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Data Driven Research and Development in RoboCup

http://robocup.tools

Heinrich Mellmann, Benjamin Schlotter, and Philipp Strobel

Adaptive Systems Group
Humboldt-Universität zu Berlin
Unter den Linden 6, D-10099 Berlin, Germany
{mellmann|schlottb|strobel}@informatik.hu-berlin.de

RoboCup provides a unique *common test scenario* for robotics, but its potential is, by far, not realized. Conducting games in RoboCup incurs high cost in terms of effort, time, and money. The scientific outcome, however, is quite limited and often not very conclusive. In most cases only the final score of the games provides feedback about the performance of a team.

Collecting more data during the competition games will help to analyze the performance of algorithms, and identify errors and areas for improvement. This kind of data can be more easily collected in a controlled experiment in a lab environment. However, the algorithms running on a robot tend to behave differently in the isolated environment of the lab compared to real conditions during a competition. Especially, analyzing and drawing conclusions about the performance of complex processes like decision making of an individual robot or the behavior on the team level poses a considerable challenge. From this perspective each RoboCup competition can be seen as a large scale collective experiment evaluating the abilities of the robots. In order to build understanding based on this large scale experiment, we need to capture data more effectively and to make this rich data comparable across the community and over time.

Teams in the standard platform league already collect data during the games. Common team communication and data sent by the game control computer during the game is recorded and made publicly available. Individual teams are collecting the data they need to analyze their teams performance and to solve bugs, e.g., images for ball detection. Many teams record videos of their games. All this data is however unorganized and there are no shared tools and common practices to effectively analyze and evaluate large amounts of data specific to RoboCup. At the same time many teams do not have access to extensive logging infrastructure, this includes in particular new teams joining RoboCup.

To adress this issue we initiated the project *robocup.tools* in 2016. The aim of this project is the development of an ecosystem of tools and practices to support collection, organization and analysis of large amounts of RoboCup-specific data enabling detailed analysis and promoting data driven research and development in RoboCup. In its scope, we developed a set of tools for automatic collection, synchronization and annotation of RoboCup data and videos, and collected a considerable amount of data during the competitions in 2018 and 2019. Over the past three years our project has received financial support from the RoboCup federation in 2017 and 2018, and from the Media Commission of the Humboldt-Universität zu Berlin. The results were presented at the RoboCup symposium in 2017, 2018 and 2019, and received overall a very positive response from the community.

In this project we plan to further improve the data collection system and move to a fully autonomous operation level. Develop stable tracking of robots and the ball in videos and integrate the detected trajectories with data from the all robots and thus obtain a reliable position ground truth for all robots on the field during a game. The fist prototypes have already

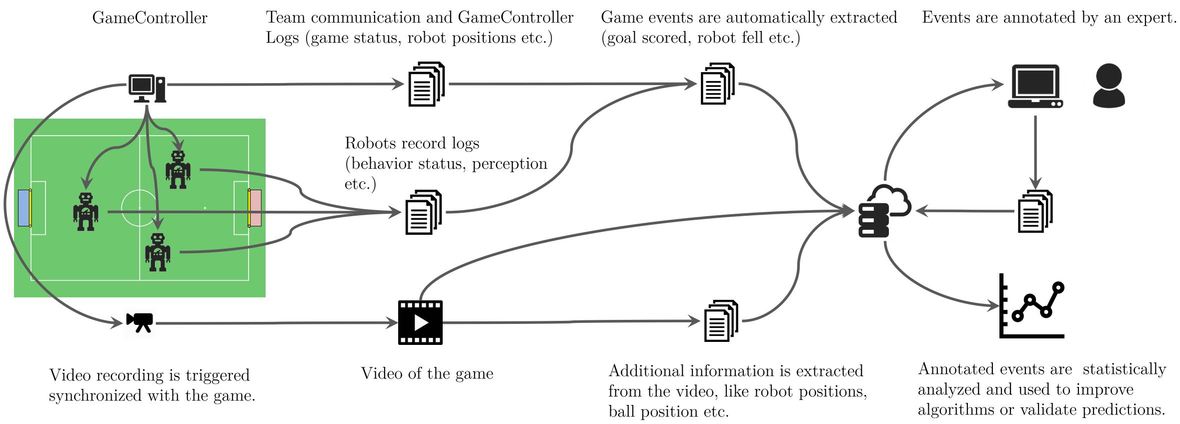

Fig. 1. Overview over the data flow of the proposed data processing ecosystem.

shown good results in isolated experiments. Ultimately we plan to collect data sets during the RoboCup competitions augmented with ground truth for robots' and ball's positions.

Acquiring robot tracking data opens the possibility to use existing research in team and agent behavior analysis from other disciplines such as sports research in RoboCup SPL. For example in the context of human soccer Le et al. [1] utilizes deep imitation learning to generate alternative strategies for defensive teams. This is done by learning on tracking data from multiple games of the same teams. In [2] trajectories are classified by a neural network in order to analyse individual agent behavior.

In the following two section we give an overview over the current state of the ecosystem and outline the aim of the project. In the following two sections we discuss the impact for the RoboCup community and present the implementation plan structured in work packages. The requested budget is outlined in the last section.

1 robocup.tools

robocup.tools is an ecosystem of tools and practices to support collection, organization and analysis of large amounts of RoboCup-specific data enabling detailed analysis and promoting data driven research and development in RoboCup. Although our current work focuses on the SPL, the developed tools and methods are applicable to other leagues.

At the current point we distinguish between three types of sources from which data can be gathered during a RoboCup soccer game: The *video* of the game, recorded by cameras on the side of the field; The *network communication* between the robots and data sent by the *game control computer* to the robots; and *log data* recorded by each individual robot.

Figure 1 depicts the used components and the data flow of the implemented system. For the collection of the data we utilize existing infrastructure within the SPL. In particular we make use of the *GameController*, a specialized software, which is used to control the games within SPL. The messages sent by the GameController are used to synchronize the different sources of the data.

In the following we briefly outline the main components that have been developed and the work that has been done thus far. Most recent results of the project have been summarized in more details in [3], and were presented during the RoboCup 2019 symposium. Further information as well as links to the demos, source code and collected data sets can be found at the project web page: `http://robocup.tools`.

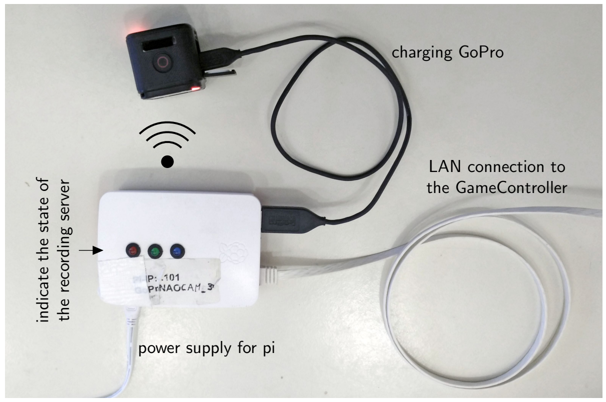

Fig. 2. System for automatic recording of synchronized RoboCup videos. The recording server is based on raspberry pi with the colored indicator LEDs. The GoPro is charged via USB from the raspberry. A LAN cable connects the pi to the GameController network. The Recording server sends commands to the GoPro via WiFi.

Automatic Data Collection and Synchronization: We developed a system for automatic recording of the game videos. A wide angle camera (currently a GoPro) is placed at the side of the field. The camera is operated by a custom built *recording server* based on raspberry pi. The overview over the recording system can be seen in the Figure 2. The recording is triggered based on commands sent by the GameController to the robots, e.g., start recording when the game starts. The video is recorded on the SD card of the camera and can be collected and stored together with the collected network communication. This procedure requires to be set up only once at the beginning of the competition and ensures that each game is recorded and *synchronized* with the corresponding network data. Depending on the available Internet connection, collected data can be uploaded to a server or directly copied by the teams from the recording computer to be used *during* the competition.

Logging Infrastructure: We have developed a comprehensive infrastructure for recording log files on individual robots during the games as well as tools for synchronizing these log files with videos of the game and inspecting them. A major design aspect was the backward compatibility of recorded data. Log files recorded by our team going back as far as 2010 are still readable and are being used.

RoboCup Data Explorer: The *RoboCup Data Explorer* is a web based server application for organization, inspection and annotation of large amounts of RoboCup data consisting of videos, network communication and log files recorded by individual robots. Figure 3 illustrates the two views of the *RoboCup Data Explorer*: overview of the available data sets on the left and *inspection and annotation view* of a selected game on the right. In the inspection and annotation view, the game events can be inspected and annotated by a human operator. The events can be extracted from the log files, e.g., game phases or instances of the robot falling, and provided through unified event interface. Different events appear in different colors on the timeline as can be seen in Figure 3 right. With a click on the event the video jumps to the time of it occurrence and plays the sequence of the event. Thus allows the human operator to quickly inspect particular events and annotate them. Such annotations can be use to analyze complex behavior patterns and also be used for machine learning. An example how this can be used for quantitative behavior analysis can be found in [4], where kick selection algorithms were evaluated.

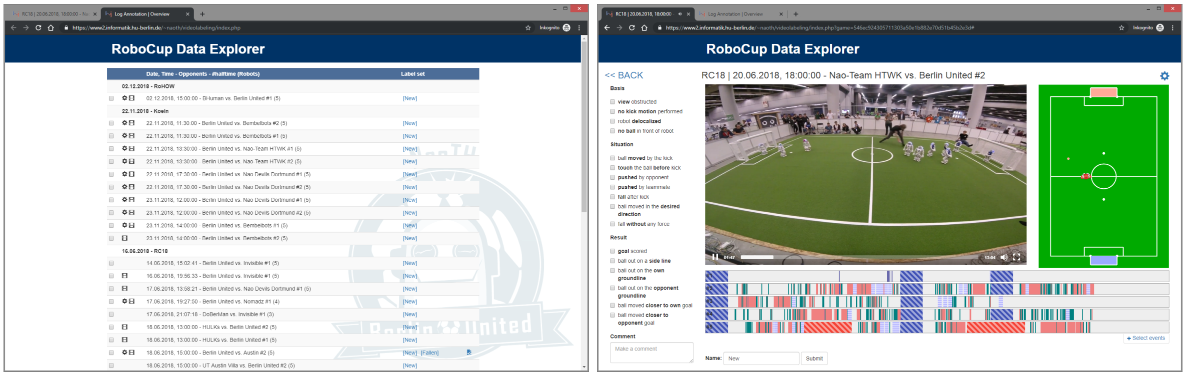

Fig. 3. Left: overview over the data collected during different RoboCup events. Right image: example session for inspection and event annotation for the first half of the game with the team *Nao Team HTWK* at the RoboCup 2018. Main components are timelines with events (game states, fall downs etc.) represented by colored buttons (bottom); visualization of the robots state, position on the field and perceived ball (right) and possible labels for the events (left).

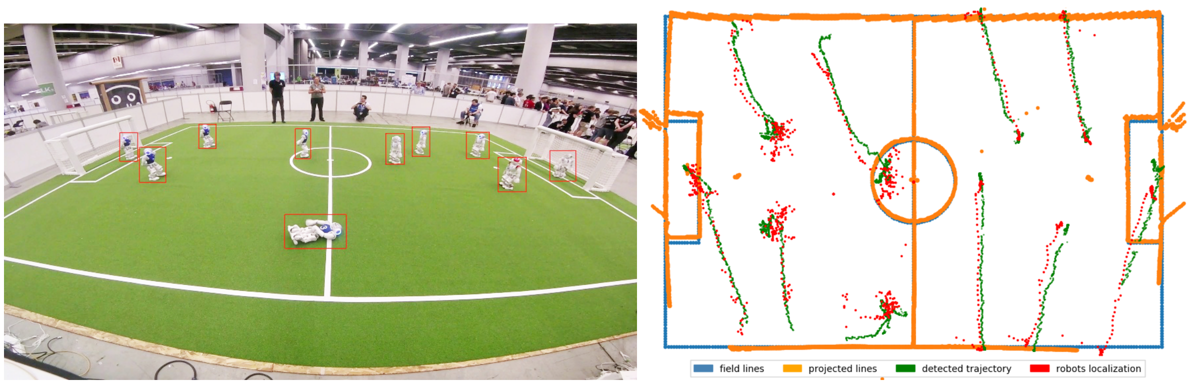

Fig. 4. Tracking of the robots on field conditions during the *Ready* phase. Left: final positions of the robots in the *READY* phase. Right: trajectories of the robots determined based on the video [green] in comparison to the communicated positions of the robots [red]. Projected line points are also shown in comparison to the model of the field. Note the goal posts being treated as lines.

Robot Detection and Tracking in Videos: We developed a prototype for tracking the robots on the field during a game based on the recorded videos. For this the robots are detected with the help of a Deep Neural Networks (DNN). The field lines are used to correct the camera distortion and to localize the camera relative to the field. This information is used to project robots positions detected in the video into the field coordinates and to track their trajectories. Figure 4 shows the robots detected in an image (left) and their trajectories (right) during the *Ready* phase of the game at the RoboCup 2019. Trajectories extracted from the video are shown alongside the estimations of the individual robots. More detailed description of the algorithm can be found in [3] alongside an empirical evaluation.

Collected Data Sets: The recording system was deployed to collect data during the German Open 2018 and 2019 as well as RoboCup 2018 and 2019. During the RoboCup competitions all five fields were recorded simultaneously. In total more that 350 synchronized videos have been recorded. More details regarding the collected data can be found in [3]. The deployment was coordinated and approved by the TC and OC of the SPL league. The collected data is publicly available and can be found through the projects homepage `http://robocup.tools`.

2 Scope of the Project

We propose to create a dataset from RoboCup 2020 data. The dataset will include videos of all competition games from the GermanOpen 2020 and RoboCup 2020 events. The games are synchronized with the GameController. Additionally the dataset will contain the robot trajectories which are extracted from the recorded video data. The video recording setup will be done as described in the previous section. For extracting the robot trajectories from video data, additional work has to be done. A proof of concept was presented in [3]. All tools will be made open source and will utilize only widely accessible and easily extensible technologies (web, python, GoPro cameras).

3 Benefit for the RoboCup Community

The source code, construction plans for the hardware as well as the collected data will be made publicly available and can be freely used for research and education. Having access to rich, well structured and searchable data opens a wide range of possibilities.

Proposed infrastructure would provide access to debugging based on real game data to a wide range of teams, enabling analysis of individual robot behavior, but also of the whole team, in particular in context of mixed teams. Many teams, in particular new ones, don't have access to extensive logging infrastructure. Even taking videos of the games can be a big effort during a competition.

Log files containing perceptual information or images can be used for teaching and research by parties outside of the RoboCup community, thereby growing it. Furthermore, researchers and students without access to a robot would be able to conduct research based on real robot data.

Human feedback can be incorporated in the form of annotations and used to analyze the performance of algorithms in real game conditions as demonstrated in [4]. This, in particular, can be used to improve the scientific grounding of RoboCup publications and make more meaningful results possible. Additionally, annotated data can be used as feedback for machine learning algorithms.

Having access to global data like robot trajectories will enable hardware leagues such as SPL to benefit from the experience of other leagues, like S2D, S3D and SSL, which have had access to similar kind of information for a long time already. Additionally ideas from sports research based on spatiotemporal data can be transferred to the SPL league.

Visual tracking of robots and the ball can be used to implement automatic refereeing system similar to SSL [5] in the future.

On the large scale we can hope for a better overview of progress across the whole league. A well organized data repository will help to visualize progress of the teams and the league as a whole over the years, which will both benefit the growing community and support its outreach efforts.

To improve the media outreach of RoboCup, videos of the games could be automatically enhanced with additional information visualized in the video, including game score, penalties and even decisions made by the robots. Provided adequate internet connection, such videos can be automatically uploaded and made available to the viewers at home right after the game, or ever streamed during the game.

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