The RoboCup Soccer Humanoid League: Overview and Outlook

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Abstract— **The goal of the RoboCup Federation is that in the year 2050 the human world champion team of soccer is going to play (–and going to loose) against the best robotic team. This best robotic team is going to be a team of humanoid robots. Thus, by the start of the Humanoid League (HL) in 2002 the RoboCup community has crossed an important watershed. Since the start the HL underwent a profound development. Competitions and challenges have changed in various ways; rules maturated in many points and gained more focus on the issues that are essential from a technical point of view; and of course the robots became better. In the RoboCup 2005 for the first time regular 2-2 games have been conducted. In 2006 we saw a further improvement of the performance of the teams. Still many open issues exist and are intensely discussed in the responsible committees and the whole Humanoid League community. In order to give an introduction to potential newcomers we give a brief overview of the short history of this league, and its current status. We point out the technical and research challenges and show that the whole league can be seen as a project, a kind of evolutionary optimization process to solve research issues – particular those related to vision processing, reactive behaviors and robust and dynamic walking.**

I. Introduction: A brief history of the Humanoid League

While the first regular RoboCup [1], [2] has been held in 1996, the Humanoid League has no sooner been established than 2002 at the RoboCup in Fukuoka [3]. The reason for this in comparison to other RoboCup soccer leagues relatively late start is presumably that biped walking was and partly still is a challenge in robotics. However, during the last some years better and better solutions to this problem have been found, are presented and tried out at the RoboCup. Following the trace from the first competition in 2002 one can see how close the RoboCup follows the state of the art. For example, the Best Humanoid of the RoboCup 2003 in Padova was a platform based on a prototype of the Honda Asimo robot. At that time the Honda Asimo has been seen as by far the best and most advanced humanoid robot. At the moment the focus has been shifted to smaller robots for several reasons which we are going to point out below.

In the first years (2002-2004) the robots were quite variant in many respects and had to be sorted into three sub-leagues in order to cope with the variety of heights between 10cm to over 2m. The competitions consisted of walking challenges, a free style competition, and penalty kick competition for all size classes. At that time external processing – even remote control was allowed. In order to make results of the competitions comparable between the very different robots performance factors had been introduced. These performance factors had to be applied to commercial platforms, remote control and external processing.

The emergence of Team Osaka in 2004 in Lisbon showed an un-precedented performance with regard to technical compactness and general perfection in their size class and in relation to the manufacturing costs. They got the Best Humanoid Award in that year. At that time their robot arose some hope that regular soccer games were indeed possible with robots of a size of roughly 40-60 cm and certain design features. These features have hitherto been adopted by most teams of the later established KidSize class.

Starting from these experiences many changes have been introduced into the competition of the year 2005 making the technical constraints more specific. Performance factors were abandoned, and external processing as well as remote control were banned from the competition. A maximum ratio between foot size and height of the center of mass had been introduced in order to encourage dynamic walking. The number of size classes was reduced from 3 to 2, of which the smaller class was called Kidsize (< 60cm) and the bigger class TeenSize. The total number of competitions remained the same, however, the free style competition was replaced by the above mentioned regular 2-2 games in the KidSize League. In the TeenSize league the conductance of 1-1 games was discussed, but could not be carried out. One aim of the technical committee was and still is to lead the development towards current research problems. Dynamic walking and stability have been the most important issues then and still are up to now, which have been enforced by the technical challenges between in the years 2005 and 2006. In the year 2005 and 2006 a rough terrain challenge has been conducted where the robots have to cross over a field of hexagonal tiles, which are of a random height. The technical challenges are changing every year.

The rules have been farther refined for the competition in 2006. in many aspects, in particular with respect to the conductance of the 2-2 games. Also the footrace competition had been introduced to the TeenSize class in order to have an

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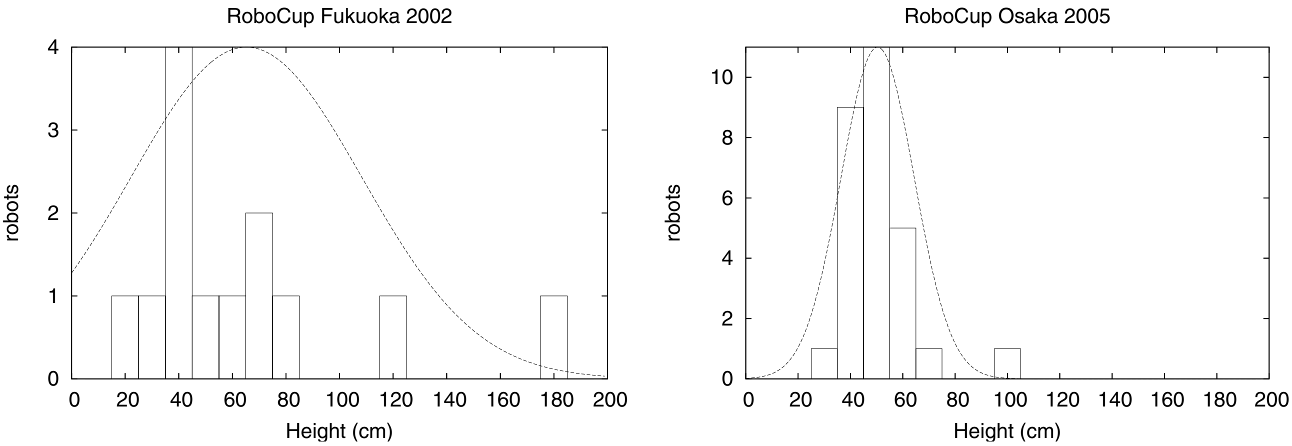


Fig. 1. Histograms of the heights of the robots that participated during the competitions in 2002 (left) and 2005 (right): The robots of the year 2005 showed a significantly smaller variance in size than the robots that participated in the first year of the Humanoid League. The Gaussian distributions show the same mean, variance as the data-sets. Only robots were counted that showed any kind of movement during the competition.

equal number of competitions in Teen- and KidSize.

The rules of 2005 and 2006 and the example of relatively cheap and powerful robots gave a new perspective to many interested people in the RoboCup community and also people from outside who were interested in setting up a team.

In 2005 a total of 20 teams from 9 countries participated. This is about twice the number of the year 2004. For the first time a real qualification process had to be introduced. Several teams had some background from other leagues and took the advantage to customize relatively successfully their software within the new league. Team Osaka got the Best Humanoid Award again, as well as in 2006 [1], after exciting finals against Team Nimbro[4] (Germany).

In the following section we want to outline the evolutionary process and describe a kind of typical robot of the Humanoid League VisiON TRYZ (used by Team Osaka and JEAP). Then we describe further plans of the Humanoid League that are currently under discussion. We focus here in particular on a joint project idea that is planned together with the 3D Soccer Simulation League, called 3D2Real. We conclude with a discussion.

II. Evolutionary Conversion and typical robots of the HL 2006

In the first years quite a variety of different types of humanoid robots participated. Fig. 1 shows the histograms over the heights of the participating robots in 2002 – the first year of the RoboCup and 2005 – which was the first year of the 2-2 competitions. Using only this one parameter one can clearly see a developmental and convergence process towards robots of sizes between 40-60 cm. Also, more and more robots participating in the RoboCup Humanoid League are exclusively manufactured for this event. The convergence is partly caused by the rules in the KidSize League that allows a maximum height exactly at the size of 60 cm, but mainly it is due to constraints that come with considerations of the mechanical design and costs. The convergence process happens mainly in the KidSize League, where the typical design concept of the robots' hardware consists of the following parts

- Servo motors (initially designed for RC toys). In particular many teams switched to RC servos that can be linked together in the RS 485 bus (similar to the well known RS 232; one example are Dynamixel DX 117 and AX 12 actuators).
- Small reliable mini PCs (e.g. handhelds, industry one board mini PCs, like PINON PNM SG3F. In order to process the vision stream of about 15 frames at a resolution of 640x480 a 600-800 MHz processor is sufficient.
- Microcontroller, these are necessary for the real time control of the servos.
- As sensors: camera (connected via USB or Firewire to the PC) and attitude sensors (gyro, acceleration sensors). Except for the feedback from the joint angles most robots do not use additional sensors.
- Wireless network (IEEE 802.11) is permitted, and can be used for the communication between the robots and in order to send start and stop signals to the robots. However, wireless networks are not reliable during the RoboCup. A fallback solution is highly recommended. The rules state that the robot has to be able to perform even if the wireless network is not working.

Whereas the KidSize robots evolved rapidly during the past 2-3 years, we expect the same development in the TeenSize yet to come. Typically, TeenSize robots are either derived from KidSize models (typically just on the lower limit of the permitted size of the TeenSize class) or we see that robots participate from initially unrelated fields of research. It is very much to hope that in the near future a TeenSize class with its

[1]Descriptions of all participating teams of 2006 can be found online at *http://www.humanoidsoccer.org/teams.html*.

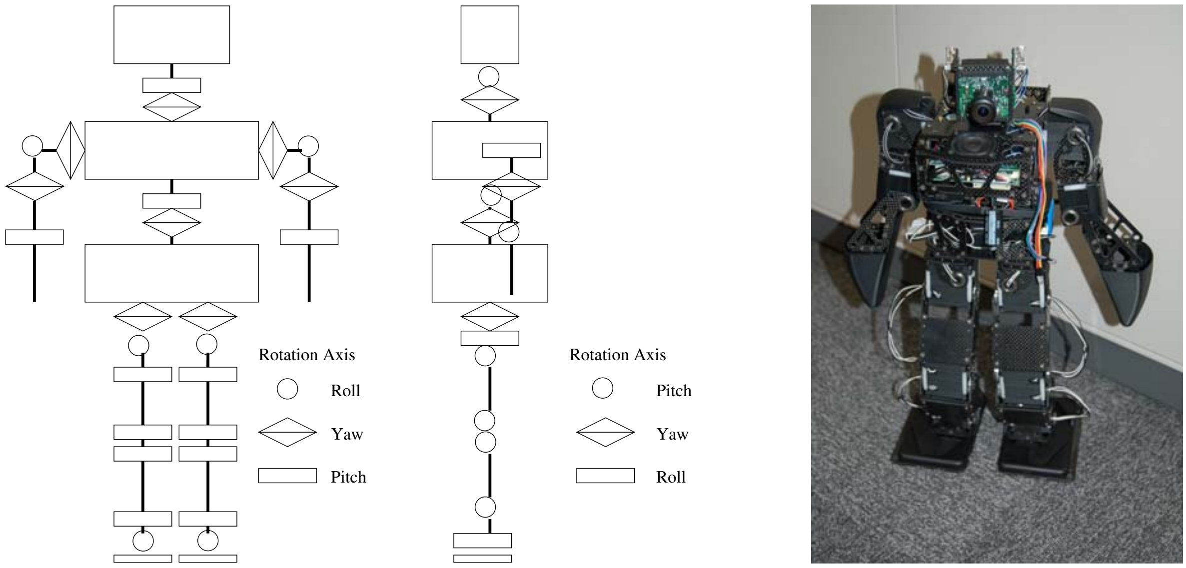


Fig. 2. The VisiON TRYZ robot: Left side a photo from the front view of the robot is depicted. One can see the camera (Philips chip-set) and the USB connectors for servicing in the head of the robot. On the left side is a schematic overview of the actuators and their attitude in relation to the robot's body.

own profile and own technology evolves.

In the following we want to describe in more detail the current robots and of Team Osaka [5] and Team JEAP [6], which – with respect to the criteria outlined above – can be seen as a typical robot of the KidSize League. We also briefly outline a typical software environment.

III. The VisiON TRYZ robot

In the RoboCup 2005 competition, the platforms of the JEAP Team (former Senchans Team) were the Fujitsu Hoap 2 and Hoap 3 robots [7]. Since the mass of these robots is over 7.5kg, there is a risk that the motors break when the robots fall down. This was a serious handicap for the competition in 2005. Therefore, at the RoboCup 2006 several VisiON TRYZ robots have been used that are fully autonomous robots, manufactured by VStone Inc. As shown in Fig. 2, this type of robots has 26 DOF and is equipped with a pan/tilt camera. Moreover, it has also acceleration sensors and gyro sensors. Inside each actuator, there is the potentiometer to detect the joint angles. The robot has 2 host controllers in the body and an actuator controller in each motor. One of the host controllers (the main controller, mini PC) performs the image processing and controls the autonomous behavior of the robot, and the other one calculates the trajectory and sensor values.

In the Humanoid League, most team adopt a color extraction system in order to detect a ball and goals. This is done in the JEAP team as well. In addition, a rapid prototyping tool to design behaviors has been programmed recently (as shown in Fig. 3). The structure of the agent code consists of a flexible framework for behavior development that originates from the software of the veteran simulation league team RoboLog. By using run-time loadable modules the design and the debugging of the behaviors can be accelerated.

Since the JST Erato Asada Project, the JEAP team's funding organization, is basically concerned with the research in cognitive developmental processes Team JEAP tries to construct the robot behaviors in a biologically inspired way where this is appropriate. An example is the robot centered coordinate system and the description of object positions in terms of the robot's neck angle.

Robot		
Height (mm)	475	
Weight (kg)	3.1	
DOF	26	
Actuators	VStone Servo	
Camera Type	Quickcam	
Controller	Main Controller	Sub controller
CPU	Geode LX 800	SH2 F7054F
ROM	4GB (Flash HDD)	384+64 KB
RAM	512 MB	16 + 512 KB
OS	Linux	None

TABLE I
VisiON TRYZ hardware specifications

In the future, it is planned to implement self-localization into our robots by using the white lines and other landmarks. Similar systems are currently being used by the Darmstadt Dribblers and Hajime Team [8]. In addition, it is planned to add a mechanism for sharing information about objects on the field using the wireless communication. Moreover, improvements of the walking model are currently carried out. Using force-sensing-register (FSR) sensors on the bottom of the robot feet to detect the reaction force from the floor, a rhythmic walking controller based on the CPG principle is adopted. As a result of this improvement, the desired trajectory of each joint can be adjusted so that the global entrainment

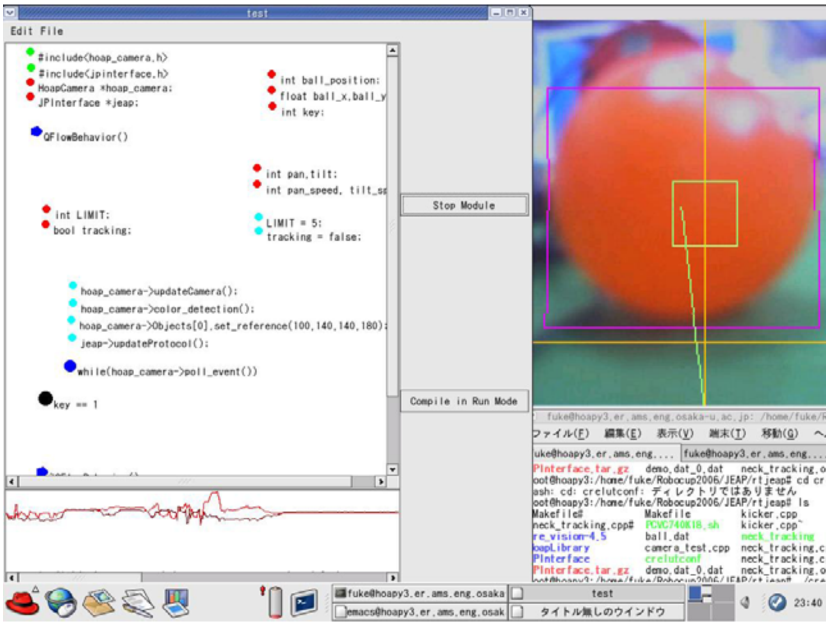


Fig. 3. Integrated modular software environment QFlowControl: The environment can be run upon the robot's main controller. Sensor data can be tracked by a simple run-time debugging tool. This kind of systems has been developed by most teams independently. They are usually highly optimized for rapid prototyping. The vision processing is integrated as a run-time module.

of the dynamics between the robot and the environment takes place. Then, as the next step, these sensors and an acceleration sensor will be used in the model in order for the robot to be able to walk over rough terrain.

IV. Future of the Humanoid League

In this section it is intended to give some overview of the current discussion that is happening within the technical committee (TC). The basis of this discussion is always the current draft of the rules [9]. We give a brief overview of this discussion. In the following section the 3D2Real project [10] is introduced, which is a joint project of the Soccer Simulation League and the Humanoid League.

As already mentioned before we distinguish two size classes in the Humanoid League. Both are separated basically by the height H of the robots. However, it is easy to fake the height by adding dynamically irrelevant parts on the robots (e.g. hairs) in order to make the appearance of the robots higher than they actually are. In order to avoid this and in order to have a sound definition that is hard to abuse, currently the height of a robot is defined as

$$H = min\{H_{top}, 2.2 \times H_{com}\}, \quad (1)$$

where H_{top} is the actual height and H_{com} is the height of the center of mass of the robot.

From point of view of the TC one of the biggest challenges is probably to lead the TeenSize class appropriately into a technological sound development. As already mentioned before different from the smaller robots we have not seen a break through in this area yet. The intention of the organizers is to establish the TeenSize class as a size class of significantly taller robots than those in the KidSize class. At the moment most of the robots participating in the TeenSize class are either non-functional or elongated derivatives of KidSize robots, which are just on the lower height limit of the TeenSize class. A clear profile of the TeenSize class is still missing.

The reasons for this unsatisfying situation are multifold: One important issue is the costs. One robot of this size class is typically several times more expensive than a humanoid robot that is designed for the KidSize class. While a robot of the KidSize class can be designed at a price of below USD 10.000 the costs for a functional Teensize robot over 1m can easily reach a multitude of this figure.

The second issue is the control problem. The handling of the control is very different. RC Servos that can handle the typical forces that appear in a robot of a size of above 1m are not available, thus motor controller units have to be designed by the team themselves.

Nevertheless, at each of the last RoboCups there have been one or two promising candidates who had to some extent the potential to serve as prototypes of the TeenSize class. At the RoboCup 2005 the Team Guroo, presented a roughly 30kg heavy robot with a size over 1m. In 2006, a fully functional TeenSize robot was presented by PAL robotics. In addition, the Darmstadt Dribblers Team presented an interesting study for a robot of the TeenSize class[8].

In order to encourage an own profile of the TeenSize class with an technology that is different from the KidSize class, the rules have been modified. Already 2005 different types of competitions from the KidSize class have been introduced. Thus, regular games are currently not conducted and are also not planned within the near future. The most important planned change for the Robocup 2007 is that the minimal height H of a robot in the TeenSize class is going to be increased from 65 to 80 cm. In this way a more distinct separation of KidSize robots from TeenSize robots is intended.

Additional changes are discussed with regard to the handling of the robots. A falling TeenSize robot is more likely to be damaged than a KidSize robot thus it has been suggested to allow robot handlers on the field who can catch a falling TeenSize robot and prevent farther damage.

Different from the TeenSize, the perspective for the next several years is relatively clear in the Kidsize class. If one has followed the discussions during the time span from 2004 to the present stage one can perceive a continuous and ongoing refinement of the discussion for the benefit of the conductance of the competition, and the challenging moment of the competition.

The discussion currently cycles around the following points:

- Increase the number of players. This has been a very emotional discussion in the past years, because the costs increase significantly with each additional player. Various test games of mixed teams have been conducted during the previous RoboCup competitions. At the moment, we are planning to increase the number of players. The most probable number at the moment is 3 players in the KidsSize in the year 2008, and further increasing numbers in the following years.
- Human-like sensors. In particular the plan is for the later future to ban the omni-vision camera. Vision sensors in other places than the head are already banned by the current rules.
- Foot size. The maximal allowed foot size in the current robots is defined as follows. The smallest rectangle covering one foot should not exceed $H^2/22$. This number has been decreased continuously from $H^2/18$ between 2004 until 2006. A further reduction is planned from 2008.

A useful measure for further milestones is the utopian sounding goal of having finals between the world champion in human soccer and robots, which will be of course humanoids. In order to achieve this target, accomplishments in several leagues have to be merged; one example how this could happen, and what benefits arise from such a merger is the 3D2Real project (see also [11]).

V. The 3D2Real Project

One problem for the RoboCup project is that throughout the leagues a lot of work is duplicated, and collaboration is rather sparse between the different leagues. This is not a desirable situation as know-how is not transferred effectively, and progress is slower than it could be since resources are bound to solve the same problems over and over again. To address this situation, the 3D2Real project [10] was initiated in 2006.

The main idea of this project is to try and use synergy effects from a collaboration between researchers in the Humanoid and the Soccer Simulation League (SSL). This collaboration includes a joint roadmap for the near future of both leagues, as well as the specification of standards and the development of tools that can be used in both leagues.

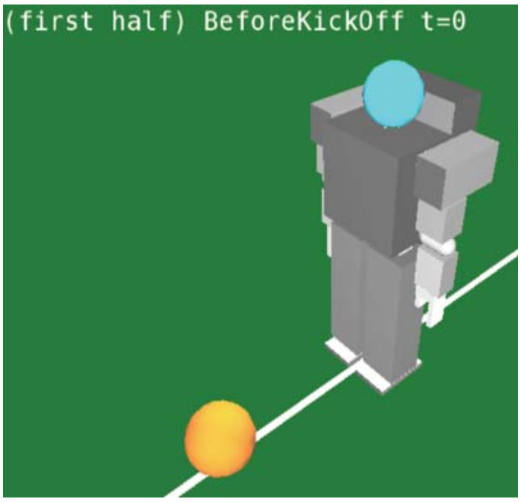
Traditionally, the SSL and the HL in RoboCup have had rather different research topics. While researchers in the HL mainly worked on the design and the low-level control of their robots, participants in the SSL were concerned with high-level strategies and collaboration. In recent years, however, there have been developments which might bring both leagues closer to each other. On the side of the SSL, there have been continuing efforts to introduce more realism into the rather abstract simulation of the SSL in order to ensure that the developed strategies can be transferred more easily to real robots. Humanoid robot simulation is the preferred choice for many participants of the SSL in order to achieve this. In the HL, on the other hand, the first multi-robot games have been held, and the great progress in controlling the robots allows researchers to approach issues of collaboration and coordination which have been extensively studied in the SSL. In short, both leagues are beginning to come closer to each other, and joint efforts in the development of tools and architectures that allow easier transfer of knowledge and technologies could speed up the mutual progress towards the 2050 goal of RoboCup.

	Soccer Simulation League	Humanoid League
Until RC 2007	real robot type implemented in 3D simulator	
RC 2007	3D SSL technical challenge: 2nd round in real robots	
2007 – 2008	Development of the CPR	
RC 2008	3D SSL finals in real robots (one type)	RoSiML models part of the HL qualification
RC 2009	3D SSL finals with several types of real robots	HL teams commit to the CPR

TABLE II

Overview of the road map towards the milestone of the 3D2Real project.

The joint road map we propose is given in table II. The goal we envision for the 3D2Real project is to have the finals of the simulation league using real robots by the year 2009. For this ambitious goal several steps are necessary in the next years to create the necessary infrastructure and tools. First, the 3D simulator of the SSL [12] has to be completed, and a real robot prototype has to be implemented as a simulation model (see e.g. Fig. 4. For the description of the robot models, the XML-based format *RoSiML* as used in the *SimRobot* simulator [13] seems promising. According to the proposed road map, a technical challenge would be held at RoboCup 2007 to test the ability to use the agent code of SSL participants on a pre-determined real robot. From 2007 until 2008, we propose the development of a *central parts repository* (CPR). This would be a collection of real robot designs, sensor and actuator models, pre-assembled robots, as well as controllers



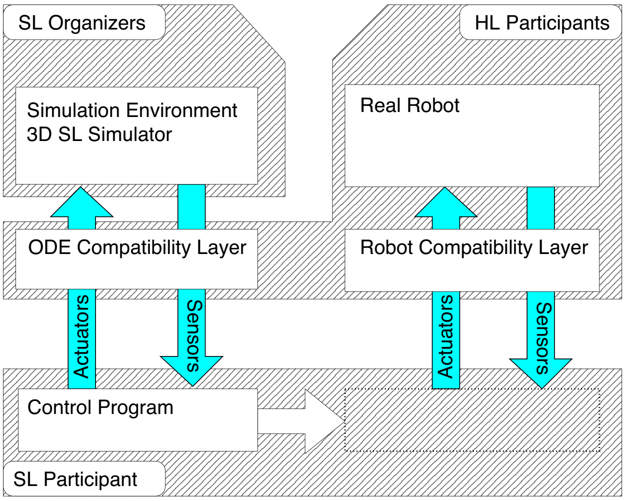


Fig. 4. 3D2Real: Left is a screen shot of a scene within a test environment of the 3D simulator. Right is a schematic sketch of the system architecture that would enable the transfer of the control program from simulation to the real robots: The hatched boxes show how the different leagues contribute to the complete system architecture of the 3D2Real project.

for certain architectures. Participants of both HL and SSL contribute to this repository according to their expertise and interest. The format would again be the *RoSiML* mentioned above. These contributions become a mandatory part for the HL qualification from 2008, and should be continued (at least) until 2009, even after the 3D SSL final has taken place using real robots.

VI. Discussion

One purpose of this work is to give an introduction and an overview to groups who are interested to participate in the Humanoid League. Not all aspects could be covered yet the authors intended to show that indeed the RoboCup serves among other things as a useful benchmark for embodied intelligence and biped walking.

The whole field of biped walking and humanoid robotics in general is evolving rapidly. The Humanoid League has to adapt to this development.

On one hand we are on a good way. The Humanoid League is currently making good progress; the performance in 2-2 games has been improved significantly between 2005 and 2006; the number of participants is increasing constantly.

As outlined in the paper we see a maturation process also in the design of the robots which shows that the teams learn to cope with the technical challenges of soccer playing robots. As described in the paper the typical robot of the current competition is a small robot that uses servo motors as actuators and a simple control structure. Important among other things the robustness of the robots. At the RoboCup only those robots are competitive that are able to perform at any time. This is still the main problem for many teams.

If one assumes the Humanoid League as huge evolutionary project this type of design can be seen as the result of the optimization process of the challenges to which the teams have been exposed so far.

On the other hand there are still many things to come and to be done in order to go on further. Fig. 5 depicts the initial road map for milestones to be achieved within the Humanoid League. Those were outlined in 1998 [14]. One can see that the league has reached some milestones since it was introduced in the RoboCup of 2002 in Fukuoka. Many milestones related to controlled walking, object recognition and ball handling have been realized.

Some other milestones have been shown to be feasible in research projects that are not related to the RoboCup. They may sooner or later be introduced to the league. One example is speech recognition.

Finally there are challenges for which so far no solutions have been found. In particular those are the ones that most researchers intuitively would associate with highly advanced artificial intelligence. In this sense there is still much work to do for our teams. We need to merge also the knowledge of the RoboCup leagues. One example how this can be done is outlined in the section about the 3D2Real project.

From point of view of the organisation the rules have always been subject to vivid discussions. The rules have maturated in many points and gained focus on the issues that are essential from a technical point of view. Thus, among other things the center of mass has been introduced to the rules, and has been set in relation to all other body measures. The competitions and challenges have advanced in various ways. In the RoboCup 2005 regular 2-2 games have been conducted for the first time. The rules for the conductance of the games have been further refined in various in the rules for 2006. Still there are many issues that need additional consideration and more fruitful discussions as we had them in the previous years. One aim of the technical committee is to lead the development towards important research problems. Dynamic walking and stability are still important issues, which have been enforced

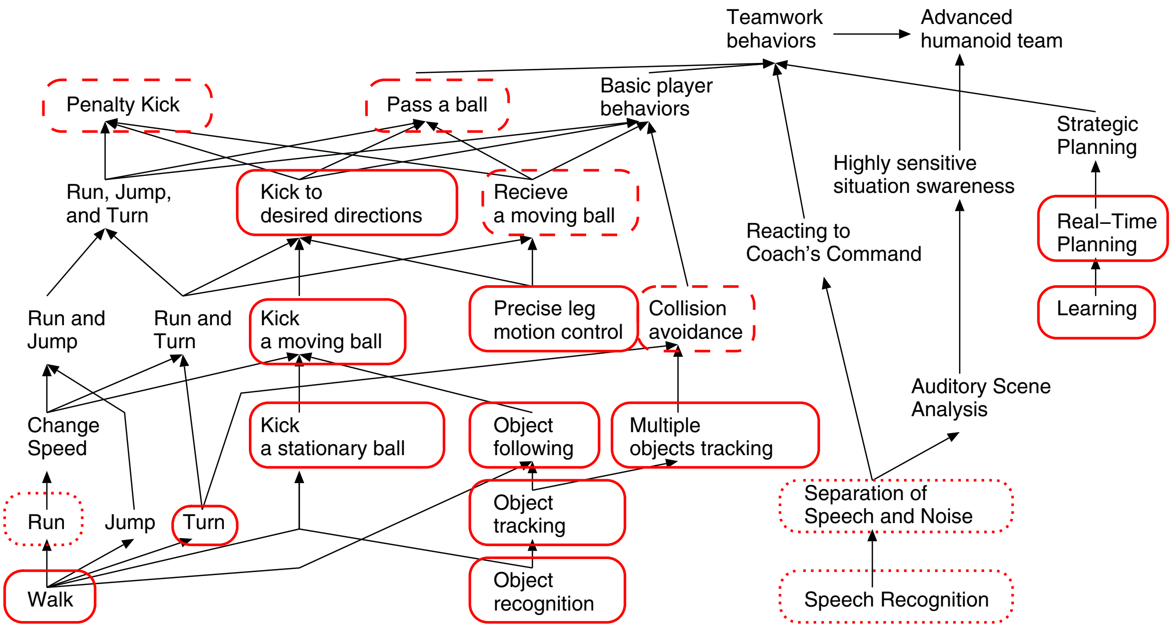


Fig. 5. Road map as suggested by Kitano and Asada in 1998 [14]: Red circled are the milestones that have been achieved up to the present; solid lines represent achieved and used in regular games; dashed lines represent milestones that were achieved in some demos or technical challenges within a RoboCup event, dotted lines represent at least partly available technologies that could be integrated into the HL.

by the technical challenges and the rules about the shape of the robot. For the following years also the rules about the sensory input need to be discussed. One example is the discussion about how human-like the sensors should be.

One thing that has not been mentioned so far is the media interest during the last 2 years. The finals of the Humanoid League were covered as live television events. Thus, Humanoid League can be a nice way to present research to a broad audience.

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