Humanoide Fußballroboter

Humanoid Soccer Robots

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Abstract

Humanoid robots are enjoying increasing popularity as a research tool. As step towards the long-term goal of winning against the FIFA world champion, the RoboCup Federation added in 2002 a league for humanoid robots to its annual soccer competitions. In this paper, the Humanoid League competitions that took place so far are reviewed. The different approaches for the design of robot hardware and the software for perception and behavior control of soccer playing humanoid robots are discussed. The paper concludes with an outlook to the future of the RoboCup Humanoid League.

Zusammenfassung

Humanoide Roboter erfreuen sich zunehmender Beliebtheit als Forschungsgegenstand. Als Schritt in Richtung des langfristigen Ziels gegen den FIFA-Weltmeister zu gewinnen, veranstaltet die RoboCup-Federation seit 2002 auch Fußballwettbewerbe für humanoide Roboter. Der Artikel blickt auf die Wettbewerbe der humanoiden Liga zurück, die bislang stattfanden. Die unterschiedlichen Ansätze des Designs der Roboterhardware und der Software zur Wahrnehmung und Verhaltenssteuerung für fußballspielende humanoide Roboter werden diskutiert. Zum Schluss gibt der Artikel einen Ausblick auf die Zukunft der humanoiden Liga des RoboCup.

1 Introduction

Humanoid robots, robots with an anthropomorphic body plan and human-like senses, are enjoying increasing popularity as research tool. More and more groups worldwide work on issues like bipedal locomotion, dexterous manipulation, audio-visual perception, human-robot interaction, adaptive control, and learning, targeted for the application in humanoid robots.

These efforts are motivated by the vision to create a new kind of tool: robots that work in close cooperation with humans in the same environment that we designed to suit our needs.

While highly specialized industrial robots are successfully employed in mass production, these new applications require a different approach: general purpose humanoid robots.

The human body is well suited for acting in our everyday environments. Stairs, door handles, tools, and so on are designed to be used by humans.

The new applications will require social interaction between humans and robots. If a robot is able to analyze and synthesize speech, eye movements, mimics, gestures, and body language, it will be capable of intuitive communication with humans.

A human-like action repertoire also facilitates the programming of the robots by demonstration and the learning of new skills by imitation.

Last, but not least, humanoid robots are used as a tool to understand human intelligence.

Addressing all of the above aspects simultaneously exceeds the current state of the art. Today's humanoid robots display their capabilities in tasks requiring a limited subset of skills.

One of these tasks is playing soccer. Kitano and Asada proposed the RoboCup humanoid challenge [10] as the millennium challenge for advanced robotics. It is to construct by 2050 a team of fully autonomous humanoid robot soccer players that is able to win a soccer game against the winner of the most recent FIFA World Cup.

To facilitate research towards this long-term goal, the RoboCup Federation organizes since 1997 annual robot competitions. A major part of these competitions is RoboCupSoccer, which is conducted in five leagues, focusing on different research aspects. While team play and learning are major topics in the simulation league, the real-robot leagues developed solutions for robust real-time perception, omnidirectional locomotion, and ball handling.

2 RoboCup Humanoid League

Motivated by the rapid progress in the wheeled and four-legged soccer leagues, the RoboCup Federation added in 2002 a league for humanoid robots to the competitions. Among the research challenges addressed in this league is maintaining dynamic stability of the robots while walking, running, and kicking. Another research issue is the coordination of bipedal locomotion and perception. FIRA established a humanoid league (HuroSot) as well.

Three international competitions took place in the RoboCup Humanoid League so far. Because the complex humanoid robots were not ready to play real soccer games, the robots had to demonstrate their capabilities by solving a number of subtasks.

In the Humanoid Walk they had to walk towards a pole, around it and to come back to the start. Scoring was based on walking speed and stability. In the Penalty Kick competition the robots faced each other. While one robot tried to score a goal, the other defended. In the Freestyle competition, the robots had five minutes to show a performance to a jury.

Each year, there was also a new technical challenge. In 2004, it consisted of an obstacle walk, a passing task, and balancing across a sloped ramp.

The RoboCup Humanoid League competition rules [12] require the robots to have a human-like body plan. They must consist of a trunk, two legs, two arms, and a head. The only allowed mode of locomotion is bipedal walking. Initially, external power supply, external computing power, remote control and the use of commercial robot platforms were discouraged by performance factors. These factors were applied to trial times and goal counts. Now, the robots must be fully autonomous. No external power, computing, or remote control is allowed. Wireless communication can be used for team coordination and game control only.

Figure 1

Fig. 1 shows some of the robots which took part in the RoboCup Humanoid League competitions. In 2002 [1], the Nagara robot was the overall winner. A Honda Asimo prototype of team HITS Firstep [9] won in 2003 [16]. Team Osaka won the 2004 competition [11] with the robot ViSiON [18].

In the remainder of the paper, I will review the hardware and software used by the teams which participated in the RoboCup Humanoid League. I will also discuss the development of the rules and future research challenges.

3 Robot Hardware

As can be seen in Fig. 1, a wide variety of robots participated in the Humanoid League competitions. The robots were grouped to classes based on their body height. In 2004 three classes were used: H40 (<44cm), H80 (<88cm), and H120 (<180cm). For the 2005 competition, the classes are reduced to KidSize (<60cm) and MediumSize (<180cm).

3.1 Base

Depending on the availability of commercial platforms and their research focus, the participating teams choose to use a commercial robot base, a construction kit, or a self-developed robot.

For example, the team Senchans employed in 2004 two Fujitsu Hoap-2 robots (50cm, 7kg, 25DOF, ≈50,000EUR) and the Vstone Robovie-M construction kit (29cm, 1.9kg, 22DOF, ≈3,000EUR). In 2003, the team HITS Firstep used a prototype of the Asimo, developed by Honda (125cm, 50kg, 26DOF, not available commercially). In contrast, the RoboSapien (40cm, 2.5kg, 7DOF, ≈100EUR), which was developed for the toy market, was used by the team NimbRo in 2004.

Examples for self-constructed robots are Robo-Erectus [19], Rope [14], Tao-Pie-Pie [2], Persia [13], Isaac [8], and Alpha [7]. These robots have between 7DOF and 22DOF, weigh between 2kg and 30kg and have a size between 30cm and 155cm. While the smaller robots are driven by RC servos, the larger ones are driven by geared DC motors.

The small servo-driven robots were more numerous than the larger robots and generally performed better. This might be due to the optimization of weight/torque ratio and control that went into RC servos. These small, lightweight, and powerful intelligent actuators were developed for model airplanes, cars, and boats.

In contrast, the used DC motor-gear-controller combinations have a lower degree of integration and are less optimized for weight/torque ratio. In addition, the backlash of planetary gears makes their control difficult. Only the harmonic-drive gears used in expansive robots like Asimo avoid this problem.

Weight reduction is not only important for the actuators, but for all other robot parts as well. Consequently, most teams used lightweight materials like aluminum or reinforced composites to construct the robot skeletons. Furthermore, the construction tried to optimize the stiffness/weight ratio. One important feature of many robots was the addition of a second bearing point for servo-driven hinge joints, which improves stiffness. Another common feature was the carving-out of material not needed for stability, in order to reduce weight.

While most robots used an external skeleton that also served as cover, the VisiON robot and RoboSapien used a plastic cover in addition to an internal skeleton. The cover protects delicate parts, like electronic boards, and improves the robot appearance. As the degree of physical robot interaction will increase, covers will be more important in the future.

3.2 Sensors

In order to perceive themselves and their environment, the robots need sensors. For proprioception, joint angle sensors, such as potentiometers and encoders were used. Accelerometers and gyros were used by some robots to estimate attitude. Some robots also had force sensors on their feet.

To perceive their color-coded environment, the robots were equipped with color cameras, placed on top of the trunk. Different approaches were used to cover a wide field-of-view. Some teams used moving cameras (e.g. Rope), some teams used wide-angle lenses (e.g. Senchans), and the VisiON robot used an omnidirectional mirror. In addition to cameras, some teams also used IR distance sensors (e.g. attached to the feet).

3.3 Computing

To interface the sensors, process their readings, make behavior decisions, and control the motors, some electronics and computing power is needed.

To interface the sensors and the actuators, microcontroller-based electronics boards were used. They include specialized hardware modules for A/D conversion and pulse generation.

In addition to the microcontrollers, many robots also included a more powerful computer. Many of these were based on the PC/104 standard for industrial computers. Few teams used off-the-shelf Pocket PCs (up to 400MHz XScale [3]) or small PCs (up to 1.7GHz Pentium M) to control their robots. The more powerfully processors allow for real-time image processing. As the degree of autonomy of the robots increases, the importance of onboard computing power will increase.

So far, some robots relied on external computing power to process video transmitted via an analogue wireless link. Many robots included a digital wireless link (WLAN or Bluetooth) to transmit debug information and to allow for remote control.

Almost all of the robots were powered by rechargeable batteries. Here, the capacity/weight ratio and the ability to deliver high currents are important parameters. It seems that Lithium-polymer batteries are currently the best choice for the power supply. In order to save weight, most teams used small batteries that lasted only for a few minutes of operation.

4 Software

Making a humanoid robot play soccer is a non-trivial tasks that requires software for perception and behavior control.

4.1 Perception

On the perception side, two main tasks can be distinguished: proprioception and computer vision.

For the servo-based robots most of the proprioception is done using potentiometers that measure the joint angles. In some robots, the potentiometer voltages are also read by a microcontroller, in order to keep track of the actual joint angles. Of course, when implementing control for DC-motor based joints, sensors for position, speed or torque are read by the microcontrollers, and preprocessed.

Similarly, force sensors, accelerometers, gyroscopes, and distance sensors are read by the microcontrollers and preprocessed there. One particularly interesting preprocessing step is the fusion of accelerometer readings and measured rotational speeds in order to estimate the attitude of a robot. This estimate can be important for walking on sloped surfaces. Relevant for feedback-based balance is also the aggregation of multiple force sensors placed in a foot sole to compute the center of pressure (COP).

Many robots also monitor the battery voltage in order to signal the need for a fresh battery.

For the perception of the environment, the images captured by the onboard color cameras must be analyzed. As in other RoboCupSoccer leagues, the computer vision heavily relies on color segmentation. Individual pixels are classified to belong to color-classes (e.g. orange for the ball, green for the field, blue and yellow for the goals). The classified pixels are aggregated to blobs and relative coordinates (angle and distance) are estimated for the key objects.

Most teams used some sort of active perception, such as turning the robot towards the object of interest, moving the camera or tilting the upper body in order to see the ball.

Visual perception in the humanoid league is more difficult than in other RoboCupSoccer leagues, because the camera moves significantly. Due to inaccuracies in posture estimation and odometry, the camera pose is not known well.

4.2 Behavior Control

Based on the information extracted from the sensors, the robots must decide how to act. Usually, this decision is done on different abstraction levels.

The lowest of these levels is the individual joint, e.g. the left knee. The servos used by most robots include electronics that generates PWM signals for the motor in order to quickly reach the target angle, which is given as a pulse train. While the motor-control of these intelligent actuators is usually not changed by the teams, such control must be implemented on microcontrollers when using combinations of DC motors, joint sensors, and motor drivers.

The next abstraction level, used by only some of the robots, is the level of a body part, e.g. the left leg. Here, multiple joints are controlled in a coordinated way, in order to reach a target leg length, a leg angle, or a foot-plate - hip-plate angle. The use of these more abstract actuators simplifies the generation of gait patterns.

On the level of the entire robot, trajectories are generated for body-parts or individual joints. Many teams implemented parameterizable motion primitives, like walk forward, turn, lie down, and kick. Here, it is important to pay attention to the stability of the robot. Due to the large feet of most robots, feed-forward control is frequently sufficient to ensure the balance of the robots. Stable trajectories are generated off-line and chained during operation. While initially the motion primitives were triggered manually, the rules require now fully autonomous behavior.

The use of preprogrammed motion sequences is also discouraged by rule changes that favor adaptive behavior. For instance, in the 2004 Obstacle Walk the position of two obstacles was not known in advance. In 2005, the ball position for penalty kicks is only roughly defined.

Because chaining of the motion primitives requires intermediate stops, some teams implemented online-trajectory generation that can be used for omnidirectional walking. Here, a target vector defines speed and direction of the robot motion as well as rotation around the vertical axis. Such a versatile gait is extremely helpful when approaching a ball and when avoiding obstacles, without loosing the robot's heading direction. This has been demonstrated in the wheeled and four-legged RoboCupSoccer leagues, where omnidirectional drives and omnidirectional gaits are used by many teams.

Figure 2

One of highlights of RoboCup 2004 was the goalie behavior of Team Osaka. As can be seen in Fig. 2, their VisiON robot jumped to the ground to defend against a shot. Afterwards, it was able to get up again. Another highlight of last year's competition was the passing demonstration given by two Hoap-2 robots of team Senchans [15], shown in Fig. 3. They used learned visuomotor mappings to implement the skills of trapping, approaching to, and kicking a ball.

Figure 3

In preparation for the competition to take place in Osaka (July 2005), the German Open (April 2005) included for the first time activities for humanoid soccer robots (see Fig. 4).

Penalty kick demonstrations were shown by the Darmstadt Dribblers (with Mr. DD and a Kondo KHR-1) and team NimbRo (with Toni [6] and Kondo [4]). The NimbRo robots were able to approach the ball using an omnidirectional walk. The robots slowed down in the vicinity of the ball. When the ball was in front of their kicking foot and they faced the goal, they performed a strong kick. If the ball did not cross the goal line, they approached it again and kicked a second time.

Figure 4

The other humanoid league activity at German Open 2005 was soccer games between Brainstormers Osnabrück and team NimbRo. Both teams used up to four augmented RoboSapien robots. These were the first humanoid robot soccer games. When playing soccer with multiple robots per team, coordination of them becomes relevant. Many approaches developed in other RoboCupSoccer leagues can be applied to the humanoid league as well.

For example, team NimbRo [5] used an off-the field computer to fuse ball observations of individual robots to a global ball estimate. This was communicated to the robots to be used in case the ball was outside their field of view. The external computer also computed team behavior, which assigned roles like goalie, primary attacker, and secondary attacker to the individual players. This computer was as well used for game control (start, stop, and kickoff) and to log all important variables.

Ball fusion and team behaviors relied on localization. To simplify the localization task, six uniquely identifiable color markers were placed around the field as landmarks. Team NimbRo used a 3D Markov grid to integrate observations of markers and goals as well as robot motion commands over time. Computer vision, probabilistic localization, behavior control, and wireless communication were implemented on a Pocket PC [4] that replaced the original head of RoboSapien.

5 Conclusions and Outlook

Despite impressive achievements of some teams, the overall performance of the soccer playing humanoids is still far from perfect. Basic soccer skills, such as robust dynamic walking and kicking without loosing balance are not possessed by all robots.

Even the best robots sometimes show instability while walking, fail to kick the ball or defend against shots not taken. Consequently, further research is needed. Within the Humanoid League, the performance of smaller, servo-driven robots in general exceeded the performance of larger robots. The only convincing larger robot so far was the Honda Asimo prototype, out of reach for almost all researchers.

On the other hand, the availability of low-cost robot bases, like RoboSapien, and construction kits, like Kondo KHR-1, makes it possible to enter the humanoid league competitions without the need for huge resources. Of course, the performance of such standardized platforms might not be sufficient to win the competitions.

As the performance of the humanoid soccer robots improves, the rules are changed to make the task harder. For instance, the allowed foot size decreases, which makes maintaining balance more difficult. Improving robustness and speed of dynamic bipedal walking will remain one of the major research issues in the Humanoid League. To correct for disturbances, it will be necessary to incorporate more feedback. First attempts have been made, e.g. by Baltes, McGrath, and John Anderson [2], who use measured angular velocities to detect the danger of falling and modify the gait pattern to prevent the fall.

The Humanoid League is moving away from isolated tasks performed by individual robots towards fully autonomous robots that cooperate in a team. For Osaka 2005, 2 vs. 2 soccer games are planned in the KidSize class. Playing soccer games will pose new challenges for the robots. They have to interact without damaging each other. The robots should be able to maintain balance, even when pushed by another robot. When a fall cannot be avoided, the robots must minimize the impact using a protective pose. Afterwards, they should be able to stand up again. Some of these issues have been investigated in the Robo-One competition [17], where remotely controlled humanoid robots engage in martial arts.

Playing soccer games also raises the bar for perception. As in other leagues, the robots must localize on the field and perceive other players. Finally, the two robots of a team must be coordinated.

The task of humanoid soccer is a complex one and the development just started. As demonstrated by other RoboCupSoccer leagues, I expect quick progress in robot hardware and software for perception and behavior control. One of the biggest challenges will be the integration of subsystems. While it is not that difficult to build a vision system or implement walking, it is hard to integrate all components necessary to play soccer onboard a humanoid robot, with both high reliability and secure recovery procedures in the case of a subsystem failure. To achieve this, the use of new materials, intelligent actuators, miniaturized sensors, and mobile computing power will be necessary.

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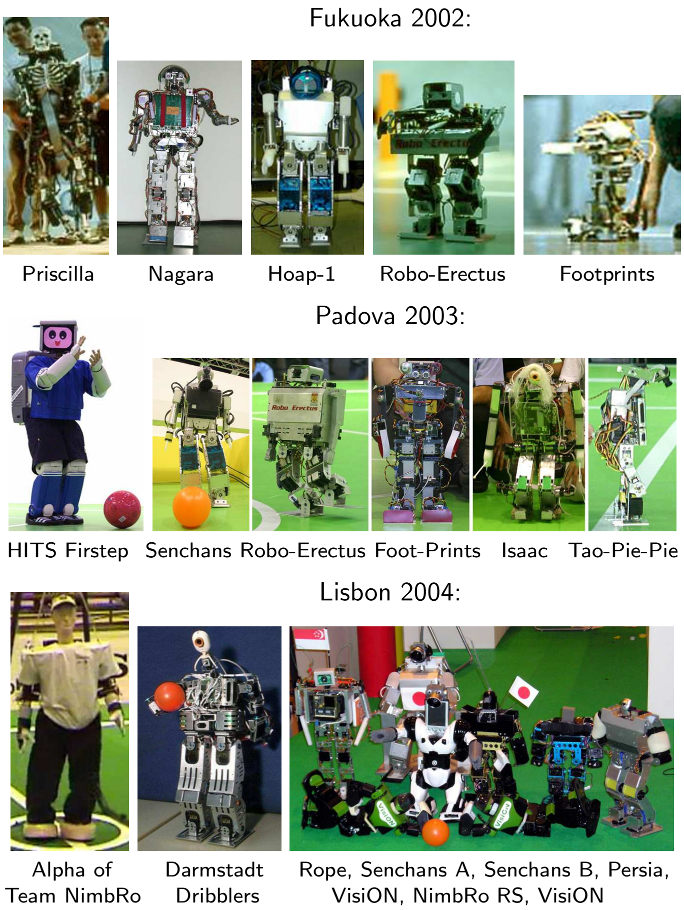


Figure 1: Some of the robots which took part in the RoboCup Humanoid League competitions.

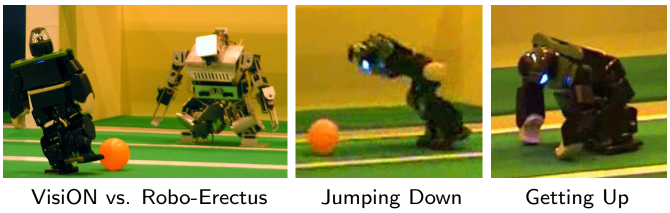


Figure 2: RoboCup 2004 Penalty Kick final.

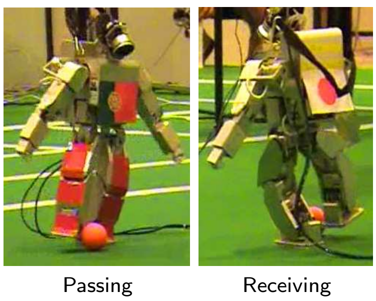
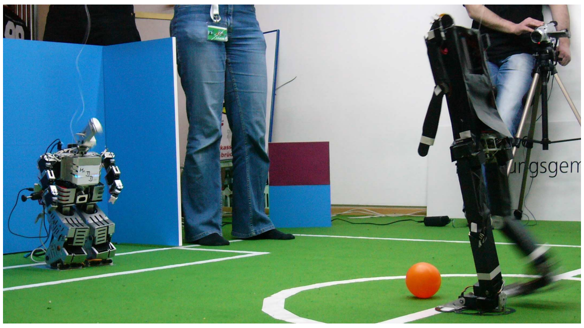
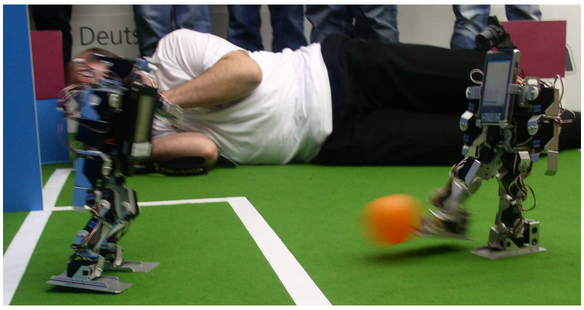


Figure 3: RoboCup 2004 passing demonstration by Senchans.

RoboSapien soccer game: Brainstormers vs. NimbRo



Mr. DD (Darmstadt Dribblers) vs. Toni (NimbRo)



Kondo KHR-1 robots of Darmstadt Dribblers and NimbRo

Figure 4: RoboCup German Open 2005 Humanoid League demonstrations.