Data Driven Research and Development in RoboCup Collection, Organization and Analysis of RoboCup Game Data http://robocup.tools

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An empirical scientific discipline requires a set of methods and practices for evaluation and comparison of proposed models and solutions. RoboCup provides a unique *common test scenario* for robotics, but its potential is, by far, not realized. Conducting games 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. In particular, analysis of the team behavior, like role change, require global synchronized data. 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. 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.

In the past year we addressed this problem within an RCF funded project. In its scope, we developed a set of tools for automatic collection, synchronization and annotation of RoboCup data and videos. The results, presented at the RoboCup 2017 symposium, received very positive response from the community. The current proposal is a continuation of this ongoing effort and a follow-up project to the RCF supported project from 2016. The aim of this project is to push forward 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. On the one hand, we will work on consolidation and integration of the developed tools, documentation and on establishing of the automatic data collection in the SPL as an integrated part of the league. On the other hand, we plan to pursue development of new components for analysis and visualization of aggregated data, and for extraction of information from videos with machine learning techniques.



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

In the following two sections we give an overview over the proposed ecosystem and summarize the current state of development. In the last section we discuss the impact for the RoboCup community.

1 Collection and Organization of RoboCup Data

We propose the development of an extensible and flexible set of tools for the collection, systematization and analysis of the RoboCup specific data. In the current stage the development will focus on the SPL league. The adaptation of the tool set to the needs of the other leagues could be a natural next step. We identify four different main technical components:

- Collection and Synchronization automatic synchronized video recording, communication data, logs recorded by the individual robots, synchronization tool for not synchronized videos;
- Storage, Formats and Query log files unrolled into a database, events as JSON, logging on robots based on Protobuf (backward compatible), access through web-interfaces;
- Mining and Extraction of Information scripts to extract events from logs (e.g., robot fell), tool for manual annotation of events, detection and tracking of objects in videos with machine learning;
- Aggregation, Analysis and Visualization statistics over events (identify systematic problems), visualization of strategies, access quality of the perception of the robots over the course of the game

Figure 1 illustrates the flow of the data through different components of the toolbox. Two additional, equally important, nontechnical components of the ecosystem are *Documentation* and *Promotion*.

One of the main key aspects is the extensibility. For this reason we believe a set of tools with standardized interfaces is the superior approach as opposed to an integrated solution. The aim is to make the system easily extensible by additional components, e.g., a video overlay [1]. In particular, individual teams should be able to adapt it according to their particular needs and research goals.

All tools will be made open source and will utilize only widely accessible and easily extensible technologies (web, python, GoPro cameras). Another important development aspect is the ability to work with *online* and *offline* data.



Fig. 2. Left figure: Example session for annotation of kick events regarding their quality in synchronized video and log data. Main components are timelines with kick events represented by colored buttons (bottom); visualization of the robots state (position on the field and perceived ball) (right side); and evaluation panel for assigning labels to the events. Right figure: Example of detected robots in a video recorded with a GoPro camera at the European Open 2016 in Eindhoven. Colored boxed illustrate the detected NAO robots with different confidence.

2 Current State of the Project

The proposed project is based on our long experience with RoboCup. This section gives a brief overview over tools and technologies which have already been developed. These components serve as proof of feasibility and will be used as the basis for the development for the proposed generalized toolbox. Further information, and links to the demos and source code of the components can be found at the project web page http://robocup.tools.

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

For automatic recording of the game videos a wide angle camera (currently a GoPro) is placed at the side of the field. The recording is triggered by the game controller commands sent to the robots, e.g., start recording when the game starts. The video is recorded 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 immediately uploaded to a server or directly copied by the teams from the recording computer to be used *during* the competition. For synchronization of the data recorded by the individual robots, as well as additional videos from other sources, a manual synchronization tool was developed. The system was tested and used to collect synchronized communication data and video during the local sponsored competition in Cologne in fall 2017. At the current point we are in contact with SPL TC and OC to arrange automated video recording for all SPL games during the RoboCup 2018.

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.



Fig. 3. Example of a visualization generated by a prototype tool for analysis of aggregated data. Finals in SPL between teams HTWK Leipzig (red, left goal) and B-Human (blue, right goal). Left image shows a heat map of player positions (without goalie). Right image illustrates the positions of the ball seen by both teams.

Extraction of Events and Annotation: A unified event interface will be at the core of the toolbox, and will allow access to the synchronized data in a standardized manner. Based on that a great variety of analysis tools can be easily built.

We developed an event based inspection and annotation tool, whereby game events extracted from log files can be inspected and annotated by a human operator. The tool was used to annotate different kick actions executed by our robots in the videos recorded during the games at the RoboCup in 2015. The kick events were automatically extracted from the log files recorded by the individual robots and aligned with the video. Thus the human annotator is able to click through the particular events and inspect them quickly. The results were used to evaluate the performance of the kick decision algorithm and were published in [2]. Figure 2 (left) illustrates an example of a labeling session for the first half of the game with the team *NaoDevils* at the RoboCup 2015.

Object Detection in Videos: Additional information can be automatically extracted from the video using machine vision techniques. Detected robots and ball can be used to verify the perception of the robots or as input for automatic referee system in a future project [3]. In the past year a robot detection and tracking based on HOG features and SVM based classifiers was developed within diploma thesis project by Dominik Krienelke. Figure 2 (right) illustrates an example for an SPL game scene with detected robots.

Data Visualization and Analysis: Communication data between the robots in the SPL league contains estimated positions of the robots and the ball. Figure 3 shows two different visualizations for aggregated positions of the robots as heat map (left) and the positions of the ball seen by the robots for both teams as scatter plot (right).

3 Benefit for the RoboCup Community

Collected data will be 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. Consider the following examples. 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.

The event based API would allow to access the data in a way which has not been available so far. Analyzing games by simply watching the videos is very hard, inspecting a few selected events is much easier. The toolbox would allow extraction of particular events, e.g., a particular robot falls more often than the others; or the robots are delocalized while being in a particular corner of the field.

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 [2]. 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 this kind of global data will enable hardware leagues like 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.

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.

Visual tracking of robots and the ball can be used to implement automatic refereeing system similar to SSL [3] in the future.

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