PROPOSAL FOR ADVANCEMENTS TO THE LLSF IN 2014 AND BEYOND

T. Niemueller and G. Lakemeyer*
{niemueller,gerhard}@kbsg.rwth-aachen.de

S. Reuter, D. Ewert, and S. Jeschke‡
[first.last]@ima-zlw-ifu.rwth-aachen.de

U. Karras¶
ulrich-karras@t-online.de

A. Ferrein†
ferrein@fh-aachen.de

D. Pensky§
pens@de.festo.com

*Knowledge-based Systems Group, RWTH Aachen University, Germany

†Electrical Engineering Department, Aachen University of Applied Sciences, Germany

‡Institute Cluster IMA/ZLW & IfU, RWTH Aachen University, Germany

§Festo Didactic, Denkendorf, Germany

¶Organization Committee, Logistics League Sponsored by Festo

ABSTRACT

The Logistics League Sponsored by Festo (LLSF) is a RoboCup league focusing on in-factory logistics applications involving task-level planning, scheduling, and automation in an industrial production workflow scenario. It is meant to spawn interest in industry for current robotics research and to provide a benchmarking domain for such applications. In this paper, we first describe the current set of rules used for the competition in 2013, outlining several advancements like variant production and (almost) autonomous judging through a referee box. We describe and propose changes for 2014, including doubling the field-size, multiple teams competing on the field at the same time, and the introduction of physical processing machinery replacing the signal light metaphor used so far, addressing the recommendations by RoboCup community members and casual visitors alike.

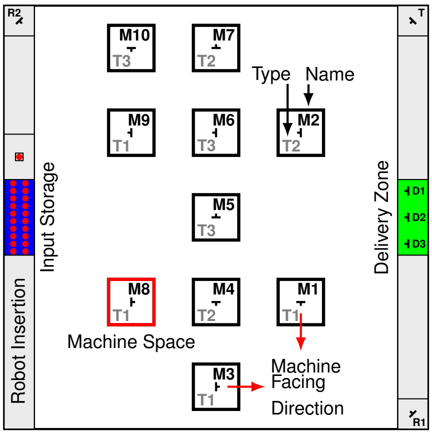
1 INTRODUCTION

The RoboCup vision is to create a team of humanoid robots which can compete with the then-to-be human world champion by 2050. Various soccer leagues have been created to work on different aspects to reach this goal. But the people driving RoboCup have also come to realize that the sustainability of this vision depends on support and cooperation with parties interested in real-world robotic applications. Additionally, already today there are technologies developed and tested in the competitions useful enough to transfer them into such out-of-lab scenarios. This is where the Logistics League Sponsored by Festo (LLSF) fits in. It focuses on the logistics aspect of an industrial production workflow, using coordinated teams of autonomous mobile robots building on technologies also developed in robot soccer leagues like self-localization, navigation, or perception.

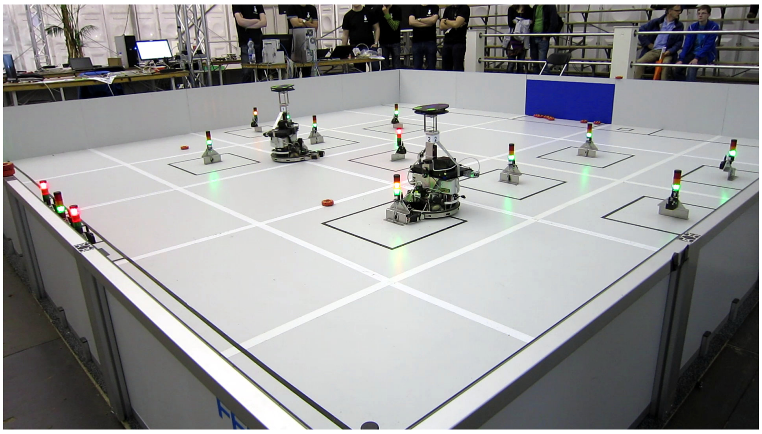
In industry, cyber-physical systems (CPS) have received a lot of attention recently. They strive to combine computational with physical processes. They include embedded computers and networks which monitor and control the physical processes and have a wide range of applications in assisted living, advanced automotive systems, energy conservation, environmental and critical infrastructure control, or manufacturing (Lee, 2008). In the LLSF, this is mapped onto a mobile robot logistics task. Issues of particular relevance are task-level planning and production scheduling, dealing with incomplete knowledge during production, coping with limits to the on-robot computational resources shared among all software and planning components, and handling uncertainty, e.g., due to machines which are undergoing maintenance or have failures at unknown times.

In 2012 the LLSF was officially founded. The task is to fetch raw materials (symbolized by pallet carrier pucks) from an input storage, move them in a particular sequence by machines with RFID readers, and finally deliver them. It builds on the Festo Robotino robot platform (Weinert and Pensky, 2011). In 2013, the dynamicity and complexity were increased by changing the rules to demand for more variable production plans. This also required the introduction of an autonomous referee box, a program that controls, monitors, and instructs the game in a knowledge-based manner. Additionally, limits regarding the computational hardware were lifted allowing to foster the integration of more robotic techniques like self-localization and navigation with collision avoidance. This was done to pave the way from a league with an automation background towards a production planning and scheduling scenario.

The major criticism about the LLSF is that it is virtually impossible to understand the game by watching it. We tried to alleviate the problem in the 2013 competitions by visualizing the game from the perspective of the referee box along with explanations. But discussions with members of the RoboCup community and casual visitors revealed that the problem remains—even got worse with the more flexible production plans. Therefore, in



(a) LLSF Competition Area 2013



(b) Competition in 2013

Figure 1: LLSF competition area and field machine in 2013

this paper we outline changes that we, (some) members of the Technical Committee (TC), the Organization Committee (OC), and Festo, the League's sponsor, envision to improve in particular on this situation, but also to gradually increase the game's complexity and thus challenge the participating teams. The main idea is to replace the signal lights representing machines by actual machines that carry out physical actions. Also, we propose to step away from a single product for which only the referee box knows the actual state, to multiple similarly shaped but differently colored products, to make it easy to observe the transformations along the production chain. We describe the (already made) decision of the LLSF to combine the two playing fields into one, on which two teams compete at the same time. This will require the avoidance of other agents in the environment during locomotion, much like humans or equipment from another manufacturer would have to be avoided in a real factory. We outline some of the implications for robot systems and required developments for the referee box.

On a related note, we report on some first discussion between the LLSF and members of the RoboCup@Work Technical Committee regarding possible connections and cooperation in the future.

The rest of the paper is structured as follows. In Sect. 2 we describe the rules and objectives of the game in 2013. The autonomous referee box is detailed in Sect. 3. With this background knowledge, we propose the envisioned changes for 2014 in Sect. 4. In Sect. 5 we report on our discussion with members of the RoboCup@Work TC. We conclude in Sect. 6.

2 GAME RULES AND OBJECTIVES IN 2013

The general intention for the LLSF is to create a simplified *factory automation scenario* with an emphasis on logistics applications. The goal is to complete production chains that require to move workpieces to a varying sequence of machines. Some intermediate steps and the delivery of final products are awarded with points. Uncertainties are introduced by randomized product demands and machine down times.

In 2013 teams of up to three robots operated in a fenced area of about $5.6\,\mathrm{m} \times 5.6\,\mathrm{m}$ as shown in Fig. 1. The Festo Robotino (Karras et al., 2011) is the sole platform at this time. Fig. 2(a) and (b) show the original Robotino 2 used in 2013, and the upcoming Robotino 3. The Robotino features omni-directional locomotion, twelve infrared distance sensors, and bumpers mounted around the base, a gyroscope, and a webcam facing forward. The LLSF allows for arbitrary extension regarding sensors or computing power. Fig. 2(c) shows the modified version of the Carologistics RoboCup team[1] (Niemueller, Ewert, Reuter, Ferrein, Jeschke and Lakemeyer, 2013b), which has an omni-directional camera system, which allows for a 360° view around the robot. An additional 2D Hokuyo URG laser scanner provides data for collision avoidance and self-localization.

On the field (cf. Fig. 1(a)) two margin areas on opposite sides contain the puck input storage, delivery zone, and several signal lights that deal as delivery gates for the final products or as recycling stations. Each puck has a programmable radio frequency identification (RFID) chip with which the different product states S_0, S_1, S_2, and P_1, P_2, P_3 are distinguished. Initially, all pucks are in state S_0. In the enclosed inner field, ten signals equipped with an RFID device mounted on its front represent production machines. Each machine is assigned a random but defined type out of the types T_1–T_5, which is initially unknown to the robots. The type determines the input and output of a machine. Pucks transition through their states by being processed through machines. The complete production tree is shown in Fig. 3. Circular nodes indicate a puck's state and rectangular nodes show the respective machine type. For example, the T_1 machine in the upper branch takes an S_0 puck as input with an S_1 puck as output. If a machine, like T_2, requires multiple inputs, these can be presented to the machine in any order. However, until the machine cycle completes, all involved pucks must remain in the machine space. The last input puck will be converted to the output puck, all others become junk and must be recycled at a recycling station. The machines indicate their state after processing a puck using light signals which the robots need to perceive and act upon.

Besides typical robotics tasks such as motion planning or self-localization, the robot needs to plan an efficient sequence of actions to produce as many products as possible in a fixed amount of time. Moreover, the robot has to deal with incomplete knowledge as it is not known in advance what machine has which type. Thus, the robots need to combine *sensing and reasoning* to incrementally update their belief about the world. Based on the knowledge gained, it has to find a strategy to maximize its production output, ideally minimizing costs such as travel distance.

3 AUTONOMOUS REFEREE BOX

Games in RoboCup in general involve machines playing a game against each other or solving real-world tasks withing certain

[1]http://www.carologistics.org

(a) Festo Robotino 2 (b) Festo Robotino 3 (c) Carologistics Robotino

Figure 2: Festo Robotino Version 2 and 3

rules and constraints. A game is judged, either by some objective utility value like goals scored in a soccer game, or subjective like a jury deciding on the performance as in RoboCup@Home. In the LLSF, we strive for a game which is observable to a machine, so that most if not all aspects can be scored automatically and compliance of the robots with the rules can be verified.

In 2012, the game was judged manually by two human referees. The production plans and hence the game was still static and rather simple. But even then overseeing the game could easily overwhelm the referees. In detail, a complete supervisory control required the referee to keep track of more than 20 pucks and their respective states, watching machine areas of 10 machines to detect pucks that are moved out of bounds, inserting late order pucks for visual triggering at certain times, and overseeing completion of the production chain awarding points and keeping a score. In fact, in 2012 we needed to review a camera recording of a game to award points in hindsight because a situation was overseen by the two human referees.

Acknowledging that problem, and with experience from other RoboCup leagues, the TC decided to implement a referee box (refbox). In leagues like the Mid-Size Soccer League (Lima et al., 2005) a referee box is the interface between human referees and the robotic players. The referees judge the game and rule compliance, and can instruct the robot players from a control machine which transmits the commands appropriately encoded for the machine via a wireless network[2]. But there, the only resource to monitor is the ball around which the game unfolds. Also, the commands given to the robots are rather simple, there are messages, for example, for starting or pausing the game, or informing the robots about game time, score, or penalized robots. In contrast, we strive for much more autonomy of the refbox and have more complex communication patterns. The refbox was implemented and first used for RoboCup 2013. The human referees still instruct the refbox, but only to start or pause the game, and to oversee the only aspect which could not be observed by the machine, i.e., the case that a puck was moved out of a machine area while it was still required there.

Beside the obvious task, to run the game, we also want to develop the refbox into a tool for benchmarking the robot systems—and its individual components if at all possible. For this, the refbox recorded all data that was communicated from and to the refbox, be it from robots or control applications. We also defined messages specifically aimed to support visualizing and benchmarking certain performance aspects, e.g., the self-localization accuracy of the robot.

3.1 Industrial Grounding

As outlined in (Niemueller, Ewert, Reuter, Ferrein, Jeschke and Lakemeyer, 2013a), for the application of CPS in manufacturing systems the requirements within the smart factory CPS must allow for horizontal and vertical communication (Vogel-Heuser et al., 2011). *Horizontal communication* refers to data exchange on the same level along the production chain, e.g., robots performing production steps. *Vertical communication* refers to information exchange between the different levels of manufacturing, management, and control. Nowadays, these are associated to organization-wide enterprise resource planning systems (ERP), manufacturing execution systems (MES) for detailed production planning across machines and the underlying supervisory control and data acquisition (SCADA).

One important issue for LLSF 2013 was to establish a simplified MES system for LLSF providing production plans and in particular a supervisory control of the game.

3.2 Tasks of the Referee Box

The refbox tasks are to control, monitor, record, and score the overall game. It communicates with visualization and instruction applications. We will now describe these aspects in more detail.

Game Control. The refbox must oversee the game implementing and checking compliance with the rules defined in the rule-book (The LLSF Technical Committee, 2013). It must post randomized orders to the robots, award points if these are delivered. To test and increase robustness of the robot systems, it also introduces randomized disturbances like machine outages.

Communication. The refbox must communicate with the robots on the field to provide information (e.g., machine assignments), send orders, and receive reports. Additionally in 2013 the refboxes of the two adjacent fields synchronized games in later tournament rounds.

Data Recording. All data sent to and from the refbox is recorded into a database based on principles described in (Niemueller et al., 2012). This data serves to document the game and to allow for a later performance analysis.

Visualization and Instruction. The game state needs to be visualized for the referees and the general audience. Additionally instructions of the referee must be conveyed to the refbox.

Machinery Control. The refbox needs to communicate with the programmable logic controller (PLC) which is used to set the

[2] Another example is the GameController of the Standard Platform and Humanoid Soccer Leagues available from `http://sf.net/p/robocupgc/`

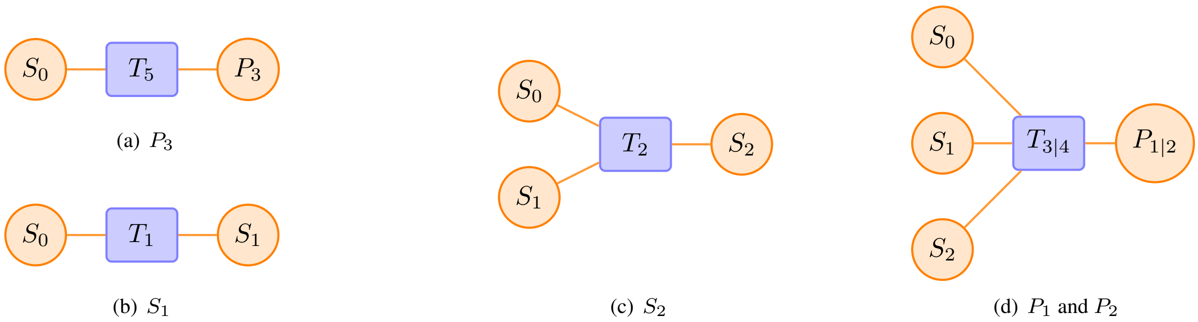


Figure 3: Production Chain Diagrams showing the machines and inputs relative to their outputs.

light signals (i.e., instruct the production machines) and read the RFID sensors on the pucks.

All of these tasks must be integrated closely. We will now describe the implementation in more detail.

3.3 Implementation

The referee box has been implemented by members of the LLSF TC. Its infrastructure is written in C++ and the game controller core in CLIPS[3]. It uses Boost[4] for some of its internals, for example asynchronous I/O and signal propagation.

CLIPS is a rule-based production system using forward chaining inference based on the Rete algorithm (Forgy, 1982). The CLIPS rule engine (Wygant, 1989) has been developed and used since 1985 and is thus mature and stable. It was designed to integrate well with the C programming language[5], which specifically helps to integrate with the refbox. For more details we refer to (Niemueller, Ewert, Reuter, Ferrein, Jeschke and Lakemeyer, 2013a).

The base program creates the environment for the CLIPS core, in which the actual game controller is implemented. This core is a knowledge-based system. The facts in the working memory are used to keep track of the state of the game and to communicate within the core. Rules trigger on specific conditions and events, For example the reception of a message, or the completion of a production cycle of a machine. A time fact is periodically asserted (currently at 25 Hz) to allow for time-based triggering, such as in the case of the production completion. This allows us to specify durative actions.

There are currently three interfaces to represent the game state and to accept commands. A textual shell which uses the ncurses library is used for quick operation by the human referee. It shows the most important information and accepts commands. A graphical user interface (GUI) has been implemented using the Gtkmm library. It features a visual display of the playing field and is focused on visualization and explanation of the game to the audience. The Carologistics RoboCup Team has published applications for Android mobiles and tablets to allow for easy monitoring of the field referee over the refbox status, and even instructing it, e.g., during training games[6].

The refbox communicates with the robots using broadcast UDP, and with control applications via TCP. All messages are specified and serialized using Google protocol buffers[7] (protobuf) for message specification and serialization. A small framing protocol allows for transmitting messages of different types over the same connection. This is particularly important in RoboCup, where network resources are scarce and combining messages and reducing the number of connection handshakes is beneficial.

The refbox has been released as Open Source software. The refbox itself and its documentation are available at `http://www.robocup-logistics.org/refbox`.

3.4 Benchmarking

An important aspect of the referee box is that it allows to record data of a game to perform benchmark analyses. There are several ways to perform benchmark tests. One way for evaluating the performance of a robot is to conduct functional benchmarks for the whole robotic system. Here, not a single component is tested separately, but the system as a whole is tested. Examples for such benchmark initiatives are RoboCup (RoboCup Federation, 2013), the NIST Urban Search and Rescue benchmark (NIST, 2013) or the DARPA Grand Challenge (DARPA, 2013). An example of benchmarking domestic service robot with a RoboCup competition is the RoboCup@Home league (Wisspeintner et al., 2010). Another recent example is the EU-funded RockIn initiative (Amigoni et al., 2013) which focuses on designing competitions specifically for benchmarks. With such competitions, the performance of different systems can be directly compared. Often, however, the possibility to measure the performance in an objective way is not given because ground-truth data taken from the competition are not available. In the context of RoboCup, there is some work on how to acquire ground-truth data for the Standard Platform League (Niemueller et al., 2011; Khandelwal and Stone, 2012; Pennisi et al., 2013); it remains, however, a central problem to establish standardized test data for comparing robot systems.

In (Niemueller, Ewert, Reuter, Karras, Ferrein, Jeschke and Lakemeyer, 2013), we outline the possibilities for developing the LLSF into a benchmark for logistics scenarios. There, we follow (Dillmann, 2004) for the important features of a benchmark:

1. the robot needs to perform a real mission;
2. the benchmark must be accepted in the field;
3. the task has a precise definition;
4. repeatability, independence, unambiguity of the test;
5. collection of ground-truth data.

The key question is what are the important aspects a standard test must include. An important dimension for logistic scenarios for CPS are supply chain optimization in an uncertain domain with

[3] `http://clipsrules.sf.net`
[4] `http://www.boost.org`
[5] And C++ using clipsmm, see `http://clipsmm.sf.net`
[6] `http://www.fawkesrobotics.org/projects/llsf-refbox`
[7] `http://code.google.com/p/protobuf/`

failing machines and varying product qualities. Supply chains describe logistic networks which comprise interlinked logistic actors. Here, not only a single-robot scenario can be tested but also a multi-robot scenario must be benchmarked. The important aspect that can be tested is the performance of the robot system as such, e.g., how good are the path planning or collision avoidance capabilities of the robot while being deployed in a real task. The tasks can vary from different command variables such as overall output of goods or operating grade of a machine. In order to evaluate these aspects, we make use of the automated referee system described above which keeps track of the score and performs data recording. In 2013, the Carologistics RoboCup team started a project to integrate and adapt the overhead camera system of the RoboCup Small Size League (Zickler et al., 2010) for automated robot and product tracking[8]. This system would make the game fully observable so it could be judged completely by the refbox. However it turned out that the camera tracking approach was still insufficient to provide reasonable data. Thus we have to develop more sophisticated solutions in the future to benchmark our logistics scenario. The team is currently evaluating a Kinect-based system like the one described in (Pennisi et al., 2013).

4 ADVANCEMENT OF THE LLSF IN 2014

In this section we outline our ideas to overcome the major problems of the 2013 LLSF RoboCup competitions. These were in particular:

1. The game play was hardly understandable for the audience. The main reason was that the different "products" (pucks) were all the same and a production step was performed only virtually on the RFID chip of a puck;

2. Teams were not competing directly against each other. Each team was on its own field. This did not reflect to competitive character of an LLSF match;

3. The field was too constrained with strictly planar surface, and fixed positions and rectangular alignment of machines.

Our new proposal addresses a modified playing field where two teams compete at the same time (Sect. 4.1) and we envision new machines where actually a transformation of products takes place (Sect. 4.2). This presupposes changes in the robot design as well as for the automated referee system. We plan to keep the changes for teams at a minimal level for the 2014 competitions. We outline the required software as well as hardware modifications in Sects. 4.3 and 4.4.

4.1 Field size and floor coating

A major decision made at RoboCup 2013 is to combine both playing fields into one with double the size of the 2013 field. Along with the merging of the two fields, Festo proposes to change the material of the field's floor. The current floor plates have several drawbacks. First and foremost are they very expensive. Additionally cutting through the material requires considerable effort. With the new machine setup (see below), we would probably need different holes and find a way to close the old ones. The connection points were also cumbersome in the past and caused sharp edges which caused trouble. While we generally intend to go for less strictly specified ground, long edges have shown to be more problematic than simply uneven floor. The proposal is to use a simple double floor (to provide room for cabling) and cover it with PVC coating. In the case double flooring turns out to be impractical, we would use single floor, covered with PVC, and mount cables to traverses or the ceiling.

[8]The project was sponsored with a project grant by the RoboCup Federation.

Multiple teams on one field—a change that the teams have already agreed on—is to have two teams on the field playing at the same time. The reasoning is to introduce more uncertainty and foster the development and implementation of flexible approaches with self-localization and collision avoidance. The proposal is to have an increasing complexity for teams during the tournament by having the teams separated in the beginning by distributing the machines partitioned in two spaces (but still allowing teams to travel anywhere at all times). Later (either in later round robin games or in the playoffs) machines would be mixed to require teams to pass by each other. This change will require a careful design of the rulebook to balance dynamicity with deadlock prevention and to disallow intentional collisions or willful obstruction of the teams (which would lead towards destructive games). We will need to come up with rules that mandate collision avoidance and punish inter-robot contact in a useful way.

In addition to multiple teams on the field we consider blocking certain paths randomly with systainers, as was done for the technical challenge in 2013. This could be done only for later phases of the tournament to increase complexity.

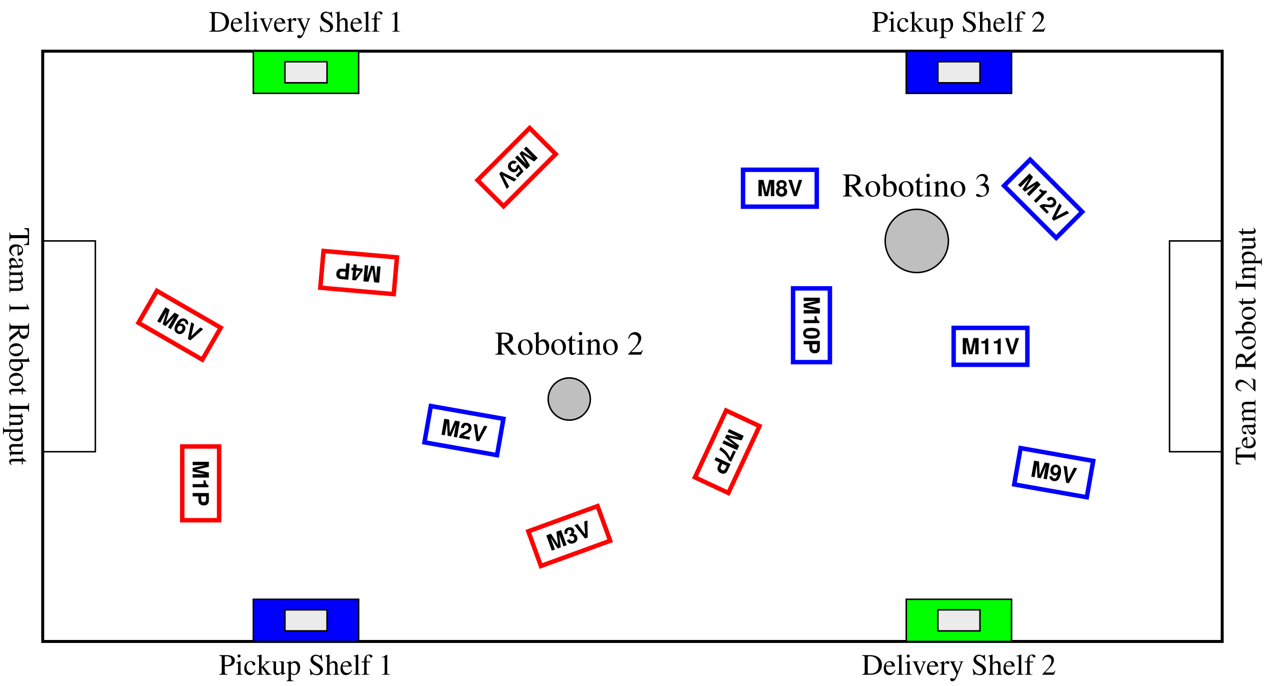
4.2 New machines: MPS

The major criticism towards the LLSF is that it is virtually impossible to understand the game from watching it, even if presented with an info display as was done in 2013 competitions. Therefore, we want to replace the light signals with their RFID devices (standing for the machines) by *Modular Production System*[9] (MPS) stations of Festo. We would stick to one or two machine types for the beginning. Each MPS station consists of an aluminum base plate of about 70 cm × 35 cm on which the machinery is mounted. Each machine provides transfer points which would be input and output of a machine (on opposing sides). Once the required input is fed into a machine, some production step is carried out, e.g., mounting a cap on a cylinder, and the resulting product is delivered to the output point, where the robot can pick it up. Due to the larger size, we propose to have 12 machines on the field in total, that is 6 for each team. Fig. 4 shows two possible layouts for the new playing field. The upper figure (Fig. 4(a)) displays a schematic layout of the playing fields machines and gives an impression of the new challenges in terms of navigation and collision avoidance for the teams. We displayed also the diameters of the Robotino robots. The Robotino platform which was used in 2013 was the Robotino 2. In 2014, also the new Robotino 3 can be used. It has several advantages over the old one such as a more precise drive and more payload. As one can see from the figure, also the platform diameter increased quite a bit. An alternative layout is presented in the mock-up in Fig. 4(b). This layout gives an impression of how the different machine types would look on the playing field.

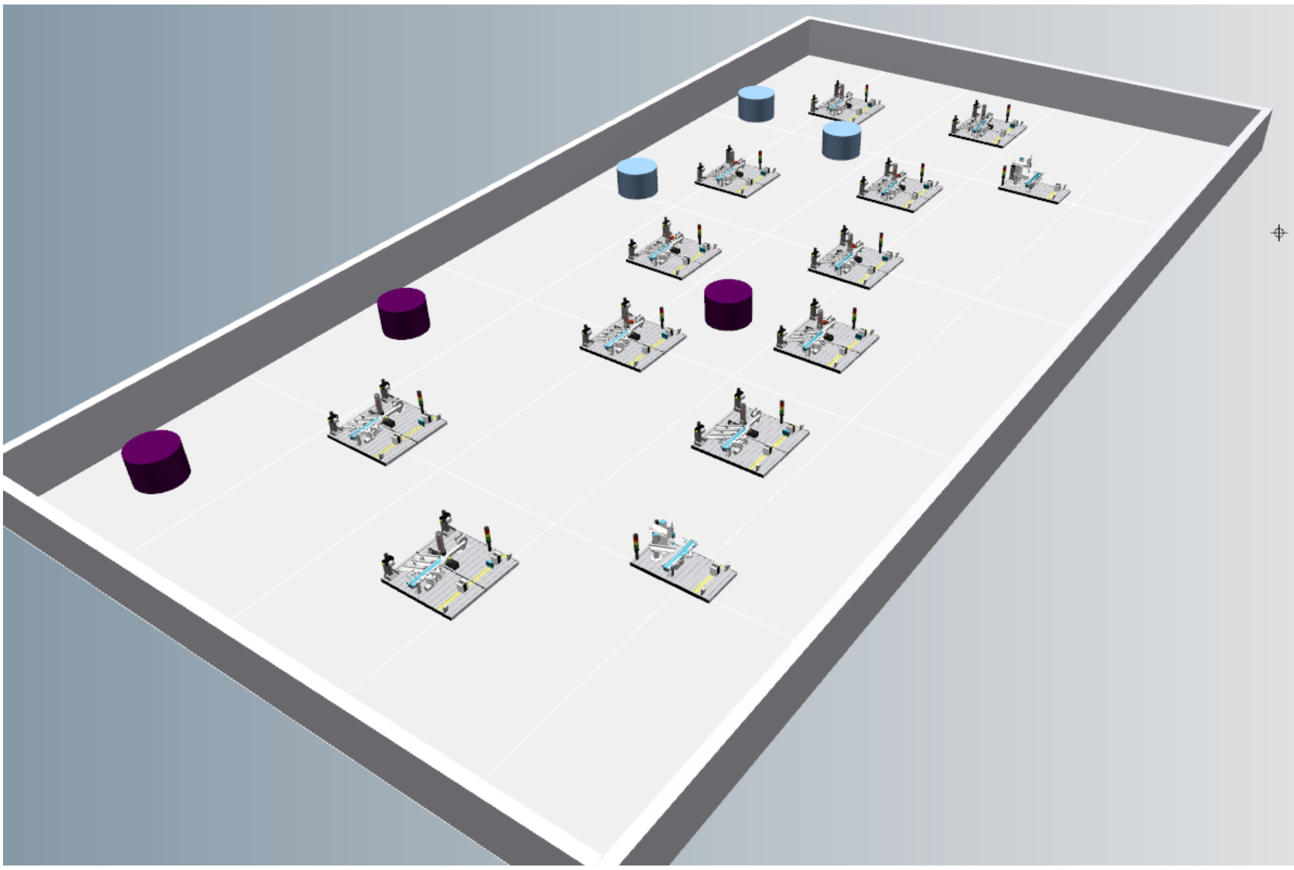
4.2.1 Envisioned machine types

We envision two machines and two shelf types necessary for a flexible production cycle.

[9]http://www.festo-didactic.com/int-en/learning-systems/mps-the-modular-production-system/



(a) Randomized assignment for proposed competition area in 2014



(b) Mock-up of an alternative layout of the new playing field.

Figure 4: Possible new field layouts for the 2014 competitions

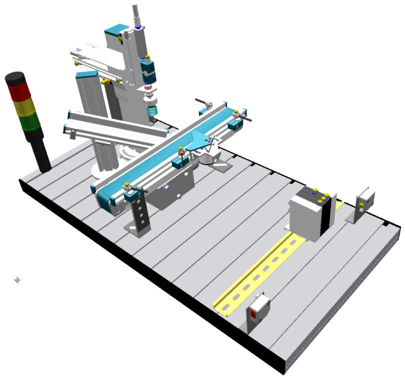


Figure 5: Pick and Place Station

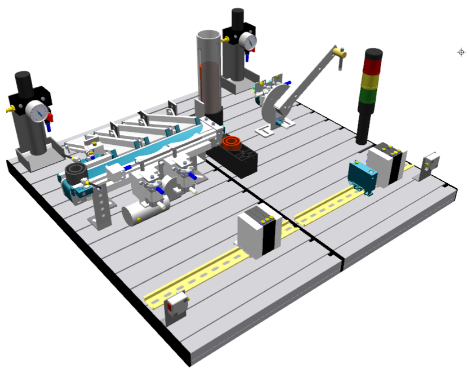


Figure 6: Variable Input/Output Station

Cap/RFID Mounting (Pick & Place). The final step of each production cycle will be mounting a cap with RFID transponder on a cylinder. The machine will be an unmodified MPS station “Pick & Place” as shown in Fig. 5.

Variable input/output (Sorter and Dispenser). Input products will be placed on a conveyor belt. A detection step will sort the input into one of two slides: for misplaced products or for desired products. The former will be simply discarded. The latter will collect input cylinders until all required inputs (statically or dynamically defined by the refbox) have been supplied. Then the cylinders on the slide are discarded and a dispenser outputs a single cylinder of specified color. A draft is shown in Fig. 6.

Raw Material Dispenser. A shelf will be equipped with passive dispensers which will supply the input products (cylinders). The material will be refilled as needed by the teams.

Delivery Station. The delivery gate will be an MPS Handling station which picks up delivered final products and places it on a slide for commissioning. In case of different final products different slides can be used. The delivery modes (active gates, acceptance/rejection) will remain as is.

4.2.2 New Materials/Products

The MPS stations manipulate small plastic cylinders similar to the Pucks currently used in the LLSF. This year we would resemble the existing scenario a little more closely and just have differently colored cylinders which are fed to a sorter and on appropriate input a defined output is produced. A final step will consist of mounting a cap with a fixed RFID tag. In Fig. 7(a), the new types of products are shown. Silver and black cylinders could be used for raw and intermediate products, while a red cylinder could represent a final product.

(a) Workpieces for MPS stations (b) Festo Robotino Gripper

Figure 7: Workpiece and gripper

4.3 System Integration

The integration of new machines on the large field for multiple concurrently playing teams is a major challenge and requires cooperation and efforts of all teams involved in the TC. The following steps are necessary: programming/modifying of controllers and adapting the refbox to control the MPS. To simplify the transition to the new processes, a light signal could be added to each MPS station indicating the current status. This way teams could reuse their systems for detecting signal lights.

4.4 Robot Requirements

The MPSs process different types of products shown in Fig. 7(a) which must be delivered to and picked up from transfer points at a height of about 15 cm. This requires that robots will add a (stationary) gripper to take and place items. Festo has offered RoboCup kits of their grippers shown in Fig. 7(b) at a reduced price, but we intend to allow custom made grippers as well. While this might sound like a major hurdle, in fact it is very similar to what teams have to do now. Go to a product and get it (now not just pushing it into a passive device but gripping it), move it to a machine and place it. Moving will become easier because the puck can now longer slide away when turning or driving backwards. Since the gripper is stationary, that is, it only needs to open and close its fingers, but not move in relation to the robot body, no additional software (like trajectory planning) is necessary. Placement of the products at the MPS will be more challenging with regards to accuracy as the tolerance of the MPS is lower than that of the current machines. The input and output slots will be highlighted with easily perceptible markers which will allow to align robots to the machines. The exact type of markers will be discussed at a later stage.

We intend to allow all Robotino versions, including the new version 3, for the upcoming competition. We propose to further allow to install additional computing power to the Robotino, as it has proven to be well perceived and accepted by the teams. Especially teams participating with Robotino 2 will need this to be able to compete with teams using Robotino 3. Machines will be placed in certain areas on the field, but with considerable variances in orientation and position. We envision to have more possible positions than machines and moving machines between games arbitrarily (randomized by the refbox). The production process will remain similar to the existing one. Products (now cylinders) must be moved from an input storage to a series of machines and finally to a delivery station. Basically, the single step machine (T1 or T5 before) are now placed at the end of the production cycle to mount a cap with an RFID chip. The variable input machine will replace the machines T2, T3, and T4. Invalid (unexpected) inputs are immediately discarded (sorted out). Valid products are stored until all expected inputs have been provided. Then the products are discarded and the output product is dispensed onto the belt and moved to the output transfer point. Examples could be a machine that takes a silver and a black cylinder and outputs a red cylinder, or a machine that takes three silver cylinders to output a black cylinder.

5 ROBOCUP INDUSTRIAL

Besides the LLSF as a full RoboCup league there also is the RoboCup@Work competition which currently has demonstration status. It targets the use of robots in work-related scenarios and utilizes proven ideas and concepts from RoboCup competitions to tackle open research challenges in industrial and service robotics (Kraetzschmar et al., 2013). The LLSF focuses mainly on logistics, task-level planning, scheduling, and supply chain optimization. It also requires a high robustness regarding repeatability and dependability, as one particular task[10] must be solved many times and over extended periods of time. The RoboCup@Work competition focuses on mobile manipulation applications with industrial objects. It is based on separately specified tests, which requires more experimental techniques, for example for manipulation planning or perception of objects like screws and bars, and less so fosters task repeatability.

In July, members of the LLSF and RoboCup@Work Technical Committee, Organization Committee, and Gerhard Kraetzschmar in his function as a RoboCup Trustee met to discuss similarities and differences of the leagues and possibilities for future cooperation. Additionally, the restriction to the Robotino platform family in the LLSF, and the dominance of the manipulator-based YouBot platform in RoboCup@Work pose further compatibility problems.

Due to the different focus areas of the two leagues there is no obvious merging of both competitions. Rather we discussed the possibility to have an industrial umbrella league—for example named *RoboCup Industrial*—in the future, under which multiple platform-, task-, or sponsor-specific leagues could operate mostly separately, but with common infrastructure and deliberate cooperation and crossover tasks where useful and possible.

For 2014, the participants of the discussion agreed to propose a common task (in LLSF terms a technical challenge, in RoboCup@Work as an optional test) to the respective TCs. This task could, for instance, involve a crossover from the RoboCup@Work arena to the LLSF competition area, handing over an object from a YouBot to a Robotino for delivery. The task will be proposed in time to the respective TCs.

6 CONCLUSION

In this paper we presented a number of fundamental changes to the field layout for the 2014 LLSF RoboCup competitions. The LLSF already underwent dramatic changes between 2012–2013 with the introduction of an automated referee system which is able to instruct the robot with flexible production plans. The referee box controls all the machines on the field and is therefore able to log all important events during game play. With these logs, it is possible to record and replay what was going on during a game. What was still needed was a possibility to log the robots' positions and the positions of the pucks in order to replay whole matches as well. With a fund from the RoboCup Federation, we started to reconfigure the Small Size League overhead vision system (Zickler et al., 2010) to meet the requirements of the LLSF and to log the positions of the robots and the products (pucks) on the playing field. A first prototype of the tracking system was tested at the 2013 RoboCup in Eindhoven. Both systems in place would allow to develop the LLSF into a benchmark for logistics scenarios as we pointed out in (Niemueller, Ewert, Reuter, Karras, Ferrein, Jeschke and Lakemeyer, 2013). For the new field layout, we are currently evaluating a Kinect-based system like the one described in (Pennisi et al., 2013).

While the introduction of the referee box went astonishing well in 2013 with all teams adhering to the refbox protocol, the major problems of the 2013 competitions in the LLSF was that for the audience it was hardly possible to understand the complex game play at a quick glance and therefore to relate to this league; even that the state of the game and the scores of both teams were visualized by the referee box could not avert the audience from walking away quickly again. With this paper we react to this problem. After the competition, we analyzed the problems and came up that root problem was that the audience would not understand the transformation of a product: a puck is pushed under a light signal which after some while starts blinking; then the robot pushes the puck to some other light signal and in the end, some random points are awarded when another light signal (the delivery station) showed a green light.

Our answer to this is fairly simple: we need machines that actually do something. With the new machine types from the Festo MPS program, the robot will place an intermediate product (a cylinder one color) on a machine with, say, a conveyor belt, the machine processes the good and after some while, the processed item (a cylinder in a different color) can be picked up at the other end of the machine. We even plan to use machines that place caps or instruments onto the cylinder for the final step of the production. The Festo MPS machines are well suited for this tasks and means a major investment from the sponsor into the playing field. This change also requires the teams to develop a new gripper as the working height of the MPS machines and the pickup and delivery shelves is at a height of 15 cm. Instead of the a simple passive gripper which pushes pucks over the ground, now an electrical or pneumatic parallel gripper at a height of 15 cm is required. Each team may build their own gripping device, but there will be an offer for the ready-to-run Festo gripper solution which can be purchased by the RoboCup teams at a reduced price.

Another major change which the Technical Committee already decided on in Eindhoven, is doubling the field size. This will impose new challenges for all teams w.r.t. navigation and localization. Apart from that and the new machines, the basic production lines will stay the same as in 2013. Whether or not the changes to the LLSF competition made in this paper will be part of the competition in 2014 still needs to be decided by the LLSF Technical Committee. Festo signaled that they will support the proposed changes by providing the machine hardware. With implementing the proposed changes we are convinced that LLSF matches will be way more attractive to watch. Also, the league will make a major step towards logistics in industrial scenarios.

ACKNOWLEDGMENTS

We would like to thank Gerhard Kraetzschmar and Nico Hochgeschwender from Bonn-Rhein-Sieg University for our discussion on possibilities for cooperation between the LLSF and RoboCup@Work leagues.

We would like to especially thank Reinhard Pittschellis and Christian Deppe for insightful discussions on the future of the LLSF and their commitment to the league.

[10]While the overall task—to complete the production chain—stays the same, the parameters are randomized, e.g. orders, machine down times, or in 2014 maybe even machine types, thus requiring planning capabilities.

T. Niemueller was supported by the German National Science Foundation (DFG) research unit *FOR 1513* on Hybrid Reasoning for Intelligent Systems.

A. Ferrein acknowledges partial support by FH Aachen University of Applied Sciences under the grant *K1-RoboCup* as well as partial support by the RoboCup Federation under grant *PPP RoboCup 2013*.

REFERENCES

Amigoni, F., Bonarini, A., Fontana, G., Matteucci, M. and Schiaffonati, V. (2013). Benchmarking through competitions, *European Robotics Forum – Workshop on Robot Competitions: Benchmarking, Technology Transfer, and Education*.

DARPA (2013). DARPA Grand Challenge, `http://www.darpagrandchallenge.com/`. (retrieved Apr 14th 2013).

Dillmann, R. (2004). Benchmarks for robotics research, *Technical report*, European Robotics Network (EURON).

Forgy, C. L. (1982). Rete: A fast algorithm for the many pattern/many object pattern match problem, *Artificial Intelligence* **19**(1): 17–37.

Karras, U., Pensky, D. and Rojas, O. (2011). Mobile Robotics in Education and Research of Logistics, *IROS 2011 – Workshop on Metrics and Methodologies for Autonomous Robot Teams in Logistics*.

Khandelwal, P. and Stone, P. (2012). A Low Cost Ground Truth Detection System for RoboCup Using the Kinect, *in* T. Röfer, N. M. Mayer, J. Savage and U. Saranli (eds), *RoboCup Symposium 2012*, Vol. 7416 of *Lecture Notes in Computer Science*, Springer, pp. 515–527.

Kraetzschmar, G., Nowak, W., Hochgeschwender, N., Bischoff, R., Kaczor, D. and Hegger, F. (2013). RoboCup@Work Rule Book 2013, *Technical report*, RoboCup. `http://www.robocupatwork.org/download/rulebook-2013-06-08.pdf`.

Lee, E. (2008). Cyber Physical Systems: Design Challenges, *11th IEEE International Symposium on Object Oriented Real-Time Distributed Computing (ISORC-08)*, pp. 363–369.

Lima, P., Custodio, L., Akin, L., Jacoff, A., Kraetzschmar, G., Kiat, N. B., Obst, O., Rofer, T., Takahashi, Y. and Zhou, C. (2005). RoboCup 2004 Competitions and Symposium: A Small Kick for Robots, a Giant Score for Science, *AI Magazine* **26**(2).

Niemueller, T., Ewert, D., Reuter, S., Ferrein, A., Jeschke, S. and Lakemeyer, G. (2013a). RoboCup Logistics League Sponsored by Festo: A Competitive Factory Automation Testbed, *Proc. of the RoboCup Symposium 2013*.

Niemueller, T., Ewert, D., Reuter, S., Ferrein, A., Jeschke, S. and Lakemeyer, G. (2013b). The Carologistics RoboCup Logistics Team 2013, *Technical report*, RWTH Aachen University and Aachen University of Applied Sciences.

Niemueller, T., Ewert, D., Reuter, S., Karras, U., Ferrein, A., Jeschke, S. and Lakemeyer, G. (2013). Towards Benchmarking Cyber-Physical Systems in Factory Automation Scenarios, *in* I. J. Timm and M. Thimm (eds), *KI 2013: Advances in Artificial Intelligence - 36th Annual German Conference on AI*, Vol. 8077 of *Lecture Notes in Computer Science*, Springer, pp. 296–299.

Niemueller, T., Ferrein, A., Eckel, G., Pirrò, D., Podbregar, P., Kellner, T., Rath, C. and Steinbauer, G. (2011). Providing Ground-Truth Data for the Nao Robot Platform, *in* J. R. del Solar, E. Chown and P.-G. Plöger (eds), *RoboCup Symposium 2010*, Vol. 6556 of *Lecture Notes in Computer Science*, Springer, pp. 133–144.

Niemueller, T., Lakemeyer, G. and Srinivasa, S. S. (2012). A Generic Robot Database and its Application in Fault Analysis and Performance Evaluation, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*.

NIST (2013). Performance metrics and test arenas for autonomous mobile robots, `http://www.nist.gov/el/isd/testarenas.cfm`. retrieved Apr 17th 2013.

Pennisi, A., Bloisi, D. D., Iocchi, L. and Nardi, D. (2013). Ground Truth Acquisition of Humanoid Soccer Robot Behaviour, *Proc. of the RoboCup Symposium 2013*.

RoboCup Federation (2013). `http://www.robcup.org`. (retrieved Oct 19th 2013).

The LLSF Technical Committee (2013). RoboCup Logistics League sponsored by Festo – Rules and Regulations 2013, *Technical report*, RoboCup. `http://www.robocup-logistics.org/rules/rulebook2013.pdf`.

Vogel-Heuser, B., and Witsch, M. (eds) (2011). *Erhöhte Verfügbarkeit und transparente Produktion*, Vol. 2 of *Embedded Systems – I Tagungen und Berichte*, Kassel University Press. `http://nbn-resolving.org/urn/resolver.pl?urn=urn:nbn:de:0002-31799`.

Weinert, H. and Pensky, D. (2011). Mobile Robotics in Education and Student Engineering Competitions, *Proc. of the IEEE Region 8 AFRICON*, pp. 1–5.

Wisspeintner, T., van der Zant, T., Iocchi, L. and Schiffer, S. (2010). Robocup@home: Results in benchmarking domestic service robots, *in* J. Baltes, M. G. Lagoudakis, T. Naruse and S. S. Ghidary (eds), *RoboCup Symposium 2009*, Vol. 5949 of *Lecture Notes in Computer Science*, Springer, pp. 390–401.

Wygant, R. M. (1989). CLIPS: A powerful development and delivery expert system tool, *Computers & Industrial Engineering* **17**(1–4).

Zickler, S., Laue, T., Birbach, O., Wongphati, M. and Veloso, M. (2010). SSL-Vision: The Shared Vision System for the RoboCup Small Size League, *in* J. Baltes, M. G. Lagoudakis, T. Naruse and S. S. Ghidary (eds), *RoboCup Symposium 2009*, Vol. 5949 of *Lecture Notes in Computer Science*, Springer, pp. 425–436.