RoboCup Logistics League sponsored by Festo

Rules and Regulations 2014

The Technical Committee 2012–2014

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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 sponsored by Festo (LLSF) 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.

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 LLSF further towards deploying Automated Guided Vehicles in industrial applications. 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 Eindhoven, 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 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 will combine the previously separated 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. Also, the production plans will be more dynamic and we will limit the number of orders to avoid blind maximum throughput production and rather foster production scheduling and planning. For 2015, we have decided to replace the signal machines by actual processing machines as outlined in [1].

1.1 The Task

Our aim is to simulate autonomous guided vehicles in industrial applications. In opposition to regular automatic guided vehicles teams shall complete the following task without human interference as successful as possible, competing with a second team against the clock.

The Logistics League's main challenge is a multistage production cycle of different product variants with self-crafted intermediate products and delivery of the final product. This genuine goal will be rewarded considerably higher than partial fulfillment of the task. Autonomous robots transport hockey pucks, which act as a placeholder for (intermediate) products, between the processing machines. A machine can basically be understood as a signal light with an attached RFID reader. Each puck carries an ID tag, which will be read and processed according to the related machine's specification. If procurable this will lead to a new puck state: a new sub-assembly is produced or prepared. Complete work orders require all related sub-assemblies of product variants (cf. Section 5.3). Such transformations can rely on more than one puck as input to be triggered.

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 short setup phase, an exploration phase (see Section 5.2.4) during which robots receive scores for correctly discovering and publishing the yet unknown types of the different machines on the field. After this phase the referee box will announce all machine types and designations. In the following production phase orders are announced by the referee box, which the robots must fulfill automatically.

The whole factory area can be used as an intermediate storage. Finally successfully assembled products are to be delivered to the correct delivery gate and get unloaded into its delivery slot. 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 LLSF, 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 gabs 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 2014

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3 Competition Area

3.1 Field Layout and Dimensions

The competition area is shown in Figure 1 and features a $11.25\,\mathrm{m} \times 5.625\,\mathrm{m}$ large arena with several RFID-mounted machines, mark-ups, stocks of raw-material and delivery zones. It is surrounded by boards of $0.5\,\mathrm{m}$ height to reduce object interference from outside the area.

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 that uses absolute coordinates. All indicated sizes of mark-ups are to be considered outside dimensions. The default width for mark-ups is $19\,\mathrm{mm}$, the default color is black, except for the recycling machines, in which case the machine space is marked with green mark-ups.

The whole area is shared among both teams on the field and any robot may travel anywhere at any time (while not obstructing or pushing other robots or machines). However, there are primary sides (split along the y-axis) for each team where a team's *input storage area*, *robot insertion area*, *production machines*, *recycling machine*, and *delivery zone* are located. We will refer to the side with positive coordinates on the x-axis as the (primary) half of team 1, and the side with negative coordinates on the x-axis as the primary half of team 2.

The robot insertion areas are located along each corner of the left competition area, with a separate mark-up line $0.4\,\mathrm{m}$ apart from the competition boundary. Next to them towards the mid, the input storage areas are located. Each input storage area has a size of $1.1\,\mathrm{m} \times 0.4\,\mathrm{m}$, is painted blue on the wall, and contains a set of 22 pucks.

The delivery zones are located to the bottom and the top of the competition area, respectively, and are painted green on the wall. Each of the three *delivery gates* in each zone is of $0.3\,\mathrm{m}$ width with $0.1\,\mathrm{m}$ space to the next delivery gate separated by black mark-ups. The delivery gates feature one signal per gate placed in the middle of each gate zone. The delivery slot resides besides a unit that is identical in construction to a production machine. Each of the three RFID devices within these gates features a black centered square of $0.1\,\mathrm{m} \times 0.1\,\mathrm{m}$ called delivery slot, which resides exactly below the RFID device.

Additionally to the delivery gates, 26 machines are placed within the competition area: 24 machines representing the multi-staged production process, and two machines to recycle consumed pallet carriers. All machines are placed within the factory area as stated in Figure 1. They are aligned in a $90°$ angle and reside in the center of a squared machine space spanned by mark-ups with $0.5\,\mathrm{m}$ each side.

The distribution and alignment of all machines is axially symmetrical to the y-axis. Thus, each team has exact the same conditions on the upper and the lower half of the competition field. Half of the production and recycling machines belong to the one team, the other half to the other team. However, whereas each recycling machine will always belong to the respective team (i.e., R1 to team 1 and R2 to team 2), production machines from one team can also be located inside the area 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 the same, i.e. the distribution will be a symmetrical one.

The center coordinates and alignment of the machine and the different delivery gate slots are presented in Table 1. Note that this field layout should be seen as a proposal for the actual competition area layout, accounting for symmetry and avoiding clustering of machine access nodes and unapproachable machines. However, the field layout can still change before the actual tournament

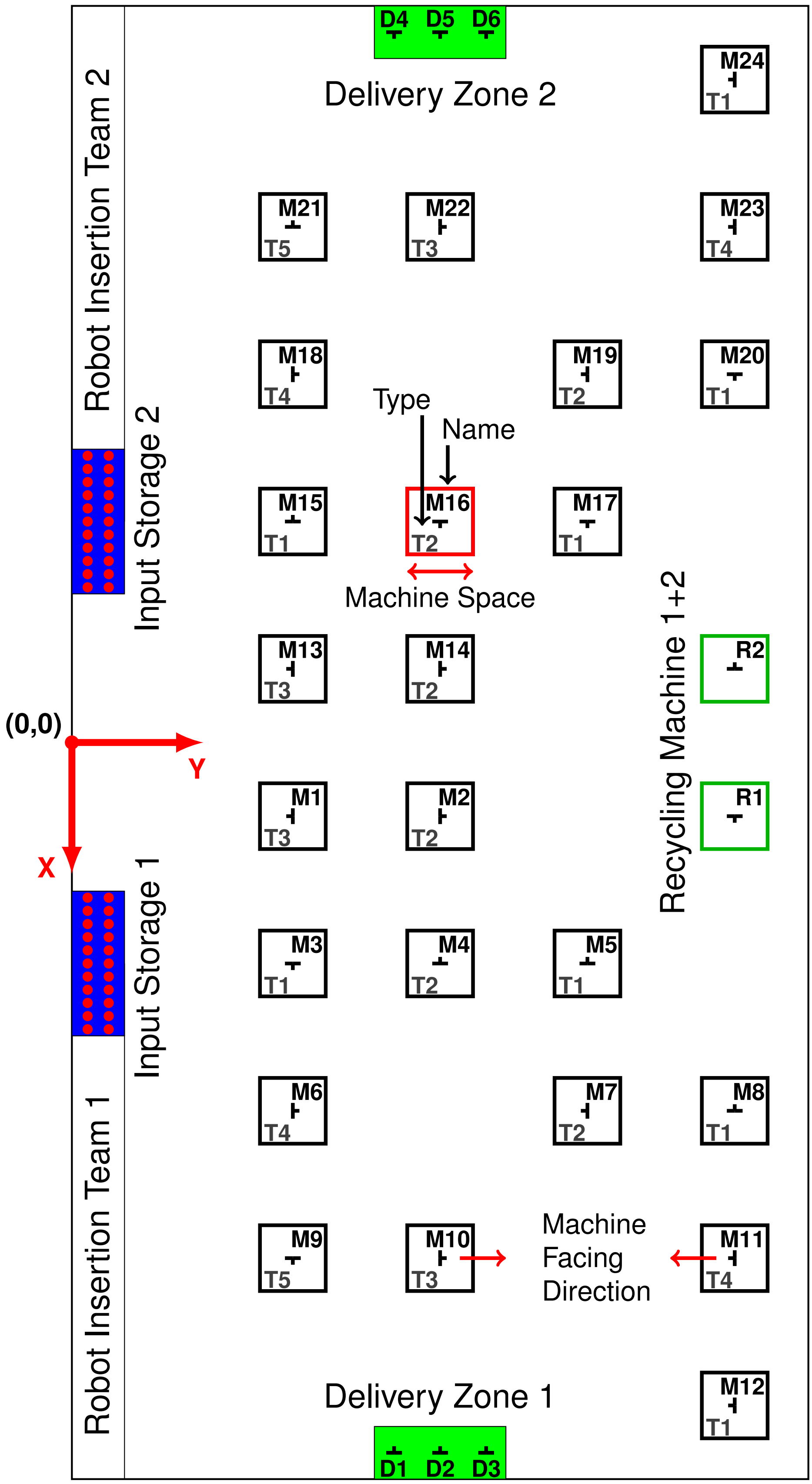


Figure 1: Competition Area

Abbr.	Type	x [m]	y [m]	Alignment
M1 / M13	Prod. Machine	$\pm$ 0.56	1.68	West
M2 / M14	Prod. Machine	$\pm$ 0.56	2.80	East
M3 / M15	Prod. Machine	$\pm$ 1.68	1.68	South / North
M4 / M16	Prod. Machine	$\pm$ 1.68	2.80	North / South
M5 / M17	Prod. Machine	$\pm$ 1.68	3.92	North / South
M6 / M18	Prod. Machine	$\pm$ 2.80	1.68	East
M7 / M19	Prod. Machine	$\pm$ 2.80	3.92	West
M8 / M20	Prod. Machine	$\pm$ 2.80	5.04	North / South
M9 / M21	Prod. Machine	$\pm$ 3.92	1.68	South / North
M10 / M22	Prod. Machine	$\pm$ 3.92	2.80	East
M11 / M23	Prod. Machine	$\pm$ 3.92	5.04	West
M12 / M24	Prod. Machine	$\pm$ 5.04	5.04	West
R1 / R2	Recycling Machine	$\pm$ 0.56	5.04	South / North
D1 / D4	Delivery Gate Slot	$\pm$ 5.34	2.45	North / South
D2 / D5	Delivery Gate Slot	$\pm$ 5.34	2.80	North / South
D3 / D6	Delivery Gate Slot	$\pm$ 5.34	3.15	North / South

Table 1: Coordinates and alignment of machines and delivery gate slots.

starts. Thus, teams should focus on a generic approach for production, allowing for easy adaptation of machine positions and alignments.

3.2 The Pallet Carrier Puck

The data-carrying RFID tag is attached on top of a hockey puck. Each pallet carrier can be identified by a unique number. The tournament puck features a diameter of $7.5\,\mathrm{cm}$ and is shown in Figure 2(a). Please consult Appendix A.3.4 for further information of the RFID tag.

3.3 Machines

All machines are identical devices consisting of a plate housing the RFID read/write device and a signal unit according to Figure 2(b). They share the same design and RFID device type. The overall size is $280\,\mathrm{mm} \times 160\,\mathrm{mm} \times 100\,\mathrm{mm}$ (height $\times$ width $\times$ depth). Confer also Appendix A for further details. Machines can be in different states, which are communicated by their signal lights.

The machine distribution (number of machines per type and team), their input(s) and output and their range of processing times is summarized in Table 2. The machines are evenly divided among both playing teams. Delivery and recycling machines for a team are always on the same side as its robot insertion area and raw input storage.

3.3.1 Machine Swapping

Depending on the tournament phase (cf. Section 6.1), some machines are swapped. That is, some machines are symmetrically exchanged among the teams, so that a team's machine is on the half

(a) Puck (b) Machine

Figure 2: Hardware equipment used within the competition field.

distant from its own delivery gates. For example, if in Figure 1 machine M9 is chosen, then team 1 would need to use M21, and team 2 would need to use M9 respectively (type remains unchanged).

Round-robin phase. One machine type out of the set T_3, T_4, T_5 is chosen randomly. All machines of that particular type are swapped.

Play-offs. Half of all machines (of any type) will be chosen randomly and swapped.

Finals. For each machine (of any type) the referee box will randomly determine if it is swapped.

3.3.2 Production Machines – During Exploration Phase

During the exploration phase the robots of each team have to explore their unknown factory environment, i.e. identify the types of the different production machines within the competition area. The frequency of machine types for each team is defined in Table 2. The machines will indicate their different types by individual light signals. In total there are seven possible light signals with at least one LED switched on (no flashing lights). The light signals and the corresponding machine types are initially unknown. The Referee Box will assign every machine type to a light signal and publish it to the robots. The exploration phase starts with the announcement of the exploration

Type	Distribution / Team	Input	Output	(Final) processing time[s]
T_1	4 times	S_0 (raw-material)	S_1	$t_1 = 3$ to 8 sec
T_2	3 times	S_0; S_1	S_2; one consumed container	$t_2 = 15$ to 25 sec
T_3	2 times	S_0; S_1; S_2	P_1; two consumed containers	$t_3 = 40$ to 60 sec
T_4	2 times	S_0; S_1; S_2	P_2; two consumed containers	$t_4 = 40$ to 60 sec
T_5	1 times	S_0	P_3	$t_5 = 20$ to 40 sec

Table 2: Production Machines - Type, Distribution and working method

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 and yellow LED turned on	The machine is processing or consuming the current data carrier.
Yellow LED flashing (at 2 Hz)	The machine detects wrong material. This can be caused by data carriers that are already consumed, sub-assemblies that do not fit to this machine type's work order or corrupted data carriers.
Red and yellow LED flashing (at 2 Hz)	The machine detects a data carrier, which belong to the opposing team.

Table 3: Production Machines - Optical Feedback during production phase

game phase by the Referee Box. An exploration information message is sent, which defines the light signals of the machine types, e.g., red and green LED switched on indicate machine type T_1. If a robot perceives the red and green LED light switched on at machine M_1, the robot has to announce that machine M_1 is of type T_1 to the Referee Box. Therefore, the robot has to send a *machine identified message* to the Referee Box. Please consult the RoboCup Logistics League Referee Box Integrator's Manual for a detailed definition of the message types.

3.3.3 Production Machines – During Production Phase

The default operating mode of all machines implies that only the green LED is turned on. This signals that the machine is ready for input. To enable the production process it is necessary to transport the pallet carrier accurately to the RFID device.

If a (intermediate) product is fed into a machine, the machine reads the RFID tag and checks whether or not the product can be processed and indicates the result by its signal light. If an appropriate product is fed to the machine, the yellow LED turns on indicating that the machine is processing the product (green and yellow LED on). If the machine needs another sub-assembly to generate an output, the green LED turns off and the yellow light indicates that the machine is waiting for the next sub-assembly. A consumed pallet carrier has to stay within the machine space borders (no part of the puck being outside the mark-up, note that if the overhead camera system is used there might be a small tolerance, but the team may not rely on this) until the production cycle of that very machine has been completed. Products resulting from violating this requirement are considered junk and will not be rewarded.

If the yellow LED is turned off after processing, further input materials are fed to the machine, the green LED indicates that the machine has finished the work order and the last carrier is transformed to its corresponding output.

If a product is fed to a machine which is not appropriate, the machine reacts with a yellow light flashing at 2 Hz. A red light indicates that the machine is in an error state. In this case no products can be processed on the machine (for details cf. Section 5.4.1). In case a data carrier is fed to a machine, which belongs to the opposing team, the red and the yellow LEDs are flashing at 2 Hz and the puck is marked as junk. Table 3 summarizes the operating modes of the production

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 and yellow LED turned on	The machine is processing the current data carrier.
Red and yellow LED flashing (at 2 Hz)	The machine detects a data carrier which belongs to the opposing team.

Table 4: Recycling Machines - Optical Feedback

machines and the corresponding signal lights.

The machine always processes the required pallet carrier delivered last, all prior components will be consumed. All machines will start processing the data carrier as soon as it enters the machine zone (i.e., the RFID device's action range) as stated in Section 3.1. They will change their operating mode according to Tables 3, 4, and 5.

In order to complete the machines' work order, the input materials have to be delivered one-by-one into the RFID device's action range. The sequence of delivered input materials is irrelevant (e.g., S_0-S_1 or S_1-S_0). Multiple data carriers in range of the device will result in erroneous behavior of the device. Consumption of materials, such as S_0 used in the production of S_2, will take 2 seconds. Unloading the machine can be done immediately after the operating mode changes away from processing. As long as the machines are used properly, they will not produce any junk. The distribution describes how many machines of the respective types will be randomly placed, resulting in a total of 12 court machines for each team.

3.3.4 Recycling Machines

During the staged production process raw-material is transformed or consumed by the machines. To use consumed raw-materials again, the robots of each team can use their corresponding recycling machine (i.e., R1 for team 1 and R2 for team 2). The recycling machine processes all supplied loading carriers back to raw-material (S_0) within 2 seconds. The optical feedback provided by the recycling unit differs from production machines and is shown in Table 4.

3.3.5 Delivery Gates

If a team finishes a variant of a final product, it has to be delivered to the customer through one of their three delivery gates. Only if the machine signals successful delivery (all lights steadily on) points are awarded. This state will last until the puck is removed by the referee. The puck may no longer be used in the game. There will be only one active gate at a time for each team. A gate is active between 60 and 180 seconds. After the gate switches, there is a grace period of 3 seconds, in which delivery will still be accepted to the formerly active delivery gate. False deliveries to an active gate will be indicated by a flashing yellow light (e.g. taking a S_0 puck to the active gate) and false deliveries to an inactive gate by a steady red and blinking yellow light. Delivering a data carrier to the delivery gate of the opposing team is indicated by red and yellow flashing light. In all three cases, the puck will be taken out by the referee and it may no longer be used in production or delivery. In case of a delivery to an active gate, the team will be awarded with the points for

Optical Feedback	Indication
Red turned on	This delivery gate is inactive.
Green turned on	This gate is active, namely the designated gate.
Yellow blinking	False delivery to active gate.
Red on, yellow flashing (at 2 Hz)	False delivery to inactive gate.
Red and yellow LED flashing (at 2 Hz)	False delivery with a data carrier belonging to the opposing team.
Red, yellow, and green turned on	Successful delivery.

Table 5: Delivery Gates - Optical Feedback

the delivery; if the gate was inactive, no points will be awarded. If, however, a pallet carrier was not successfully delivered, the pallet carrier will remain where it is. See Table 5 for the possible delivery gate signal states.

4 Referees

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

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 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. The head referee has the upper hand when there is a referee disagreement and then announces the final decision.

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 re-positioning pucks after pushing or remove pucks that were delivered to a delivery gate if and only if the delivery gate has either accepted (all LED steady on) or rejected (yellow blinking with or without red light on or blinking). Field referees are responsible for making the decision whether a team may take out a robot for maintenance.

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 fixed. The machine type of each production machine will be randomized prior to each match. The processing time of each machine type will be determined in the same way, so the waiting time during a match will be static for each machine of all machine types (e.g. all T1 could have 7 seconds processing time). The active delivery gate will also be randomized prior to each match, but during a match the active gate can switch. At the beginning, each team has the responsibility to place up to 22 raw materials (pucks in S_0 state) in their input storage, initially spread as shown in Figure 1 or in another fashion as chosen by the team. The pucks may only be touched by a robot after the game has started. In particular, they may not be re-positioned for better alignment if they have been pushed or moved by a robot during the game.

5.2 Game Phases

5.2.1 Team Setup

No team member is allowed to enter the competition area prior to or during a match. All robots which are to participate in the game need to be in the game area during setup. All robots are allowed to roam through the entire area, autonomously or teleoperated. However, no robot is allowed to touch any pallet carrier during setup; infringements will be punished as *misbehaving robot*. The referee box will control the setup period. When the game starts, all robots need to be in the insertion area; no robot is allowed to be in the factory area at start-up. If a robot is not able to move to the insertion area, the team has to call upon the referee for *robot maintenance*.

5.2.2 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.

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 neither the calling team nor another robot would have any advantage in the current game situation from the take-out. An advantage would be, for instance, to take out a robot, if two robots are hindering each other. It is up to the discretion of the referee when to allow the robot maintenance.

After a robot has been taken out for the first time, it is handed to the team. The team can perform any repairs to the robot and/or the robot's software. The repair time may take at most 120 seconds. If the robot is not returned to the field in time, it is disqualified from the ongoing game.

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 robot is placed in the robot insertion area. The team has 15 seconds quick setup time, which is limited to basic instructions like initial localization or software start-up.

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 5.4).

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.

5.2.3 Game Start

All matches will start at the exact time scheduled by the organization team. From this point on, all robots must be located within the robot insertion area and the teams involved are allowed to start their robots to work autonomously within one minute (the game time will already start during this time). This can be done by issuing one single distinct command via any kind of interface or pressing a single button on the robot.

5.2.4 Exploration Phase

With the start of the game, the exploration phase begins. All machines indicate their type using steady light signals. The signal light encoding of machine types will be published by the referee box as described in Section 3.3.2 and in detail in the RoboCup Logistics League Referee Box Integrator's Manual. The robots are to roam the environment and announce the detected types of their 12 production machines to the referee box. Each properly reported signal scores 4 points, each signal reported wrongly will give -3 points penalty. A minimum of zero points will be accounted for the exploration phase. Production or moving pucks is not allowed during the exploration phase. The exploration phase ends either after four minutes or immediately after both teams have each reported their respective set of 12 field machines.

5.2.5 Production Phase

With the end of the exploration phase production begins, which lasts 15 minutes. The referee box publishes all information regarding products and machines. This includes position, orientation, and type of each machine, as well as the different product variants that can be produced.

5.3 Production Portfolio

The production portfolio is presented in Figure 3, which shows a production chain diagram with the machines and their respective inputs and outputs. The multi-staged production processes can be repeated as long as enough pallet carriers can be provided to complete the cycle. The different machine types are specified in Section 3.3.

5.3.1 Production Plan

The referee box will announce orders throughout the game in an incremental fashion. Each order will consist of the products to produce, the amount thereof, and delivery time slots. In each game, orders with a fixed delivery value of 80 points will be placed[1]. These points only include the final

[1]This number is based on experience from the game reports and database logs of the competition in 2013. The number can be adjusted during the tournament by the Technical Committee, should this turn out to be necessary.

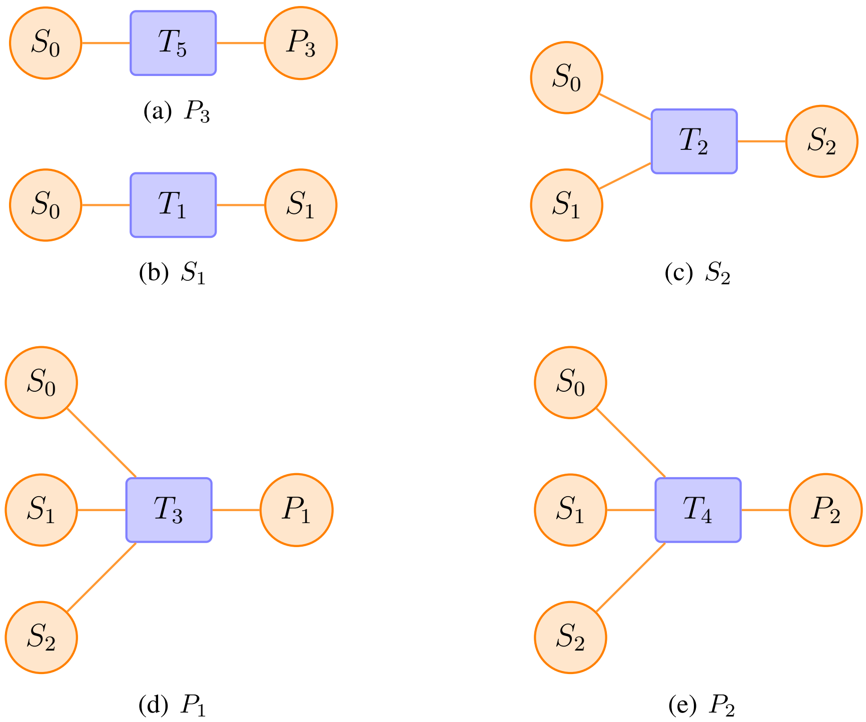


Figure 3: Production Chain Diagrams showing the machines and inputs relative to their outputs.

production step and delivery. Each order will require one or more products of a specified product type to be delivered. 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 duration shall be long enough to cover at least the production time of the final machine in the production chain and 30 seconds of travel time. The orders shall be posted with a uniform distribution over the whole game time (but there is 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 P_1 and P_2 will not begin in the first 300 seconds. An order will be announced between 10 and 60 seconds before the delivery time slots starts.

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.

5.4 Special Events during a Match

Any referee can interrupt the match at any time. After the referee box is stopped, all robots have 5 seconds to stop all robot movement. Robots that do not stop within the time limit will be treated in the same way as misbehaving robots (cf. Section 5.2.2). The match time will be paused during the interruption.

5.4.1 Machine Downtime (out of order)

The refbox will take down machines randomly out of the pool containing all production machines. 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 6 to 8 of such triggered events during a match. The machines affected will remain out of order for 30 to 120 seconds. Every machine can only be forced out of order once per match. The recycling machines will be taken down exactly once per match, with a downtime of 20 to 40 seconds. If a machine turns offline during processing or consumption of mounted a pallet carrier, it will afterwards resume the process (extending the overall processing time by the down time).

5.5 Task Fulfillment and Scoring

Table 6 provides the itemized clearance of all task related processes and their scoring.

5.6 Obstruction Penalty

Teams are penalized with -2 points for obstruction when delivering a data carrier to a machine of the opposing team. In this case, the puck becomes junk and cannot be recycled or used afterwards. If the robot leaves the machine space without the puck, the puck will be removed by a field referee.

5.7 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 or puck 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 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 don't 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.
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 this, a pushing foul will be called.

Reported	Exploration Phase	Points
Correctly	Correctly determine a machine type and report it successfully to the refbox	+4
Incorrectly	Wrongly reported machine type	-3
Round Total	A maximum of 48 points can be achieved by correctly reporting all 12 production machines. A minimum of 0 points is awarded.	0 – 48

(a) Scoring scheme for the exploration phase

Sub-task	Production Phase	Points
Produce S_2	Finish the work order of a machine type 2	$+4$
Produce product variant P_1	Finish the work order of a machine type 3	$+12$
Produce product variant P_2	Finish the work order of a machine type 4	$+12$
Produce product variant P_3	Finish the work order of a machine type 5	$+0$
Delivery	Deliver one of the final product variants to the designated loading zone at the time specified in the order	$+10$
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
Just-in-time Production	The final production step of a successfully delivered good has been completed within the order time window	$+5$
Recycle	Taking a consumed material from a machine that completed its work cycle to the recycling machine	$+5$
Obstruction Penalty	Deliver a data carrier 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 6: Scoring Schemes

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 puck of the opposing team within a fenced area (machine or input area) by at least one puck diameter is a pushing foul. The referee will move the puck back to its original position.
13. If a robot loses his puck during collision avoidance or in case of a collision, the puck will not be replaced.
14. 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 7 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 Navigation and dynamic collision avoidance

A robot fleet consisting of three robots has to show that it can reach a certain goal location avoiding collisions with static obstacles and other moving robots. Two teams compete against each other at the same time. Team 1 places their robots inside the competition area with $x > 4.79$m (i.e., near the delivery gate at the bottom), team 2 at $x < -4.79$m (i.e., near the delivery gate at the top). All robots from each team must then reach the opposite starting area faster than the opposing fleet. A robot reaches this area if at least half of the robot's volume crossed the border. For

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 7: Infringements

each robot not participating in the robot fleet consisting of three robots, the team has to travel another distance from one delivery gate to the other. Robot collisions will be handled the same as for the main challenge of the Logistics League, and are therefore punished accordingly. The team, which reaches the respective goal location the fastest, wins. If no team reaches the goal within three minutes, the robot fleet with the overall shortest distance to the goal wins. Depending on the number of participating teams and certain time constraints, the tournament mode will be announced before the competition starts.

6.4.2 Approaching an MPS station

The Modular Production System (MPS)[2] is a toolset to create simplified production lines for automation education. In preparation for the scheduled introduction of MPS stations in 2015 (cf. [1]), this technical challenge requires teams to approach, feed, and unload an example MPS station. One robot will be required to use any gripping device to handle a workpiece. The challenge will be to

1. receive one workpiece from a shelf
2. approach a "Pick & Place" station and hand over the workpiece
3. approach the backside of this station
4. wait to receive the completed workpiece
5. transport it to one empty shelf spot and unmount it.

Teams may add markers of any kind to the MPS station and shelf to support their approach. These markers have to be removable, residue-free and mounted/unmounted in a reasonable short amount of time before each test run.

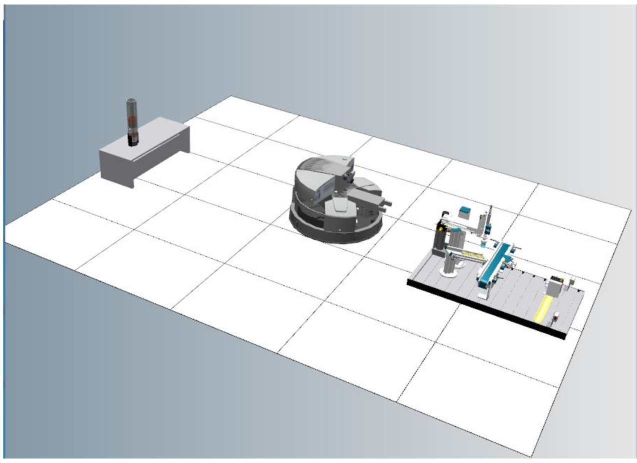
Each team has 10 minutes to conduct a test run with field exclusivity. Once they choose to begin, they have 3 minutes to complete the challenge. Each step will be awarded with points. If all points are completed in time, the fastest team wins.

The installation will be available throughout the whole time of the tournament. Festo will provide one standardized gripper per team over the course of a tournament. Custom constructions are welcome.

Workpiece. The workpieces are round objects with a diameter of 40 mm and are of red, black, or silver color. They are made of plastic, cf. Figure 4(b). The team can choose any of the workpieces.

MPS station The MPS station is mounted on a rectangular profile plate of size 350 mm $\times$ 700 mm with a height of 30 mm. The transfer points (MPS and shelf) are 148.165 mm above ground, the workpiece has to be lifted completely above this height. The transfer point is the center of the conveyor belt. Relative to long side of the base plate it is located 375 mm from one side and 325 mm from the other. The belt has a width of 45 mm and is at the transfer point height. With this information teams can create a mockup of this machine for training and development of custom manipulation devices.

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



(a) Demo Scene (CIROS) of MPS approach

(b) Selection of MPS workpieces

Figure 4: Approaching an MPS station: The challenge scenario and used workpieces

6.4.3 Free 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.

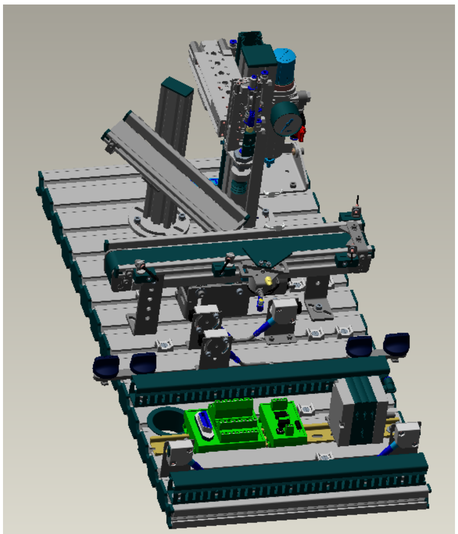
The team leaders of non-presenting team will judge the performance and rate it with points between 0–10. The team with the highest sum of points will win this challenge. The other teams are ranked in decreasing point order.

6.4.4 Conducting the Challenges

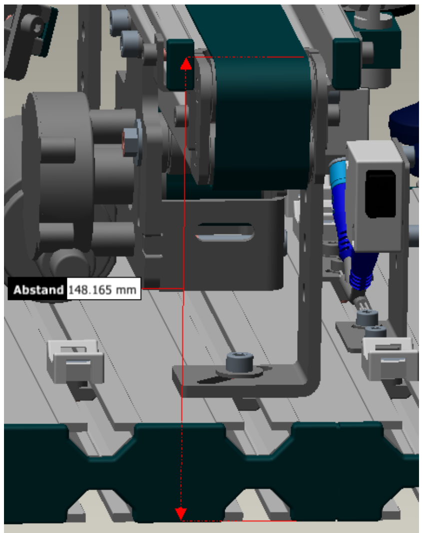
The technical challenges are conducted in the following way. The team leaders of each participating team agree on a date and time during the tournament for the Technical Challenge in their first team leader meeting. For each type of challenge, a time slot is assigned, in which teams can participate once 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.



(a) Overview Pick & Place



(b) Interface point height

Figure 5: The MPS station in detail

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). It is furthermore strictly forbidden to implement any kind of RFID device into the Robotino. There must be no changes to the controller or mechanical system. The pushing device is defined as a passive, non-mechanical load handling attachment. The robots peripherals must not exceed the maximum total height of 0.7 m. Additional hardware (sensors, computing equipment, etc.) must be within a circle of a diameter of 0.65 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 cm (Robotino 2) or 0.10 cm (Robotino 3) wide ring around the robot. The only additional actuator allowed is one pushing device for pucks which can be the original or a modified one. It however must not exceed the following outside dimensions (including possibly added sensors): 0.25 m $\times$ 0.15 m $\times$ 0.05 m (width $\times$ depth $\times$ height). The puck must be visible from above while inside the pushing device.

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).

To allow identification by the overhead camera system of the referee box, all robots must wear unique colored labels on top of the robot. The labels will be provided by the organizing committee. Teams must provide appropriate mounting capabilities such that the labels are freely and completely visible from above. The markers are round labels of approximately 20 cm in diameter printed on paperboard.

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 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

The referee box (refbox) is a software system that runs on a system provided by the Organization 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[3] (protobuf). The protocol definition and technical parameters are described in detail in the RoboCup Logistics League Referee Box Integrator's Manual.

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

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 5.2.3). 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.

8.6 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 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.3.3.

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$\times$ 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 6: 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 $4\,\mathrm{cm}$ to $30\,\mathrm{cm}$. 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 × Ethernet
- 6 × USB 2.0
- 2 × PCI Express expansion slot
- Wireless LAN according to 802.11b/g, client or access point mode
- 2 × RS232
- 1 × Parallel port and 1 × 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 Open-Robotino forum at `http://www.openrobotino.org`.

Webinterface HTML5-based user interface provided by webserver 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 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 mm
- **Height including housing:** 210 mm
- **Overall weight:** approx. 11 kg
- **Maximal payload:** about 6 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 rpm and nominal torque of 3.8 N cm. Integrated planetary gear unit with a gear ratio of 4:1. Omni-directional wheels of diameter of 80 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 7(a).

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

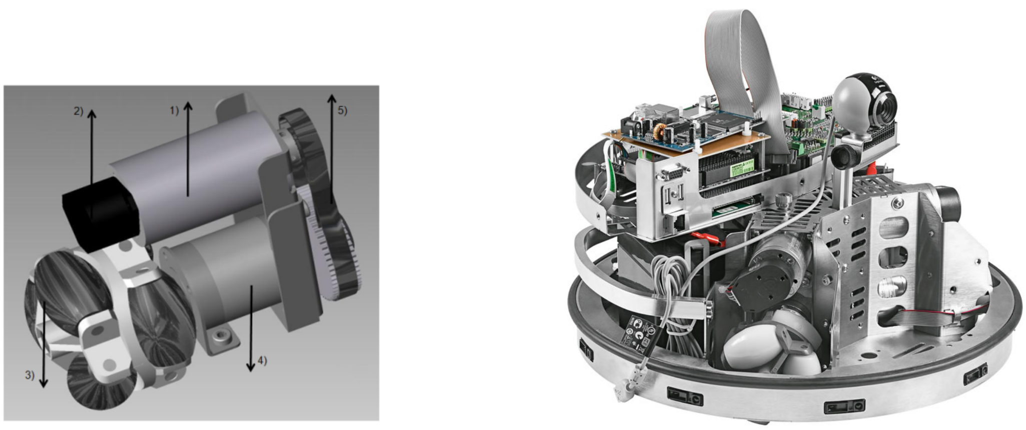
A.2.3 Sensors

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 $4\,\mathrm{cm}$ to $30\,\mathrm{cm}$. 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 $0\,\mathrm{V}$ to $10\,\mathrm{V}$. The sensing range is $0\,\mathrm{mm}$ to $6\,\mathrm{mm}$. 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 7: 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:

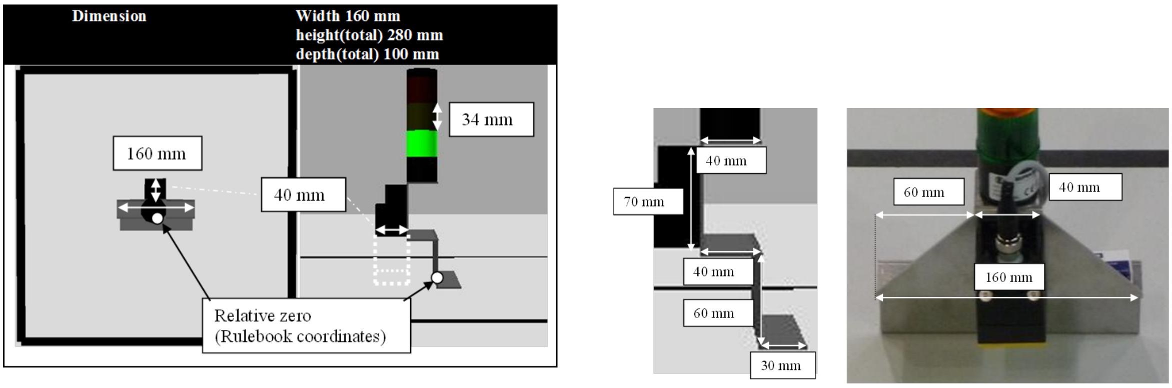
- C++ and C
- C#
- .net and JAVA
- MatLab and Simulink
- Labview

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.3 Machines



(a) Ranges and dimensions of a signal (b) Ranges and dimensions of the supporting brackets

Figure 8: Machine Details

A.3.1 Signal

Dimension & diameter	36 mm
height(total)	147 mm
Segment height	34 mm, including 5 mm unlighted border
Lifespan	max. 50.000 h
Connector	Bottom, 2 m supplied Compatible to the I/O-Terminal of MPS(r) units.
Safety	IP65
Voltage	24 V
Current	3×40 mA
Kind of current	DC
Operating mode	-20 °C to 50 °C
Signal type	Static LED
Signal	Ultra-bright LED
Source	Festo # 549843

Table 8: Technical specification of the signal

A.3.2 RFID device

Technical data of the read/write head	Housing rectangular
Housing and working dimensions	$40\,\mathrm{mm} \times 40\,\mathrm{mm}$ with the centered RFID tag.
Housing height	$65\,\mathrm{mm}$
Operating voltage	DC
Housing material Plastic	PBT-GF30-V0, black
Material active face Plastic	PA6-GF30, yellow
Operating voltage	$10\,\mathrm{V}$ DC to $30\,\mathrm{V}$ DC
DC rated operational current	$\leq 80\,\mathrm{mA}$
Data transfer	inductance coupling
Working frequency	$13.56\,\mathrm{MHz}$
Radio communication and protocol standards	ISO 15693
Read/write distance	max. $115\,\mathrm{mm}$
Output function	4-wire, read/write
Electrical connection	Connectors M12 $\times$ 1
Vibration resistance	$55\,\mathrm{Hz}$ ($1\,\mathrm{mm}$)
Shock resistance	$30\,\mathrm{g}$ ($11\,\mathrm{ms}$)
Protection class	IP67
Operating voltage display	LED green

Table 9: Technical specification of the RFID device

A.3.3 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 10: Technical specification of the wifi equipment

A.3.4 Data carrier

Dimension	⌀20 mm
Height	2.5 mm
Data transfer	inductance coupling
Working frequency	13.56 MHz
Memory	read/write
Memory type	EEPROM
Memory size	128 B
Freely usable memory	112 B
Number of read operations	unlimited
Number of write operations	105
Typical read time	$2\,\mathrm{ms\,B^{-1}}$
Typical write time	$3\,\mathrm{ms\,B^{-1}}$
Radio communication and protocol standards	ISO 15693

Table 11: Technical specification of the data carrier

References

[1] 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.