Agilo RoboCuppers: RoboCup Team Description

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Abstract. This paper describes the *Agilo RoboCuppers*[1] – the RoboCup team of the image understanding group (FG BV) at the Technische Universität München. With a team of five Pioneer 1 robots, equipped with CCD camera and a single board computer each and coordinated by a master PC outside the field we participate in the Middle Robot League of the Third International Workshop on RoboCup in Stockholm 1999. We use a multi-agent based approach to represent different robots and to encapsulate concurrent tasks within the robots. A fast feature extraction based on the image processing library HALCON provides the data necessary for the onboard scene interpretation. In addition, these features as well as the odometric data of the robots are sent over the net to the master PC, where they are verified with regard to consistency and plausibility and fusioned to one global view of the scene. The results are distributed to all robots supporting their local planning modules. This data is also used by the global planning module coordinating the team's behaviour.

1 Introduction

Our research group started working on robot soccer at the beginning of 1998 considering it as a very challenging and interesting research domain for several reasons. The main challenge is to combine several complex computer domains, like vision, robotics, and artificial intelligence to one real system of several autonomous hard- and software components which perform together one common task. For this, multiple agents need to collaborate. They should be able to organize themselves, to learn how to act in specific situations, and to handle with uncertain data. The basic conditions are quite harsh: a dynamically changing environment is to be observed in real time and fast moving objects like ball and opponents must be recognized, tracked, and considered within planning methods for controlling the movement of the own robots.

The aim of our activities on robot soccer is to develop software components, frameworks, and tools which can be used flexibly for several tasks within different scenarios under basic conditions, similar to robot soccer. This can be used

[1] The name is derived from the Agilolfinger, which were the first Bavarian ruling dynasty in the 8th century, with Tassilo as its most famous representative.

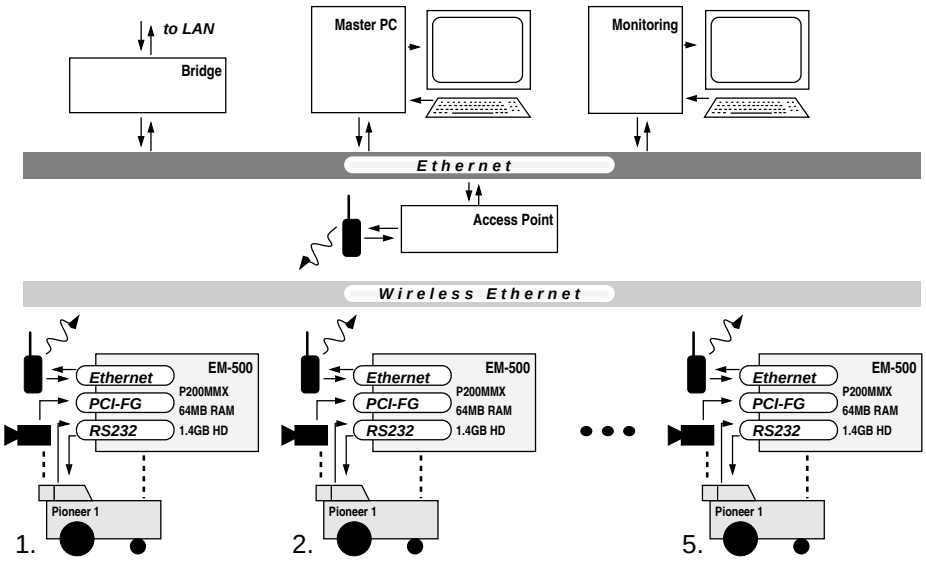

Fig. 1. Hardware architecture.

for teaching students in vision, artificial intelligence, robotics, and, last but not least, in developing large dynamic software systems. For this reason, our basic development criterion is to use inexpensive, easy extendible standard components and a standard software environment.

This paper is organized as follows. Section 2 presents the employed hardware, namely robots and computers. It follows in section 3 the description of some fundamental concepts concerning the overall system structure. Details on the design of the most important components are given in section 4.

2 Hardware Architecture

Our RoboCup team consists mainly of five Pioneer 1 robots [1] each equipped with a single board computer. They are supported by a master PC or coach, and one monitor PC for displaying the robot's data and states. Since the team size was reduced to four robots, the fifth robot will be used as a substitute. The single board computers are mounted on the top of the robots, firmly fixed – mechanically and electrically. All robot computers are linked via a 10 MBps radio ethernet network [4, 5]. A master computer is located outside the soccer field and is linked to the radio ethernet, too. It can also be used for debugging purposes, monitoring the robots' planning states and feature extraction processes. The operating system for all computers is Linux. Figure 1 gives an overview of the hardware architecture.

Figure 2 (a) shows one of our Pioneer 1 robots. Each of them measures 45 cm × 36 cm × 56 cm in length, width, and height and weighs about 12 kg. Inside the robot a Motorola microprocessor is in charge for controlling the drive motors, reading the position encoders, for the seven ultrasonic sonars, and for

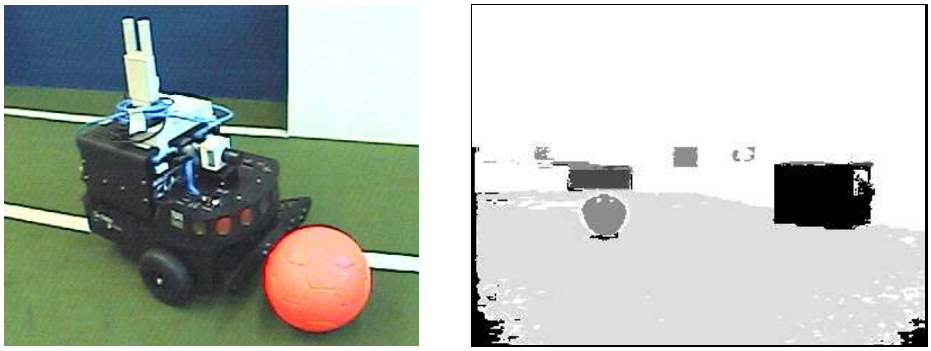

Fig. 2. (a) Odilo – one of our Pioneer 1 robots – and (b) what he percepts of the world around him.

communicating with the client. In our case this is a single board computer (EM-500 from [2]) which is mounted within a box on the topside of the robot. It is equipped with a Pentium 200 MHz processor, 64 MB RAM, 2.5" hard disk, onboard ethernet and VGA controller, and an inexpensive BT848-based [7] PCI video capture card [3]. PC and robot are connected via a standard RS232 serial port. A PAL color CCD camera is mounted on top of the robot console and linked to the S-VHS input of the video capture card. Gain, shutter time, and white balance of the camera are adjusted manually. For better ball guidance we mounted a simple concave-shaped bar in front of each robot. A kicking device is under construction and will replace the bar as soon as it is available.

3 Fundamental Software Concepts

The software architecture of our system is based on several independent modules, each these performs a specific task. Software agents control the modules, they decide what to do next and are able to adapt the behavior of the modules they are in charge for according to their current goal. For this, several threads run in parallel. Figure 3 depicts the software architecture of our system.

The modules are organized hierarchically, within the main modules basic or intermediate ones can be used. The main modules are image (sensor) analysis, robot control, local planning, information fusion, and global planning. The latter two run on the master PC outside the field, the others on the single board computers on the robots.

Beside the main modules there are some auxiliary modules, one for monitoring the robots, extracted sensor data and planning decisions, one for interacting with the system or with particular robots, and one for supervising the running processes. A large number of basic functions define fundamental robot behaviors, provide robot data, and realize different methods for extracting particular sets of vision data.

As for the communication between different modules, we strictly distinguish between controlling and data flow. One module can control another by sending

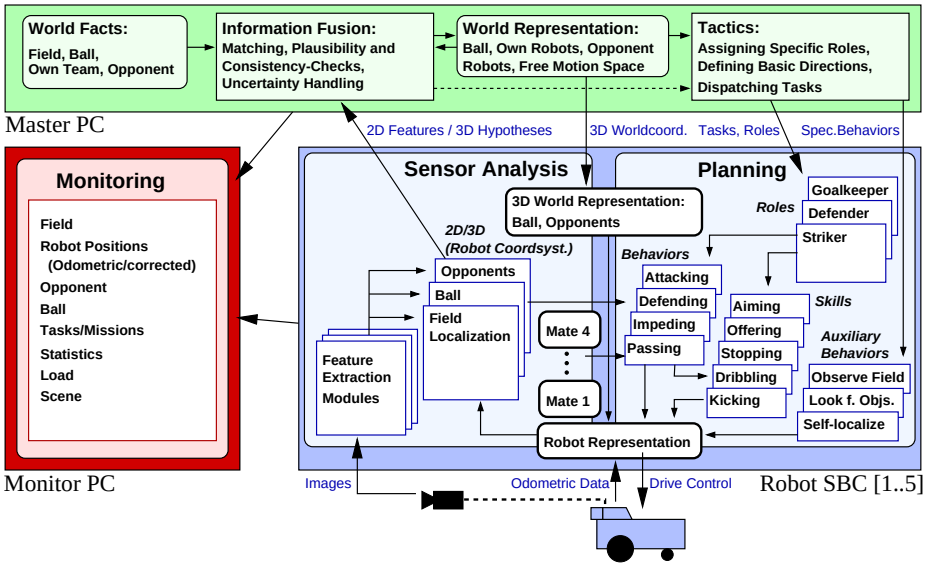

Fig. 3. Software architecture.

messages to the appropriate agent. Data accessed by various modules is handled in a different manner. For this, a special sequence object class was defined. This offers a consistent concept for exchanging dynamic data between arbitrary components [9]. The most important features of these objects are:

- A list of previous sequence values is maintained allowing access to values from the past. Values which are to old will be "forgotten".
- A time stamp is attached to all sequence values. Features get the same time stamp as the data from which they were extracted.
- The sequence objects "know" their functions for updating the sequence.
- Side effect functions can be defined which are performed after updating a sequence, and others, if the update failed.
- Update is automatically triggered by querying a new sequence value.
- Sequence values can be interpolated or predicted in the case that a value is requested for a time between two available values or for a future time, respectively.
- Sequence objects are global and thread-save, i.e. one module can be in charge for setting the values appropriately and other modules can use their values at the same time.
- Sequence data can easily be made transparently global over a network. So all robots as well as the master PC can access the data of the other robots.
- Special functions used in conjunction with sequences are modelled as objects called *functors*. This provides a uniform interface for flexible function handling.
- The sequence objects in conjunction with their associated functors represent a network or data flow graph which can easily be (re)configured dynamically during the running process.

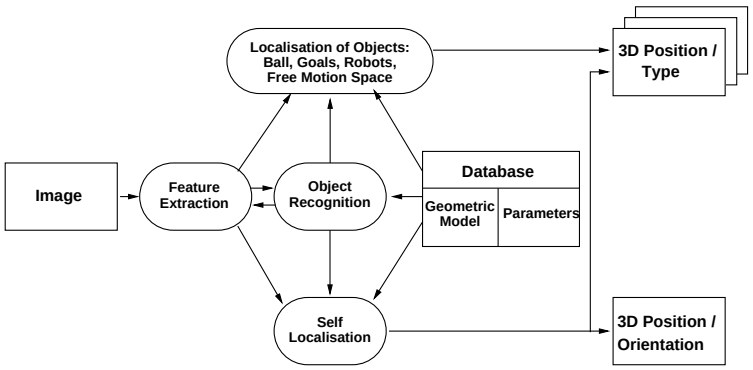

Fig. 4. Data flow diagram of the vision module.

The agents are responsible for triggering sequences, which are needed in the current situation, and to configure the sequences, functors and the graph built by them according to the current robot task.

4 Components

In this section we present some of the main features of the most important components of our system, namely vision, data fusion and planning. These components are implemented as software modules using the object-oriented programming language C++.

4.1 Vision

The vision module is a key part of the whole system. Given a raw video stream, the module has to recognize relevant objects in the surrounding world and provide their positions on the field to other modules. This is done with the help of the image processing library HALCON (formerly known as HORUS [8, 6]). This tool provides efficient functions for accessing, processing and analysing iconic data, including framegrabber access and data managment. The framegrabber interface was extended to features for capturing gray scale images and color regions at the same time. For this we use the YUV-image data provided by the video capture card. The color regions can be achieved very fast by a two-dimensional histogram-based classificator, which describes color classes as regions in the UV-plane and uses a brightness intervall as an additional restriction. Gray scale images, color regions and the extracted data are provided by sequence objects as described in section 3. As a compromise between accuracy and speed we capture the images with half the PAL resolution clipping the upper 40 percent. This results in a resolution of 384×172 with a frame rate of 7 to 10 images per second.

In general, the task of scene interpretation is a very difficult one. However, its complexity strongly depends on the context of a scene which has to be interpreted. In RoboCup, as it is defined in the present, the appearence of relevant

objects is well known. For their recognition, the strictly defined constraints of color and shape are saved in the model database and can be used. These constraints are matched with the extracted image features such as color regions and line segments (see Fig. 2 (b) and 4).

Besides recognizing relevant objects with the help of the color regions, a second task of the image interpretation module is to localize the recognized objects and to perform a self-localization on the field if needed. To localize objects we use the lowest point of the appropriate color regions over the floor in conjunction with a known camera pose relative to the robot. From this we can determine their distance and position relative to the robot. Self-localization is performed by matching the 3D geometric field model to the extracted line segments of the border lines and – if visible – to a goal. A subpixel accurate edge filter performed on the gray-scale image (Y-channel) supplies contours from which, after removing radial distortions, straight line segments are extracted. Both, an absolute initial localization as well as a successive refinement, compensating the error of the odometric data have been implemented.

4.2 Information Fusion

The information fusion module has to combine the fragments of information, which are provided by our robots, and form a consistent view of the world. This component is supposed to have two representations of the world: The geometrical one consists of the position, orientation, and velocity vector of all robots and the ball. Another representation is based on a grid covering the soccerfield and its contents. This will mainly be used for consistency checks and for global planning.

Information concerning uncertainties of the robot data is provided by the robots in conjunction with the odometric data. It is represented by ellipsoids where the volume of the ellipsoid corresponds with its uncertainty.

4.3 Planning

Planning is done on two levels: A *central, global* planner coordinates the different team members. Furthermore a *local* planner runs on every robot and controls its behavior.

Each robot has its own data and view of the current situation. This data is usually restricted to objects within the current sight of view or previously seen objects. Information about other objects is obtained from the global data distributed from the information fusion module. This global and local data together is used as the base for choosing an appropriate action. This is done by a special planning agent, the captain, who is responsible for deciding continuously, **what** to do next. This decision is passed to the pilot who works out, **how** this target can be achieved. For this, the pilot can use more or less complex driving commands of a special robot class. The action selection may also be influenced by the current *role* of the robot which can change during the game (except for the goalkeeper).

The task of the *global planner* is to coordinate the robots. E.g., if several robots try to reach the ball, the task of the global planner is to choose the most promising of them as forward and asks the others to change their role so that they do not impede the selected forward. Decisions of the global planner are driven by the world view provided by the information fusion module. Therefore, the global planner depends on a stable connection to all robots. In case of an instable or disturbed interconnection the robots may also work properly controlled only by their local planner.

5 Experiences gained from previous RoboCup competitions

As a result of our participation in the RoboCup'98 in Paris and the Vision'98 Tradefair RoboCup in Stuttgart, we summarize the following:

- We have made good experiences with concentrating on our main scientific goals – robot vision and intelligent control of distributed systems – by combining robust standard components for the robot hardware. However, one should not underestimate the effort to establish and maintain a running robot system.
- A good monitoring system is inevitable for debugging and analyzing within a distributed robot system. This is particularly true with a system sharing global data for coordination.
- The lack of a kicking device is a main disadvantage in terms of competition.
- An efficient self-localization as well as a global data fusion are some of the key components of a successfull robot team. For this a robust radio communication hardware is an essential condition.

Building up and maintaining a RoboCup team is a great challenge and needs huge personal efforts and a lot of time. Thus we hope that we will still have enough resources in future to continue our interesting and promising work.

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