and the camera focal length, and they are referred to in [23].

In addition, the image targets of the sprint game are discussed. The end line and a beacon marker (a filled red circle in this paper) are used for image targets of the sprint game. Therefore, the parameters used in the sprint game are the line angle (θ_{line}), the horizontal offset of the beacon marker (X_{offset}) and the minimum distance of the robot to the line ($Dist_{line}$), as shown in Fig. 5.

In order to verify the accuracy and reliability of the proposed visual localization approach, three kinds of experiments were done in this paper to verify the visual localization performance with respect to the different image targets used in the weightlifting and sprint games. The image targets are a weight-bar, a line and a beacon marker, as indicated in Figs. 4 and 5.

The camera used in this paper is the same as in the authors' previous work [23]. The resolution of images is 320 pixels × 240 pixels. The other camera parameters, such as the virtual focal length, can be referred to [23]. The experiment conditions are also described. The first experiment is to evaluate the visual localization performance for a weight-bar, and the accuracy for P_{bar} and θ_{bar} were recorded and compared with actual values. In this experiment, 27 trials were done and recorded. These trials are arranged by placing the weight-bar randomly in a 25 cm × 30 cm area with different angles. The angle for the experiments ranges from -15° to 15°. Hence, this experimental area is reasonable for the weight-bar localization in the first stage of the weightlifting game.

The second experiment is to examine the visual localization performance for a line, and the accuracy for $Dist_{line}$ and θ_{line} were recorded and compared with the actual values. In this experiment,

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