ROBOT SOCCER: A MULTI-ROBOT CHALLENGE

EXTENDED ABSTRACT

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Abstract Robot soccer opened a new horizon for multi-robot research: Teams of autonomous robots need to respond to a highly dynamic and uncertain environment including other teams of robots. Furthermore, soccer robots have clear and specific goals to accomplish. The multi-robot system relies both on robust autonomous individual robots and teamwork. We have developed new algorithms for localization, navigation, and teamwork, to demonstrate real-time performance in this multi-robot adversarial task. Robot soccer has also a strong entertainment component attracting researchers and crowds of spectators. RoboCup-2001, the international robotic soccer competitions held for the first time in the United States in 2001, joined more than 500 participants, 200 robots, and a few thousand spectators.

Keywords: Multi-robot adversarial environments, real-time autonomous robots

1. Introduction

The late Herbert A. Simon, in the conclusion of his lecture at the Earth-ware Symposium at Carnegie Mellon on "Forecasting the Future or Shaping it?" [3] said: "Here around CMU, we have been amazed, amused, gratified, and instructed by the developments in robot soccer. For four years, and with rapidly increasing skill, computers have been playing a human game requiring skillful coordination of all the senses

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and motor capabilities of each player, as well as communication and coordination between players on each team, and strategic responses to the moves of the opposing team. We have seen in the soccer games, an entire social drama, played out with far less skill (thus far) than professional human soccer, but with all the important components of the latter clearly visible. Here we see, in a single example, a complex web of all the elements of intelligence and learning – interaction with the environment and social interaction, use of language – that artificial intelligence has been exploring for half a century, and a harbinger of its promise for continuing rapid development. Almost all of our hopes and concerns for the future can be examined in miniature in this setting, including our own role in relation to computers."

Herb Simon's lecture goes on very interestingly forecasting our interactions with computers and robots. But his impressions and assessment of robotic soccer set a tremendous and exciting responsibility for our multi-robot research.

In robotic soccer, robots face a very dynamic and uncertain environment where they have to achieve very clear goals, such as score a ball into an opponent goal. Robotic soccer teams need to effectively integrate perception, action, and cognition in real-time. Each team of robots needs "to close the loop," as I always say. Robots need to continuously live in a cycle, perceiving the world, deciding what to do, and performing its actions. One of the main challenges has shown to be exactly this ability to close this "autonomy loop," namely to perceive the environment, make decisions about the actions to take, actually take actions in the world, and continuously again perceive the environment, make decisions, and act.

We have been developing several different teams of autonomous robot soccer players that offer different technical challenges of perception, action, and cognition.

2. Teams of Robots

One of the main challenges of robotics is the integration of many research accomplishments into a single *complete* robot. Research remarkably advances in several separate directions, but a complete robot requires the integration of many different capabilities. In addition, there is a real research challenge on how to create *groups* of robots rather than single individual ones.

Actually developing real robots as opposed to simulation is far from trivial. One of the main bottlenecks is the robot's perception. Robots need to be able to accurately and reliably infer the state of the world.

Global Perception and Distributed Action. The small-size robot soccer RoboCup league allows for global perception by a camera that view the complete field. Figures 2 and 2 show some of different teams of small-wheeled soccer-playing robots that we have developed at Carnegie Mellon [4, 5].

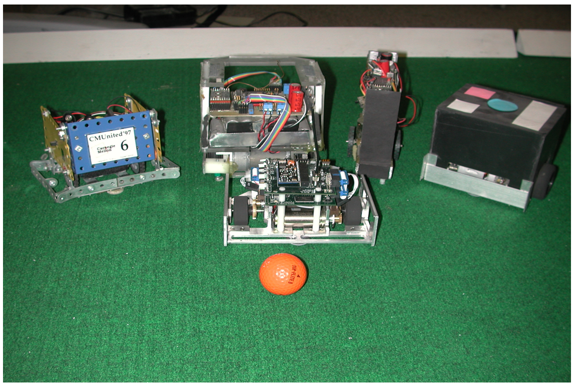

Figure 1. Small-Wheeled Soccer Robots - Carnegie Mellon teams since 1997. Thanks to Sorin Achim, Michael Bowling, Kwun Han, and Peter Stone.

Each participating team designs and builds their own robots under specific size constraints. These robots play on a field of approximately the size of a ping-pong table. They play with an orange golf ball. The robot teams are allowed to hang a vision camera over the playing field that has a global vision of the complete world. This global perception problem proved to be more complicated than it may seem. Indeed, processing images globally in real time with eleven moving objects at high speeds is in itself a real perception challenge. But, the processed images of the global view of the world are available to each robot in a team. The image can be passed to an off-board computer that remotely controls the robots usually through radio. Interestingly, because the robots now have a complete view of the positions of all the other teammates and opponents, they can effectively use this information to strategically collaborate as team members.

The robots achieve teamwork by playing different roles in the team. With five robots, we have developed behaviors for attacker, mid-fielder, defender, and goalie robots. The robots use reactive behaviors, mapping the state of the world at each moment and deciding which action to take. We have developed an algorithm that coordinates multiple attacking robots in which one robot goes to the ball and the other robots move to position themselves in an adequate open area to anticipate a possible pass. The robots run an objective function optimization, SPAR, that

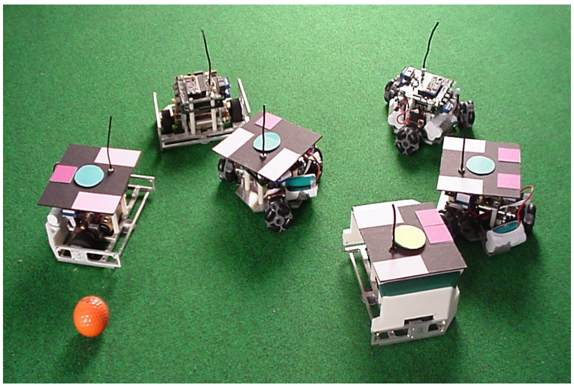

Figure 2. Small Soccer Robots - Carnegie Mellon team for 2001 and 2002. Thanks to Michael Bowling, Brett Browning, James Bruce, and Ravi Balasubramanian.

strategically positions robots to be *attracted* to the goal and ball (i.e., minimizing their distance to the goal and to the current position of the ball), and to be *repulsed* from the other robots (i.e., maximizing their distance to the other robots). The combination of role behaviors and SPAR allowed the robots to demonstrate effective teamwork.

On-board Perception, Cognition, and Action. The Sony RoboCup legged league offers where robots are fully autonomous. The Sony robots have vision and computational power on board of the robots. Figures 3 and 4 shows the legged robots that we have used in the last years. We have used the Sony legged robots since their very first version in 1998 [6, 7].

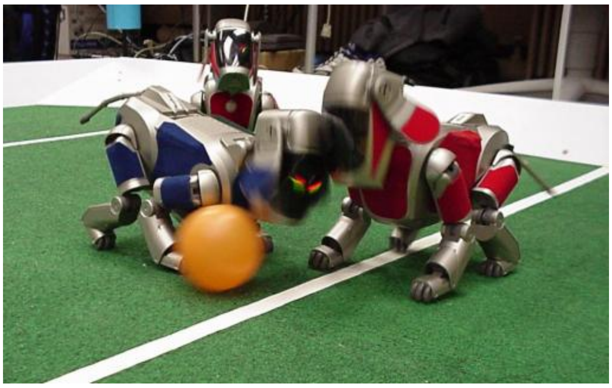

Figure 3. Sony Legged Soccer Robots - The Carnegie Mellon 1999 and 2000 robots. Thanks to James Bruce, Scott Lenser, and Elly Winner.

The robots are autonomous, and have on-board cameras. The on-board processor provides image processing, localization and control. The robots are not remotely controlled in any way, and as of now, no communication is possible in this multi-robot system. The only state information available for decision making comes from the robot's on-board colored vision camera and from sensors which report on the state of the robot's body. The vision algorithm is hence of crucial importance as it provides the perception information as the observable state. Our vision system robustly computes the distance and angle of the robot to the objects and assigns confidence values to its state identifications [1].

Figure 4. Sony Legged Soccer Robots - The Carnegie Mellon 2001 robots. Thanks to James Bruce, Martin Hock, Scott Lenser, and Will Uther.

The preconditions of several behaviors require the knowledge of the position of the robot on the field. The localization algorithm is responsible for processing the visual information of the fixed colored landmarks of the field and outputting an (x, y) location of the robot. Because effective robots are small and given the dynamics of the game, the robots' motion can be affected by external sources beyond the robot's own control (e.g., referee, other robots' pushing, slanted walls). We developed a new sensor-resetting probabilistic localization algorithm was devised which allows robots to use their sensor input to rapidly adapt to changes in their position [2].

Finally, our behavior-based planning approach interestingly provides the robot the ability to control its knowledge of the world. Behaviors range from being based almost solely on the visual information to depending on accurate localization information. Furthermore behaviors vary as a function of the confidence of the robot in its world model [8]. The robots for RoboCup-2002 will be able to communicate between themselves. This will open a new opportunity for multi-robot coordination.

All the teams in the RoboCup legged robot league use this same Sony hardware platform. This creates a very interesting research question, as now all the robots have in principle the same perception and motion low-level capabilities. And therefore their eventual different performance should be mainly the cognition aspect. However, this is indeed not the case. Although they do differ at the cognition level, it is still a challenge to program the robots *to use* their similar hardware. So some robots move faster or see better than other robots.

3. Conclusion

The examples of robot soccer illustrate the challenges of building complete autonomous robots that can perform active perception and sensor-based planning while playing a multi-robot game. The robot soccer games have shown to be not only a true source of entertainment but a great source of advances in robotics research.

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