CS Freiburg's Participation at RoboCup'98: The World Champions in Robotic Soccer*

Bernhard Nebel, Wolfgang Hatzack, Thilo Weigel,
Jens-Steffen Gutmann, Immanuel Herrmann,
Frank Rittinger, and Augustinus Topor
Institut für Informatik
Albert-Ludwigs-Universität Freiburg
Am Flughafen 17, 79110 Freiburg

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Abstract

Robotic soccer is a challenging research domain that can be used to explore new problems and to demonstrate new techniques. We participated in RoboCup'98 in order to explore the problems of cooperation in multi-robot-systems and to demonstrate our self-localization techniques based on laser range finders. In this paper we sketch the main technical points of our team, give a description of the process of developing our team before and during the competition, and describe how we viewed the competition in general.

1 Robotic Soccer: A Scientific Challenge

Developing a team of soccer playing robots has been proposed by Mackworth [9] as a challenge for Artificial Intelligence and Robotics. It requires to solve problems in the design of autonomous agents, multi-agent collaboration, strategy acquisition, real-time reasoning, robotics, sensor fusion and more. In addition, it is necessary to integrate the solutions in order to build an autonomous soccer playing robot. For these reasons, robotic soccer seems to be an ideal domain for developing new solutions to the above mentioned problems and to study how to integrate different techniques. In order to put this challenge in concrete terms,

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Kitano *et al.* [7] founded the *RoboCup Federation* that regularly carries out workshops, conferences and competitions.[1] In 1997, the first robotic soccer world championship – *RoboCup'97* – had been held in Nagoya, Japan, as part of the *International Joint Conference on Artificial Intelligence (IJCAI)*. Games have been carried out in three different leagues:

Simulation League: The field of play is provided by a *Soccer Server*, a simulator of a soccer field. This server simulates all movements of the ball and the players. A team consists of no more than 11 soccer agents.

Small Size League: The field has the size of a ping pong table (152.5cm $\times$ 274cm). The maximum diameter of a circular robot is 15cm, while the maximum length of a rectangular robot is 18cm with a width of 10cm. A team consists of no more than 5 robots.

Middle Size League The field size is about 4.50m $\times$ 8.20m and a team consists of no more than 5 robots. The size of the robot should be within a circle of 50cm diameter or 45cm square.

The winning team in the simulation league came from the *Humboldt University*, Berlin, and the small size champion was a team from the *Carnegie Mellon University* (CMU), Pittsburgh. Since the final in the middle size league ended in a draw even after playing the extra time, the title has been awarded to both the *Dreamteam* from the *Information Science Institute* of the *University of Southern California* and the *Trackies* from *Osaka University*. A report on the competition and research results presented at the RoboCup workshop can be found in [6].

2 From the Decision of Building a Team to its Implementation

Watching the robots playing in the *middle size league* at RoboCup'97, one could get the impression that a game consisted mainly of hardware failures, uncoordinated movements, missed chances, and own goals. While some of this unsatisfying performance can probably be attributed to problems with the vision systems and radio communication, there seemed to be in general the problem that the robots only had a quite vague idea of their own position on the field.

We believe that knowing the position and orientation is one of the most basic capabilities of a robotic soccer agent. It appears to be an important prerequisite for implementing fundamental robotic soccer abilities such as planning shortest collision-free paths to the ball or kicking the ball into the direction of the opponent

[1] More information about the *RoboCup Federation* can be found at `http://www.robocup.org`.

goal. We also believe that an explicit world model is a necessary prerequisite for playing an aesthetic and effective game.

The arguments above played a prominent role in a discussion Kurt Konolige and some of the authors had in a cafe in Freiburg during the German AI conference in September 1997. Finally, Kurt suggested that instead of arguing hypothetically, we should try to build a robotic soccer team that makes advantage of the *self-localization techniques* developed in our group [5, 4, 1] in order to prove our point. After a few days of thought and discussions, we decided to really go for it.

In October 1997, we started the design and planning phase. Parallel to it we started to acquire the necessary hardware, which was a very time-consuming activity. Often, it took more than two months before the hardware arrived. Also the integration of the new hardware required some effort, in particular, because everything had to be done for each robot, i.e., five times.

From the end of February to the end of June 1998, the development took place. A custom kicking device was added and the software was implemented, tested, and tuned. End of June we felt ready for a first test game against a team from Tübingen, in which we did well enough. Our robots worked reliably and we were even able to score some goals.

While the development time of four months seems to be rather short, it must be taken into account that we already had worked with Pioneer robots – the platforms we used to build our soccer agents – and laser range finders for more than one year. Furthermore, the development of some of the key components such as the self-localization method and the communication structure were already started end of 1997.

3 CS Freiburg: Reliable Self-Localization, Explicit World Models, and Cooperative Play

As mentioned above, we already had some experience with self-localization techniques using laser range finders, but within the RoboCup context it was possible to use a very efficient and robust domain specific approach [11]. This approach makes use of the rectangular structure of the field and is able to determine the position and orientation of the robot with an accuracy of a few centimeters and degrees – modulo 180° due to the symmetry of the field.

Since our laser range finders are mounted well above the height of the ball, they can not be used for ball-recognition. For this reason, we use a commercially available vision system that returns the ball position in pixel coordinates. These are transformed into position coordinates relative to the robot using interpolation between trained pairs of pixel coordinates and real-world positions. Further, the estimation of the ball position is refined using the sonar sensors [10].

All the information perceived by a single robot is integrated into its *local world model*, from which the robot derives adequate actions such as searching and approaching the ball, planning paths and moving along these paths, dribbling with the ball into the direction of the opponents goal, and finally kicking the ball into the goal. These basic soccer abilities have been implemented using the *Saphira* system [8] that comes with the Pioneer robots.

However, due to sensory limitations a single robot is hardly able to perceive the environment completely. For example, the ball can be reliably seen only up to distance of 3–4 meters and the laser range finders have only a 180° view. In order to compensate for these limitations, the information perceived by all our robots is sent to an external server outside the field, where it is used to create a *global world model* that is made available to all robots.

As tests on our own exercise field demonstrated, a single robot performed quite successfully. However, it soon turned out that a team with more than one robot, all equipped with similar behaviors, has a coordination problem. We could observe many situations in which our robots ended up hooked together around the ball and finally got stuck. A straight forward method to resolve this problem was to assign disjoint areas of competence to the robots, where each area is associated with a distinguished role such as left defender, right defender, left forward and right forward. The resulting performance was much better, because interference occurred only rarely, namely, in situations where the ball was located at the border between competence areas.

While this scheme seemed to be effective most of the time, it proved to be counter-productive when one of our defenders was able to get the ball. Although the defender would be theoretically able to dribble the ball across the field and kick it into the opponent goal, it was not able to do so because it was confined to its area of competence. We finally modified this scheme so that a robot can leave its area when it is in possession of the ball. Furthermore, it signals all team mates to go away so that it is not blocked by them.[2]

4 RoboCup'98 – The World Championship

With 16 teams, the number of participants in the middle size league was significantly higher than last year, when only 6 teams were present. Obviously, the idea of Kitano et al. [7] to consider robot soccer as a challenge for AI and robotics was taken seriously by the community.

4.1 Preparing for the Games

During the first two days we were busy with testing our robots in the new environment. For example, the surface of the field (carpet instead of PVC) and

[2] A more detailed description of our team can be found elsewhere [2, 3, 11].

the light setting (bright halogen headlights instead of neon tubes) were different than at our home field. Fortunately, no major changes were necessary – even the problem with the strong lights could be solved easily by attaching sun glasses to the cameras.

4.2 Qualifying Round, First Match: CS Freiburg – NAIST

On the third day we had our first official game against the team from the Nara Institute of Technology (NAIST). Since their robots were a few centimeters to small for our laser range finders, we asked them to put on markers on their robots that are visible to our laser range finders. Regrettably they refused to do so (which is against the rules), and some members of the organization committee had to intervene before they finally agreed and the game started.

The strategy of the NAIST robots was not quite soccer-like. As soon as their robots saw the ball, they all pushed it in a concerted effort in the direction of our goal. Our robots tried to get the ball if it was in their area, but a single robot had no chance and was pushed aside. After a long struggle and many stuck situations during which nothing happened because the robots were completely blocked, the NAIST team finally arrived in front of our goal and pushed the ball together with our keeper into the goal, which is not prohibited by the RoboCup rules so far.

Of course, we were shocked since our team had no chance to demonstrate its abilities and we thought that all of our effort of the last months was in vain. However, during the second half we could profit from a situation in which the NAIST robots blocked themselves and where one of our forwards put us finally out of our misery by scoring a goal. The whole match was very haltingly and strenuous and ended 1:1, so the regular playing time was followed by a penalty shootout. No team scored a goal, which has two reasons: first, our goal keeper was fast enough to intercept the ball which was only pushed by the NAIST scorer (it had no kicking device), and second, our scorer could not see the opponent goal keeper.

This first game taught as that our rigid division of the field into disjoint competence areas is not well-suited for robot soccer. There were many situations in which one of our forwards was blocked by opponent robots, the ball lying freely in its area, only a few centimeters away from a team mate that did not play the ball because it was out of its area of competence. We solved this shortcoming late at night by merging the forward areas, i.e., both forwards are now responsible for the whole opponents half. To avoid interference, we use the same communication scheme that is used by the defenders when they dribble the ball across the field – the robot which is in the best position to play the ball sends its team mates to their default home positions.

4.3 Qualifying Round, Second Match: CS Freiburg – Dreamteam ISI

In our second match we had to compete with one of the reigning champions, the *Dreamteam* from ISI/USC. Their team consists of fast and hectic robots that are hard to control – they often bump into walls or run into other players, or even into goals. They scored most of the goals at RoboCup'97, but 25% of them were own goals. In fact, in one game at RoboCup'97 they scored four goals, but the game ended 2:2. Apparently, this weakness was still present at RoboCup'98. One of the qualifying games ended 2:1, although the opponent was not present on the field.

At the beginning of the match the *Dreamteam* seemed to control the game because of their speed. They approached the ball much faster and were more often in possession of the ball than our robots. However, they had problems playing the ball in our half because our defenders moved precisely to the ball and intervened in time. Soon the Dreamteam scored the only goal in this match, not very surprisingly, it was an own goal.

During this game we were less tensed than in our first game, because on some occasions our robots showed the beginnings of soccer playing abilities that we intended. But we also realized that our robots are too slow when dealing with the ball. They handle the ball with careful precision, but in some situations a little bit more courage seemed to be appropriate.

4.4 Qualifying Round, Third Match: CS Freiburg – Real Magicol

The *Real Magicol* team had problems with their robots and did not line up for their first qualifying game. For our game they managed to line up with a working goal keeper and four stationary field players, at least. We did not exactly cover ourselves with glory and scored three goals, though. This was enough to become the top of the table and together with NAIST we were qualified for the quarter final.

4.5 Quarter Final: CS Freiburg – Yale

The Yale robots were very fragile – if they moved into a wall, they blew their fuses if they were not switched off in time. Several times they ran towards our goal even if the ball went astray a few seconds ago. And sometimes they pushed our robots away although no ball was present, which is a foul according to the RoboCup rules. So most of the time we were playing the ball and had several chances to score a goal – two times we succeeded.

The Yale team was our first opponent that we had under firm control from beginning to end. We really enjoyed watching this game, although one of our forwards missed several clear chances to score a goal due to problems with its vision system. But it was clear to see that our recent modifications were fruitful and that our team was now in a really good shape.

4.6 Semi Final: CS Freiburg – Osaka University

Most of the time the second reigning champion, the team from Osaka University, played flank attacks and tried to move the ball from the sides into our goal. But our goal keeper was well-prepared for such cases and additionally our defenders barred the way of the forwards successfully. On the other hand our forwards had an easy job with Osaka's goal keeper, which was equipped with a 360° camera but nevertheless seemed to be disoriented and inattentive most of the time. Finally the game ended 3:0.

This was definitely our best game so far, although the Osaka team was a demanding opponent. During the last two games it turned out that our team was very successful in seizing obvious opportunities to score a goal and fortunately most games offer many such opportunities to tap the ball in.

4.7 Final: CS Freiburg – T-Team Tübingen

To the surprise of everybody, the two teams in the final were both from Germany and participated for the first time at a RoboCup competition. However, taking into consideration that Germans learn to player soccer already before they start school, and that most people from Japan and the United States know soccer only very superficially, the success of the two German teams might be less surprising. In addition, it is a well known fact that German soccer is already very mechanical – making it easy to implement it on robots.[3]

The final game was a big event. Many people from the media were present and interviewed us during the game. All spectator seats were filled and there was a lot of tense. Could we show again the superiority of our approach?

Having not lost any game yet and having scored a number of goals gave us some confidence. However, we also knew that soccer always is a game of chance. Tübingen had two promising scoring chances that were saved by our goalie, whereas we had four chances from which we could turn two into goals. So the final ended 2:0, and we became world champions (see Fig. 1).

4.8 Results in other Leagues

In the small size league the team *CMUnited* from CMU defended their championship successfully with a 3:1 victory over *Roberoos* from the *University of*

[3]This explanation should not be taken too seriously.

Figure 1: *CS Freiburg* and their coaches. Front, left to right: Berti, Otto, Franz, Jupp, and the goalie Sepp. Rear, left to right: Bernhard Nebel, Augustinus Topor, Wolfgang Hatzack, Immanuel Herrmann, Thilo Weigel, Steffen Gutmann

Queensland, who took second place. In the simulator league the defending champion *AT Humboldt* from the Humboldt University Berlin came second – in this league the winning team also came from CMU. Finally, this year there was also a *legged robot league* with three small legged robots manufactured by Sony per team ... and the CMU team became world champion in this league as well.

In summary, it can be said that the participating teams became much stronger and games were substantially more soccer-like than last year. For example, the simulator league champion of 1997 participated this year and had been beaten by several teams. Also the games in the small and middle size league were more exciting and less random than last year. Almost certainly the next world championship in 1999 will be on an even higher level than this year.

5 Conclusion and Future Directions

We gained a lot from our participation at RoboCup'98. Of course, everybody needs a lift now and then, and the media met us with an overwhelming response. But also our team improved a lot in the course of the championship, because we were confronted with situations we did not anticipate. Fortunately, we could adapt our robots to cope with many problems, e.g., by implementing a different cooperation strategy. In addition, we also learned from discussions with other teams. Finally, our primary intention to demonstrate the advantage of reliable self localization and sensor-fusion techniques has been put into action successfully.

Our superiority is not only backed up by our victory, but also from a comparison of the four best teams. While the other three teams won not more than three games and lost up to two games during regular playing time, we won five games and only one game ended in a draw. The goal differential of the other teams is 3:2, 8:4 and 9:4, while ours is 12:1 – altogether our team scored 25% of all goals. In a national competition beginning of October 1998, we proved that this performance was not an accident. Again, we did not loose any game and won the tournament.

But still a lot of work has to be done in order to meet the challenge of RoboCup'99, where we expect to play against much improved teams. We plan to focus on better synchronization of sensor inputs in order to obtain more precise information about moving objects, and we will try to improve ball handling. Hopefully, these two features will enable us to implement ball interception and ball passing behaviors. Also, we will try to make the role assignments more flexible and to implement sophisticated strategic abilities. Finally, we intend to make more and better use of the global world model.

References

[1] J.-S. Gutmann, W. Burgard, D. Fox, and K. Konolige. An experimental comparison of localization methods. In *Proceedings of the International Conference on Intelligent Robots and Systems (IROS'98)*. IEEE/RSJ, 1998.

[2] J.-S. Gutmann, W. Hatzack, I. Herrmann, B. Nebel, F. Rittinger, A. Topor, T. Weigel, and B. Welsch. The CS Freiburg team. In M. Asada, editor, *RoboCup-98: Robot Soccer World Cup II. Proceedings of the second RoboCup Workshop*, Paris, France, July 1998.

[3] J.-S. Gutmann, W. Hatzack, I. Herrmann, B. Nebel, F. Rittinger, A. Topor, T. Weigel, and B. Welsch. The CS Freiburg robotic soccer team: Reliable self-localization, multirobot sensor integration, and basic soccer skills. In M. Asada and H. Kitano, editors, *RoboCup-98: Robot Soccer World Cup II*, Lecture Notes in Artificial Intelligence. Springer-Verlag, Berlin, Heidelberg, New York, 1999. To appear.

[4] J.-S. Gutmann and B. Nebel. Navigation mobiler Roboter mit Laserscans. In P. Levi, T. Bräunl, and N. Oswald, editors, *Autonome Mobile System 1997*, Informatik aktuell, pages 36–47, Stuttgart, Germany, 1997. Springer-Verlag.

[5] J.-S. Gutmann and C. Schlegel. Amos: Comparison of scan matching approaches for self-localization in indoor environments. In *Proceedings of the 1st Euromicro Workshop on Advanced Mobile Robots*, pages 61–67. IEEE, 1996.

[6] H. Kitano, editor. *RoboCup-97: Robot Soccer World Cup I*, volume 1395 of *Lecture Notes in Artificial Intelligence*. Springer-Verlag, Berlin, Heidelberg, New York, 1998.

[7] H. Kitano, M. Asada, Y. Kuniyoshi, I. Noda, E. Osawa, and H. Matsubara. RoboCup: A challenge problem for AI. *The AI Magazine*, 18(1):73–85, 1997.

[8] K. Konolige, K. Myers, E. H. Ruspini, and A. Saffiotti. The Saphira Architecture: A Design for Autonomy. *Journal of Experimental and Theoretical Artificial Intelligence*, 9:215–235, 1997.

[9] A. K. Mackworth. On seeing robots. In A. Basu and X. Li, editors, *Computer Vision: Systems, Theory, and Applications*, pages 1–13. World Scientific Press, Singapore, 1993.

[10] A. Topor. Ballerkennung beim Roboterfußball (in German). Studienarbeit, Albert-Ludwigs-Universität Freiburg, Institut für Informatik, Freiburg, Germany, Jan. 1999.

[11] T. Weigel. Roboter-Fußball: Selbstlokalisierung, Weltmodellierung, Pfadplanung und verhaltensbasierte Kontrolle (in German). Diplomarbeit, Albert-Ludwigs-Universität Freiburg, Institut für Informatik, Freiburg, Germany, Jan. 1999.