Robo-Erectus: Humanoid Soccer Robot Team

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Abstract. This paper provides a brief description of a low-cost autonomous humanoid soccer robot Robo-Erectus (RE) developed in the Advanced Robotics and Intelligent Control Centre at Singapore Polytechnic. To develop a low-cost humanoid platform which is affordable for many researchers, our RE humanoid robots have been intentionally designed to have low-torque servo motors and low-precision mechanical structures so that the cost can be significantly reduced. Inspired by human's remarkable capability of utilizing perceptions, we also conduct a research aimed at synthesizing humanoid gaits through the incorporation of both perception-based and measurement-based information. For this reason, a fuzzy reinforcement learning (FRL) agent has been developed to implement perception-based humanoid walking and kicking pattern generation. We demonstrate that it is possible for a humanoid robot to start its walking and kicking with the perception-based information and then refine its gait through further reinforcement learning. The proposed control and learning methods have been successfully tested on our newly developed RE humanoid soccer robots which won second place in the RoboCup 2002 Humanoid Walk competition and managed first place in the RoboCup 2003 Humanoid Free Performance competition.

1 Introduction

Humanoid soccer robot league is a new international initiative to foster robotics and AI technologies using soccer games [1]. The humanoid league is more challenging than the existing wheeled or multi-legged robotic soccer game because the dynamic stability of humanoids needs to be well maintained while the robots are walking, running, kicking and performing other tasks. Furthermore, soccer-playing humanoid robots will have to handle the ball with both feet and hands, and be robust enough to deal with challenges from other players.

Humanoid gait generation and adaptation have their own challenges. Since the information available for humanoid gait synthesis is a mixture of measurements and perceptions, a neural fuzzy system with unique capabilities of dealing with both numerical data and linguistic information is a naturally good choice. For this reason, a fuzzy reinforcement learning (FRL) agent [8, 9] with a neuro-fuzzy architecture is proposed to demonstrate how the perception-based information can be incorporated in the FRL agent to initialize its action network, critic network and evaluation feedback module so as to improve humanoid gaits by learning.

This paper is organized as follows. The soccer-playing humanoid platform developed at Singapore Polytechnic is introduced in Section 2. In Section 3, we describe the control and learning issues for the Robo-Erectus. Concluding remarks and some major technical challenges in this field are addressed in Section 4.

2 Configuration of Robo-Erectus

A soccer-playing humanoid should have high DOF (degree-of-freedom) to achieve various behaviors, such as locating and kicking a ball, avoiding obstacles, shooting or passing the ball, and etc. To implement these behaviors, the following four fundamental motions are needed: (i) keeping the humanoid balance (static or dynamic stability); (ii) moving the swing leg; (iii) operating a grasping object; (iv) controlling visual attention.

To implement the above-mentioned behaviors, we have developed different types of humanoid robots named Robo-Erectus (see Table 1). Our first generation soccer playing robot Robo-Ercetus, which came to second at the First RoboCup Humanoid League – Humanoid Walk, is shown in Fig. 1. The newly developed RE50II and its DOF arrangement are illustrated in Fig. 2. Fig. 3 shows a penalty kicking experiment conducted in our laboratory, where one RE40II acts as a kicker while another RE40II performs as a goal-keeper.

Table 1. Specifications of the Robo-Erectus' family

	RE40I	RE40II	RE50II	RE80II
Height	40 cm	40 cm	50 cm	80 cm
Weight	2.5 kg	4 kg	5 kg	7 kg
Total DOF	10	22	22	22
DOF arrangement	Legs – 5 x 2	Neck – 2 Arms – 4 x 2 Legs – 6 x 2	Neck – 2 Arms – 4 x 2 Legs – 6 x 2	Neck – 2 Arms – 4 x 2 Legs – 6 x 2
Sensors	accelerometers, force sensors, gyros, range sensors and etc.			
Vision	stereo camera			
Controller	Multi-control mode: (1) PC; (2) Microcontroller; (3) PDA; (4) Wireless			
Power	NiMH batteries			

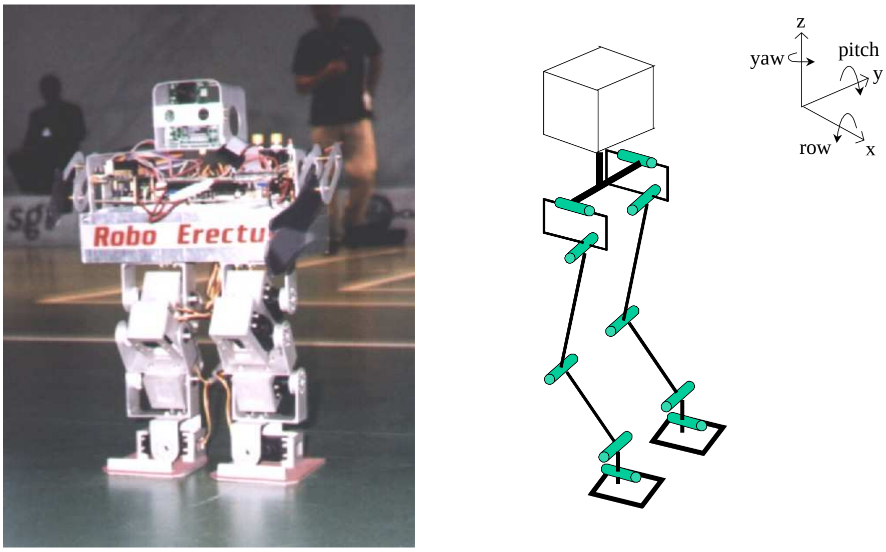

Fig. 1. The first generation Robo-Erectus at the RoboCup Humanoid League 2002

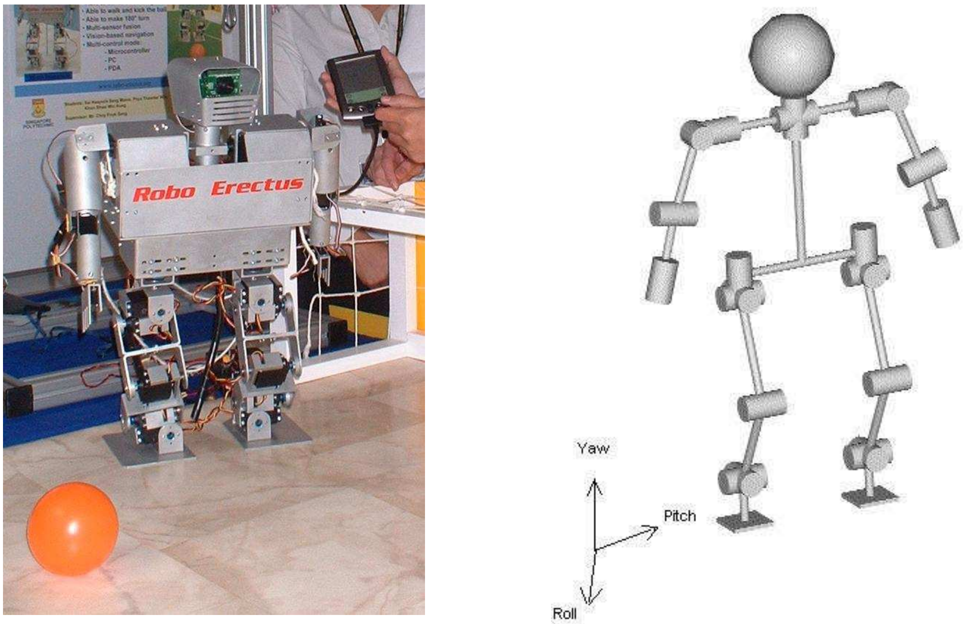

Fig. 2. The second generation Robo-Erectus RRE50II (controlled by PDA) and its DOF arrangement

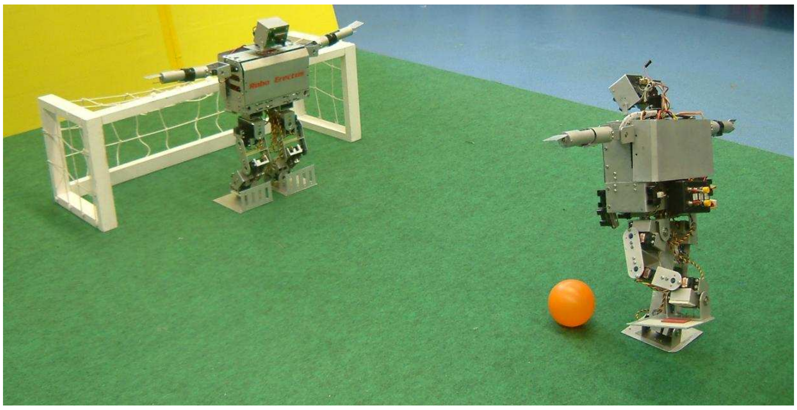

Fig. 3. Humanoid penalty kicking (one RE40I acts as a kicker while another RE40II performs as a goalkeeper)

The humanoid robot needs various kind of sensors, e.g. visual sensor for recognizing objects; posture sensors for detecting the robot's balance; force and tactile sensors for detecting contact to others and falling down, and so on. To develop a low-cost soccer-playing humanoid platform which is affordable for many researchers, we have to use low-cost components. Our RE humanoid robots have been intentionally designed to have low-torque motors and low-precision mechanical structures so that the cost can be significantly reduced. For example, the actuators of RE humanoid robots are low-cost servo motors which have limited torque and accuracy. Some sensors and servo motors used in Robo-Erectus are shown in Fig. 4. We also note that PINO [6] used the similar design concept to achieve a low-cost humanoid platform.

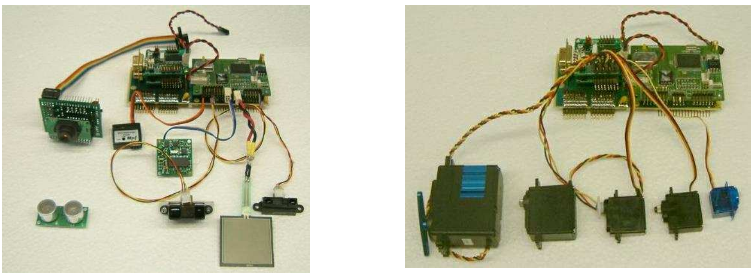

Fig. 4. Various sensors and servos used in Robo-Erectus

3 Basic Control and Learning Issues for Robo-Erectus

The overview of the proposed hierarchical control system for Robo-Erectus is shown in Fig. 5. The path planning level deals with path planning, obstacle crossing and gait selection using high level sensorial information. The gait synthesizer receives gait phases, step length, speed and lift magnitude from the path planning level, and then repetitively generates the joints reference commands for each control cycle during each gait phase.

In order to reduce the complexity of the humanoid gait synthesis problem, many researchers assume that the gait synthesis in the sagittal and frontal planes is independent. Therefore, as shown in Fig. 6, there are two FRL agents, namely, FRL Agent-x and FRL Agent-y for sagittal and frontal planes respectively. Each FRL agent only searches its relevant state-action space so as to speed up learning. The FRL architecture and its learning method can be found in [8, 9].

Humans usually evaluate their walking behavior in a heuristic way. For example, to evaluate humanoid dynamic balance in the sagittal plane, a penalty signal r_x should be given if the humanoid robot falls down in the same plane, that is, x_{zmp} is not within the supporting area in the sagittal plane. However, this kind of two-value evaluative feedback signals can only describe the simple “go – no go” or “fall down – stand” walking states. It is surely not biologically plausible. To provide more detailed information on evaluative feedback, we may use our perceptions to evaluate the humanoid dynamic walking.

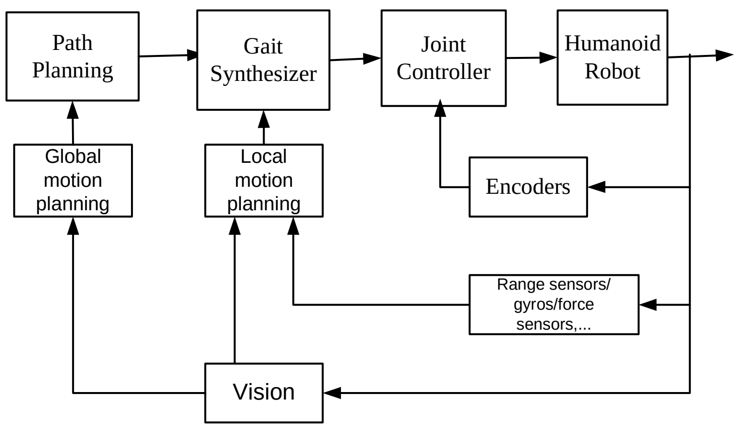

Fig. 5. Schematic diagram of the hierarchical control system for the RE humanoid robot

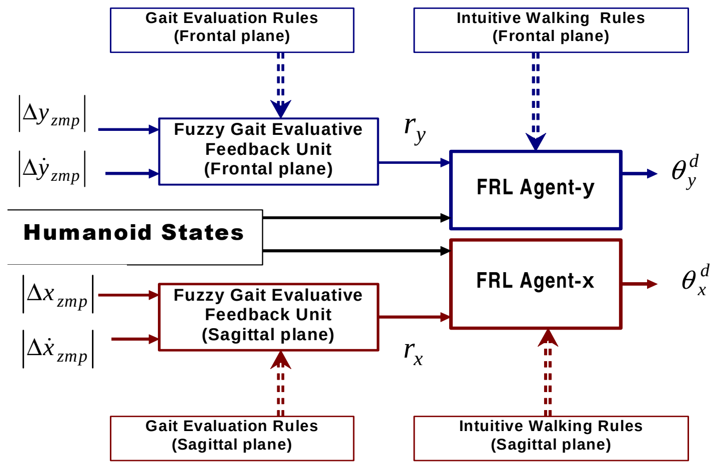

Fig. 6. Block diagram of the humanoid gait synthesizer using two independent FRL agents

3.1 Humanoid Walk

Before implementing humanoid walk, a simulation [4] was conducted to generate an initial gait for the humanoid robot (see Fig. 7). By considering the humanoid performance constraints, fuzzy reinforcement learning was used to further improve the gait. Fig. 8 shows the angular trajectories of the thigh joint before and after learning. The walking sequence of RE40II after learning is shown in Fig. 9.

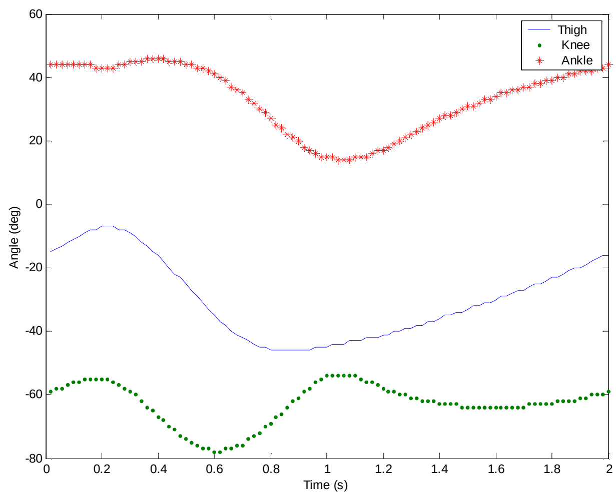

Fig. 7. The initial gait generated by the simulator

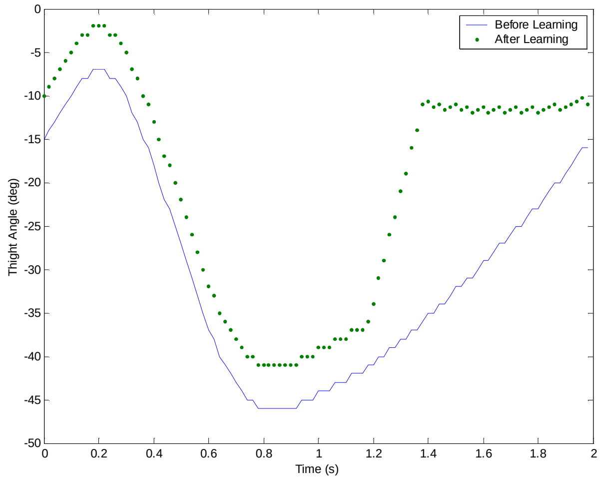

Fig. 8. The angular trajectory of the thigh joint (before and after learning)

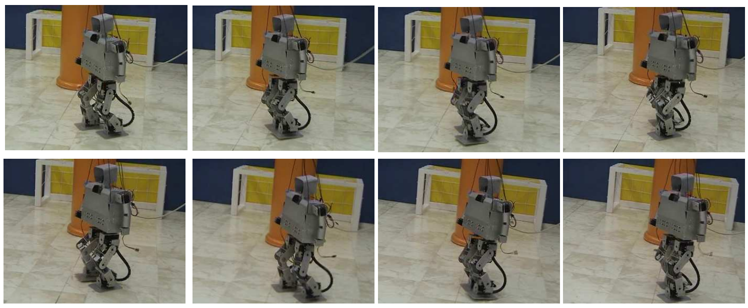

Fig. 9. The humanoid walking sequence (after learning)

3.2 Penalty Kick

To plan humanoid kicking trajectory, we have to consider some kicking constraints [3], e.g. the Maximum Kicking Range (MaxKR), the Effective Kicking Range (EKR), the Minimum Kicking Moment (MinKM) and so on. The challenge for the humanoid kick is that the zero moment point (ZMP) [5] must stay in the supporting area for the kicking cycle. By considering all the kicking parameters, an initial kicking pattern was generated using Kicking Pattern Generator developed by our Humanoid Robotics Group. Fig. 10 illustrates the initial angular trajectories for the kicking leg (hip, knee and ankle joints). As for the standing leg, the ankle joint is used to reduce the kicking effect. Its angular trajectory is shown in Fig. 11. In Fig. 12, it can be seen that the

ZMP always stays in supporting area during the kicking cycle. The proposed kicking planning approach has been successfully tested on our RE humanoid robot. The kicking sequence of RE40I is shown in Fig. 13.

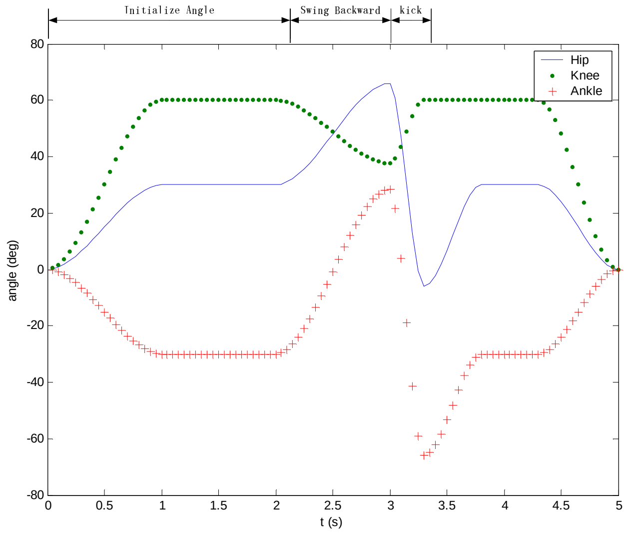

Fig. 10. The angular trajectory of the kicking leg (hip, knee and ankle joints)

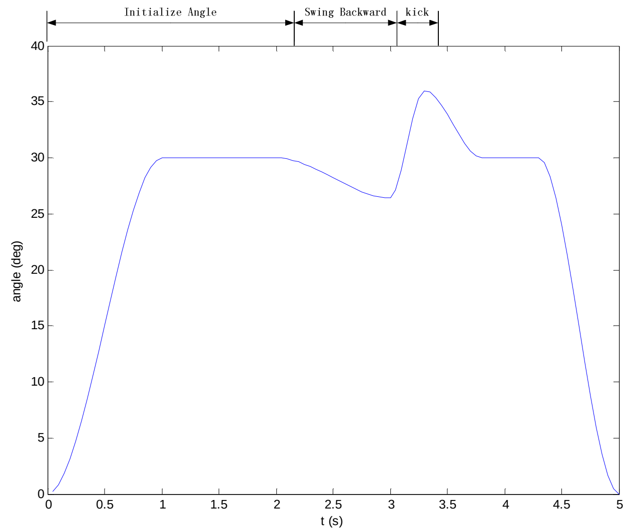

Fig. 11. The angular trajectory of the standing leg (ankle joint)

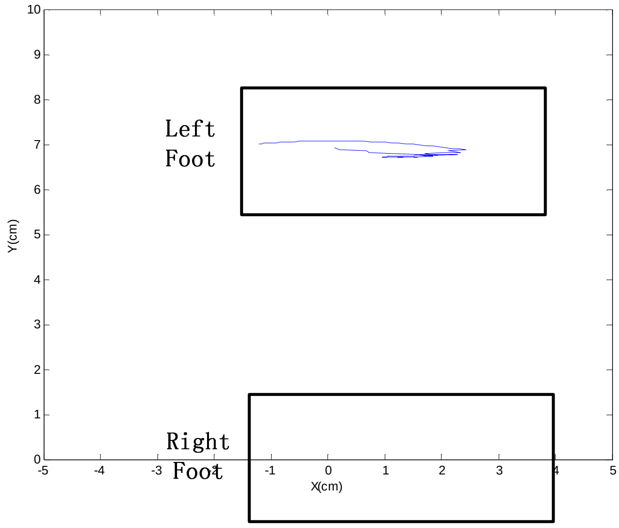

Fig. 12. The ZMP trajectory during kicking (left leg is standing)

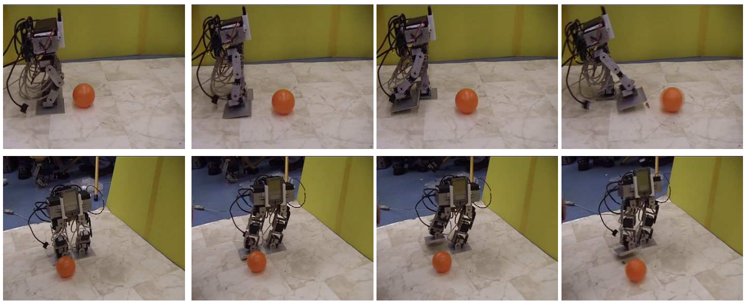

Fig. 13. The humanoid kicking sequence

4 Concluding Remarks

The Robo-Erectus project [12] aims to develop a low-cost humanoid platform so that educators and students are able to build humanoid robots quickly and cheaply, and to control the robots easily. We are currently working towards to further develop this platform for educational robots, service robots and entertainment robots. Our Robo-Erectus has participated in both the 1st and 2nd Humanoid League of RoboCup, won 2nd place in the Humanoid Walk competition at the RoboCup 2002 and managed 1st place in the Humanoid Free Performance competition at the RoboCup 2003 [11].

By using the proposed fuzzy reinforcement learning approach, we demonstrate that the Robo-Erectus is able to start walking from an initial gait generated from perception-based information on human walking, and learn to further tune its walking and kicking behavior using reinforcement learning. Note that humans do not just learn a task by trial and error, rather they observe other people perform a similar task and then repeat them by *perceptions*. How to utilize perception-based information to assist imitation learning [2] will be a new challenge in this filed. We will also look at how to coordinate perception and biped locomotion for humanoid soccer robots.

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