See, Walk, and Kick: Humanoid Robots Start to Play Soccer

Sven Behnke

Albert-Ludwigs-Universität Freiburg, Computer Science Institute

Abstract

Robotic soccer superseded chess as a challenge problem and benchmark for artificial intelligence research and poses many challenges for robotics. While simulated, wheeled, and four-legged robots have been playing soccer games for some years now, the RoboCup Humanoid League raised the bar again. This paper describes the mechanical and electrical design of the humanoid robots, which team NimbRo constructed for RoboCup 2006. The paper also covers the software used for perception, behavior control, communication, and simulation. Our robots performed well. The KidSize robots won the Penalty Kick and came in second the overall Best Humanoid ranking.

KEYWORDS: ROBOTIC SOCCER, HUMANOID ROBOTS, WALKING, KICKING, TEAM PLAY

Introduction

What drives thousands of researchers worldwide to devote their creativity and energy to make robots bring a ball into a goal? The answer lies not only in the fascination of the soccer game, but rather in the quest to advance the fields of artificial intelligence research and robotics. AI researchers started to investigate games early-on. Simon predicted in 1958 that computers would be able to win against the human world champion within ten years (Simon & Newell, 1958. Playing chess was viewed as epitome of intelligence. The dominant view at that time was that human intelligence could be simulated by manipulating symbols. While the world champion in chess was defeated by a machine in 1997 (Newborn, 1997), human intelligence is still far from being understood.

The basis for intelligent action is the perception of the world. Already this seemingly easy task frequently exceeds the capabilities of current computer systems. Perceptual processes, which interpret the flood of sensory stimuli to make it accessible for behavior control, are mostly unconscious. Hence, we are not aware of the difficulties involved. The performance of our perceptual system becomes clear only when trying to solve the same task with machines. This applies to behavior control as well. Human locomotion, for example, does not seem to be problematic. That walking and running on two legs is not an easy task becomes clear only when one tries to implement it on a real robot.

Based on these observations, a view on intelligence has established itself over the last two decades that does not rely on manipulating symbols, but emphasizes the interaction of an agent with its environment (Brooks, 1990; Pfeifer & Scheier, 1999). Embodiment and situatedness of an agent in a rich environment enables feedback from the actions of the agent to sensory signals. The complexity is increased significantly when the environment does not only contain passive objects, but other agents as well.

The RoboCup Federation organizes since 1997 international robotic soccer competitions. The vision of RoboCup is to develop by the year 2050 a team of humanoid soccer robots that wins against the FIFA world champion (Kitano & Asada, 2000). Soccer was selected for the competitions, because, as opposed to chess, multiple players of one team must cooperate in a dynamic environment. Sensory signals must be interpreted in real time and must be transformed into appropriate actions. The games do not test isolated components, but two systems compete with each other. The score allows comparing systems that implement a large variety of approaches to perception, behavior control, and robot construction. The presence of opponent teams, which continuously improve their system, makes the problem harder every year. Such a challenge problem focuses the effort of many research groups worldwide and facilitates the exchange of ideas.

RoboCupSoccer Humanoid League

The RoboCupSoccer competitions are held in five leagues. Since the beginning, there is a league for simulated agents, a league for small wheeled robots which are observed by cameras above the field (SmallSize), and a league for larger wheeled robots where external sensors are not permitted (MiddleSize). A league for the Sony Aibo dogs was added in 1999 (Four-legged) and a league for humanoid robots was established in 2002. In the Humanoid League, robots with a human-like body plan compete with each other. The robots must have two legs, two arms, a head, and a trunk. Size restrictions make sure that the center of mass of the robots is not too low, that the feet are not too large, and so on. The robots are grouped in two size classes: KidSize (up to 60cm) and TeenSize (>65cm). The humanoid robots must be able to walk on two legs and must be fully autonomous. They may communicate with each other via WLAN.

Figure 1. Some of the robots that competed in the RoboCup 2006 Humanoid League.

Because the construction and the control of humanoid robots is more complex than that of wheeled robots, initially, there were only less demanding competitions held, but no soccer games played, in the Humanoid League. In 2005, 2 vs. 2 soccer games were started in the KidSize class. The soccer rules follow the FIFA laws, with some simplifications. E.g., the offside rule is not observed and objects are color-coded to simplify perception. Fig.1 shows some of the humanoids that participated at RoboCup 2006.

Humanoid Soccer Robots of Team NimbRo 2006

Fig. 2 shows Paul, one of the NimbRo KidSize 2006 robots and Robotinho, our 2006 TeenSize robot. As can be seen, the robots have human-like proportions. Their mechanical design focused on simplicity, robustness, and weight reduction. The KidSize robots have a height of 60cm and weigh only 2.9kg, including batteries. They have 20 degrees of freedom (DOF): 6 per leg, 3 in each arm, and two in the trunk. Robotinho is 100cm tall and weighs only 5kg. It has 21DOF with an additional roll joint in the trunk. The joints are driven by Dynamixel actuators. In the hip of the KidSize robots and the legs and trunk of Robotinho, we use two actuators per axis. Robotinho has additional spur gears in the hip and in the trunk. The skeleton of the robot is constructed from aluminum extrusions with rectangular tube cross section. We removed all material not necessary for stability. The feet and forearms are made from elastic carbon composite material. Each robot is equipped with a HCS12 microcontroller board, which manages the detailed communication with all Dynamixels. This board also interfaces an attitude sensor, which is located in the trunk. We use a 520MHz Pocket PC as main computer, which is located in the upper part of the robots. This computer runs behavior control, computer vision, and wireless communication. The robots are powered by Li-poly rechargeable batteries.

Figure 2. Paul (KidSize) and Robotinho (TeenSize).

Our robots need information about themselves and the situation on the soccer field to act successfully. The KidSize robots are equipped with two wide-angle cameras. Robotinho has only one camera. The wide field of view of the cameras allows the robots to see their own feet and objects above the horizon at the same time (see Fig. 3). Our computer vision software detects the ball, the goals, the corner poles, and other players based on their color in YUV space. We estimate their coordinates in an egocentric frame, using the inverted projective function of the camera. The relative coordinates suffice for many relative behaviors like positioning behind the ball. To support higher behaviors and team coordination, we estimate the pose of the robot on the soccer field by triangulation over pairs of landmark observations, i.e. detected goals and corner poles. The Pocket PCs are equipped with wireless network adapters. We transmit debug information to an external computer via UDP, where it is logged and visualized. In the opposite direction the game state (kickoff, penalty, etc.) is transmitted to the robots. In order to be able to design behaviors without access to the real hardware, we implemented a physics-based simulation for the robots with the Open Dynamics Engine.

The behavior control for our robots is based on a framework that supports a hierarchy of reactive behaviors. It is structured both as an agent hierarchy (joint – body part – player – team) and as a time hierarchy. The speed of sensors, behaviors, and actuators decreases when moving up in the hierarchy. The lowest level of this framework contains position control for individual joints. It is implemented on the Dynamixel actuators. The joints of a body part are controlled using a kinematic interface that provides, e.g. leg angle, leg length, and foot angle, relative to the trunk. This interface is used to implement basic skills like omnidirectional walking (Behnke, 2006), kicking, and getting-up behaviors (Stückler, Schwenk & Behnke, 2006). Omnidirectional walking allows the robots to combine walking in forward/backward direction with lateral walking and turning on the spot. The robots change the desired walking direction and walking speed based on visual feedback, without the need for stops. The basic skills are used by soccer behaviors like searching for the ball, approaching the ball, avoiding obstacles, and defending the goal. These behaviors activate according to the perceived game situation. Finally, on the team level, the robots communicate via a wireless network to share information about the world state and to negotiate roles like attacker and defender.

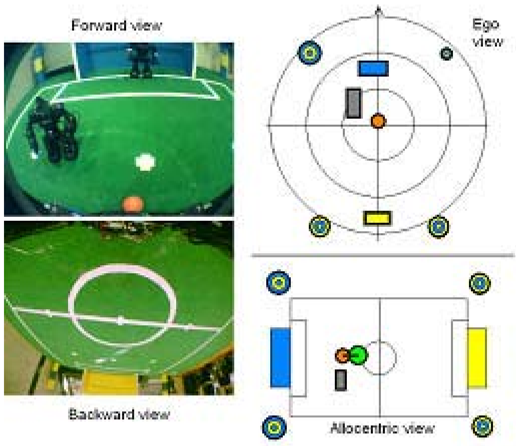

Figure 3: Left: Images of the two cameras of the KidSize robot. Upper right: Egocentric coordinates of key objects detected in the image. Lower right: Localization on the soccer field.

Results and Conclusion

Our robots performed well at RoboCup 2006. In the 2 vs. 2 soccer round robin, the KidSize robots played two games and scored 12:0 goals. They won 6:1 against ROPE (Singapore) in the quarter final and 6:2 against Darmstadt Dribblers & Hajime (Germany, Japan) in the semi-final. In the final, they met Team Osaka (Takayama et al., 2006), as in 2005. Our robots played well in the first half and scored a lead of 4:0. Team Osaka was able to reach a draw of 4:4 after regular playing time. The final score was 9:5 for Team Osaka. Our KidSize robots also kicked penalties very reliably. In the Penalty Kick competition they scored in 31 of 34 attempts and won the final 8:7 against Team Osaka. In the technical challenge, our robot Gerd was one of the two robots able to walk across the rough terrain. Our robots also scored in the passing challenge. Our TeenSize robot Robotinho reached the final of its Penalty Kick competition. In the overall Best Humanoid ranking, our KidSize robots came in second, next only to the titleholder, Team Osaka. Videos of our robots at RoboCup 2006 can be found at http://www.NimbRo.net.

Playing soccer with humanoid robots is a complex task, and the development has only started. So far, there has been significant progress in the Humanoid League, which moved in its few years from remotely controlled robots to soccer games with fully autonomous humanoids. Many research issues, however, must be resolved before the humanoid robots reach the level of play shown in other RoboCupSoccer leagues. For example, the humanoid robots must maintain their balance, even when disturbed (Renner & Behnke, 2006). In the next years, the speed of walking must be increased significantly. At higher speeds, running will become necessary. The visual perception of the soccer world must become more robust against changes in lighting and other interferences.

The 2006 competition showed that most teams were able to kick penalties, but that soccer games are much richer and more interesting. In the team leader meeting after the competition, the majority voted for abandoning penalty kick as a separate competition. Instead, the KidSize teams will focus on soccer games. Unfortunately, most teams do not feel ready to increase the number of players to more than two players per team. This limits the possibilities for team play. As the basic skills of the humanoid soccer robots improve every year, teams will be able to leverage the experience from the other RoboCup leagues when focusing on the more complex soccer behaviors and on team play.

References

Behnke, S. (2006). Online trajectory generation for omnidirectional biped walking. In Proc. of IEEE Int. Conf. on Robotics and Automation (ICRA'06), pp. 1597-1603

Brooks, R. (1990). Elephants don't play chess. Robotics and Autonomous Syst., 6:3-15

Kitano, H. & Asada, M. (2000). The RoboCup Humanoid Challenge as the millennium challenge for advanced robotics. Advanced Robotics, 13(8):723-737

Pfeifer, R. & Scheier, C. (1999). Understanding Intelligence. The MIT Press

Renner, R. & Behnke, S. (2006): Instability Detection and Fall Avoidance for a Humanoid using Attitude Sensors and Reflexes, In Proc. of IROS'06, Beijing

Simon, H. A. & Newell, A. (1958). Heuristic problem solving: The next advance in operations research. Operations Research, 6(1):1-10

Stückler, J., Schwenk, J.& Behnke, S. (2006) Getting back on two feet: Reliable standing-up routines for a humanoid robot. In Proc. of IAS-9, Tokyo, Japan

Takayama, H., Matsumura, R., Shibatani, N., et al. (2006) Team Osaka (Kid size) Team Description Paper. In RoboCup Humanoid League Team Descriptions, Bremen.