



RoboCup@Work

Rulebook

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Chapter 1

Introduction

1.1 RoboCup@Work in a Nutshell

RoboCup@Work is a new competition in RoboCup that targets the use of robots in work-related scenarios. RoboCup@Work utilizes proven ideas and concepts from RoboCup competitions to tackle open research challenges in industrial and service robotics. With the introduction of this new event, RoboCup opens up to communities researching both classical and innovative robotics scenarios with very high relevance for the robotics industry.

Examples for the work-related scenarios targeted by RoboCup@Work include

- loading and/or unloading of containers with/of objects with the same or different size,
- pickup or delivery of parts from/to structured storages and/or unstructured heaps,
- operation of machines, including pressing buttons, opening/closing doors and drawers, and similar operations with underspecified or unknown kinematics,
- flexible planning and dynamic scheduling of production processes involving multiple agents (humans, robots, and machines),
- cooperative assembly of non-trivial objects, with other robots and/or humans,
- cooperative collection of objects over spatially widely distributed areas, and
- cooperative transportation of objects (robots with robots, robots with humans).

The RoboCup@Work scenarios target difficult, mostly unsolved problems in robotics, artificial intelligence, and advanced computer science, in particular in perception, path planning and motion planning, mobile manipulation, planning and scheduling, learning and adaptivity, and probabilistic modeling, to name just a few. Furthermore, RoboCup@Work scenarios may also address problems for which solutions require the use and integration of semantic web technology, RFID technology, or advanced computational geometry.

Solutions to the problems posed by RoboCup@Work require sophisticated and innovative approaches and methods and their effective integration. The scenarios are defined such that the problems are sufficiently general and independent of particular industrial applications, but also sufficiently close to real application problems that the solutions can be adapted to particular application problems with reasonable effort.

A RoboCup@Work competition has only recently become a feasible idea for several reasons: The

arrival of new, small, and flexible robot systems for mobile manipulation allow more university-based research labs to perform research in the above-mentioned areas. Advances and a revived interest in the use of simulation technology in robotics enable research groups to perform serious research without having a full set of costly robotics and automation equipment available.

The robotics and automation industry is recently shifting its attention towards robotics scenarios involving the integration of mobility and manipulation, larger-scale integration of service robotics and industrial robotics, cohabitation of robots and humans, and cooperation of multiple robots and/or humans. Last but not least, there is a huge interest by funding agencies and professional societies in well-designed and professionally performed benchmarks for industry-relevant robotics tasks. RoboCup@Work is designed as an instrument to serve all these needs.

We would like to acknowledge the following people for contributing to the development of the RoboCup@Work league.

- Rainer Bischoff
- Daniel Kazcor
- Arne Hitzmann
- Frederik Hegger
- Herman Bruyninckx
- Sven Schneider
- Jakob Berghofer

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1.2 Organization of the League

1.2.1 League Committees

The following list of committees is implemented for RoboCup@Work.

1.2.1.1 Executive Committee

Executive Committee (EC) 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 EC presents the league and its achievements to the RoboCup Federation every year and gets feedback to organize the league. All EC members are also members of the Technical Committee. EC members are elected by the Board of Trustees and appointed by the President of the RoboCup Federation, they serve 3-year terms. The current EC members are:

- Walter Nowak, *Locomotec GmbH*
- Nico Hochgeschwender, *Bonn-Rhein-Sieg University*

1.2.1.2 Technical Committee

The *Technical Committee* (TC) is responsible for technical issues of the league, most notably the definition of the rules, such as compliance of the robots with rules and safety standards, the qualification of teams, the adherence to the rules as well as the resolution of any conflicts that may arise during competition. The current TC members are:

- Jan Carstensen, *Leibniz Universität Hannover*
- Sebastian Zug, *Otto-von-Guericke-University Magdeburg*
- Yiyan Wang, *Singapore Polytechnic*

1.2.1.3 Organizing Committee

The *Organizing Committee* (OC) is responsible for all aspects concerning the practical implementation of competition, most notably for providing the competition arenas, ensuring their conformity with the rules, and any objects and facilities required to perform the various tests. Further, the Committee is responsible for assigning space to teams in the team area, the organization and scheduling of meetings, the nomination and scheduling of referees, the scheduling and timely execution of tests and stages, recording and publishing competition results, and any other management duties arising before, during, and after a competition. The current OC members are:

- Philipp Busse, *Otto-von-Guericke-University Magdeburg*

- Asadollah Norouzi, *Singapore Polytechnic*
- Weiwei Shang, *University of Science and Technology of China*

1.2.2 League Infrastructure

In order to provide a forum for continuous discussions between teams and other stakeholders, the league builds and maintains an infrastructure consisting of a web site, mailing lists, and repositories for documentation, software, and data. The infrastructure is complemented by a minimum infrastructure to be built and maintained by teams, i.e. teams should eventually create their own web page to which the RoboCup@Work League's web pages can be linked.

1.2.2.1 Infrastructure Maintained by the League

Website The official website of RoboCup@Work is at

<http://www.robocupatwork.org>.

This web site is the central place for information about the league. It contains general introductory information plus links to all other infrastructure components, such as a league wiki, the mailing lists, important documents such as this rule book, announcements of upcoming events as well as past events and participating teams.

Mailing Lists The league maintains several mailing lists:

`rc-work@lists.robocup.org` This is the general RoboCup@Work mailing list. Anyone can subscribe, but a real name must be provided either as part of the email address or being specified on the mailing list subscription page. The list is moderated in order to avoid abuse by spammers. New members can subscribe to this list here: <http://lists.robocup.org/listinfo.cgi/rc-work-robocup.org>.

`rc-work-tc@lists.robocup.org` This is the mailing list for the TC. Posts from non-members have to be approved by the list moderator. Approvals will be given only in well-justified cases.

Repositories Several repositories are publicly available under the official RoboCup@Work Github account:

<https://github.com/robocup-at-work>

The repositories provide among others, 3D models for the manipulation objects, PPT cavities and arena elements, as well as the sources to this rulebook, the implementation of the referee box and various tools.

1.2.2.2 Infrastructure Maintained by Teams

Each team is requested to build and maintain a minimum infrastructure for its team. This infrastructure consist of

- team web site,
- team contact, and
- team mailing address.

The team web site should contain the following information:

- Name of the team, and team logo, if any
- Affiliation of the team
- Team leader including full contact information
- List of team members
- Description of the team's research interest and background
- Description of specific approach pursued by the team
- Description of the robot(s) used by the team
- List of relevant publications by team members

The team contact should be the official contact of the team. Usually, for university-based teams, this would be an academic person such as a professor or post-doc, who should, however, be responsive and be able to answer quickly when contacted by email.

The team mailing address should be an email alias, which should be used to subscribe the team to the general RoboCup@Work mailing list. The email alias should at least include the team contact and the team leader.

1.3 Participation in the Competition

Participation in RoboCup@Work requires successfully passing a qualification procedure. This procedure is to ensure the quality of the competition event and the safety of participants. Depending on constraints imposed by a particular site or the number of teams interested to participate, it may not be possible to admit all interested teams to the competition.

1.3.1 Steps to Participate

All teams that intend to participate at the competition have to perform the following steps:

1. Preregistration (may be optional; currently by sending email to the TC)
2. Submission of qualification material, including a team description paper and possibly additional material like videos or drawings
3. Final registration (qualified teams only)

All dates and concrete procedures will be communicated in due time in advance.

1.3.2 Qualification

The qualification process serves a dual purpose: It should allow the TC to assess the safety of the robots a team intents to bring to a competition, and it should allow to rank teams according to a set of evaluation criteria in order to select the most promising teams for a competition, if not all interested teams can be permitted. The TC will select the qualified teams according to the qualification material provided by the teams. The evaluation criteria will include:

- Team description paper
- Relevant scientific contribution/publications
- Professional quality of robot and software
- Novelty of approach
- Relevance to industry
- Performance in previous competitions
- Contribution to RoboCup@Work league, e.g. by
 - Organization of events
 - Provision and sharing of knowledge
- Team web site

1.3.3 Team Description Paper

The *Team Description Paper* (TDP) is a central element of the qualification process and has to be provided by each team as part of the qualification process. All TDPs will be included in the CD proceedings of the RoboCup Symposium. The TDP should at least contain the following information in the author/title section of the paper:

- Name of the team (title)
- Team members (authors), including the team leader
- Link to the team web site
- Contact information

The body of the TDP should contain information on the following:

- focus of research/research interest
- description of the hardware, including an image of the robot(s)
- description of the software, esp. the functional and software architectures
- innovative technology (if any)
- reusability of the system or parts thereof
- applicability and relevance to industrial tasks

The team description paper should cover in detail the technical and scientific approach, while the team web site should be designed for a broader audience. Both the web site and the TDP have to be written in English.

1.4 Organization of the Competition

1.4.1 Teams

The TC and OC will jointly determine the number of teams permitted to participate in a competition well in advance. The rules shall enable a competition with up to at least 24 teams lasting not more than four full days. The number of people to register per team is not restricted by default, but may be limited due to local arrangements. Teams that plan to bring more than four members are advised to contact the OC beforehand. During registration, each team has to designate one member as team leader. A change of the team leader must be communicated to the OC. The team leader is the only person who can officially communicate with the referees during a run, e.g. to decide to abort a run, to call a restart, etc. The team leader can ask the OC to accept additional teams members for these tasks.

During on-site registration and upon request by the OC a team has to nominate one or more referees for the competition. If a team fails to provide referees in an appropriate way, the OC chooses an arbitrary member of the team for this position.

1.4.2 Team Practice and Use of Arenas

The teams will be given an opportunity to practice with their robots either in the competition arenas or in special test arenas, if available. The frequency and lengths of practice periods will be decided by the OC on site. The OC will also decide about if and how many teams may use an arena simultaneously and can decide on a practice schedule for teams wishing to use the arenas. Arenas may be modified between practice time and competition runs.

1.4.3 Stages and Tests

The OC may decide to split the competition into several stages. The competition design may foresee that only a smaller number of teams qualifies for a consecutive stage. An exemplary competition design could foresee a first stage with all qualified teams, a second stage with only the best 10 teams from the first stage, and a finals stage with the best 5 teams of the second stage.

Each stage is composed of a sequence of tests. The OC and the TC will jointly determine the type and number of tests in a stage and schedule the tests. Each test may be executed in one or multiple runs. The term run designates a single trial of a test for each team.

1.4.4 Scoring and Ranking

For each test the calculation of scores is defined individually, comprising points for achieving certain subtasks, points for winning a run and penalty points.

If not specified otherwise, the following set of scoring rules applies for each test:

Teams may use simplifications, which will result in a reduction of scores for the given run:

- Use of external sensors: -200 points
- Use of other external objects (e.g. to support localization): -100 points
- Use of own loading or unloading areas: -200 points

Additional simplifications are specified for individual tests. These reductions do not count as penalty points. Teams that want to make use of the simplifications above have to announce them in advance of the competition to the TC. The TC might forbid the use of specific elements for simplification if these are not in the spirit of the league or may cause disproportionate advantages for a team.

Penalty points are given as follows, each time again the incident occurs:

- A manipulation object is lost or placed anywhere outside of the service areas: -100 points
- Robot caused a collision with the environment: -50 points
- Restart used: -200 points

Controlled collisions between a robot and the environment are allowed, i.e. slightly touching a loading area with the robot's base or gripper. As soon as a robot starts to move environmental elements or the wheels start to spin (wheel-spin), it will be considered as a collision and the running test will be aborted. A controlled collision can only occur during manipulation operations.

If the projection of any part of a robot touches a barrier tape marking a virtual wall it counts as a collision. Touching or Passing a Barrier Tape when entering or exiting the arena does not count as collision.

When an object lost contact to the robot or touches the ground, it is not considered as being carried anymore (e.g. an object falls off the gripper or from the transportation platform).

All teams fully complete a perfect run will receive a completion bonus of 0.75 points per second left on the run time. These points are only awarded if the run is perfect, i.e. all objectives reached without any penalties.

A team cannot get less than zero points for one run. The scores of the tests of the first stage are summed up, and the teams with the highest sums proceed to the next stage.

In case of a tie, the OC will either schedule a deciding run or continue with a higher number of participants.

Each test provides a set of so-called feature variations encoding the overall variability of the test (e.g. whether obstacles can occur or not, number and type of manipulation objects). To enhance comparability among different test runs, all teams will have to perform the same test instances as specified in Table 3.1.

1.4.5 Common Procedures

The order in which the teams have to perform a run is determined by a draw by the OC. The order will be made public at least one hour before slot of the particular test.

A run is preceded with a 5 minutes preparation time. This time begins once the previous team has left the start area. During a run and the preparation time team members are not allowed inside the arena, except the referees allow it (e.g. to check if everything is set-up according to specification).

The preparation time starts as soon as the previous team has left the start area. If the preparation time runs out the run time will start, this can happen when the previous team is still in the arena. When a team is ready, the robot is connected and the team leader signals that the robot is ready, the time will be stopped.

When the preparation time ends, all team members must immediately leave the start area and are no longer allowed to interact with the robot, the only interactions allowed are unplugging network or power cables.

Before the run starts the team has to check if the arena is setup correct (e.g. all manipulation objects are placed according to task specification, obstacles are placed correct). If the team is ready the run may start as soon as the previous team has left the arena.

The referees start a run by sending the start signal from the referee box.

A run ends when

- the duration for the given test has passed,
- when the task has been finished by all robots,
- when the referees decide to stop it, or
- when the team leader of the team whose turn it is decides that the run can be finished earlier as no more progress is expected.

During a run, teams may only interact with the robot or enter the area if explicitly allowed by the referees.

If the robot at any point during the run does not show any progress for 2 minutes, the run will be aborted. This includes repeating the same behavior and not leaving the start arena as a team might not be entirely prepared, or is having connection issues.

After each run, the teams must leave the arena within one minute.

1.4.6 Restarts

Teams might use one so-called restart in a run. Restarts have the following aspects:

- Per run, at most one restart is allowed for a team, if not specified otherwise in a test.
- At any time during a run, the team can call for a restart to the referees.
- When the referees acknowledge the call for restart, the team may enter the arena. The time will continue running.
- The arena and the robot will be reset exactly to the setup at the beginning of the run (except the timer for the run). Random elements such as obstacles or object positions remain like before.
- The points for this run achieved so far are reset to zero (including possible penalty points). After the run, a penalty score for the restart will be applied.
- The referees decide when the arena is prepared again for the restart. If the robot is not yet ready, teams can keep trying to get it ready until the time for the run is over.
- As soon as the team signals that the robot is ready, the task specification is sent again.
- Afterwards the start signal is sent from the referee box.

1.4.7 Referees

The referees have to ensure the correct execution of the tests. They may interrupt runs if they suspect breaches of rules, see possible danger for humans or possible damages of robots and the environment. If a suspected breach of rules may be discussed after the run and cases no danger to others the run should continue, therefore the referee should announce his suspicion as fast as possible. Beside these general tasks, the referees are responsible for

- controlling the referee box (1 referee),
- supervising the robot and counting collisions (2 referees from different positions), and
- scoring results.

A team of referees supervise all runs of one test. If the referees disagree the TC will decide. The appointment of the referees has to be announced to the teams in combination with the test schedule.

1.4.8 Meetings and Language of Communication

Both the TC and the OC may organize several special meetings during a competition, such as referee meetings, team leader meetings, etc. The meetings will be announced locally. It is the responsibility of the team to inform itself about the organization and scheduling of such meetings.

Each team is expected to send at least one representative to such meetings. If the meeting refers to specific roles, such as referee or team leader, the person designated by the team to fill this role is expected to participate.

The language for all communication in the league is English.

1.4.9 Code of Conduct and Disqualification

Teams and team members are expected to maintain a friendly and cooperative atmosphere throughout a competition and contribute to a vivid work environment and to scientific exchange before, during and after a competition.

The TC may disqualify individual team members or a whole teams during a competition for severe reasons, such as repeated breach of rules.

1.4.10 Wireless LAN

A wireless LAN will be provided by the league. The usage of this WLAN is mandatory, any other WLAN is forbidden. The WLAN will be Dual-Band. There might be more than one WLAN (e.g. one per arena).

1.4.11 Use of External/Control Devices

No external devices are allowed (e.g. remote controls) in general. Exceptions may be certain simplifications leading to reduction of points as described in Section [1.4.4](#), or in particular tests. All communication of the robots with external elements must be wireless. Cable connections between the robot and external devices are not allowed during competition runs.

A team may set up an additional external computer to monitor the operation of their robot(s) during a run. This monitoring system must be designed such that no manual interaction through keyboard, mouse, or any other input device is required during a run. Team members must keep their hands off the keyboards and mice of all their computers during a run. It must be clear at all times that no manual or remote control is exerted to influence the behavior of the robots during a run. Exceptions may be specified by particular tests, e.g. for tasks where handing over objects to humans is required.

Chapter 2

General Rules

Each of the particular tests defined later in this document may define its own scenario. In this document, a scenario consists of elements such as the

- environment,
- objects that affect navigation,
- objects that are to be manipulated,
- objects with which robots interact,
- number of robots allowed per team,
- number of teams competing simultaneously in the same arena,
- task to be performed by a team, and
- the criteria for evaluating a team's performance.

In order to avoid excessive development efforts for each specific test and to allow reuse of partial functionalities the scenarios are built from a reasonably small set of components, which are later put together in different ways. This section describes these elements.

2.1 Design of Robots

The robots used for competition shall satisfy professional quality standards. The concrete definition of these standards is to be assessed by the TC, comprising aspects such as sturdy construction, general safety, and robust operation. It is not required that the robots are certified for industrial use.

2.1.1 Design and Constraints

The robots need to comply with certain size constraints. A robot, including all parts attached to it as used in the competition, must be able to move by itself into a configuration so that it fits into a cube of side lengths 80 cm x 50 cm x 80 cm (length x width x height). If all the robot's parts, such as manipulator or anything able to protrude outside of the previously specified cube, are fully extended, the system must still not exceed a cube of side lengths 120 cm x 80 cm x 160 cm (length x width x height). The organizers may specify further constraints, such as weight

limits. If a team would like to apply a robot with deviating robot dimensions, it should contact the TC. Exceptions for specific robots are possible in case of small differences.

Electric, pneumatic, and hydraulic actuation mechanisms are permitted, provided that they are constructed and produced according to professional standards and meet safety constraints. Combustion engines and any kind of explosives are strictly forbidden. Robots may not pollute or harm their environment in any way, e.g. by loss of chemicals or oil, spilling liquids, or exhausting gases. Furthermore, constraints on the noise generated by a robot in operation may apply. These will be communicated in due time.

Further, the following assumptions are made about the kind of robots used in the competition:

The manipulator of the robot should be designed and mounted on the robot such that it can grasp objects which will be placed in heights of between 0 cm and 40 cm above the floor.

- At least one of the robots used by a team is mobile and moves on wheels. No specific assumptions are made about the kinematic design, but the mobile robots should be able to move on basically flat, sufficiently firm surfaces.
- The robots have at least one manipulator and are able to grasp objects, which are graspable by a parallel gripper with a jaw width of at least 5 cm and do not weigh more than 300 g.
- The manipulator of the robot should be designed and mounted on the robot such that it can grasp objects from heights between 0 cm and 25 cm above the floor.
- The robots use sensors to obtain information about their whereabouts in the environment and the task-relevant objects. The major types of sensors that may be used by the robots include:
 - Laser range finders (cf. models by Hokuyo or Sick)
 - Color CCD cameras (cf. any kind of USB camera)
 - 3D cameras (cf. any kind of camera with depth information)
- The design of the scenario should be such that the robots can solve the tasks safely and robustly using (all or a subset of) these sensors.

If there are even vague doubts about the eligibility of using particular designs, parts, or mechanisms, the team should consult the TC well in advance.

The robots have to be marked such that a clear distinction of robots used by different teams during a test is possible for spectators. The OC can define the concrete types of markers to be used. In this case the markers are not taken into account when checking the robot's size constraints. The markers shall not interfere with safe operation of the robot.

The TC may require that robots are equipped with a wireless communication device of some sort (e.g. 802.11n), in order to communicate task specifications to the robots.

Future competitions may foresee the use of RFID sensors in the scenario design.

2.1.2 Behavior and Safety

In general, all robots shall be operated with maximum safety in mind. Any robot operation must be such that a robot neither harms humans nor damages the environment. A team must choose the operating parameters of their robot, e.g. the motion velocities for a robot base or a manipulator, or the grasp forces of a gripper, such that it can guarantee the safe operation of their robots.

All robots must have a mechanical mechanism for immediately stopping the robot in cases of emergency. This mechanism must be clearly visible and easily accessible. The OC may request the proof of a robot's safety (e.g. the correct operation of an emergency stop) anytime during the competition and exclude teams that cannot satisfy safety requirements.

When participating in a competition, the team may operate the robot only in their own team area, in the arenas provided (possibly constrained by a schedule assigning periods of time for exclusive use of the arena by a team or a group of teams), and in any other areas designated by the organizers for robot operation. Any operation of robots outside of these areas, e.g. in public areas or emergency paths, require prior permission by the OC.

2.2 Referee Box

The TC shall provide a referee box that supports the evaluation of the competition. It applies the time measuring, generates the tasks according to the chosen test configuration and monitors the competition. For this purpose each robot has to transmit a keep-alive signal every second during all phases (initialization, preparation, game, finish).

The referee box

1. announces the start of the preparation time,
2. communicates the task specifications,
3. starts each competition run, and
4. closes a successful run after reaching the endzone, or
5. aborts the run in case of a time lapse.

When the robot is initialized, it starts immediately to transmit its beacon signal. The referee box answers with a state information. If the previous robot has left the arena, one of the referees starts the seconded phase by pushing a button. The referee box transmits a new state message that informs the robot about the beginning of the initialization phase. Inside the referee box a timer is started which initiates the start of the execution phase after transmitting the test parameters. During the run the robot is able to activate the external devices and to receive their status information. This run phase is terminated by a second timer that alerts after the duration defined in the instance table. The TC provides a Robot Operating System (ROS) based interface of the referee box as well as an reference implementation. The Referee box implementation and its documentation is available under the following link:

https://github.com/robocup-at-work/at_work_central_factory_hub

The referee box visualizes the current state of the competition run, time measurements, the task specification and robot positions for visitors. Team information (name, affiliation, contact information) are given too in this context.

2.3 Design of the Environment

2.3.1 Size of the Arena

The size of a competition arena is a rectangular area not lesser than 2 m x 4 m and not more than 10 m x 12 m. An orientation is always associated with the arena. An arbitrary wall is designated as North orientation, and the wall to its right is designated as East and so on. The orientations will be assigned by the local league chair or/and the TC as soon as the arena is built up. Figure 2.1 shows one possible example of an arena configuration, while Figure 2.2 illustrates the topology.



Figure 2.1: An exemplary setup of a RoboCup@Work environment.

2.3.2 Floor

The floor is made of some firm material. Examples include floors made of concrete, screed, timber, plywood, chipboard, laminated boards, linoleum, PVC flooring, or carpet. Some examples are illustrated in Figure 2.3. Floors may neither be made of loose material of any kind (gravel, sand, or any material which may damage the functioning of the robots' wheels) nor may such

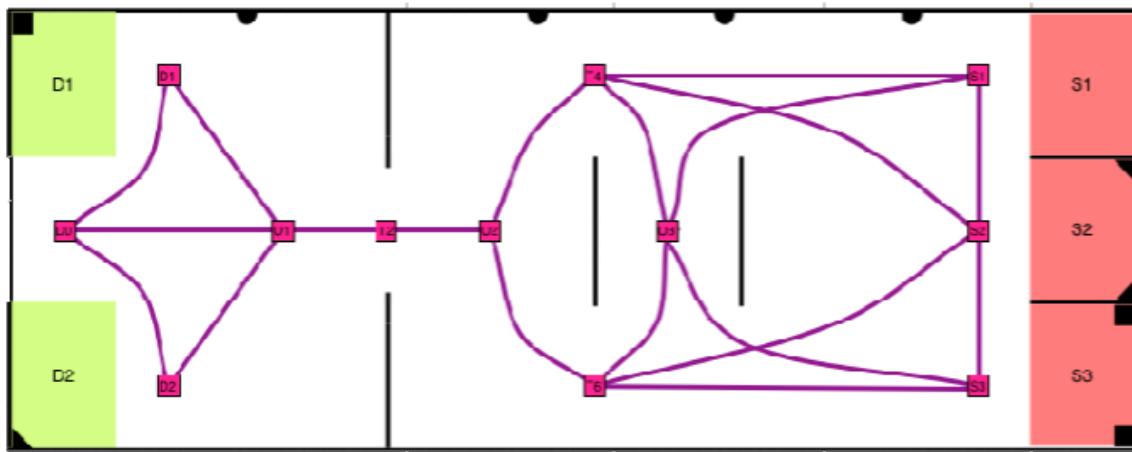


Figure 2.2: Topological map with five service areas (D1, D2, S1, S2, S3). The purple squares define places.

material be used on top of the floor. Liquids of any kind are not allowed. The floor may have spots of unevenness of up to 1 cm in any direction (clefts, rifts, ridges, etc.).

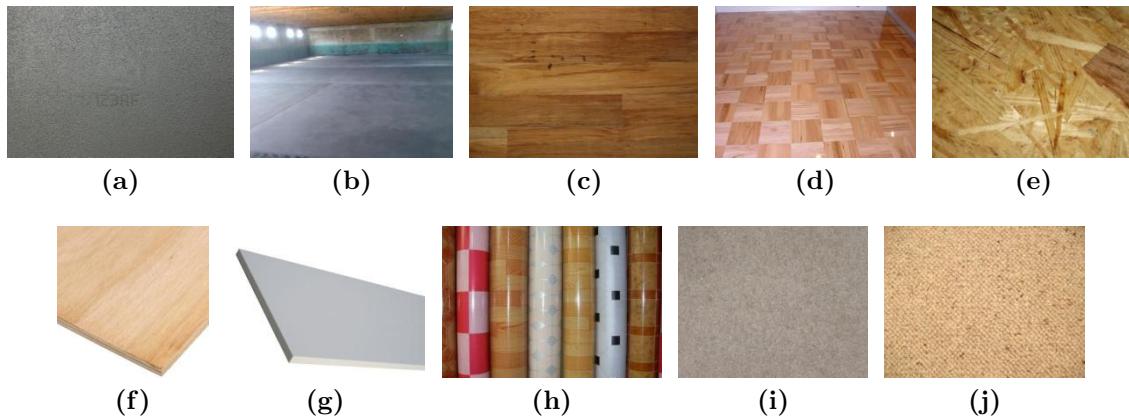


Figure 2.3: Examples of floors that can be used for RoboCup@Work arenas.

2.3.3 Walls

The competition arena is partially surrounded by walls. The height of the walls is not lesser than 20 cm and not more than 40 cm. One or more gates may be foreseen, where robots can enter or leave the arena. Gates may or may not be closable. The walls have a mostly uniform color. Small visual elements like logos or advertisements may be placed on the walls.

2.3.4 Service Areas

Arenas contain one or more service areas, which have specific purposes for a particular test. Examples include loading and unloading areas, conveyor belts, rotators, storage areas, etc. Service areas may contain specific environment objects, such as shelves, racks, etc. They may be accessible from different locations, i.e. it might be possible to reach an area from two or more sides. Note that service areas can have different heights. If a service area has a height of zero cm, a tape will mark the area (see Figure 2.4). The tape will be on the floor and will be blue/white striped. This tape may be crossed, and does not count as a collision. If the robot touches an manipulation object while navigating, this will be handled as a collision. If a service area will have a height of 5 cm there will be a wall with 10 cm height surrounding it.



Figure 2.4: Barrier tape used to mark service areas with 0 cm height.

2.3.5 Containers

As in many industrial settings, the RoboCup@Work environment may be equipped with several containers (see Figure 2.5). They can store any kind of manipulation object defined in Section 2.4.1. Robots are supposed either to grasp one or multiple objects out of containers or to place previously grasped objects into them. Several containers can be present in the environment and are always associated with a service area. That means that the container itself will be placed on top and within the manipulation zone defined in Section 2.4.2. It is also possible that more than one container is placed on top of a single service area. The constraints defined in Section 2.4.2 apply also to the containers.

Currently, a container itself does not need to be manipulated or transported by the robot.



Figure 2.5: Containers can be used for grasping objects out or placing objects into them.

2.3.6 Shelves

Service areas may foresee the use of shelves and shelf units as depicted in Figure 2.6. Objects to be delivered or removed from shelves have to be placed or picked sideways. The height of the shelves should be not lesser than 5 cm and not more than 40 cm. The color of the shelf surface is a bright uniform color such as white or light gray, unless a test specifies a different color. Since the shelf is a new element in RoboCup@Work, the robots are supposed to manipulate objects only on the lower level plane. The shelf surface may be specially designed in order to serve specific purposes, e.g. holding objects.



Figure 2.6: A shelf with two levels and uniform colored surfaces.

2.3.7 Places

An arena designed for a particular test may foresee the definition of a set of designated places, which are locations in the arena that can be referred to by a unique, symbolic identifier. These identifiers are used e.g. for the task specification, possibly in conjunction with other information, such as an orientation. Places may be marked by markers of some sort.

2.3.8 Obstacles

An arena defined for a particular test may foresee the use of obstacles. Obstacles may be passive (i.e. not able to relocate by themselves) or active (e.g. other robots). The size of obstacles should be not lesser than 10 cm x 10 cm x 5 cm; there is no upper bound on the size. The details about the dynamic objects are not known before the competition and will be chosen by the OC on-site. Examples for obstacles are trash bins, boxes, big aluminium profiles or even other robots.

2.3.9 Floor Markers

The arena used for a particular test may foresee the use of floor markers for designated places. The design of these floor markers are rectangular black-and-white images as used by the AR-ToolKit library:

<http://www.hitl.washington.edu/artoolkit>

The black inner square of the markers is at least 8 cm x 8 cm large with an additional white border of at least 12 cm side length. Figure 2.7 and 2.8 depict some examples of these markers.



Figure 2.7: Example of a floor marker.

2.3.10 Barrier Tape as Virtual Walls

The arena may include virtual walls marked by either striped yellow/black or white/red barrier tape on the floor (see Figure 2.8). If any part of a robot passes over such a tape it is considered as a collision with a usual wall.

The red/white tape is used to frame the entrance and exit area. The robot is allowed to cross this kind of barrier only at the beginning of a test to enter arena and at the end for leaving. In contrast, the yellow/black one denotes an obstacle which the robot is never allowed to cross.

The blue/white tape is not considered a virtual wall but marks the areas of 0 cm height (see Section 2.3.4).

2.3.11 Entrance and Exit

If possible, the arena should have one entrance and one exit, which are equipped with laser barriers. These barriers are used for timekeeping by the referee box.

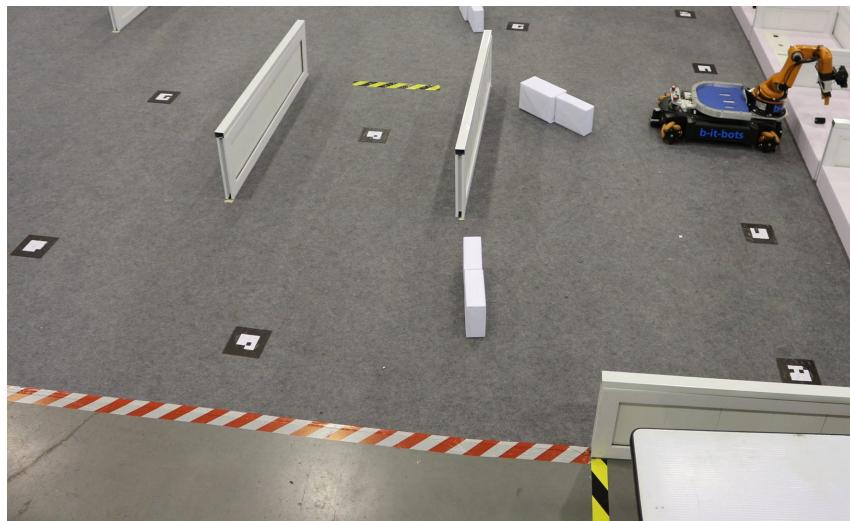


Figure 2.8: Example of barrier tape used during RoboCup 2015. The red/white tape is used for the entrance and exit, while the yellow/black one denotes an obstacle.

2.3.12 Setup of the Arena

The arena must be surrounded by either walls or barrier tape. The only exceptions are the entrance and exit. There must be a route to all places and markers relevant for a test which has a minimum width of 55 cm.

2.4 Design of Manipulation Tasks

2.4.1 Manipulation Objects

The manipulation objects in RoboCup@Work shall include a wide range of objects relevant in industrial applications of robotics. They eventually cover any raw material, (semi-)finished parts or products as well as tools and possibly operating materials required for manufacturing processes.

The intention is to start with a simple set of objects of different shapes and colors. Every year, the spectrum shall then be widen in at least one aspect. The initial set of objects includes basic standard screws and nuts in various sizes and weights as shown in Table 2.1 and Table 2.2. Objects of one kind can slightly vary e.g. considering the surface.

2.4.2 Manipulation Zone

The manipulation zone defines the area where objects can be placed. Thereby, the following constraints need to be satisfied:

Object	Symbolic Description	Weight	Details
	F20_20_B	49 g	Small aluminium profile (black) Height: 20 mm Width: 20 mm Length: 100 mm
	F20_20_G	49 g	Small aluminium profile (gray) Height: 20 mm Width: 20 mm Length: 100 mm
	S40_40_B	186 g	Big aluminium profile (black) Height: 40 mm Width: 40 mm Length: 100 mm
	S40_40_G	186 g	Big aluminium profile (gray) Height: 40 mm Width: 40 mm Length: 100 mm
	M20_100	296 g	Screw ISO 4014 M20 Length: 100 mm
	M20	56 g	Small nut ISO 4032 M20
	M30	217 g	Big nut ISO 4032 M30
	R20	14 g	Plastic tube Inner diameter: 20 mm Outer diameter: 30 mm Length: 45 mm

Table 2.1: RoboCup@Work manipulation object set.

Object	Symbolic Description	Weight	Details
	Bearing_Box	102 g	Bearing box Height: 25 mm Width: 45 mm Length: 50 mm Inner diameter: 32 mm
	Bearing	42 g	Bearing Height: 13 mm Inner diameter: 15 mm Outer diameter: 32 mm
	Axis	40 g	Axis Diameter: 27 mm Length: 96 mm
	Distance_Tube	5 g	Distance tube Height: 10 mm Inner diameter: 28 mm Outer diameter: 32 mm
	Motor	20 g	Motor Diameter: 42 mm Length: 87 mm

Table 2.2: RoCKIn manipulation object set.

- The maximum depth of the manipulation zone is 20 cm.
- The minimum distance between objects to each other is 2 cm.
- The minimum distance of the beginning of the manipulation zone to a wall is 10 cm.
- There is an offset of 2 cm from the border of the service area to the manipulation zone.

Note, the constraints do not permit, that objects can be partially occluded dependent on the viewpoint.

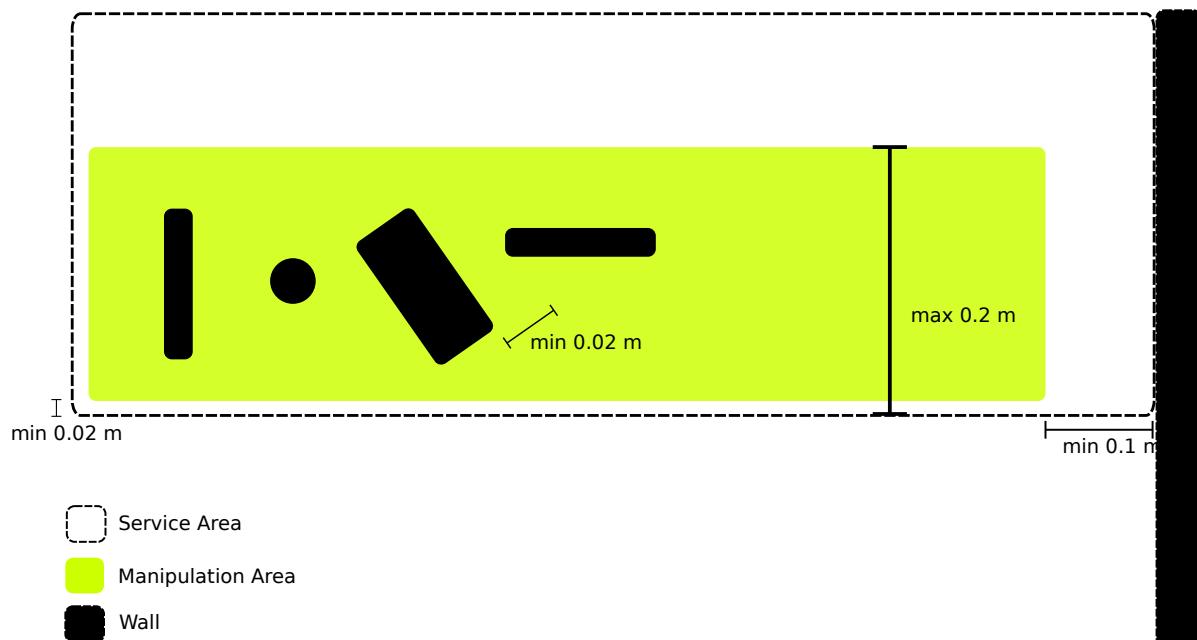


Figure 2.9: Manipulation zone: the green color indicates the area where objects can be placed on a service area by the referees.

2.4.3 Placement of Objects

For the placement of manipulation objects the following terms are used:

- Position: point within 2D coordinate system of a service area,
- Rotation: rotation around vertical axis of a service area,
- Orientation: rotation around horizontal axes of a service area, i.e. whether the object is standing upright or lying on its side
- Pose: combination of position, rotation and orientation.

2.4.4 Grasping Objects

If not specified differently in a test, the following definition applies to decide if an object counts as being grasped from a service area.

An object counts as grasped from a service area, when the object was moved outside of the source service area. Outside means, that the vertical projection of the objects convex hull does not touch the service area any more.

The last point shall enable to let the robot pick up an object in order to analyse its type, e.g. by holding it close to a camera on the robot.

If the robot handles an object, but does not fulfill all points above, the object does not count as being grasped, and neither points for grasping a required object, nor penalty points for grasping an unspecified object are given. Still, if the object drops to the ground or an uncontrolled collision occurs, the normal penalty points apply.

2.4.5 Placing Objects on Service Areas

If not specified differently in a test, a manipulation object counts as placed on a target service area if any part of the object is touching the surface of the service area and the object is not moving at the end of the run. An object does not count as placed when it is dropped (e.g. dropped from a height above 5 cm).

The pose of the object on the service area can be chosen freely by the robot.

Chapter 3

Tests

The actual competition contains a set of so-called tests. A test is specified in terms of it's purpose and focus, environment features and eventually manipulation objects involved. Further, a concrete specification of the task is given and the rules to be obeyed.

Each test has different variability dimensions. That is, which objects to be manipulated, how many locations to visit, from which height to grasp etc. These dimensions are described in Section 3.6 whereas in Section 3.7 test instances for 2016 are defined based on the general test description and instantiation of the variability dimensions.

3.1 Basic Navigation Test

Purpose and Focus of the Test The purpose of the *Basic Navigation Test* (BNT) is to check whether the robots can navigate well in their environment, i.e. in a goal-oriented, autonomous, robust, and safe way.

As the navigation problem is in the focus of robotics research for a long time and many approaches for solving it and its subtasks (like exploration, mapping, self-localization, path planning, motion control, and obstacle avoidance) exist, the focus of this test is to demonstrate that these approaches function properly on the robots used by the teams and in the environment defined by the test. The arena used for this test contains all elements that affect or support navigation: walls, service areas, places, arena objects, wall markers, and floor markers. In addition, obstacles may be placed in the environment.

Scenario Environment The arena used for this test contains all elements that affect or support navigation: walls, service areas, places, arena objects, wall markers, and floor markers. In addition, obstacles may be placed in the environment.

Manipulation Objects This test does not include any objects for manipulation.

Task For the navigation test, a single robot is used. The robot will be sent a task specification, which is a string containing a series of triples, each of which specifies a place, an orientation, and pause duration. The robot has to move to the places specified in the task string, in the order as specified by the string, orient itself according to the orientation given, cover a place marker, pause its movement for the time in seconds as specified by the pause length, and finally leave the arena through the gate.

The task specification consists of:

- A destination location, e.g. WS01, SH02, CB03 or WP12
- An orientation (N, S, W, E)
- A duration in seconds

The duration is always set to 3 seconds in order to make validation easier for the referees.

Rules The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- After the team's robot enters the arena, it must move to the places given in the task specification and assume the orientation specified after the place. The robot may reach a destination by choosing any path.

- The robot must visit the places in the order given by the task specification. It is possible to skip a place of the task specification and continue with the next one. In cases where the robot skipped one or multiple places there may be multiple possible matchings between places reached and places specified. In that case for calculating scores the matching is taken which leads to the highest score for the team.
- A destination is counted as reached when the robot covers the place marker as much as the complexity level demands. The orientation must not deviate more than 45 deg.
- When a destination is reached, the robot must stop its movement for the number of seconds specified by the break.
- The time is stopped when the robot has completed the task and left the arena. If the team cannot complete the task within the designated time, the run will be stopped.

3.2 Basic Manipulation Test

Purpose and Focus of the Test The purpose of the *Basic Manipulation Test* (BMT) is to demonstrate basic manipulation capabilities by the robots, like grasping, turning, or placing an object.

The focus is on the manipulation and on demonstrating safe and robust grasping and placing of objects of different size and shape. Therefore, only minimal movement of the robot is required.

Some minor movement is intentionally designed into this test in order to force the teams to perform dynamic assessment of the situation (e.g. estimating positions of manipulation objects, determining grasp positions, etc.) and to avoid that solutions depending on completely known initial situations and well-calibrated systems are possible.

Scenario Environment The arena used for this test contains basically all elements as for the Basic Navigation Test. Additionally to environmental elements (walls, service areas, floor markers, etc.), different manipulatable objects will be placed on the service areas.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 3.1.

Task A single robot is used. The robot can be placed in an arbitrary starting location by the team. The task consists of a sequence of grasp and place operations, with a small base movement in between. The objective is to move a set of objects from one service area into another. The task is finished once all objects are moved or when the time foreseen for the run ends.

The task specification consists of:

- The specification of the initial place (e.g. WS03, CB01, SH02)
- A source location, given as place (any one)
- A destination location, given as place (any one, but nearby the source location)
- A list of objects to manipulated from the source to the destination service area
- The specification of a final place for the robot (which does not need to be reached)

Rules The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- The team can setup the robot anywhere inside the arena.
- The robot will get the task specification from the referee box.
- A manipulation object counts as successfully grasped as defined in Section 2.4.4
- A manipulation object counts as successfully placed, if the robot has placed the object into the correct destination service area as described in Section 2.4.5.

- The time is stopped when the robot has completed the task by placing the last object of the task specification. If a team cannot complete the task within the designated time, the run will be stopped.

3.3 Basic Transportation Test

Purpose and Focus of the Test The purpose of the *Basic Transportation Test* (BTT) is to assess the ability of the robots for combined navigation and manipulation tasks. The robots have to deal with flexible task specifications, especially concerning information about object constellations in source and target locations, and task constraints such as limits on the number of objects allowed to be carried simultaneously, etc.

Scenario Environment The arena used for this test contains all elements as for the Basic Manipulation Test. Besides that all areas may contain objects.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 3.1.

Task A single robot is used, which is initially positioned outside of the arena near a gate to the arena. The task is to get several objects from the source service areas (such as SH02, WS09, or CB02), and to deliver them to the destination service areas (e.g. WS11 and SH05). Robots may carry up to three objects simultaneously.

The task specification consists of two lists: The first list contains for each service area a list of manipulation object descriptions. The descriptions are similar as those used for the Basic Manipulation Test. The second list contains for each destination service area a configuration of manipulation objects the robot is supposed to achieve. The configuration specification is similar as used in the Basic Manipulation Test.

The term line in the task specification can be ignored.

Rules The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- The robot has to start from outside the arena.
- The robot will get the task specification from the referee box.
- After the team's robot starts, it must move into the arena and attempt to complete the task.
- A manipulation object counts as successfully grasped as specified in Section 2.4.4.
- A manipulation object counts as successfully placed, if the robot has placed the object into the correct destination service area as described in Section 2.4.5.
- It is not allowed to place manipulation objects anywhere except for the robot itself and any of the available service areas.
- A robot may carry up to three objects at the same time.

- The time is stopped when the robot has completed the task (delivered all objects to the right locations and left the arena through the exit gates). If a team cannot complete the task within the designated time, the run will be stopped..

3.4 Precision Placement Test

Purpose and Focus of the Test The purpose of the *Precision Placement Test* (PPT) is to assess the robot's ability to grasp and place objects into object-specific cavities. This demands advanced perception abilities (to recognize the correct cavity for each object) and manipulation abilities (to grasp and place the object in such a manner that it fits into the cavity).

Scenario Environment The same arena as for the Basic Manipulation Test is used whereas the plane of one service arena includes object-specific cavities as shown in the Figure 3.1. For each object used in the test, there will be one specific cavity. The cavity has the dimension of the object plus a 2 mm offset for each dimension. At most five cavities are used in the test.

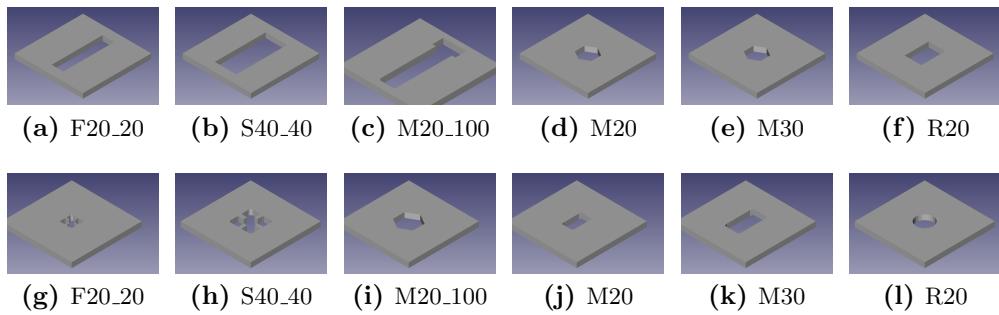


Figure 3.1: Illustration of horizontal (top row) and vertical (bottom row) cavities for the different kind of manipulation objects.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 3.1.

Task A single robot is used. The robot is placed by the team freely within the arena. The objective of the task is to pick the objects which are placed on one service area and make a precise-placement in the corresponding cavity at the service area with the special PPT platform (an example configuration is illustrated in Figure 3.2).

The task consists of multiple grasp and place operations, possibly with base movement in between, which will, however, be short. The task is finished once the objects are picked up and placed in the corresponding cavities or when the time foreseen for the run ends. Note that the placement of the object in the cavity is finished when the object is fallen into the cavity (i.e. at least some part of the object has to touch ground floor underneath the cavity).

All objects to be transported in a run of a team and the corresponding cavities share the same orientation, either horizontal or vertical. This may vary between different teams and different runs.



Figure 3.2: The PPT platform including five cavity tiles

Rules The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- The robot will get the task specification from the referee box.
- A manipulation object counts as successfully grasped as specified in Section 2.4.4.
- An object counts as placed correctly if it fell through the correct cavity and touches the ground beyond. It may happen that an object blocks the cavity for the next object, e.g. by standing upright on the floor. In that case a referee may remove that object (which remains to count as a successful place). If the referee is not able to do so and the robot places another object into the blocked cavity, it counts as a correct placement if it would have been successful without the blocking object.
- The time is stopped when the robot has placed the last object correctly. If a team cannot complete the task within the specified time, the run will be stopped after it is exceeded.

3.5 Conveyor Belt Test

Purpose and Focus of the Test The purpose of the *Conveyor Belt Test* (CBT) is to assess the robot's ability to manipulate moving objects which are placed on a conveyor belt and/or rotating turntable. The test demands fast perception and manipulation skills in order to pick up objects from a moving surface.

Scenario Environment The same arena as for the Basic Manipulation Test is used. In case that the arena does not already includes such a device (see Figure 3.3), it will be added only for this particular test. The OC may choose to use a rotating turntable instead of a linear conveyor belt in order to simplify the setup of the arena. The particular choice shall be announced before the competition. An area besides the conveyor belt is left free so that a robot can drive there and grasp the objects from the belt. The other sides might not be accessible, because the device is placed into a corner. The conveyor belt should have a wireless mechanism to turn it on.



Figure 3.3: Illustration of a conveyor belt and rotating table used in the competition.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 3.1.

Task A single robot is used. The robot is placed by the team in some starting position outside of the arena. Initially the conveyor is switched off (i.e. the belt is not moving) and all objects are put on the belt with a distance between them determined by the TC. The task of the robot is to navigate to the location of the conveyor belt and to grasp all objects from the moving belt before they fall off at the other end of the belt. If a turntable is used, the objects can pass multiple times in front of the robot, until the maximum time for the run is over. The robot is supposed to place the grasped objects on the robot itself. The task is finished once the robot successfully grasped all objects or the foreseen time of the test has been exceeded.

There are two options to determine when to switch on the conveyor belt: The robot starts it itself, using the wireless mechanism or a team member can give a signal to the referees to switch

on the conveyor belt.

Teams can decide during the run to give the signal to the referees, e.g. when the robot failed to start it itself.

Rules The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- The objects are placed on the conveyor before the run starts
- The robot will get the task specification from the referee box.
- After the team's robot starts, it must move inside the arena.
- Either the robot itself starts the conveyor belt, or a team member can give a signal to the referees to switch on the conveyor belt..
- The objects have to be grasped actively from the moving belt. The robot is not allowed e.g. to wait at the end with a particular basket and collect the falling objects from the end of the conveyor belt. Further, wiping the objects to the side is also not allowed.
- A manipulation object counts as successfully grasped, if the robot has lifted the object and moved it outside of the area of the conveyor belt as specified in Section 2.4.5.
- The time is stopped when the robot has completed the task.

3.6 Test Variability

The different optional parameters and configurations for each task are mentioned in Section 2.3 and 2.4. Figure 3.4 summarizes the possible variations and emphasizes aspects that may be chosen.

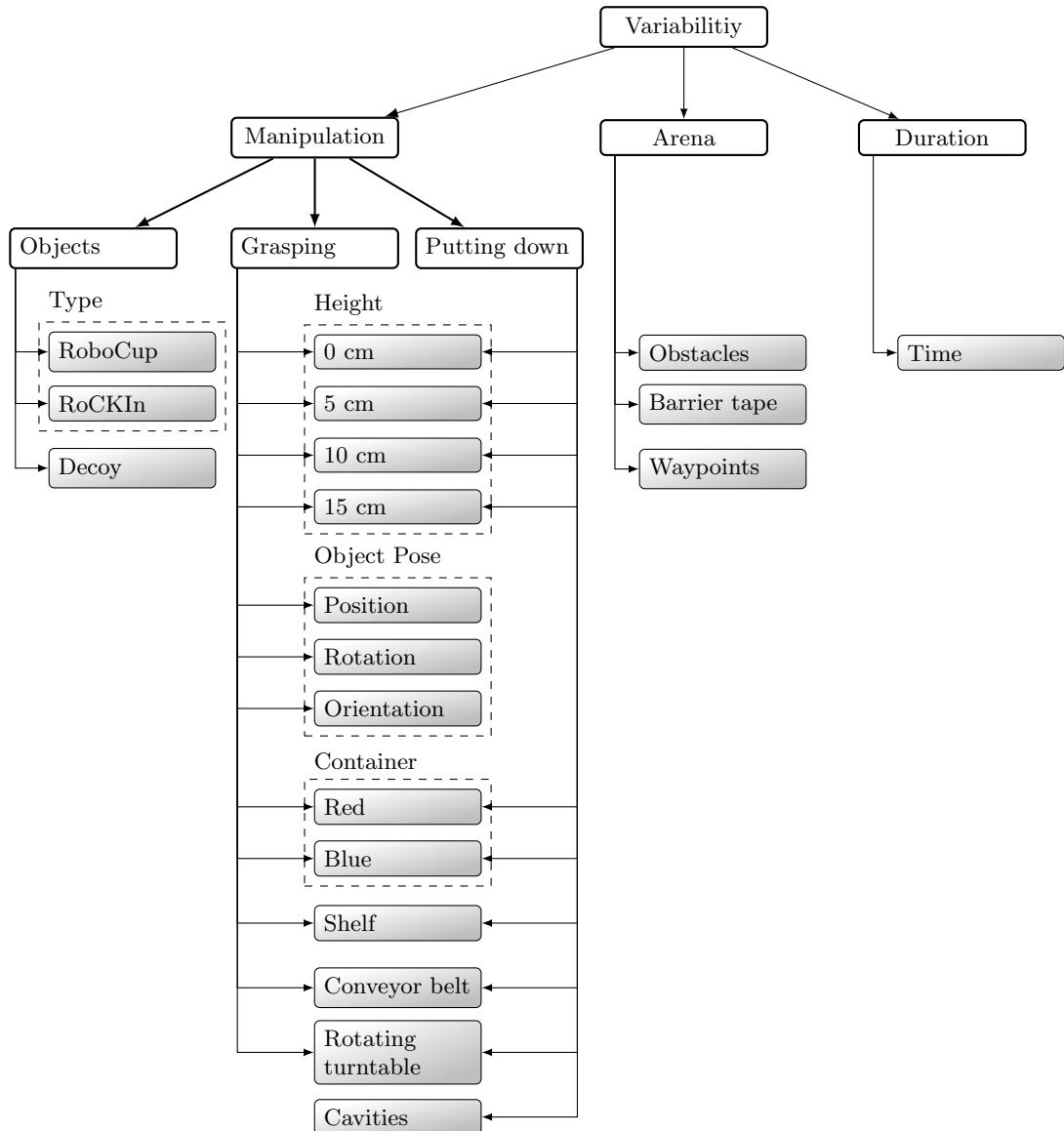


Figure 3.4: Aspects of variability that maybe integrated in a specific instance of a test.

3.7 Test Instances 2016

The following instances may occur as an instance of the run. Ranking of the teams will be based on the sum of the achieved points in all the tests.

			Instances									
			(1) BNT	(2) BMT	(3) BTT1	(4) BTT2	(5) BTT3	(6) PPT	(7) CBT1	(8) CBT2	(9) Final	
Manipulation	Objects	RoboCup@Work	RefBox		3	5	2	4	3	3	3	5
		RoCKIn	Team		2							
			RefBox				3	3			5	
	Grasping	Decoy	RefBox			3		3				5
		Height	RefBox		10 cm	10 cm	10 cm	0 cm 10 cm 15 cm	10 cm			0 cm 5 cm 10 cm 15 cm
		Shelf unit	RefBox									2
		Position	Referee	●	●	●	●	●	●	●	●	
		Rotation	Referee	●	●	●	●	●	●	●	●	
		Orientation	Team	●	●	●	●	●	●	●	●	
		Conveyor belt	RefBox							3		
Putting down	Arena	Rotating turntable	RefBox							3	1	
		Height	RefBox		10 cm	10 cm	10 cm	0 cm 10 cm 15 cm	10 cm			0 cm 5 cm 10 cm 15 cm
		Shelf unit	RefBox				1					1
		Cavity platform with decoy	RefBox						●			1
		Red container	RefBox				1	1				1
		Blue container	RefBox				1	1				1
		Rotating turntable	RefBox				1	1				
Duration	Arena	Obstacles (static)	Referee	2			2	2				2
		Barrier tape	Referee	2		1						2
		Waypoints	RefBox	9								
Duration			RefBox	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	10min

Table 3.1: Instances of the RoboCup@Work 2016 competition (The OC will choose the runs among this selection).

	Instances								
	(1) BNT	(2) BMT	(3) BTT1	(4) BTT2	(5) BTT3	(6) PPT	(7) CBT1	(8) CBT1	(9) Finals
correct destinations reached	50								
correct object grasping		100	100	100	100		300	300	100
correct object placing		100	100	100	100	300			100
completing whole task	50	100	100	100	100	100	100	100	100
maximum attainable points (time bonus not included)	500	1100	1100	1100	1500	1000	1000	1000	2100

Table 3.2: Instances of the RoboCup@Work 2016 competition (The OC will choose the runs among this selection).

Chapter 4

Open Source Award

4.1 Introduction and Motivation

In order to foster the development of new teams and to increase cooperation among established teams, the league announces an Open Source Award. As demonstrated in other RoboCup major leagues, releasing software and/or hardware as open source fosters the overall progress of the league. Similarly, to other open source awards in RoboCup, all institutions, persons and teams who took part in national and international RoboCup@Work competitions in 2016 or the previous year are eligible to participate.

4.2 Application

The application should contain the following items:

- A technical report and description (max. 8 pages in Springer LNCS style) about the open source artifact (software/hardware or both). The report should briefly describe the open source project objectives, design decisions and most importantly should exemplify its importance for the RoboCup@Work competition and community.
- A online reference, documentation, tutorial (e.g. website, Github page etc.) for the presented open source material. This includes also statements about licensing (e.g. which kind of open source license such as GPL, LGPL, Apache, etc.) and usage.

Application deadline is the: 01.05.2016. Application material needs to be send via email to: rc-work-tc@lists.robocup.org. Please note, in case the evaluation committee receives only applications which do not fulfill the desired level of quality, the award will not be given in 2016. The winner(s) will be announced during the RoboCup 2016 award ceremony.

4.3 Evaluation

Evaluation is performed by an external jury chosen by the EC and TC. The evaluation criteria are the following:

- Relevance: *Is the presented material relevant for RoboCup@Work? Can the material be applied in the context of RoboCup@Work?*
- Originality: *Does the presented material solve a problem/issue in RoboCup@Work in a very appealing, general approach?*
- Technical Quality: *Is the presented material well-designed and well-developed. This also includes coding style etc.?*
- Presentation: *Is the presentation of the material appealing and complete for RoboCup@Work purpose?*

Chapter 5

Technical Challenges

In order to value very specific capabilities required in RoboCup@Work technical challenges are part of RoboCup@Work. These challenges are designed to be included into the mayor competition after they have shown a potential as a benchmark in industrial robotics and have been at least solved in principal. Each technical challenge is separately awarded. That means, teams can solely participate in the challenges without competing in the main competition.

5.1 Basic Assembly Test

In order to foster the development of the league and expand towards more complicated domains, an assembly challenge will be held. The focus is to show new and challenging aspects of assembly which can be performed by small service robots.

5.1.1 Purpose and Focus of the Test

The purpose of the *Basic Assembly Test* (BAT) is to demonstrate basic assembly capabilities by the robots, like combining objects, by fitting or attaching them together. The focus is on the manipulation towards assembly, e.g. force fitting or the preparation of objects to be attached by e.g. external devices and machines. This can include holding an object in place for another robot, machine or human to assemble it.

5.1.2 Scenario Environment

The arena used for this test contains all elements as for the Basic Navigation Test. In addition to environmental elements (such as walls, service areas, floor markers, etc.), different manipulatable objects will be placed on the service areas. On top of the service area, a car model will be mounted and fixed, so that the robot will not be able to move the car (see Fig 5.1). The axle will be red, the tire blue and the car model will be neither.

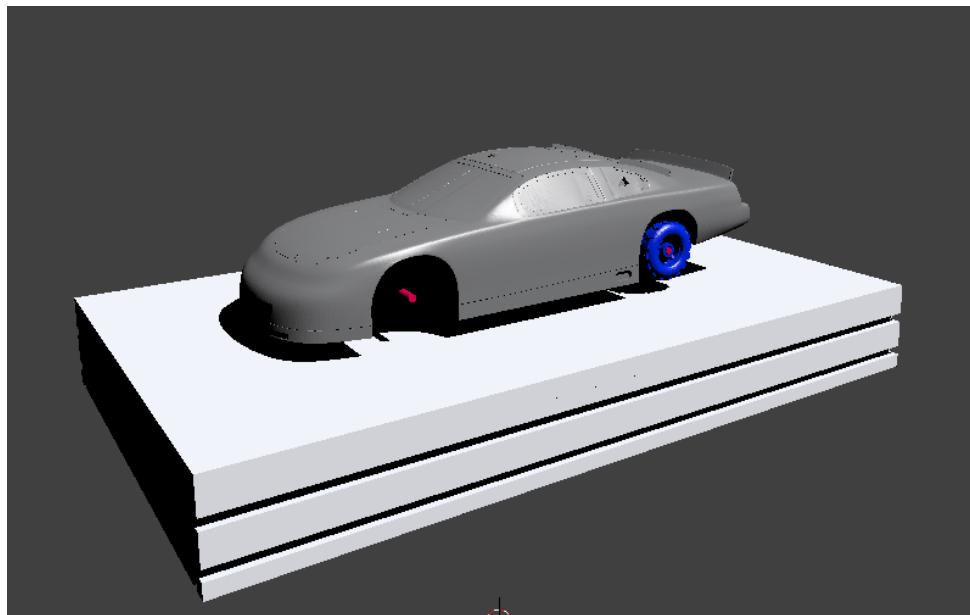


Figure 5.1: A example scene for the Basic Assembly Test. The actual car model may differ, but the wheels (*blue*) need to be fitted onto the axes (*red*).

5.1.3 Manipulation Objects

The manipulation objects in this test may include the objects specified in Table, as they can still be inside of the arena and function as decoy objects. [2.1](#). The set of objects is extended by:

All objects can be printed using a 3D-printer (e.g. axis and wheel), the car model is only for visualization purposes. All parts are available as STL files in the official RoboCup@Work *model* repository (see Section [1.2.2.1](#)).

5.1.4 Task

A single robot is used. The task consists of a sequence of assembly operations, with a small base movement in between. The objective is to collect a set of objects and perform an assembly option. The robot will be given instruction where to pick up the wheels and where to assemble them. The task is to fit the wheels onto the axes. The wheels and the axes need to be detected by the robot. A few wheels may be already assembled. Therefore it is necessary to detect where a wheel is still missing. The wheels designated for assembly will lie flat on the service areas.

The task specification consists of:

- Location(s) of the wheels
- Location(s) where the assembly takes places

5.1.5 Rules

The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- At the beginning of a team's period, the team will get the task specification.
- The team must set-up the robot in the designated start area.
- An assembly object counts as successfully assembled when it is attached to the correct object or is in place for the external device to perform the assembly.
- An assembly objects counts as assembled wrong when it is assembled wrong (e.g. fitting a second tire on one axle)
- The maximum time and the number of assemblies to be performed will be determined during the event by the TC.

5.1.6 Scoring

Points are awarded as follows:

- | | |
|---------------------|-------------|
| • correct assembly: | 100 points |
| • wrong assembly: | -100 points |

	Symbolic Description	Weight	Details
	T50	20 g	Radius: 50mm Height: 34mm

Table 5.1: Examples of assembly objects

Abbreviations

BAT	Basic Assembly Test	50
BMT	Basic Manipulation Test	34
BNT	Basic Navigation Test	32
BTT	Basic Transportation Test	36
CBT	Conveyor Belt Test	40
EC	Executive Committee	7
OC	Organizing Committee	7
PPT	Precision Placement Test	38
ROS	Robot Operating System	19
TC	Technical Committee	7
TDP	Team Description Paper	10

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