RoboCup Logistics League

Rules and Regulations 2015

The Technical Committee 2012–2015

Christian Deppe   Daniel Ewert   Nils Harder
Sören Jentzsch   Nicolas Meier   **Tim Niemueller**
Sebastian Reuter   **Alain Rohr**   **Wataru Uemura**

Revision Date: Wednesday, July 1st 2015

Contents

1   Introduction

The future of Production Industry lies with smarter systems. With current developments pursuing the goal of more aware, more decentralized behaviors in factories, a scientific platform for applied research is required. The RoboCup Logistics League (RCLL) is determined to develop into a state-of-the-art platform for mobile robotics education and research. This industrial motivated league keeps the focus on challenges promoting precise actions and robust long-enduring execution, and further encourages external data supported autonomy.

Please note that the league has been renamed from Logistics League Sponsored by Festo to RoboCup Logistics League. It has matured in recent years and has become an established league under the RoboCup umbrella. Festo continues to support the league, but its committees determine the direction of development.

This year's competition is laid out in the pages to come. It ensures the same and fair circumstances for all participants. It neither dictates nor suggests the way how to fulfill the task, but is meant to develop the RCLL further towards a Smart Factory environment where robots act as autonomous entities working in an environment with specified, yet to some degree uncertain and dynamic, agency. This includes current challenges of developing industry-wide standards for Cyber Physical Systems for production processes like designing plug-and-produce capable systems.

After an exciting RoboCup in João Pessoa, we look forward to a new scale of competition that will emerge from initiatives around the globe. In 2012 we had our first Logistics League World Champion. In 2013 we introduced the Referee Box (refbox) changing the competition at its core by introducing a flow of information. This allowed for more dynamic games and the automatic tracking of scores, and to relax the hitherto existing regulations regarding additional computing power. In 2014 we merged the formerly separate playing fields into a single one, on which both teams compete at the same time, introducing the need for self-localization, collision avoidance, and increased spatial coordination complexity. Additionally, the production schedules became more dynamic in that orders were posted dynamically and less frequently and there were times with no orders. This year, in 2015, we introduce actual physical processing machines based on the Festo Modular Production System (MPS). This will make the game easier to understand for the audience and introduce new challenges. For one, the production schedule has again become more flexible and dynamic, by introducing color-coded rings of which a varying number can be requested to be mounted in a specific order for a certain product. Additionally, the league makes its first steps towards requiring manipulation capabilities on the robots. We are thereby following our long-term evolution goals outlined in [2].

1.1   The Task

Our aim is to provide a simplified Smart Factory environment. The teams must complete the following task without human interference, competing with a second team against the clock. In the RCLL, autonomous robot agents have to handle the logistics of materials through several (dynamic) stages to produce final goods to fulfill orders. The machines are specific MPS stations.

The Logistics League's main challenge is a multistage production cycle of different product variants with self-crafted intermediate products and delivery of final products. This genuine goal will be rewarded considerably higher than partial fulfillment of the task. Autonomous robots transport small products between the processing machines. Machines are MPS stations which complete a particular refinement step like mounting a colored ring or top-most cap. If procurable this will lead to a new sub-assembly or final product (cap). Complete work orders require all related sub-assemblies of product variants (cf. Section 5.6.1).

This work flow is controlled by a referee box broadcasting information via wifi (see Section 8.2). The work flow itself is divided into three different phases: a setup phase (see Section 5.4), an exploration phase (see Section 5.5) during which robots receive scores for correctly discovering and publishing the light states of the yet unknown different machines on the field. After this phase the referee box will announce all machine types and designations. In the following production phase (see Section 5.6) orders are announced by the referee box, which the robots must fulfill automatically.

Finally, successfully assembled products are to be delivered to the correct conveyor belt of the team's delivery station. The factory area has to be treated in the best possible way. Any possible damage to the field, opposing robots or the machines will be penalized by the referee.

1.2 Agreements & Regulations

In the RCLL, all teams are obliged to use the Robotino robotic system from Festo Didactic GmbH & Co. KG with certain freedoms and limitations. This includes the current version, Robotino 3, as well as the phased-out Robotino 2. Section 7 describes the specific constraints.

1.3 Rules Philosophy

The goal of this industrially inspired league is to complete the tasks as quickly and reliably as possible. Each team should act within the meaning of a cooperative and fair behavior, even if everyone wants to be the better one. Teams should not search for gaps or inconsistencies in the rulebook to achieve advantages in the competition. Instead, we ask explicitly to bring such gaps to our attention. Since the rulebook cannot cover all possible cases, we consider a general gentleman agreement: "One should treat others as one would like others to treat oneself".

2 League Administration

2.1 Technical Committee 2015

The technical committee (TC) is responsible to update and publish the rulebook, to decide on technical questions during the tournament, and to communicate with the league stake holders on technical advancements. Current members of the TC are (in alphabetical order):

Christian Deppe, Festo Didactic GmbH & Co. KG, Denkendorf, Germany
Sören Jentzsch, fortiss GmbH, An-Institut Technische Universität München, Munich, Germany
Tim Niemueller, RWTH Aachen University, Aachen, Germany
Alain Rohr, HFTM Technical Institute of Applied Science Mittelland, Biel, Switzerland
Wataru Uemura, Ryukoku University, Shiga, Japan

To get into contact with the TC use the mailing list

robocup-logistics-tc@lists.kbsg.rwth-aachen.de

2.2 Organizing Committee 2015

The organizing committee (OC) is responsible for organizing the RoboCup competitions, to communicate to the RoboCup Federation trustees and chairs the requirements of the league, and to inform and attract new teams to the league. Current members of the OC are (in alphabetical order):

Alexander Ferrein, FH Aachen University of Applied Sciences, Aachen, Germany

Ulrich Karras, priv. Dozent, Essen, Germany
Sebastian Reuter, RWTH Aachen University, Aachen, Germany

To get into contact with the OC use the mailing list

`robocup-logistics-oc@lists.kbsg.rwth-aachen.de`

2.3   Executive Committee 2015–2018

Executive Committee members are responsible for the long term goals of the league and thus have also contact to other leagues as well as to the RoboCup federation. The Executive Committee presents the league and its achievements to the RoboCup federation every year and gets feedback to organize the league. All committee members are also members of the Technical Committee. Executive Committee members are elected by the Board of Trustees and appointed by the President of the RoboCup Federation; they serve 3-year terms.

Ulrich Karras, priv. Dozent, Essen, Germany
Tim Niemueller, RWTH Aachen University, Aachen, Germany

2.4   Website and Mailinglist

The website of the RoboCup Logistics League is available at

`http://www.robocup-logistics.org`

A mailing list for general announcements and discussion about the league is available at

`https://lists.kbsg.rwth-aachen.de/listinfo/robocup-logistics`

3   Competition Area

3.1   Field Layout and Dimensions

The competition area is shown in Figure 1 and features a $12\,\text{m} \times 6\,\text{m}$ large arena with 24 rectangular zones of $2\,\text{m} \times 1.5\,\text{m}$ with 12 randomly distributed machines. The field is partially surrounded (at least 50% but not more than 70%) by wall elements of at least $0.5\,\text{m}$ height. The origin and coordinate system of the competition field is drawn in Figure 1 and will be intrinsically referred to for each statement within this rulebook. The normal floor of the exposition-rooms is used, it will be reasonable flat. The whole area is shared among both teams on the field and any robot may travel anywhere at any time (while not obstructing for an extended period of time or pushing other robots or machines). However, there are primary sides (split along the y-axis) for each team where a team's *robot insertion area*, and *Base and Delivery Stations*, are located. We will refer to the side with positive coordinates on the x-axis as the (primary) half of team cyan, and the side with negative coordinates on the x-axis as the primary half of team magenta.

The robot insertion areas (gray area on figure) is outside of the main game area. All 12 machines, 6 per team are placed within the factory area as stated in Figure 1. The positions and alignments in the figure are just exemplary. During the competition these are arbitrary and will change from match to match. Machines have two kind of sides: active (wide, where the robot interacts) and ignored (narrow) edges. It is guaranteed that the active sides will be accessible and that two machines always have either sufficient distance for two robots to interact with both machines or that they will not face each other. There are no such guarantees for the narrow edges. For later tournament phases

there might be two machines directly face to face on the narrow edges (that the robots must take into account when approaching/leaving a machine, especially if the machines are from different teams).

The distribution and alignment of all machines is axially symmetrical to the y-axis. Thus, each team has similar conditions on both halfs of the competition field. Both teams have an exclusive set of 6 out of the 12 machines each. Machines from one team can also be located on primary side of the opposing team. We will later discuss the concept of the production machine distribution for each team in detail. For now, note that the conditions for each team will be similar, i.e. the distribution will be symmetrical.

The center coordinates and the size of the zones in which the machines are placed can be seen in Figure 1. Note that this field layout is a proposal for the layout, accounting for symmetry and avoiding clustering of machine access nodes and unapproachable machines. However, the actual distribution and alignment of machines on the competition area will change before the actual game starts. Thus, teams should focus on a generic approach for production, allowing for dynamic adaptation of machine positions and alignments.

3.1.1 Moving on the Field

The robots are free to move on the field. However, robots may not leave the main area (surrounded by the partial walls). That is, when connecting all wall segments with the shortest possible edges, robots may not move such that the base is fully outside this area. For example, in Figure 1, the red robot is outside the intended area and thus in an illegal position.

Robots that leave the competition area illegally are considered as *misbehaving robot* and punished accordingly (cf. Section 5.2).

3.2 Machines

Machines are based on the Modular Production System (MPS)[1] by Festo Didactic GmbH & Co. KG. The MPS provides a number of stations which make up the machines used in the competition. The stations have a rectangular base shape of $0.35\,\text{m} \times 0.7\,\text{m}$ with a height of about $1\,\text{m}$ depending on machine type. The machine has individual application modules that provide different functionality.

All machines share the same basic layout: a trolley, conveyor belt, and signal light. A machine is movable by four wheels with $0.1\,\text{m}$ clearance. Both narrow sides of the trolley are closed by plexiglas and have a handle. All physical interfaces like conveyor belt inputs and outputs, shelves, and slides for additional bases on ring stations are accessible at $89.8\,\text{cm}$ height.[2] Working space between guiding lanes is $4.5\,\text{cm}$. Setup lanes and shelves feature approximately the same space for handling and adjusting.

Based on these shared properties, there are four kinds of machines:

Base Station (BS) acts as dispenser of base elements (Figure 3). The application modules are three magazines of base elements. There is a single BS per team.

Cap Station (CS) mounts a cap as the final step in production on an intermediate product (Figure 4). The application module is a vacuum pick & place module. A base element with a cap must be taken to the machine and is then unmounted and buffered in the machine. The cap is then mounted on the next intermediate product taken to the machine. There are two CS per team.

---

[1]For more information see `http://www.robocup-logistics.org/links/festo-mps`.

[2]Note however, that due to small variances and unevenness in the floor there may likewise be small variances in the working height of some or all parts of a station.
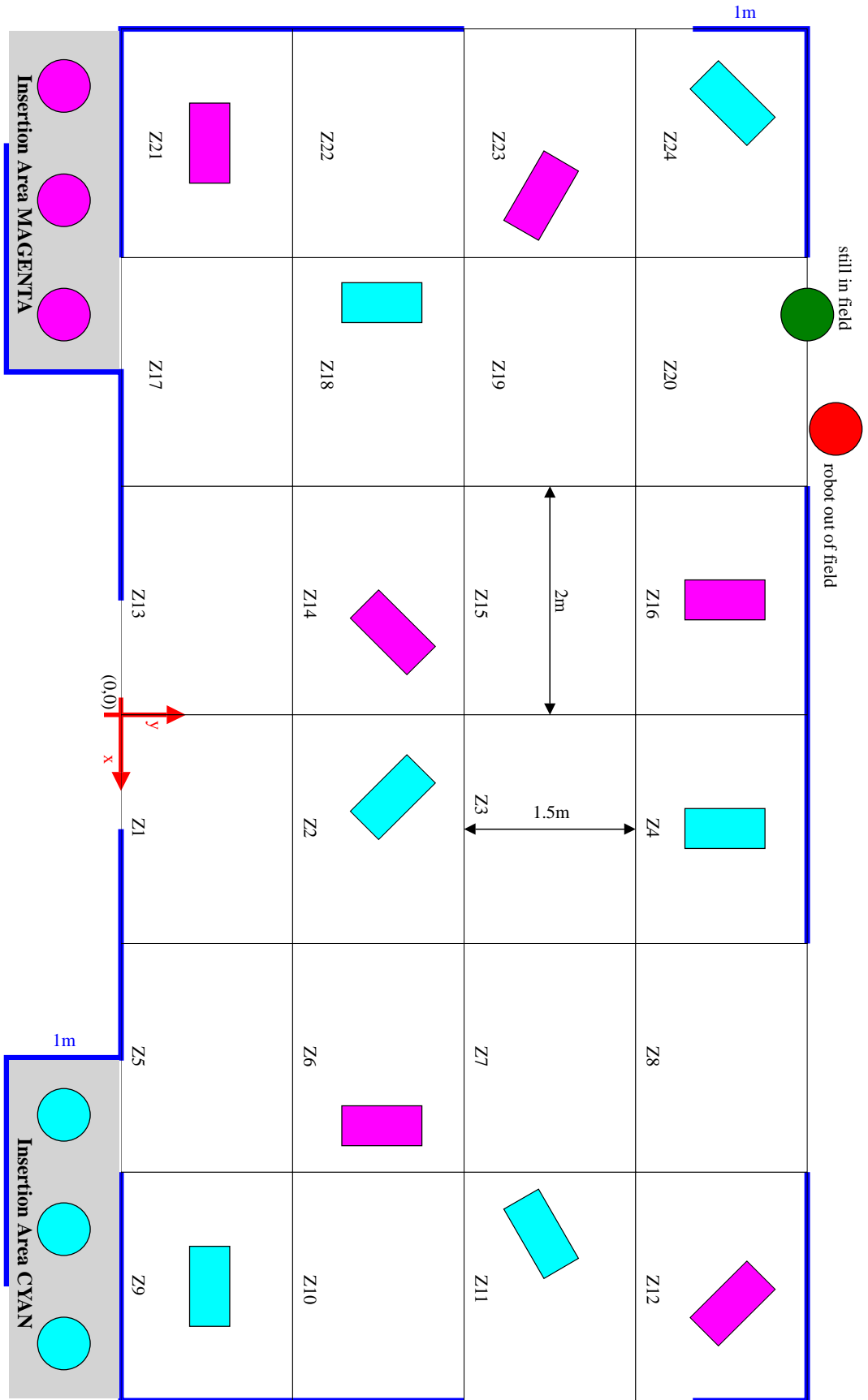
Figure 1: Competition area: squares indicate possible machine placements, circles denote robots. Cyan and magenta are team assignment colors. Thick blue lines are wall elements. The thin black inner lines indicate zones. The green robot is at an acceptable position, while the red one would have to be penalized for leaving the field. Grey areas are insertion areas where robots start.

5
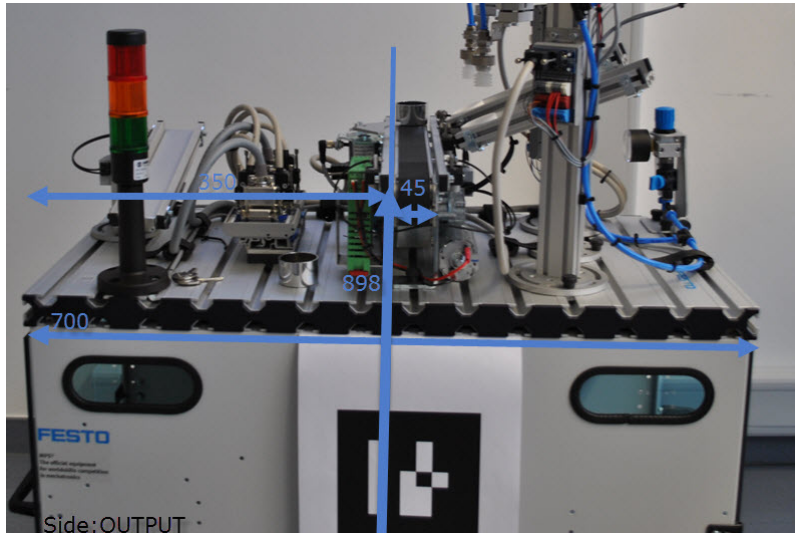
Figure 2: General Machine Layout

(a) Base Station Portrait
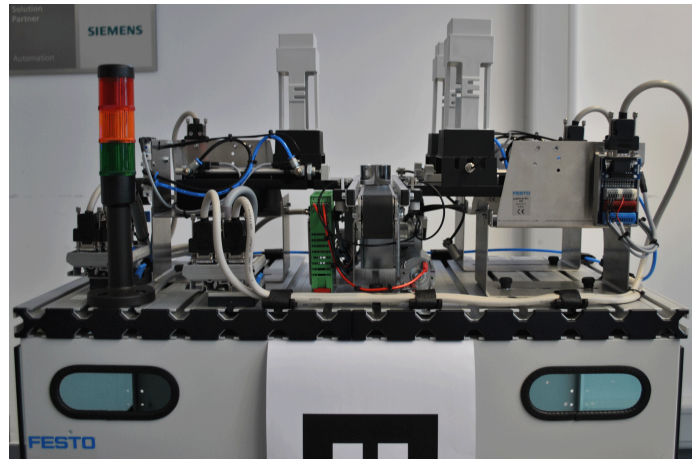
(b) Base Station Output side

Figure 3: Base Station

Ring Station (RS) mounts one colored ring out of two available colors on an intermediate product (Figure 5). Each RS has two vacuum pick & place units as application modules with separate unique colors which are determined new for each game. There is an additionally pre-fill slide which is used for some colors (specified anew for each game) to add base elements. There are two RS per team.

Delivery Station (DS) Accepts completed products. The stations contains three conveyor belts (Figure 6). The robot has to setup the proper one for a specific order (cf. Section 3.2.4). The delivered products are verified by either the referees or an automated external vision system. There is one DS per team.

Machines of type CS and RS are called production machines as they perform refinement steps on a product during the production phase.

	Machine	Input		Output	
		Tag ID	Tag	Tag ID	Tag
Cyan	CS 1	1		2	
	CS 2	17		18	
	RS 1	33		34	
	RS 2	177		178	
	BS	65		66	
	DS	81		82	
Magenta	CS 1	97		98	
	CS 2	113		114	
	RS 1	129		130	
	RS 2	145		146	
	BS	161		162	
	DS	49		50	

Table 1: Machine tags are ALVAR tags with the given IDs.

Type	Distribution	(Final) processing time[s]
Base Station (BS)	1 per team	minimum physical time
Cap Station (CS)	2 per team	$t_2 = 15$ to 25 sec
Ring Station (RS)	2 per team	$t_3 = 40$ to 60 sec
Delivery Station (DS)	1 per team	$t_5 = 20$ to 40 sec

Table 2: MPS - Type, Distribution and processing times
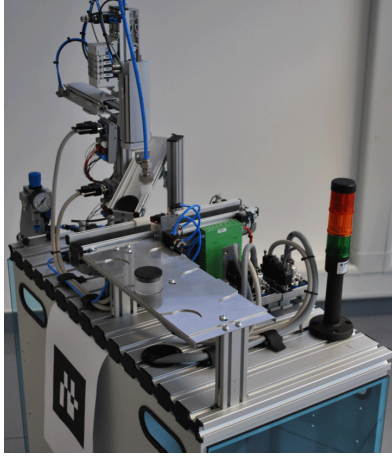
(a) Cap Station Portrait
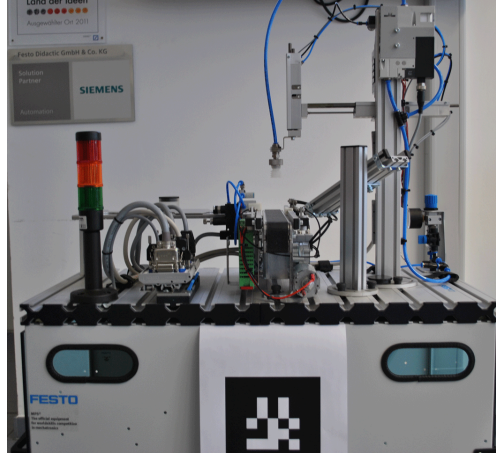
(b) Cap Station Output side

Figure 4: Cap Station

(a) Ring Station Portrait
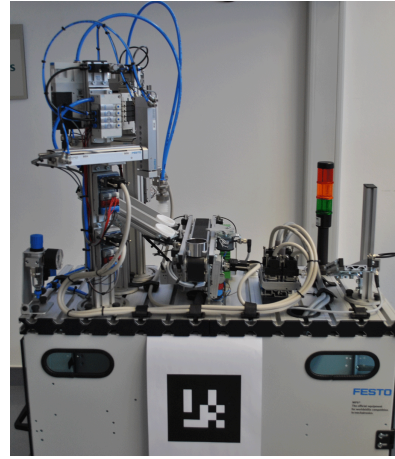
(b) Ring Station Output side

Figure 5: Ring Station

3.2.1 Markers

Each machine will feature two *markers* based on ALVAR AR tags, one will be placed on the input, another one on the output side. The marker will be horizontally centered below the conveyor belt. The vertical distance (between tag and conveyer belt) will be about $35\,\text{cm}$. The markers will be mounted at the same position on all machines in a best effort fashion. But teams should expect to calibrate individually per marker. All markers used are depicted in Table 1. They are available for printing on the RoboCup Logistics website.

3.2.2 Machine Swapping

Each team has a primary half (cf. Section 3.1). However, some machines will be swapped, that is, some machines will not be located in the primary half.

For each game, one CS and one RS of each team will be chosen randomly and swapped with the corresponding machine of the other team on the non-primary half – that is two machines in total per team. The CS and RS will be swapped with the symmetrically positioned machine of the same type of the other team.

Figure 6: Delivery Station Portrait

Optical Feedback	Operating mode
All LEDs turned off	The machine is physically offline, caused by a real error, which should not happen during the competition.
Red LED turned on	The machine is out of order.
Green LED turned on	The machine is idle and ready.
Green LED flashing	The machine has accepted the setup command (flashes for up to 3 seconds).
Yellow LED turned on	The machine is currently busy.
Red and yellow LED flashing (2 Hz)	Machine is broken, for example because a product was fed without proper setup of the machine.

Table 3: MPS - Optical Feedback during production phase

3.2.3 MPS – During Exploration Phase

During the exploration phase the robots of each team can explore their unknown factory environment by identifying where the different MPS are located and what light signal pattern is shown.

The Referee Box assigns each machine to a team and a zone (Figure 1) at the start of the exploration phase,[3] but the exact position and alignment within these and if this zone contains an MPS at all will not be communicated. Each MPS is assigned an individual light signal pattern randomly. The pattern consists of steady lights only, i.e. no flashing lights, resulting in seven possible light states with at least one light switched on. For details how to perform the exploration phase cf. Section 5.5.

After a successful report, the respective MPS will show a blinking green signal indicating visually for spectators that the MPS was indeed explored successfully. For a wrong report, the station will show a red flashing light.

3.2.4 MPS – During Production Phase

In the production phase a production machine performs refinement steps on a product such as mounting an additional ring or a cap. Machines operate in a transaction style. That is, before using a machine it must be setup for a specific mode. Then the input products can be fed into the machine and the re-

---

[3]Note that in 2015 the BS and DS are assigned to fixed zones, the mapping is: C-BS in Z9, M-BS in Z21, C-DS in Z4, and M-DS in Z16. The prefix "C-" means team cyan, "M-" means magenta. The position and orientation within the zone remains variable.

9

finement step commences. Eventually, after the production period is completed, the resulting product is delivered on the output lane.

A light signal mounted near the output lane (cf. Section 3.2) indicates the state of the machine. In the default operating mode, the green light is turned on. This signals that the machine is ready for setup or input. When setup is performed, the machine will flash the green light for up to 3 seconds (it immediately switches to a new state, e.g. if a product is fed into the machine before the three seconds have expired). When a product is fed to the input, the signal light indicates the processing condition. If the machine accepts the input and starts processing the yellow light will be turned on steadily for as long as the processing is performed. Once processing completes, the signal light switches back to a steady green light. If a product is fed for which additional bases were required but which have not been delivered, the machine will flash the red and yellow light and will be out of order (cf. Section 5.7.2). The light signals are summarized in Table 3.

In the production phase, machines must be setup before they can be used. This applies to all machine types BS, DS, CS, and RS. If the machine is not properly setup before used, it will go to a temporary out-of-order state (cf. Section 5.7.2).

The following describes the communication and reactions of the machines during the production phase. For the actual messages we refer to the integrator's manual [1].

BS The BS setup message denotes the color of the base element that should be dispensed. After receiving the message, the refbox will instruct the MPS to immediately provide a base of the desired color.

DS The DS setup message denotes the slide the product should be delivered to. The DS will consume any workpiece provided, but points can only be scored if the DS was properly setup.

CS The CS setup message initiates either the retrieval or the mounting of a cap. For retrieving, a base (with a cap mounted on top) from the machine's shelf must be fed into the machine. The machine will then take the cap off the base and buffer it. For mounting, a workpiece must be provided onto which the cap is mounted.

RS The RS setup message must state which of the two colors to prepare and retrieve. Each RS is responsible for two specific colors. Some colors require loading the RS with additional bases (cf. Section 5.6.2). If the desired color requires additional bases (cf. Section 5.6.1), the machine expects to receive them first. Once the required number of additional bases has been received, the intermediate product can be fed into the machine. It receives a ring of the desired color and moves the processed product to the output.

The setup and use of a machine follows a transaction style. Once the machine has been setup, the full cycle can be completed (committed). But if a robot desires, it can cancel the production on the machine, unless the intermediate product has already been fed into the machine.[4] Canceling will invalidate any additional bases that have been taken to the machine. There may be only one transaction running at a time. If a second setup is performed without canceling the first the machine will be temporarily broken (cf. Section 5.7.2).

3.2.5 Delivery Station

Once an order is completed, the product has to be shipped to the Delivery Station (DS). Before the workpiece is fed into the machine, the robot has to setup the desired delivery lane (i.e., which truck to load it on).

---

[4]Note that canceling is not available in 2015.

3.3 Products and Workpieces

Workpieces denote raw material and intermediate stages during production. These are also named products with emphasis on the finished product that can be delivered. For product complexities refer to Section 5.6.1, for the compilation of the production plan to Section 5.6.2.

(a) Workpiece base elements and caps.

(b) Renderings of intermediate rings (rings are colored in competition).
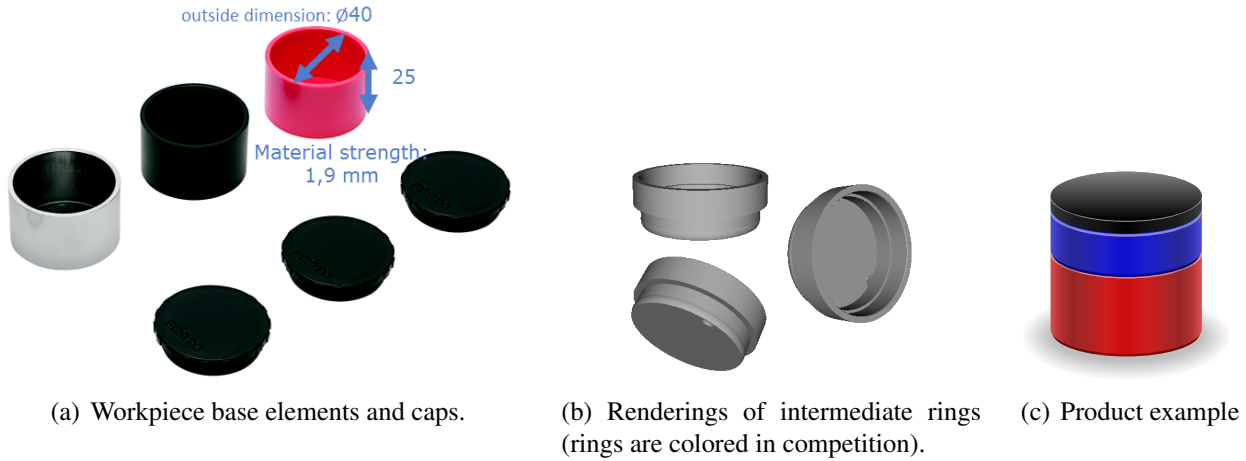
(c) Product example

Figure 7: Workpiece elements and product example.

The workpieces consist of the following elements:

Base The base is the lowermost element in each production. Bases are dispensed by the base station (BS) and bases with mounted caps are available on the cap stations (CS). Bases are available in the colors red, black, and silver.[5]

Ring Rings are mounted in intermediate production steps at ring stations (RS). A product requires, zero, one, two, or three intermediate rings of distinct color (cf. Section 5.6.1). The order of the rings matters. The ring colors are blue, green, yellow, and orange.

Cap Caps are the topmost element in each production. They are obtained by taking pre-assembled base-cap combinations available on the shelf to the cap station (CS). Caps can be black or gray.

Only one workpiece or a composite product must be grasped and transported per robot at once. Storage magazines on the robot or similar are prohibited. All products will incorporate exactly one base unit allowing a single unified handling device to be used for all operations involving workpieces.

4 Referees

Referees manage the overall game, make sure that the rules of the game are followed, and instruct and monitor the referee box.

---

[5]Note that **in 2015**, **orders** from the referee box **will only mention red bases** as to simplify the task and the transition from the 2014 game. This will change in 2016, but the colors may be changed for better visibility. This is subject to discussion of the league members and the TC.

4.1   Referee Delegation

Each participating team of the tournament must provide at least two team members which act as referees. These referees must be announced at the beginning of the tournament and are fixed throughout the whole competition (unless the participant drops out of the tournament, e.g. because of illness). The referees must meet the following criteria. They must

- be available for each game that they are assigned to and appear 5 minutes prior to the game start time (schedule to be announced by Organizing Committee at beginning of the tournament)

- have good knowledge of the rulebook and the applied rules

- participate in the referee briefings (organized by Organization and Technical Committees)

- be able to lead a game and communicate with the teams in English.

4.2   Tasks and Responsibilities

Each game requires 3 referees. One referee will run and oversee the referee box. Two field referees observe the field, announce rule violations, and communicate with the teams and refbox referee. Each field referee is assigned to a particular field half. The referee named first on the schedule is the head referee and is responsible for the team cyan and their corresponding field half. The head referee has the upper hand when there is a referee disagreement and then announces the final decision. The second listed referee assumes the liability of the team magenta.

The refbox referee has to operate the control machine during the game, observe its status to ensure the correctness of the digital representation and automatic scoring, announce critical situations to the field referees, and start and stop the game on request of the field referees. The refbox referee must also enter robot restarts and observe the time remaining to bring back a robot, or announce if a robot may no longer participate in the game (second restart).

The field referees observe the game from the side of the field or from any position on the field (e.g., to better understand the game situation). They shall avoid robots spatially on the field, but ultimately robots are expected to avoid collision with human referees. Field referees are also responsible for removing fallen products from the playing-ground. Field referees are responsible for making the decision whether a team may take out a robot for maintenance. And they observe the correct refill procedure of their field half.

Each referee may call a pause of the game at any time, e.g. if robots must be penalized or disentangled after a collision. Referees may explicitly pause the game to convene and discuss an unclear situation as to avoid hasty decisions. Such pauses shall be short-lived as to follow the competition schedule.

4.3   Liability Waiver

Referees cannot be held liable for:

- any kind of injury suffered by a player, official or spectator

- any damage to property of any kind

- any other loss suffered by any individual, club, company, association or other body, which is due or which may be due to any decision, which he may take under the terms of the rules of the game or in respect of the normal procedures required to hold, play and control a match.

4.4 Complaint Procedure

Rule issues are not to be discussed during a game. Referee decisions are binding for the game. A team may protest and challenge a game by executing the following complaint procedure. The procedure is also automatically invoked if a referee decides to abort a game for any reason (e.g. field damage, lighting failures, burning robots).

To initiate the complaint procedure, the team leader of the challenging team is to contact a member of the Technical Committee within 10 minutes after the respective game has ended. The member of the Technical Committee then invokes a team leader conference in cooperation with the Organizing Committee. In this conference, the following parties participate: the referees of the game in question, not less than half of all registered team leaders, and the Technical Committee (counseling). The situation shall be resolved by unanimous consent or by vote of the team leaders (majority of team leaders participating in the conference is sufficient).

All teams are reminded that while this is a competition, the league is also about *cooperative* research and evaluation and complaints should be handled in a fair and forthcoming way.

5 Game Play

A match is defined by two contesting teams competing within the same identical competition area. Each team consists of a maximum of 3 robots. Each match consists of 5 minutes of setup time, a maximum of 4 minute exploration phase, and a 15 minute production phase. The three phases of the game are detailed below.

5.1 Environment Setup

The physical distribution and alignment of the production machines is dynamic. The field will be organized as described in Section 3.1. The referee box will determine the assignment of the machines to the zones at the beginning of a game randomly. The machines will then be placed anywhere within their assigned zone (similar on both sides of the field mirrored at the field's Y-axis). The color for cap and ring stations will be randomized prior to each match. The processing time of each production step (i.e. per ring color and per cap mounting machine) will be determined in the same way. The target delivery slide will be randomized per order. During the setup phase (cf. Section 5.4) each team has the responsibility to fill the input magazines on their base station. The elements may only be touched by a robot or by designated persons after the game has started.

5.2 Interruptions and Robot Maintenance

During a match and while the robot is active on the field no manual interference or manipulation of the robot in hardware, software, configuration, instructions, or whatsoever, is allowed. Teams may visualize robot data on computers at the field, but existing keyboards must be covered with a sheet of paper in order to assert a fair game without manual interference.

Each team is allowed to maintain each robot once per game. The team has to call upon the referee for *robot maintenance*. The referee should judge the game situation carefully and should allow the robot to be taken out for maintenance, if the calling team would have any advantage in the current game situation from taking out the robot. An advantage would be, for instance, to take out a robot, if two robots of the same team are hindering each other. It is up to the discretion of the referee when to allow the robot maintenance.

Another reason for maintenance is a *misbehaving robot*. Several infringements in this rulebook demand that the robot be taken out, e.g. leaving the field (cf. Section 3.1.1).

Because the new generation of Robotinos is relatively heavy and bulky, up to two team members are allowed to remove a robot from the field. Or the robots may be driven out manually by remote control using a joystick, gamepad or similar. Human commands must be mapped directly to motion commands, no autonomous driving is allowed. In both cases (driving out and taking out) the robot must leave the field through the closest opening in the wall unless this would interfere with the game. In that case, the next closest exit may be chosen (referee decides). There will be a corridor (about 1 m) around the field where the robot can drive or be carried to the insertion area for re-participation.

The repair time may take at most 120 seconds, starting from the moment of driving or taking out the robot. After a robot has been taken out for the first time, the team can perform any repairs to the robot and/or the robot's software. To return the robot into the game, the team asks the referee to place back the robot onto the field. After the referee accepts the motion, the team has 15 seconds quick setup time, which is limited to basic instructions like initial localization or software start-up. The robot may leave the insertion area onto the field (autonomous driving). If the robot is not returned to the field in time, it is disqualified from the ongoing game.

The referee can interrupt the game at any point in time, but should do so rarely as not to interfere with the overall game flow (also cf. Section 5.7).

If a robot needs to be taken out for the second time, either on request or as decided by the referee, it is disqualified from the current game. It may no longer communicate with the still active robots and must be taken out of the competition area.

5.3 Game Start

All matches will start at the exact time scheduled by the Organizing Committee with the setup phase (cf. Section 5.4). Once the exploration phase starts, no more interference with the robot is allowed. The robot must react to the referee box game state messages to start the game play autonomously.

5.4 Setup Phase

No team member is allowed to enter the competition area prior to or during a match, except in cases of robot maintenance (cf. Section 5.2) or machine refill (cf. Section 5.6.3). All robots which are to participate in the game need to be in the insertion area during setup (not in the game area where the machines are located). The referee box will control the setup period and automatically switch to the exploration phase after 5 minutes.

5.5 Exploration Phase

With the start of the exploration phase, the referee box announces the mapping from zones to teams and from light patterns to type strings. As described in Section 3.2.3, all MPS show a steady light signal as randomly chosen by the referee box. The robots have 4 minutes to roam the environment and announce their 6 MPS for a successful exploration to the referee box. Concretely, the referee box expects a *machine identification message* with a tuple consisting of zone, machine name (as encoded in the markers), light pattern, and type string. Please consult the referee box Integrator's Manual [1] for a detailed definition of the message types. Reports are only accepted for MPS of the respective team over the private encrypted team channel. Only the first report for each MPS is processed, all additional ones will be silently ignored. The scoring is shown in Table 4(a). A minimum of zero

| (a) C_0 | (b) C_1 | (c) C_2 | (d) C_3 |
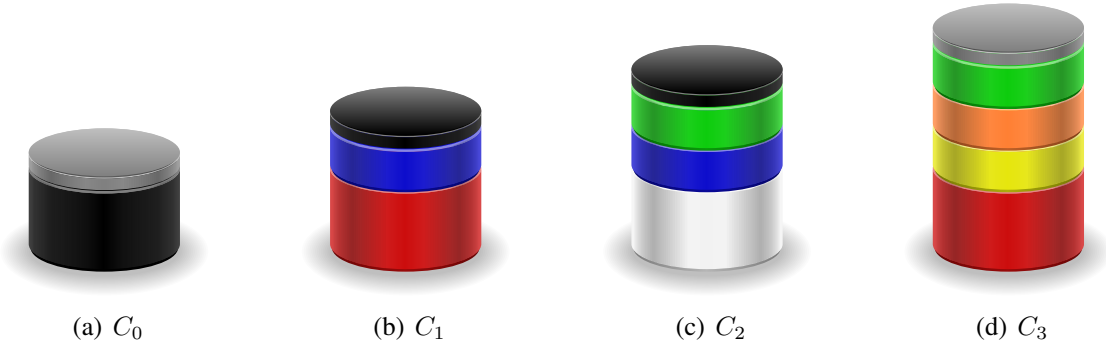
Figure 8: Products are composed of a base element and a cap with zero, one, two, or three intermediate rings representing the product complexity. The complexity level is stated as the number of required intermediate rings. The base element colors are red, black, and silver, the ring colors are blue, green, yellow, and orange, and the cap colors are either gray or black.

points will be accounted for the exploration phase. The exploration phase ends either after the time has passed or immediately after both teams have each reported their respective set of 6 MPS.

Moving or processing workpieces at an MPS is not allowed during the exploration phase.

5.6 Production Phase

With the end of the exploration phase the production phase begins, which lasts 15 minutes. The referee box publishes information regarding products and machines. This includes machine zones and contained colors of ring and cap stations, as well as the different product variants that can be produced (cf. Section 3.3). The refbox posts orders (cf. Section 5.6.2) which then must be fulfilled by the robot teams. Using production machines requires interaction through communication with the refbox described in Section 3.2.4.

Starting with the play-offs phase of the tournament (cf. Section 6.1) the game must be won by one of the teams by a higher score. If after the regular game time there is a draw, the game will automatically and without interruption be extended by 5 more minutes. If after five minutes there is still no winner, the team scoring the first points during the extension will win. If no points were scored a coin toss decides.

5.6.1 Production, Color Complexities, and Additional Bases

The portfolio comprises many different product variants and is categorized by the four available *product complexity* levels shown in Figure 8. The lowest complexity C_0 consists of just a base and a cap and requires to load the CS with the proper cap color and then processing a properly colored base at that machine. The highest complexity C_3 requires a base with three mounted rings and a cap. For a product, the colors of base, rings, and cap as well as the order of the rings are of importance.

The product complexities do not account for *additional bases* that are required for some colors. (Depending on the ring color, the robot has to deliver an *additional cap* to a RS first in order to get a ring.) We therefore distinguish *color complexities* as CC_0, CC_1, and CC_2 depending on whether zero, one, or two additional bases are required for a color. The referee box ensures that there will always be some orders for C_1 products where the ring color does not require additional bases, i.e. with color complexity CC_0 – but not necessarily all C_1 orders have this constraint.

(a) Production of complexity C_0 only mounting a cap on a BE as shown in Figure 8(a).

(b) Production of complexity C_1 with a single intermediate ring according to Figure 8(b).

(c) Legend

(d) Complexity C_2 with two rings (cf. Figure 8(c)). RS 2 requires an additional base (of any color) for the green ring.

(e) Production of the highest complexity C_3 with a three intermediate rings according to Figure 8(d). Note that RS 2 requires two additional BE (of any color) for the orange ring and another one for the green ring.

Figure 9: Production Chains of four example products (cf. Figure 8). Blue boxes represent machines. RS 1 mounts yellow and blue, and RS 2 orange and green rings. Mounting an orange ring requires one additional BE (of any color). Similarly two additional BE are required for a yellow ring. Cap stations require a BE (of any color) with a cap of the matching required color. *Note that this is a particular example. The actual production chains and requirements for additional BEs are determined randomly by the referee box for each game.*

5.6.2 Production Plan

The referee box will announce orders throughout the game in an incremental fashion. Each order will consist of the product variant to produce, the amount thereof, and a delivery time slot. An order therefore specifies a production chain to be accomplished for fulfillment. Figure 9 shows some example production chains of the four different complexities. The complexity is specified by the number of required intermediate rings from C_0 (no ring) to C_3 (three intermediate rings). As specified in Section 5.6.1, some specific steps require additional bases to be added to the machine after setup (cf. Section 3.2.4). This depends on the specific color, it is randomized per game and announced by the refbox.

In each game, orders with a fixed delivery value of 160 points will be placed[6]. These points only include the final delivery. The complexities of orders will be similar for all games within a phase. But the actual production chains are randomized. Each order will require one or more products of a specified product type to be delivered. The product is specified in terms of base color, rings (color and order), cap color, and possible delivery gate. The delivery time slot will have a randomized start time. The duration will be randomized between 30 to 180 seconds. The end time shall be within the game time. The orders shall be posted with a uniform distribution over the whole game time (but there is

---

[6]This number is currently a best guess as experience with the new production plan is not yet available. The number can be adjusted during the tournament by the Technical Committee, should this turn out to be necessary.

not necessarily an open order for a particular product at a specific time, or any order at all). The first order will be posted within the first 120 seconds of the game (but not necessarily at the beginning of the game). Orders for the products of complexity C_2 or C_3 will not begin in the first 300 seconds. An order will be announced before the delivery time slots starts. For C_0 products the lead time ahead of the start of the time window is 60 to 120 seconds, for C_1 it is 120 to 300 seconds, and for C_2 and C_3 orders the time is between 300 and 600 seconds. Two early orders will be posted that are announced in the first third of the game with a delivery time window in the last third.

In all tournament phases (cf. Section 6.1), the teams playing on the field at the same time will get the same production plans, but other games will have their own.

The multi-staged production processes can be repeated as long as enough material can be provided to complete the cycle (also cf. Section 5.6.3). The different machine types are specified in Section 3.2.

5.6.3 Machine Refill

The teams are responsible for refilling the machines (base elements, rings, and caps). Each team has to designate one team-member as a *"replenisher"* who must be specified to the corresponding "field half/team" referee before each game. Only this team member will be allowed to access the field area and only in case of a recent refill procedure. The replenisher must not obstruct other robots and should interfere as little as possible. The machines can only be refilled when a magazine is empty. In this case the field-operator may enter the competition-area without asking the referee.

The teams are free to choose their assembly and placement of products. For example, teams can fill any number of bases into a BS or CS, on a CS the team can fill any number of spots on the shelf and at positions of their choosing. However, the color assignment of bases on the BS must be obeyed, as otherwise the BS will deliver the wrong bases.

5.7 Special Events during a Match

Any referee can interrupt the match at any time. After the game is paused, all robots have 3 seconds to stop any movement. Robots that do not stop within the time limit will be treated in the same way as misbehaving robots (cf. Section 5.2). The match time will be paused during the interruption.

5.7.1 Scheduled Machine Downtime

The refbox will take down machines randomly out of the pool containing the RS and CS. It will do so at random points of time and with the same conditions for both teams, i.e., affecting the same machines for both teams. There will be 2 of such triggered events during a match. The machines affected will remain out of order for 30 to 60 seconds. Every machine can only be forced out of order once per match. If a machine turns offline during processing a product it will afterwards resume the process (extending the overall processing time by the down time). The downtime is indicated by a steady red light. Base elements fed into the machine while out-of-order are accepted when the machine gets back online, with the same constraints mentioned in Section 3.2.4.

5.7.2 Broken Machine Downtime

If a machine is improperly instructed or used, the machine will go into a failure state. The machine cannot be used for 30 seconds and until repaired. That is, if damage was inflicted on the machine or the referee needs longer to repair the machine the game continues and the machine will be offline for a longer time. Any production that was running will be aborted and any product which was being

processed is no longer available and will be removed by the referee. Any additional bases delivered to the machine will be void. The downtime is indicated by a flashing red light.

5.8 Task Fulfillment and Scoring

Table 4 provides the itemized clearance of all task related processes and their scoring. Note that all points related to a product, including the points for finishing intermediate step like mounting the last ring on higher complexity products, are awarded on delivery only. Products, which are not delivered, do not score. That includes half-finished products at the end of the game in particular. Production points are also awarded for later deliveries, that is, points for steps like mounting the cap are awarded in full for as long as there was or is an order active for that specific product if there are still items in the order remaining, i.e. not the full amount of ordered products has been delivered.

5.9 Obstruction Penalty

As the Logistics League follows the idea of having both active teams compete alongside each other, instead of directly against each other, we punish intentional obstruction of the opposing team.

This applies in particular to the input and output area in front of any MPS. All robots are allowed to enter this space, but robots must not obstruct opposing robots which intend to approach their MPS. Concretely, that robot must give way and release an approachable path to the MPS within a time window of 10 seconds. If a robot cannot follow this rule, a pushing foul will be called according to Section 5.10.

Furthermore, teams are penalized with -2 points for obstruction when delivering a workpiece to a machine of the opposing team. In this case, the workpiece becomes junk and cannot be used afterwards.

5.10 Pushing Rules

With multiple teams on the field at the same time, robots must implement ways for collision avoidance. At the same time, they shall not interfere with the goods of the other team. The case where a robot of one team bumps into or moves a robot of another team we call "pushing".

The following rules shall be obeyed by the robots and provide the guidelines for referees to call for improper behavior of a robot due to pushing.

1. Pushing occurs only between robots of different teams.

2. Robots must drive such that they try to avoid physical contact with robots from the opposing team. However, physical contact per se does not represent an offense.

3. All robots should be equipped with appropriate sensors to detect situations of physical contact with other robots (direct pushing situations).

4. If physical contact with other robots cannot be avoided, it must be soft, i.e. at slow speed and with as small physical impact as possible, in order to avoid damage to itself and other robots. Robots moving at high speed must significantly decelerate before a collision occurs with another robot.

5. If a destruction collision is immediate and the robots do not react, the referee should use the refbox to send a stop command to all robots. Every team has to react to the stop command by immediately stopping their robots.

Reported	Exploration Phase	Points
Correctly	Correctly determine a machine type of your team and report it successfully to the refbox	+8
Incorrectly	Wrongly reported machine type	-6
Round Total	A maximum of 48 points can be achieved by correctly reporting all 6 production machines. A minimum of 0 points is awarded.	$0 - 48$

(a) Scoring scheme for the exploration phase

Sub-task	Production Phase	Points
Finish CC_1 step	Finish the work order for a color requiring one additional base	+5
Finish CC_2 step	Finish the work order for a color requiring two additional bases	+10
Finish C_1 pre-cap	Mount the last ring of a C_1 product	+10
Finish C_2 pre-cap	Mount the last ring of a C_2 product	+30
Finish C_3 pre-cap	Mount the last ring of a C_3 product	+80
Mount cap	Mount the cap on a product	+2
Delivery	Deliver one of the final product variants to the designated loading zone at the time specified in the order	+20
Late Delivery	An order delivered within 10 seconds after an order is awarded a reduced score. For delivery time slot end T_e and actual delivery time T_d in seconds the reduced score is given by $20 - \lfloor T_d - T_e \rfloor * 2$	up to +20
Wrong delivery	Deliver one of the final product variants to the designated loading zone out of the requested time range or after all products requested in the period have already been delivered	+1
False delivery	Deliver an intermediate product	0
Obstruction Penalty	Deliver a workpiece to a machine, which belongs to the opposing team	-2

(b) Scoring scheme for the production phase

Task	Game Commentary	Points
Accepted Commentary	Commentate at least one half of the game continuously on microphone in English to the public	+10

(c) Scoring scheme for game commentary

Table 4: Scoring Schemes

6. Whenever a robot produces direct physical contact with another robot while moving, it must stop movement immediately in that direction (and choose a new direction for movement).

7. If pushing occurs between a moving and a standing robot, the moving robot causes the pushing situation and is responsible for resolving it. If it is not able to do so, a pushing foul will be called.

8. If pushing occurs between two moving robots, both robots are responsible for resolving the pushing situation. If one robot continues pushing by moving in its initial direction, while the other robot is recognizably reacting and trying to take another direction, the foul will be called on the pushing robot.

9. If two robots encounter physical contact and cannot resolve the situation because they get entangled, the referee may issue a pushing foul on both robots.

10. If, in the opinion of the referee, physical contact between two robots is not soft, or if one or both of the robots do not change direction after encountering physical contact, a pushing foul will be called.

11. When a pushing foul is detected the responsible team has to use up their restart for the stuck robot to start at the insertion zone again. The other team can decide within 10 seconds to restart their involved robot in the insertion zone without it counting as a penalty restart.

12. Moving a workpiece of the opposing team at their MPS is a pushing foul. The referee will move the workpiece back to its original position.

13. Intentional obstruction of the opposing team is a pushing foul, as described in Section 5.9.

14. If a robot is restarted or called to maintenance, loses his workpiece during collision avoidance or in case of a collision, the workpiece will not be replaced and is removed by the referee.

15. The league reserves its right to disqualify clearly malicious teams.

6 Tournament

The tournament is organized in a main competition and three technical challenges. Teams can decide to participate in any of those.

6.1 Tournament Phases

There will be three stages in the main competition, a round-robin phase for all participating teams, playoffs for the best four teams from the round-robin phase, and the finals. The best two teams of the playoffs play the grand finale to decide which team will become the next Logistics League champion, whereas the other two teams compete in the small final for the third place.

Round-Robin phase. The first stage is a group phase and will be played as a round-robin. The teams will receive the true points they scored during the competition. The points will be accumulated in this phase and the teams will be ranked according to the accumulated points in descending order.

Playoffs. At the playoff stage, the scoring scheme will be different. As each team in this phase directly competes with an opposing team, the team that scores more points as the direct opponent, will be announced as the winner and 3 points will be awarded to this team. A loss will be awarded with 0 points. Additionally, if both teams are unable to score any points during the match by delivering or producing goods, both teams will receive 0 points. In case of a draw within the playoffs, the game time will be extended by 5 minutes unless both teams scored zero points. This will be announced by the refbox instead of a game closed message. If this extension leads to a draw too, the overall regular points of the teams will determine the match winner. If the overall points are equal too, a direct comparison between the teams in question will decide. If this fails to resolve the situation, the teams will approach a coin toss to determine the winner.

Finals. The best two teams of the playoff phase will advance to the grand finale, the remaining two teams will compete in the small finals for the third place. The team that scores more points after the regular game time wins. If there is no winner after the regular time, the game continues for 5 more minutes. If after this time there is still no winner, a coin toss will decide.

The detailed seeding will be created at the event. Although the idea is to allow each participant to challenge each other team, the league can be adjusted to meet time requirements.

6.2 Game Commentary

In addition to scoring in the exploration and the production phase, points are also awarded if a team provides an English commentary on microphone to the public throughout the game. The commentary should communicate the overall problems to be solved within this league, the actual events taking place, but also give an insight on the own team and how they solved certain tasks. It does neither have to be perfect, nor to be a flawless stream of information. The commentary should be continuous, but short pauses are acceptable. At the end of the game the referees decide if the commentary duties were met and award the according team with 10 points. If both teams are willing to commentate on the game, the game time is shared according to the team specification (e.g., team 1 commentates the first half, team 2 the second half). However, the teams can also make custom arrangements to split the overall time.

6.3 Penalties

The catalog in Table 5 represents the decision basis for the referees not being exhaustive or binding.

6.4 Technical Challenges

Within the league, the technical advances should be documented from year to year. Therefore, the Technical Challenge is introduced. Each team should prepare for participating in any number of the following tasks. However, participation has no influence on the normal game results, but the winner will be awarded by a certificate.

6.4.1 Markerless Machine Recognition and Production

Currently, machines have markers that allows for recognizing their respective types and relative position. The idea of this challenge is, to remove the markers and still be able to recognize the type of a machine and feed a base element onto the conveyor belt.

Issue	Sanction
Premature movement	No robot is allowed to move until the referee announced the start of the match. The faulty robot will be grounded for 2 minutes.
Damaging factory equipment	Theoretical damage to the real factory equipment as a result of collisions and negligent actions. This behavior will be punished as a minor rule break.
Not showing up	A team not showing up at all. The team will be removed from the tournament unless the team leader can provide a sincere explanation.
Manual Interference	A manual interference of a team, i.e. touching a robot without the referee's permission, during the game will be punished as a major rule break.
Breaking a minor rule	A rule infringement with minor impact on the team performance or competition mechanics. Upon decision of the referee, 25 % of the scored points of the team at the time of the infringement will be deducted, at least 1 point.
Breaking a major rule	A rule infringement with considerable impact on the team performance or competition mechanics. Upon decision of the referee, 50 % of the scored points of the team at the time of the infringement will be deducted, at least 5 points.
Arguing with the referee	There will be no discussions during a match. Each team can make a motion to protest a certain match and its result which will be dealt with after the match. There will be a warning. Continued disregard will result in a time punishment to the team's current or next match.
Disregarding rules of conduct	Following the rules of conduct should be self-explanatory. Upon disregard, the referee will impose sanctions ranged from time punishments to the team's complete removal from the tournament.

Table 5: Infringements

For this challenge, the markers will be removed or otherwise hidden. Any sensor feedback is allowed to recognize the machine, but no kind of markers or other indicators is allowed to be added to the machine or the environment. The general idea is to test this as an advancement of the league for future events. Distances between robots and the machine are measured as the shortest distance from MPS trolley to robot base on the ground. The maximum achievable score in this challenge is 40 points – up to 10 for the recognition and production parts each, up to 10 for the explanation and methodologies, and up to 10 for the public release of the source code.

Recognition The refbox will randomly select two zones and machine types. The machines are placed in the center of the respective zones. The robot must approach the machine one after another and use only sensors mounted on the robot to recognize the physical type of the machine. The machines can be of any type.

The recognition part scores up to 10 points – 5 points for each machine. Of these 5 points, 2 points are awarded for proper approach (robot standing at the input or output side of the machine facing towards the machine with a distance of no more than $0.5\,\mathrm{m}$) and 3 points for correct recognition. The recognition must be provided clearly visible on a screen or by text-to-speech output.

Production The refbox will randomly select a CS machine. The machine will be pre-filled with a cap. The robot must then retrieve a base element without cap from the shelf of the CS (at least one spot will be filled with such a base element), feed it into the cap station, and retrieve the finished product on the output side.

The production part scores up to 10 points. 3 points are awarded for a proper approach (robot standing at the input or output side of the machine facing towards the machine with a distance of no more than $0.25\,\mathrm{m}$, note that the distance is shorter than for the recognition part). Another 4 points are awarded for properly feeding the base into the machine and the final 3 points are awarded for successfully retrieving the finished product (moving with the product to a minimum distance of $0.5\,\mathrm{m}$ of the machine).

Explanation and Methodology The teams need to explain their used methods and techniques. The jury of team leaders each gives scores from 0 (insufficient or no explanation) to 10 (excellent explanation and useful methods). The rounded up average of these points is added. Teams which have released the source code to their approach on the web score up to 10 points. The jury again vote points depending on the documentation and wealth of the implementation from 0 (no source code provided) to 10 (source code provided as readily usable package including all necessary dependencies). If a package is only usable within a non-disclosed software framework, the release cannot score more than five points.

6.4.2 Playing in Simulation

From this year on a simulation of the RCLL will be made available, based on previous work [3]. The simulation software[7] including technical documentation will be publicly available on GitHub (`https://github.com/robocup-logistics`).

The simulation uses Gazebo and the exact same referee box to simulate the environment reactions similar to the real game. We envision this simulation to be a basis for a simulation RCLL sub-league to attract a wider range of participants, but also to ease entering the robot competition.

This year teams will compete within the simulation as a Technical Challenge in a slightly shortened version of the real game. The referee box will immediately start with the production phase and

---

[7]`https://www.fawkesrobotics.org/projects/llsf-sim/`

posts three orders at the beginning. The maximum game time will be less than 10 minutes. Depending on the number of participants within this challenge, the OC decides on the playing mode. The same rules of the real game apply to this simulation challenge, if applicable. Notable differences are, for example, that there is no robot maintenance. Games in the simulation will run unattended and no human interaction is allowed.

Hardware Setup   The simulation will run on at least three computers. One machine will be provided which runs the simulation itself (Gazebo and referee box) at real-time factor as close to 1.0 as possible with visualization enabled. Each team needs to provide one or more computers to run the software for up to three simulated robots of their team. The teams connect remotely to the simulation using the Gazebo middleware.

Robot Models and Plugins   Teams are allowed to create and use their custom robot model, which they can derive from a standard robot model available with the simulation software. However, custom plugins are not allowed this year, robot models must be fully based on plugins contained within the software or already available in Gazebo. Sensor-wise the available plugins will at least cover the brightness sensor, distance sensor, laser range finder, gripper, and the webcam which all come with the standard Festo Robotino 3.0. Teams are encouraged to contribute to this repository of plugins until May 1st 2015, the RCLL TC will then decide on their admission until May 31st 2015.

Competition Area   The competition area can be expected to be similar to Figure 1, however, the MPS locations will be randomized as in the real game.

Abstraction Level   Teams need to utilize their robot sensors to perceive the environment, there will be no available ground truth published to the robots by the simulation software. That is, robots need to recognize signal lamps via cameras as well as localize themselves via sensors attached to the robot.

6.4.3   Open Challenge

Each team will be given 5 minutes to showcase their robot team, e.g. show some new robotics developments. This may involve any task as long as it is performed with at most three Robotino robots within the competition area. For the time of the free challenge, any software or hardware modification is allowed, even though otherwise disallowed in the regular competition. This may be used to showcase ideas for future developments of the league and to highlight particular advances in the system of the presenting team.

The team leaders of non-presenting team will judge the performance and rate it with points between 0–10. The team with the highest sum of points will win this challenge. The other teams are ranked in decreasing point order.

6.4.4   Conducting the Challenges

The technical challenges are conducted in the following way. The team leaders of each participating team agree on a date and time during the tournament for the Technical Challenge in their first team leader meeting. For each type of challenge, a time slot is assigned, in which teams can participate once in the challenge. Each team can register for any of the challenges. All team leaders have to be present at the time of the challenge to judge the other teams. The OC is responsible to conduct the Technical Challenge and can appoint team leaders as support. Each challenge will have a separate ranking. In each ranking, the team on the last rank will receive 0 points, the last-but-one ranked team will receive 1 point etc. The points for each ranking will be added and the team with the most points accrued over all challenges will be awarded with the Logistic Leagues Technical Challenge Award.

7 The Robotino System

All participants have to design their competition Robotinos within the following specifications. For a detailed technical description of the basic hardware, refer to the Appendix A. Robotino 2 is still allowed, however, we strongly recommend using the Robotino 3 as the robot hardware platform from this year on.

Any kind of sensors can be changed or added to the Robotino platform. However, it is not possible to implement sensors that require modifications outside the Robotino area (e.g. Northstar, indoor GPS). There must be no changes to the controller or mechanical system. The robots peripherals must not exceed the maximum total height of $1.1\,\mathrm{m}$ including the tower and the table on top. Additional hardware (sensors, computing equipment, etc.) must be within a circle of a diameter of $0.65\,\mathrm{m}$ (for both, Robotino 2 and 3) or centered at the robot's rotational center-point. Additional hardware may only occupy up to 25% of this additional $0.14\,\mathrm{m}$ (Robotino 2) or $0.10\,\mathrm{m}$ (Robotino 3) wide ring around the robot. The only additional actuator allowed is one gripping device for workpieces which can be the original or a modified one. It also must be within the same diameter of the other additional hardware. The gripper is allowed to transport one workpiece at a time. And the gripper must release the workpiece for safety whenever the referee wants to take out it. For example, if the referee presses the release button or key, the gripper releases the workpiece.

It is allowed to install additional computing power on the Robotino. This may either be in form of a notebook/laptop device or any other computing device that suits the size requirement of the Robotino competition system. Furthermore, it is allowed to communicate with an additional computing device off-field. This device may be used for team coordination and/or other purposes. However, communication among the robots and the off-field device is not guaranteed during the competition.

7.1 Markings

All field robots must be assigned a single unique number out of the set $\{1, 2, 3\}$. The number must be written on the robot in one or more places and clearly visible from all directions, e.g. printed adhesive labels placed on top or the sides of the robot. The number must be the same as is announced in the beacon signal to the referee box (cf. Section 8.2).

For audiences and observers to distinguish both teams, all robots must wear their respective unique colored label which is either cyan or magenta. The Velcro will be provided and is suggested to be placed on the tower's side of each robot, the actual color-coded rings are then dynamically divided among the playing teams.

8 Communication

Robots have to operate autonomously, that is, without any human interference during the game. Communication among robots and to off-board computing units is allowed only using wifi (cf. Section 8.7). Communication is not guaranteed and may be unavailable during parts of the game. Interruptions must be expected and are no reason to pause or abort a game, even if they endure for long periods of the game.

8.1 Bandwidth Allocation

No minimum bandwidth is guaranteed. The amount of communicated data over the wifi connection shall not exceed $2\,\mathrm{Mbit/s}$. Even though the lower layers could provide for more bandwidth, the

overall available frequency spectrum and wifi channels have to be shared, not only within our own league. Generally, a conservative use of bandwidth resources is advised. Should a frequently or endured exceedance of the bandwidth limit become known, or if the overall bandwidth limit must be reduced due to outer circumstances, the TC can monitor the network traffic and demand reduction in communicated data as necessary.

8.2 Referee Box (refbox)

The referee box (refbox) is a software system that runs on a system provided by the Organizing Committee. It controls the overall game, monitors feedback from the robots, and awards points. It is instructed by an assisting human referee and keeps a log of all relevant game events. The final game report will be produced by the referee box. While we strive for a maximum of automation of this control task, we rely on the human referee for final judgment, in particular for border or under-specified cases, and will provide the largest set of override abilities feasible.

The refbox is the single point of instruction for robots during the game. After game setup has finished, game state information and orders are announced by the refbox. Commands must be acknowledged. In certain situations (for example during the exploration phase) for successful and true communication with the refbox points are awarded. The aim is to reduce human interference year by year to a minimum as to exhibit the widest autonomy during the game possible. Ultimately, the refbox should be able to fully control the game by itself, transforming all participants, team members, and visitors alike into pure spectators of the game, sometimes providing maintenance and crisis intervention when necessary.

The communication from the refbox to the robot is a datagram-oriented broadcast protocol based on Google protocol buffers[8] (protobuf). The protocol definition and technical parameters are described in detail in the RoboCup Logistics League Referee Box Integrator's Manual [1]

8.3 Remote Control

Remote operation or instruction of any kind of the robots is forbidden at all times during a game. The only allowed interaction is for the start-up (cf. Section 5.3). Any failure to comply with this rule will lead to immediate disqualification of the infringing team.

8.4 Monitoring

Passive monitoring, i.e. receive-only communication from a base station of the robots' performance is allowed. However, the overall bandwidth limit may not be exceeded. If the referee has any reason to belief that a monitoring application might be used for instruction, he can demand the shutdown of the monitoring software (also refer to previous section on Remote Control).

8.5 Inter-robot Communication

Robots currently active on the field can freely exchange any information that supports a coordinated team play. Robots not actively participating in the game, for example because they have been irrevocably removed from the current game, may not communicate with the other robots. It is forbidden to communicate with any sensors that are not physically attached to the robot, including, for example, but not limited to a camera aside the field. Likewise any off-robot actuator is forbidden.

---

[8]Available at `https://code.google.com/p/protobuf/`

8.6 Communication Eavesdropping and Interference

Communication of another team may neither be eavesdropped on nor be interfered with. Teams not currently active shall disconnect from the field access points.

Monitoring of bandwidth used or of possible misbehavior may only be performed by members of the TC or an appointed delegate. Any indication of misbehavior will be discussed by the team leader convention and may result in penalties or disqualification from the tournament.

8.7 Wifi Regulations

In order to provide the optimal possible solution for wireless communication during the event, all teams are required to use the $5\,\text{GHz}$ wifi equipment. They are furthermore required to connect their Robotinos wifi unit to the access point provided. All teams can also rely on wifi clients supplied by Festo but are not required to. A detailed description concerning the infrastructure can be found in Appendix A.2.6.

A Engineering Reference

A.1 The Mobile Robot System Robotino 3

The mobile robot system Robotino is a platform with open mechanical and electrical interfaces for the integration of additional devices like sensors or motors. By default power is supplied via two exchangeable $12\,\mathrm{V}$ lead gel batteries which permit a running time of up to two hours. Robotino is driven by 3 independent, omni-directional drive units. They are mounted at an angle of $120°$ to each other. The three omni-directional drive units of Robotino defines it as being holonomic, meaning that the controllable degrees of freedom equals the total degrees of freedom of the robot. The drive units are integrated in a sturdy, laser welded steel chassis. The chassis is protected by a rubber bumper with integrated switching sensor.

A.1.1 Robot Dimensions (w/o extension tower)

- **Diameter:** $450\,\mathrm{mm}$

- **Height including housing:** $290\,\mathrm{mm}$

- **Overall weight:** approx. $22.5\,\mathrm{kg}$

- **Maximal payload:** about $30\,\mathrm{kg}$

A.1.2 Drive Unit

- **3× omni-directional wheels:** $120\,\mathrm{mm}$

- **Fed by DC three motors:** $3600\,\mathrm{rpm}$

- **Gear transmission ratio 32:1** $22.5\,\mathrm{kg}$

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

Figure 10: Robotino 2 and Robotino 3 without extension tower

The motor speed will be controlled via a PID controller implemented on a Atmel microprocessor of the controller board of Robotino.

A.1.3 Sensors

Robotino is equipped with 9 vertical mounted infrared distance measuring sensors which are mounted in the chassis at an angle of $40°$ to one another. Robotino can scrutinize all surrounding areas for objects with these sensors. Each of the sensors can be queried individually via the controller board. Obstacles can thus be avoided, clearances can be maintained and bearings can be taken on a selected target. The sensors are capable of accurate or relative distance measurements to objects at distances of $4\,cm$ to $30\,cm$. Sensor connection is especially simple including just one analogue output signal and supply power. The sensors' evaluation electronics determines distance and read it out as an analogue signal. The anti-collision sensor is comprised of a switching strip which is secured around the entire circumference of the chassis. A reliably recognizable signal is thus transmitted to the controller unit. Collisions with objects at any point on the housing are detected and, for example, Robotino is brought to a standstill. The inductive proximity sensor is supplied as an additional component. It serves to detect metallic objects on the floor.

The default webcam camera is plugged in via USB and is capable of full HD 1080p video with auto light correction and two built in microphones for stereo sound with noise-canceling.

A.1.4 Controller Board

Robotino is powered by an exchangeable Embedded PC - COM Express layout combined with a custom made sensor board.

Embedded PC according to COM Express specification

- Embedded Intel Core i5, 2.4 GHz, Dual-Core

- 8 GB RAM

- 64 GB SSD (exchangeable)

- Operating system: Linux Ubuntu 12.04 (64-bit)

Embedded PC interfaces

- $1 \times$ Ethernet

- $6 \times$ USB 2.0

- $2 \times$ PCI Express expansion slot

- Wireless LAN according to 802.11b/g, client or access point mode

- $2 \times$ RS232

- $1 \times$ Parallel port and $1 \times$ VGA port

- Wireless LAN Access Point following the standards 802.11/b/g.

- The access point supports client mode, optional WPA2 encryption.

Motor control

- micro-controller with 32-bit microprocessor and separated Ethernet interface

- Including $1 \times$ additional motor output and encoder connector

- $8 \times$ analog inputs from 0 V to 10 V (50 Hz)

- $8 \times$ digital inputs/outputs with 24 V, short circuit proof and overload protected

A.1.5   Power supply

- $2 \times$ 12 V lead-fleece rechargeable batteries with 9.5 Ah capacity each

- Operating time(default batteries): up to 4 hours

- Power supply for additional components: 13 x 24 V, 13 x GND

- Internal charger for lead-gel and NiMH rechargeable batteries

- 24 V power supply for charging batteries

A.1.6   Software

Pre-installed is Ubuntu Linux 12.04 LTS operating system. The main part of the controller is the Robotino server, a real time Linux application. It controls the drive units and provides interfaces to communicate with external PC applications via wifi. Also provided: API 2.0 with libraries which allow you to create applications for Robotino in numerous programming languages:

- C++ and C

- C#

- .net and JAVA

- MatLab and Simulink

- Labview

- Robot Operating System (ROS)

- Microsoft Robotics Developer Studio

You may find a lot of examples concerning using the different API's in the public OpenRobotino forum at `http://www.openrobotino.org`.

Web interface   HTML5-based user interface provided by web server running on Embedded PC for setup and configuration using SmartPhone, Tablet or PC/Notebook User interface supporting program management, manual control, network setup, status display and options Help system: online manual for getting started, details on all components and introduction into programming

Robotino View   For a quick start or Hardware testing there is proprietary drag and drop Software Robotino View. Graphical programming environment for external PC running on Windows XP, Vista, Windows 7 or Windows 8.

- Main program using sequential function chart according to IEC 61131

- Reusable subprograms based on function blocks

- Library for function blocks and devices

- Global variables for communication between subprograms

- Program interpreter to run programs on Embedded PC autonomously

Additional information as well as accessories can be obtained through
`http://www.robocup-logistics.org/links/festo-robotino-3.`

A.2   Robotino 2.0 (phase-out model)

The mobile robot system Robotino is a platform with an open mechanical interface for the integration of additional mechanical devices and an open electrical interface to integrate easily additional sensors or motors of devices. Power is supplied via two $12\,\mathrm{V}$ lead gel batteries which permit a running time of up to two hours. The scope of delivery likewise includes a charging device. Robotino is driven by 3 independent, omni-directional drive units. They are mounted at an angle of $120°$ to each other. The three omni-directional drive units of Robotino, defines the robot as being holonomic, meaning that the controllable degrees of freedom equals the total degrees of freedom of the robot. The drive units are integrated in a sturdy, laser welded steel chassis. The chassis is protected by a rubber bumper with integrated switching sensor.

A.2.1   Robot Dimensions

- **Diameter:** $370\,\mathrm{mm}$

- **Height including housing:** $210\,\mathrm{mm}$

- **Overall weight:** approx. $11\,\mathrm{kg}$

- **Maximal payload:** about $6\,\mathrm{kg}$

A.2.2   Drive Unit

Each of the 3 drive units consists of the following components: DC Dunker motor with nominal speed of $3600\,\mathrm{rpm}$ and nominal torque of $3.8\,\mathrm{N\,cm}$. Integrated planetary gear unit with a gear ratio of 4:1. Omni-directional wheels of diameter of $80\,\mathrm{mm}$. Toothed belt with gear wheels providing a transmission ratio of 4:1. Altogether this provides a gear transmission ratio of 16:1. Incremental encoder with a resolution of 2048 increments per motor rotation. The motor and gear arrangement is shown in Figure 11(a).

   The motor speed will be controlled via a PID controller implemented on a Atmel microprocessor of the controller board of Robotino.

A.2.3 Sensors

Robotino is equipped with 9 infrared distance measuring sensors which are mounted in the chassis at an angle of $40°$ to one another. Robotino can scrutinize all surrounding areas for objects with these sensors. Each of the sensors can be queried individually via the controller board. Obstacles can thus be avoided, clearances can be maintained and bearings can be taken on a selected target. The sensors are capable of accurate or relative distance measurements to objects at distances of $4\,cm$ to $30\,cm$. Sensor connection is especially simple including just one analogue output signal and supply power. The sensors' evaluation electronics determines distance and read it out as an analogue signal. The anti-collision sensor is comprised of a switching strip which is secured around the entire circumference of the chassis. A reliably recognizable signal is thus transmitted to the controller unit. Collisions with objects at any point on the housing are detected and, for example, Robotino is brought to a standstill. The inductive proximity sensor is supplied as an additional component. It serves to detect metallic objects on the floor.

The inductive proximity sensor must be attached to the mounting furnished for this purpose, and must be connected to the I/O interface. The output voltage is $0\,V$ to $10\,V$. The sensing range is $0\,mm$ to $6\,mm$. Path tracking can also be implemented with the two included diffuse sensors. Flexible fiber optic cables are connected to a fiber-optics unit which works with visible red light. Reflected light is detected. Different surfaces and colors produce different degrees of reflection. However, gradual differences in reflected light cannot be detected. The sensors must be attached to the mountings furnished for this purpose, and must be connected to the I/O interface.

Robotino is equipped with a color webcam. The webcam is equipped with a USB interface. Also, there will be integrated a digital Gyroscope providing a high accuracy of the odometry in the virtual factory.

A.2.4 Controller Board – 2010 Revision
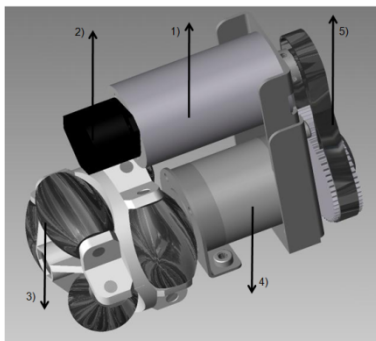
(a) Drive unit with motor (1), encoder (2), omni-directional wheel (3)
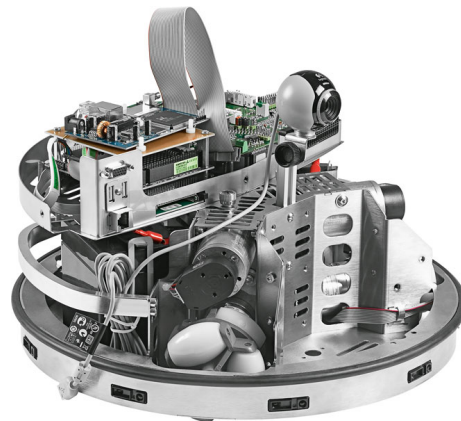
(b) Festo Robotino 2 inside view

Figure 11: Robotino 2 internals

The controller housing is connected to the wiring in the chassis via one plug-in. Thus you can easily take off the controller housing and you have direct access to the mechanical system. The controller system of Robotino is divided into two parts – an embedded PC and a micro-controller interface card: The Controller of Robotino consists of an embedded PC and a micro-controller interface board. The main controller is the embedded PC 104 plus controller with the 500 MHz processor AMD LX800.

The PC has a SDRAM of 128 MB and is provided with a 1 GB flash card. There are numerous communication interfaces on board:

- 2×100 Mbit/s Ethernet

- $2 \times$ external USB, $1 \times$ on-board USB-connector

- $2 \times$ RS232

- $1 \times$ Parallel port and $1 \times$ VGA port

- Wireless LAN Access Point following the standards 802.11/b/g.

- The access point can be switched into a client mode. As an option you may use WPA2-coding.

A.2.5 Software

Pre-installed is an Ubuntu Linux operating system with real time kernel running on the embedded PC 104. The main part of the controller is the Robotino server, a real time Linux application. It controls the drive units and provides interfaces to communicate with external PC applications via wifi. There is an API with libraries which allow you to create applications for Robotino in numerous programming languages:

- C++ and C

- C#

- .net and JAVA

- MatLab and Simulink

- Labview

You may find a lot of examples concerning using the different API's in the public OpenRobotino forum at `http://www.openrobotino.org`.

Robotino View   Robotino View is a graphical programming language with numerous prepared function blocks you can easily connect via input and output parameters to establish more complicated function diagrams. You can use these function diagrams as subprograms for more complex programming sequences. To build up general programming sequences Robotino View follows the international standard IEC 61131-3. You may run Robotino View on an external PC and Robotino View communicates directly with the Robotino Server on the PC 104 via wifi in order to control the robot system. The function blocks receive a direct feedback of the hardware components such that you can live interact with the robot system. On the other hand you can download Robotino View programs into the PC 104 in order to run the applications completely autonomously. There is a well defined interface to develop own function blocks in C++ or Lua.

Image Processing   Depending on the Robotino version it might happen that the standard web camera only provides image data by JPEG compression. This is very useful if you run your image processing on the PC and exchange the data via wifi. However, if you would like to run your image processing algorithms on the Robotino controller then the processor is not powerful enough in order to pack and to unpack the image data in a reasonable time. Thus we recommend for running image processing algorithms on the Robotino controller to use a camera without JPEG compression, e.g. use the low cost Logitech web camera C250.

A.2.6   Wifi equipment

Festo AP	LANCOM L-322agn
Transfer rate	Up to $108\,\mathrm{Mbit\,s^{-1}}$
Data link protocol	802.11 a/g/n
Frequency	$5.0\,\mathrm{GHz}$
IP-distribution	172.26.200.xxx for LAN clients(DHCP)
	172.26.101.xxx for the Robotino devices
	172.26.1.xxx for Robotinos
Subnet Mask	255.255.0.0
Encryption	Unsecured
SSID	Separated for both teams:
	RobotinoEvent.1
	RobotinoEvent.2
Festo Clients	3COM WL-560
Power Supply	Clients: $12\,\mathrm{V}$, $1\,\mathrm{A}$,
	Most Laptops cannot power them
	via USB!
Connector	Ethernet

Table 6: Technical specification of the wifi equipment

References

[1]   Tim Niemueller. *Referee Box for the RoboCup Logistics League – Integrator's Manual*. http://www.robocup-logistics.org/refbox. Knowledge-Based Systems Group, RWTH Aachen University. 2015.

[2]   Tim Niemueller, Gerhard Lakemeyer, Alexander Ferrein, Sebastian Reuter, Daniel Ewert, Sabina Jeschke, Dirk Pensky, and Ulrich Karras. "Proposal for Advancements to the LLSF in 2014 and beyond". In: *Proceedings of 16th International Conference on Advanced Robotics – 1st Workshop on Developments in RoboCup Leagues*. Montevideo, Uruguay, 2013.

[3]   Frederik Zwilling, Tim Niemueller, and Gerhard Lakemeyer. "Simulation for the RoboCup Logistics League with Real-World Environment Agency and Multi-level Abstraction". In: *Proc. of RoboCup Symposium*. João Pessoa, Brazil, 2014.