RoboCup@Work

Rulebook

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In July 2019 our league lost one of the initiators and founding members. Prof. Dr. Gerhard Kraetzschmar has been very active in many functions within the RoboCup-Community for decades. We are grateful for his efforts, advises and motivation and will respect his memory.

How to cite this rulebook

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```
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  author = {Asadollah Norouzi, Sebastian Zug, Deebul Nair,
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}
```

Contents

Chapter 1

Summary of Changes

This chapter provides an overview for experienced teams that know the rules and just need an update on what is new for the specific year. All new teams are strongly advised to read the whole rule book thoroughly.

1.1 Changes 2022

[Martin] Changes:

- Added siunix-package in preamble
- Added caption option in todonote in preamble
- Added Rotating Table description, and drawing
- Updated Shelf description, and drawing
- Added some labels
- Added Final in tests chapter (was already written)
- Containers descriptions and example, moved to manipulation
- object description and printed rocking objects
- new objects

1.2 Adjustments for the virtual RoboCups

Due to the Covid-19 pandemic, the 2020 and 2021 international robocups are cancelled. Some of the leagues, including the RoboCup@Work league, will be held online. As this brings new challenges for the teams (e.g. arena building) and the committees (comparing teams and scoring), the technical committee decided to set some rules regarding the arena setup, scoring, general participation rules and the Technical Challenges.

These can be found in chapter 6.

1.3 General Changes

- BNT will be excluded from the instance list. According to the adapted scoring of the last year (rewards for reaching correct destinations) a separate run focusing on navigation is not necessary anymore.
- The preparation time was increased to 3 minutes (1 minute in 2019).
- The classification of a collision (major/minor) is more specific now (see 5.1).
- The Referee Box avoids object distribution patterns, where one manipulation zone is target AND source of a transportation task
- The minimum passage width of 80cm was clarified in Section 3.3
- The meaning of the different types of tape in the arena was modified. Please review Sections 3.3, 5.3 and 5.4

1.4 Robot Requirements

- The size constraints for the robots were removed to allow more versatile robot designs. However, the arena specification declares 80 cm as the minimum distance between fixed arena elements. Teams with bigger robots will have disadvantages regarding navigation, as they may get stuck in narrow arena passages. See 3.1.1.
- A more precise definition of the emergency (hard) stop was defined.
- A cap on the battery capacity of 500Wh was given
- A speed cap of 1.5m/s was introduced for safety

1.5 Team Requirements

- All teams are required to bring appropriate storage equipment(e.g. lipo bags) for their batteries to the competition
- All teams must educate their team members in correct battery usage

1.6 Scoring

- The penalization of barrier tape was changed to a relative deduction. Barrier tape now induces a 5% penalty on the final points of the run, up to 20%.

1.6.1 Technical Challenges

- The Cluttered Pick Test was more clarified. The test involves now picking **and placing** of three objects. Also Points for navigation are not given anymore.
- Another challenge regarding the definition of a uniform simulation environment was added.

Chapter 2

Introduction

2.1 RoboCup@Work in a Nutshell

RoboCup@Work is a 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

Please use the following citation for RoboCup@Work:

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@InCollection{Kraetzschmar2014,
  Title = {RoboCup@Work: Competing for the Factory of the Future},
  Author = {Kraetzschmar, Gerhard K. and Hochgeschwender, Nico and Nowak, Walter
  and Hegger, Frederik and Schneider, Sven and Dwiputra, Rhama and Berghofer, Jakob
  and Bischoff, Rainer},
  Booktitle = {RoboCup 2014: Robot World Cup XVIII},
  Publisher = {Springer International Publishing},
  Year = {2015},
  Editor = {Bianchi, Reinaldo A. C. and Akin, H. Levent and
  Ramamoorthy, Subramanian and Sugiura, Komei},
  Pages = {171-182},
  Series = {Lecture Notes in Computer Science},
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}
```

2.2 Organization of the League

2.2.1 League Committees

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

2.2.1.1 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:

- Asadollah Norouzi, *Singapore Polytechnic*
- Christoph Steup, *Otto von Guericke University Magdeburg*

2.2.1.2 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:

- Marco Masannek, *Nuremberg Institute of Technology*
- Lucas Reinhart, *University of Applied Sciences Würzburg-Schweinfurt*
- Kenny Voo, *Nanyang Technological University*
- Martin Sereinig, *University of Innsbruck*
- Leander Bartsch, *Otto von Guericke University Magdeburg*

2.2.1.3 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:

- Franziska Labitzke, *Otto von Guericke University Magdeburg*
- Hauke Petersen, *Otto von Guericke University Magdeburg*
- Sally Zeitler, *Nuremberg Institute of Technology*
- Yusuf Pranggonoh, *?*

2.2.2 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.

2.2.2.1 Infrastructure Maintained by the League

Website The official website of RoboCup@Work is at

https://atwork.robocup.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 3D models for the manipulation objects, their corresponding PPT cavities, and all arena elements. Additionally, the sources to this rulebook, the implementation of the referee box, and various tools can be found.

2.2.2.2 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.

2.3 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.

2.3.1 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, a promotional videos and possibly additional material like designs or drawings
3. Final registration (qualified teams only)

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

2.3.2 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 promo video
- Team web site

2.3.3 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. Alongside the TDP, the TC will - starting 2019 - also require a video file presenting the robot, see Section 2.3.4.

2.3.4 Promotional Video

In order to better judge the quality of a team's qualification, the TC asks every team, established or new, to submit a video file describing the robot and its design. The video should clearly demonstrate the robot's ability to perform the tasks required in the challenge, such as autonomous navigation, picking, and placing. Desired elements include visualizing the sensory capabilities of the robot, i.e., seeing what the robot sees, and the plan currently followed by the robot. Spoken language/an audio stream is not required. Ideal video resolution is 1080p with a 16:9 ratio. For large files, please provide a download link. This file will also be played as explanatory and promotional material during the competiton.

2.4 Organization of the Competition

2.4.1 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. Furthermore, each team is asked to provide a member able to answer interview questions about the team and the robot during the team's run. This member may be the same person as the referee, in order to not further strain small teams.

2.4.2 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. The OC provides a power supply and LAN switch connecting team laptops, refbox and robots in the competion arena in order to reduce the preparation effort for the teams.

2.4.3 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.

2.4.4 Common Procedures

One hour before a test the OC requests the capability of each team to participate. This decision is binding, i.e., withdrawn teams can not decide to participate after all. The order in which the teams perform is determined randomly by the OC. The particular ordering will be made public at least 45 minutes before the start time of the specific test.

A run is preceded with a 3 minutes preparation time. This time begins once the previous team has left the arena. During preparation time, team members are allowed in the start area to set up their robot, and one team member may check the correct set-up of the arena, as well as position objects that are to be positioned by the team.

The preparation time starts as soon as the previous team has left the arena. If the preparation time runs out, the run time will start automatically. Once a team is ready and the robot is connected to the refbox, the team leader signals that the robot is ready, and the run starts. In case the referees still block the arena, the preparation time is stopped at zero seconds, meaning the team has to leave the start area, but the run time does not start yet.

Upon start of the run, 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, it is the team's resposibility to check if the arena is set up correctly (e.g. all manipulation objects are placed according to task specification, obstacles are placed according to the rules). Teams are encouraged to setup their robots as much as possible during the run of the preceeding team or even before the test, including localization and testing basic functionality. However, the team should only connect to the refbox once their preparation time starts.

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 all the tasks have been finished by the robot,
- when the referees decide to stop it, or
- when the team leader of the performing team decides to abort the run.

During a run, teams may only interact with the robot or enter the arena 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 by the referees. This includes repeating the same behavior, standing still, or not leaving the start arena due to lack of preparation or connection issues.

After each run, the teams must leave the arena immediately.

2.4.5 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.

2.4.6 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.

2.4.7 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.

2.4.8 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 then one WLAN (e.g. one per arena).

2.4.9 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 5.1, 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 3

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.

3.1 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.

3.1.1 Design and Constraints

There are no constraints regarding the size and weight of the used robots, but that they have to fit in the arena defined in section 3.3. The minimum passage width is 80cm. The used robots must be able to maneuver in that space.

The used batteries may not exceed 500Wh of capacity for safety. 300Wh of capacity is recommended. See subsection 3.1.2 as well.

The maximum speed of the robots may not exceed 1.5 m/s. The robot should also be able to halt in a reasonable space on concrete floor.

All robots must have an emergency stop button. The emergency stop has to be a hard stop mechanism, that ensures that the energy transfer to all actuators is stopped immediately and the robot halts. The mechanism must be a red emergency stop button that is clearly visible, easily accessible and per wire attached to the robot. A wireless emergency stop button is optional but not sufficient. 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.

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:

- 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 40 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.

3.1.2 Behavior and Safety

For safety the robots have to meet the constraints in section 3.1.1. 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.

The used batteries shall be handled with care and all team members must be educated in the correct usage, charging and storage of the batteries of the team. For lithium batteries appropriate storage bags must be used by the teams. The OC supplies a fire extinguisher for lithium batteries at the competition. If this is not sufficient for the used batteries of a team. The team is responsible for supplying an appropriate fire extinguisher by themselfs. The OC and TC control the observance of this rules.

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.

3.2 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 (indicated by a sound signal of the refbox).

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 a reference implementation. The Referee box implementation and its documentation is available under the following link:

https://github.com/robocup-at-work/atwork-commander

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.

3.3 Design of the Environment

The competition is held in an arena resembling an example layout of industrial manufacturing facilities. The arena is a static 2D environment consisting of walls, tables and obstacles with a size of atleast 10 m^2 and not more than 120 m^2. An example layout is shown in fig. 3.1.

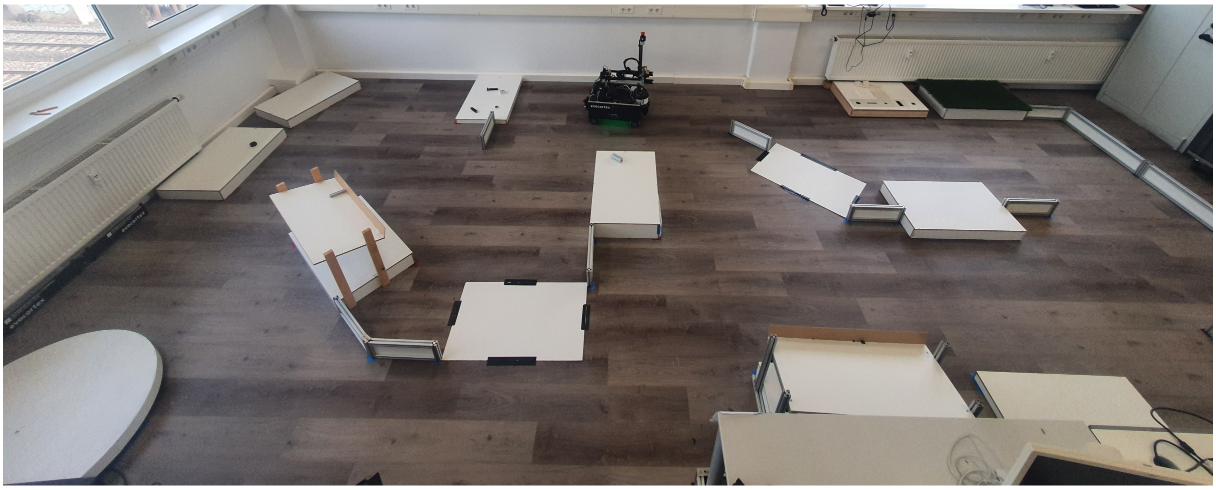


Figure 3.1: An exemplary setup of a RoboCup@Work environment.

Layouts may include rooms and hallways to create more realistic scenarios. Service areas (see section ??) mark the locations for robots to perform tasks. Each requested service area must be accessible via atleast one path of 80 cm width.

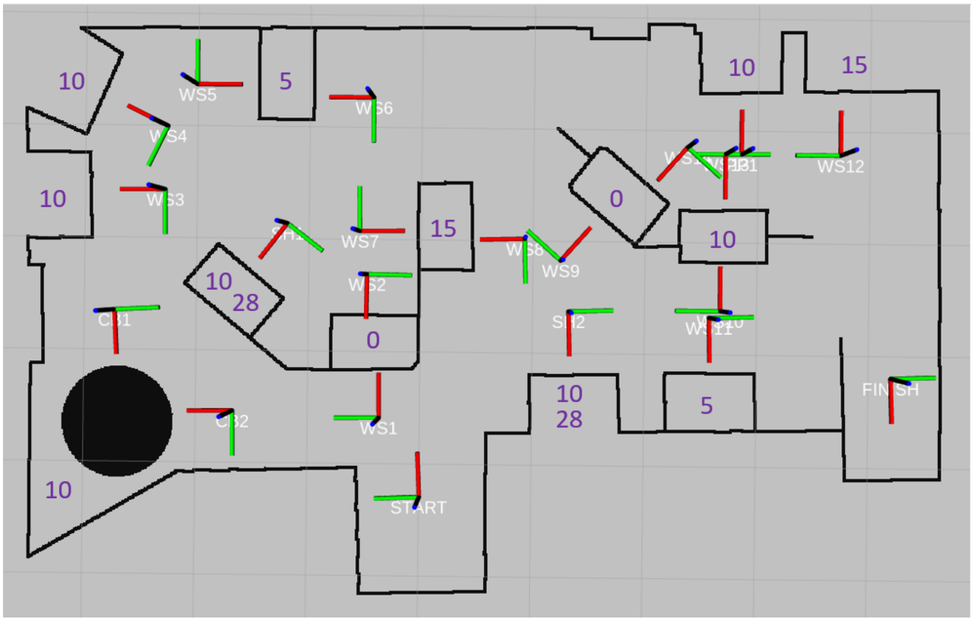


Figure 3.2: Annotated 2D map of the environment in fig. 3.1

Each competition has a new and unique layout designed by the actual TC members. It should feature:

- Area 10 m^2 - 120 m^2
- Minimum distance between arena elements atleast 80 cm
- Widespread service areas entailing robot movements
- Multiple paths between service areas
- Start and Finish areas

3.3.1 Service Areas

A service area indicates a location for a robot where tasks (e.g. picking or placing objects) have to be performed. Such a location is usually a table with a flat white top (see fig. 3.1), but can also be a rotating table, shelf, precise placement station or any other type needed for a specific task. In order to successfully reach a service area, robots must position themselves in front of the service area in a way that allows manipulation of the objects of interest. To enable robots to reach such a position, a rectangular area with 80 cm width must be kept free of obstacles (see fig. XX TODO).

The arena layout must define where the "front" of a table is. Figure 3.2 gives an example for the definition of the position of each service area, marking them as WSx (Workstation x), SHx (Shelf x) and CBx (Conveyor Belt x). The orientation only indicates the direction of the service area. It does not specify the robot's heading, which may be chosen by teams according to their individual robot design.

Tables that can be used from both sides (see fig. 3.1) are sometimes defined as two seperate workstations (e.g. WS5 & WS6). However, manipulation of a service area requires the robot to have its center in the rectangular area defined in fig. XX TODO. This means that manipulation of the opposite service area is NOT allowed (see 3.5.1), even though it would be physically possible. This rule also applies to the two positions for the rotating table (CB1 and CB2). This makes smaller physical layouts possible that still provide the ability to create complex navigation challenges due to the amount of locations to visit.

Two special service areas are the START and FINISH positions. Both are rectangular areas for the robot to be positioned at the start or the end of a run. The service areas are marked using tape that may be crossed and are optionally equipped with light barriers used for time keeping.

3.3.2 Walls and virtual Walls

The arena consists of outer and inner walls used to build structures, create obstacles or function as protection barriers for teams and viewers. Walls may be either physical (plank) or virtual (tape). The arena is completely enclosed by walls (both types!), meaning robots are not allowed to exit the arena during a run.

The height of a physical wall must be not less than 20 cm and no more than 40 cm. Most walls have a uniform main color (white), but may be enforced by metal (aluminum framework) and decorated with sponsor logos or ads.

Virtual walls are made of red and white tape (Tesa signal red/white) of 5 cm width. This tape may never be crossed during a run and is mainly used to close gaps in the physical outside walls.

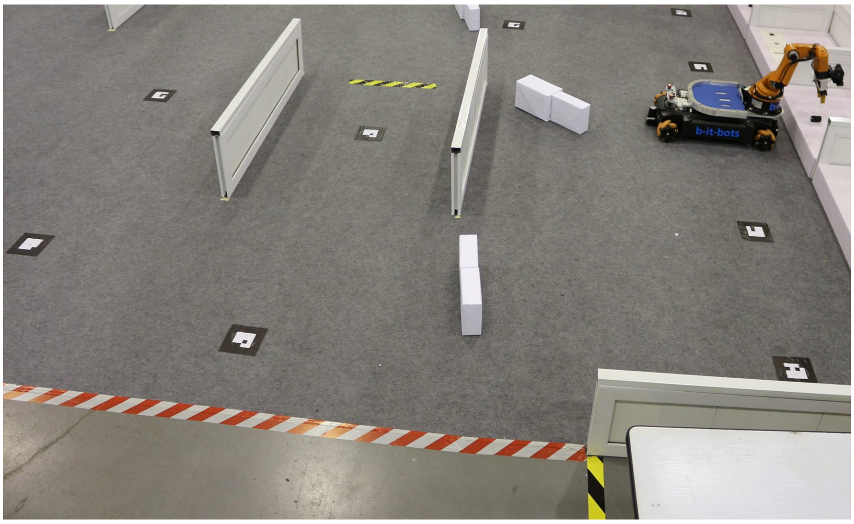


Figure 3.3: Example of barrier tape used during RoboCup 2015. The red/white tape is used to indicate virtual walls , while the yellow/black one denotes a virtual fence.

Figure 3.3 also shows black and yellow tape (Tesa signal black/yellow). This tape is referred to as 'Barrier Tape' and marks virtual fences. Such tapes are mainly used inside the arena to add obstacles.

3.3.3 Obstacles

In addition to the static arena elements, semi-dynamic obstacles may be placed inside the arena before a competition run begins. The position of such obstacles is decided by the referees during the setup phase of the run and randomized between different run types.

Obstacles may block paths partly or completely, as long as all active service areas are still reachable. There are three main obstacle placement types:

- **Blocking:** A narrow section is completely blocked by the obstacle, which means that no robot can physically pass it (< 20 cm).
- **Semi-Blocking:** The obstacle reduces the distance between arena elements below the minimum width for a path. The path therefore counts as blocked, meaning that there must exist another valid path to all active service areas. Robots are still allowed to use all paths if they fit through the smaller gaps.
- **Non-Blocking:** The obstacle adds or enlarges an arena element but keeps all paths intact.

Obstacles can be either physical or virtual. Physical obstacles measure atleast 2 x 2 x 20 cm (l x b x h) and may be made of any non-transparent, firm material (wood, metal). Some examples are bins, shipping boxes and wall elements. Their color is not specified. All physical obstacles are treated like any other arena element during a run, including the rules for collisions.

Virtual obstacles are marked using the Barrier Tape from section 3.3.2. These virtual fences recently have been introduced to the league, which is why collisions with them are treated differently (see REF SCORING).

3.3.4 Arena Element Specifications

3.3.4.1 Markup Tape

LEANDER

Used to mark tables, start fin etc.

3.3.4.2 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 3.4. Floors may neither be made of loose material of any kind (gravel, sand, or any material which may damage the functioning of the robot's wheels) nor may such 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 3.4: Examples of floors that can be used for RoboCup@Work arenas.

3.3.4.3 Workstations - TODO

However, from 2020 on and in order to make the competition more realistic, the heights of the service areas will be variable, allowing the OC to adjust them before each test run. If a service area has a height of zero cm, a tape will mark the area (see Figure 3.5). The tape will be on the floor and will be blue/white striped. The surounded area may be covered by a white sheet of paper fixed by the tape. The OC is responsible to replace it in case of pollution or tears. This tape may be crossed, and does not count as a collision. If the robot touches a manipulation object while navigating, this will be handled as a collision.

Figure 3.5: Barrier tape used to mark service areas with 0 cm height.

Until 2017, service areas have always been represented by white coloured surfaces with no other decoy objects on it than the official ones in Tables 3.1 and 3.2. However, this does not represent real life scenarios. The robot might have to pick objects from different colored or dirty places. Also there could be other industrial items on the surface area that the robot must avoid. In order to make the operating environment more realistic, different kinds of arbitrary surfaces (Figure 3.6) with decoy industrial items (Figure 3.7) have been introduced. To facilitate the participation of newer teams that are yet focused on more basic functionalities, the integration of arbitrary surfaces is by now limited to:

- One service area during the BTT1.
- Two service areas during the BTT2.
- Two service areas during the BTT3.
- Three service areas during the final round.

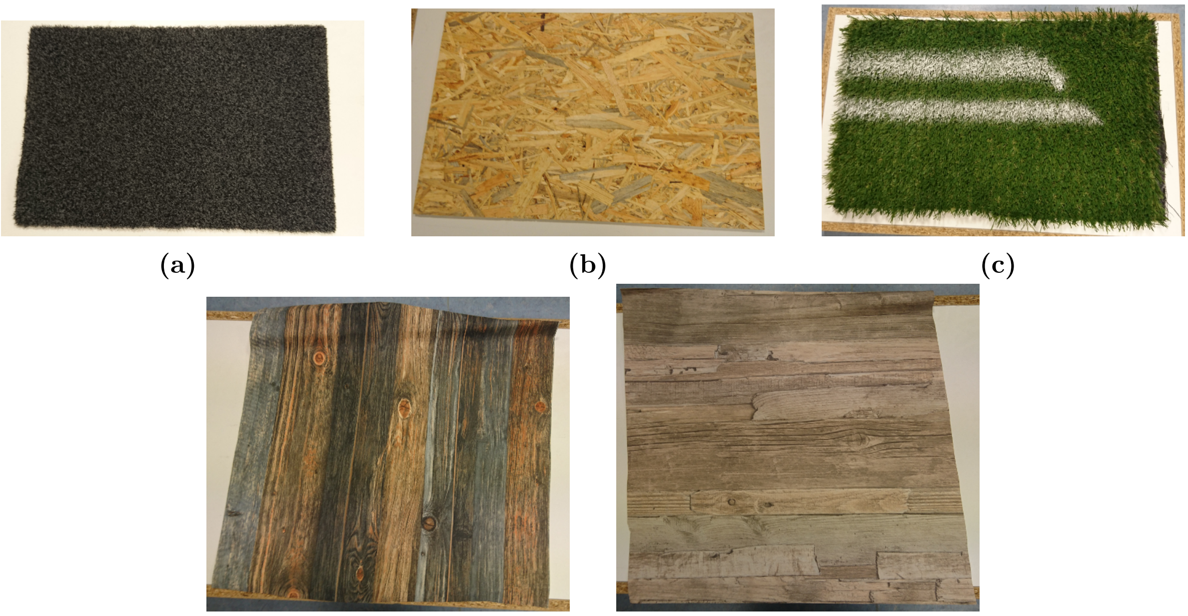
3.3.5 Shelves

In Basic Transportation Test three and the final runs (BTT3 in 4.3, finals 4.6) Service areas may foresee the use of shelves and shelf units as depicted in Figure 3.8.

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 be more than 40 cm.

The workspace on the bottom shelf is considered like a standard workspace on a 10cm table. The first 15cm $\pm$ 2cm has not to be covered by the top shelf.

The top shelf surface may be specially designed in order to serve specific purposes, e.g. holding objects. Objects to pic up are always placed on the bottom shelf, during the competition a placement of a delivered object has to be done on the top shelf.



(a) (b) (c)

(d) (e)

Figure 3.6: Examples of arbitrary surfaces used for service areas.

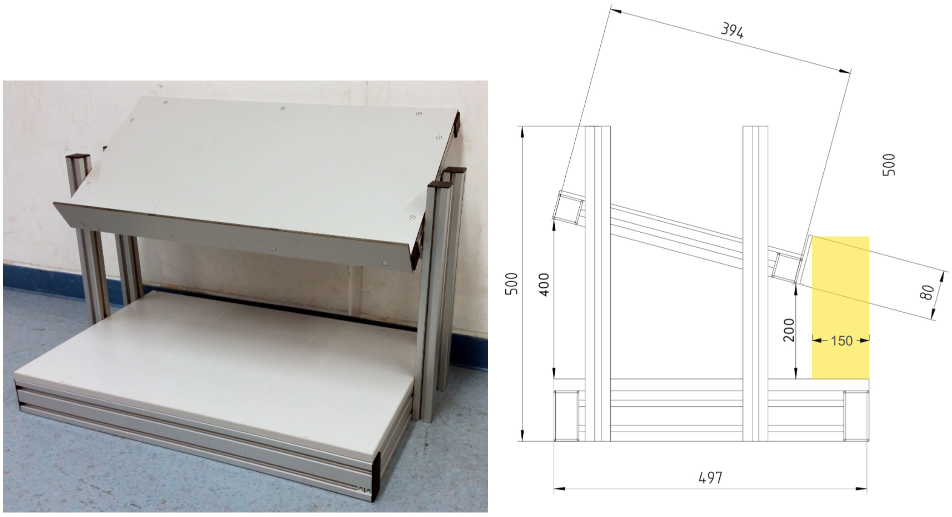
(a) (b)

Figure 3.7: Examplary configuration of the working desks

3.3.6 Rotating Table

[Martin] minimum and maximum speed has to be discussed

For the Rotating Table Test (RTT in Section 4.5) a rotating table as depicted in Figure 3.9 is used. Objects to be removed from the table have to be placed with a boarder of 2cm in a so defined grasp region. The height of the table should be not lesser than 8cm and not be more than 12cm. The diameter of the table should be not lesser than 50cm and not more than 100cm.



(a) A shelf with two levels and uniform colored surfaces. (b) Technical draw of shelf configuration.

Figure 3.8: Exemplary shelf and generic technical drawing.

The table has to have a white surface colour. The rotating speed of the table depends on the diameter. The objects speed should be able to vary between $0.2\mathrm{m\,s^{-1}} \leq v_{object} \leq 0.5\mathrm{m\,s^{-1}}$ and has to be adjusted by the referees before a team starts its run to a fixed value. This is changed after each run to another random chosen value in this range. During the run of a team the speed is static. Example: For a table with diameter $d_{table} = 1\mathrm{m}$, objects are placed on a grasp region with the diameter $d_{object} = 0.8\mathrm{m}$ with $\omega_{table} = \frac{2 \cdot v_{objects}}{d_{grasp}} = \frac{2 \cdot 0.2}{0.8} = 0.5\mathrm{rad\,s^{-1}}$ and with $n_{table} = \frac{\omega_{table}}{2 \cdot \pi} = \frac{0.5}{2 \cdot \pi}$ the minimum rotational speed of the table $n_{table} = 0.0796\mathrm{s^{-1}}$ (rounds per second) can be calculated.

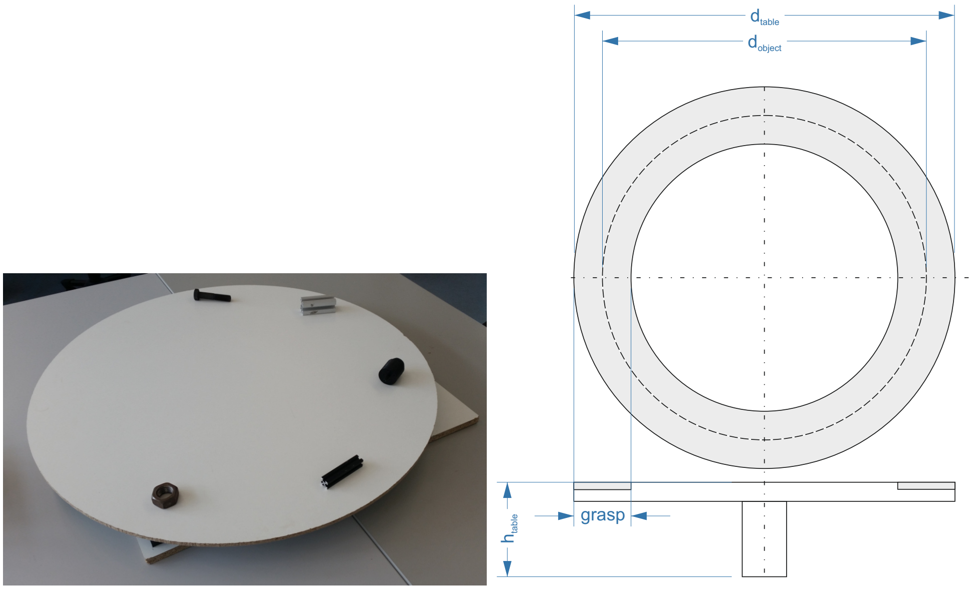
3.4 Design of Navigation Tasks

Every task has some navigation involved in it. Successful navigation will be awarded in every test according to Table 5.3. If not defined differently in the respective test, a navigation is successful when the robot reached the service area as defined in section 3.4.1.

REMARK: Since 2020 the BNT test is removed from the set of tests done at the competition. Remark that points for reaching service areas are given in all tests, so that teams which are only able to navigate with their robot can still achieve points in all tests.

3.4.1 Reaching a Service Area

A service area counts as successfully reached if the robot would be able to manipulate the service area it is standing on. The manipulation range will be subjectively evaluated by the referees.



(a) A rotationg table with some objects. **(b)** Technical draw of rotating table.

Figure 3.9: Exemplary rotating table and generic technical drawing.

3.5 Design of Manipulation Tasks

3.5.1 Manipulation Zone

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

- 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 as 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.

3.5.2 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,

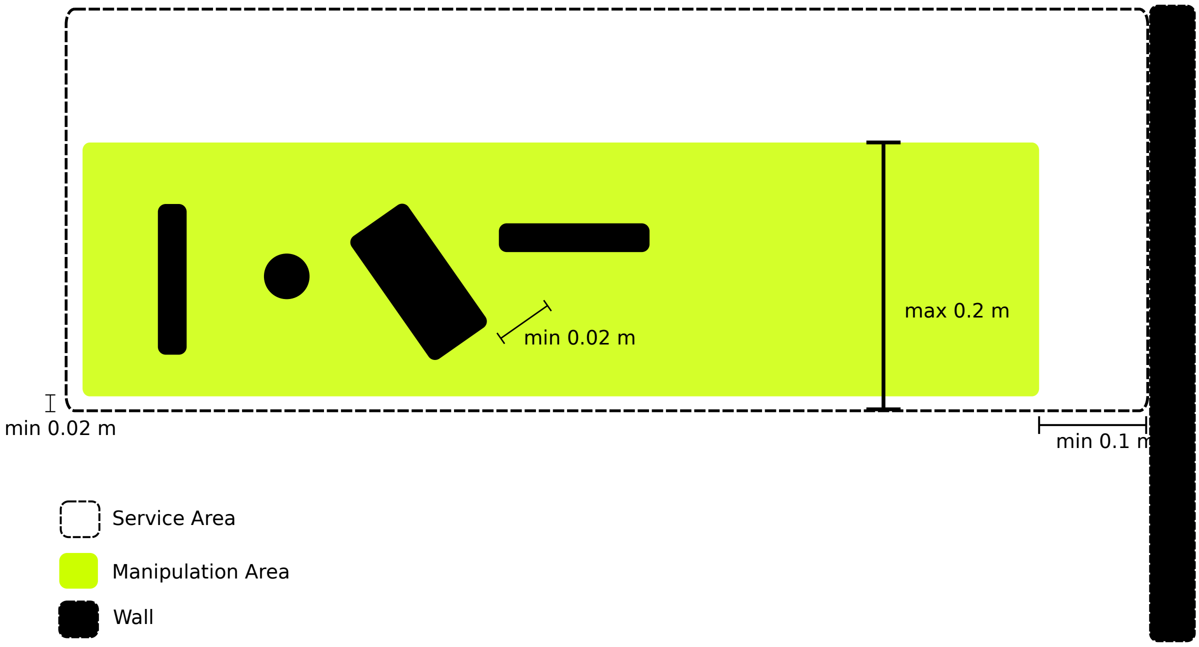


Figure 3.10: Manipulation zone: the green color indicates the area where objects can be placed on a service area by the referees.

the spectrum shall then be widen in at least one aspect. The initial set of objects includes basic standard screws and nuts with various sizes and masses as well as so called rocking objects as shown in Table 3.1 and Table 3.2. Objects of one kind can slightly vary e.g. considering the surface and coating colour. Rocking objects are spare parts from the KUKA you-bot platform often used in the competition, due to the fact that the KUKA you-bot and the rocking objects are not longer produced in future those objects will be replaced with other standard parts used in industry.

REMARK: In 2022 teams has the option to use a set of original rocking objects or a set of 3D printed rocking objects. The set of 3D printed objects has to be printed in standard grey/silver colour using fine quality settings and PLA as printing material. An example is given with PLA Silver, RAL number 9006, thickness 1.75 or 2.85, not specified in detail (example material from amazon). Figure 3.11 shows an example of all rocking objects printed with a fused filament fabrication (FFF) 3D printer.

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.

REMARK: THIS OBJECTS ARE JUST EXAMPLES, NOT FINAL! In 2023 a new

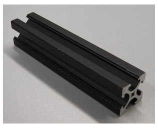
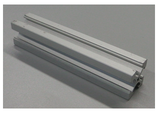
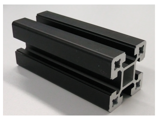
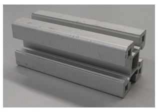
Object	Symbolic Description	Mass	Details
	F20_20_B	49 g	Small aluminium profile Coating/Colour: black anodized Height: 20 mm Width: 20 mm Length: 100 mm
	F20_20_G	49 g	Small aluminium profile Coating/Colour: gray anodized Height: 20 mm Width: 20 mm Length: 100 mm
	S40_40_B	186 g	Big aluminium profile Coating/Colour: black anodized Height: 40 mm Width: 40 mm Length: 100 mm
	S40_40_G	186 g	Big aluminium profile Coating/Colour: gray anodized Height: 40 mm Width: 40 mm Length: 100 mm
	M20_100	296 g	Screw ISO4014, DIN 931, CSN 021101, PN 82101, UNI 5737, EU 24014 Coating/Colour: blank, black burnished Size: M20 $\times$ 100
	M20	56 g	Small nut ISO4032, DIN934, CSN 021401, PN 82144, UNI 5588, EU 24032 Coating/Colour: blank, black burnished Size: M20
	M30	217 g	Big nut ISO4032, DIN934, CSN 021401, PN 82144, UNI 5588, EU 24032 Coating/Colour: blank, black burnished Size: M30

Table 3.1: RoboCup@Work manipulation object set.

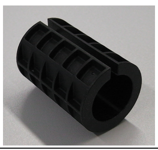
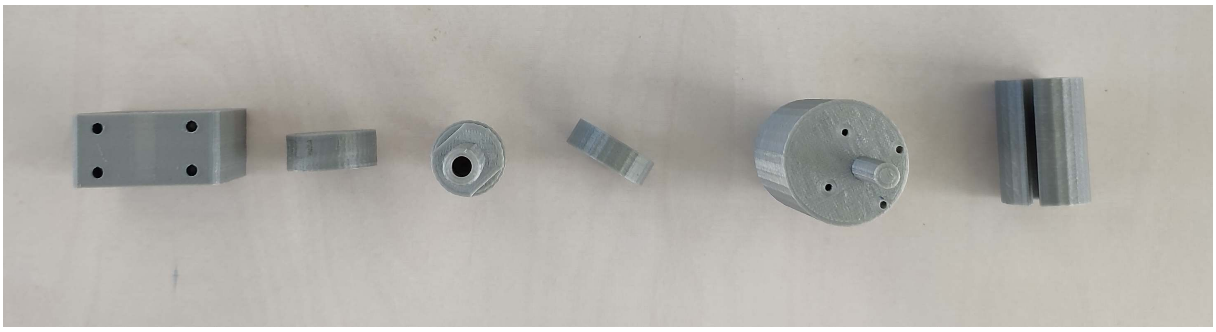
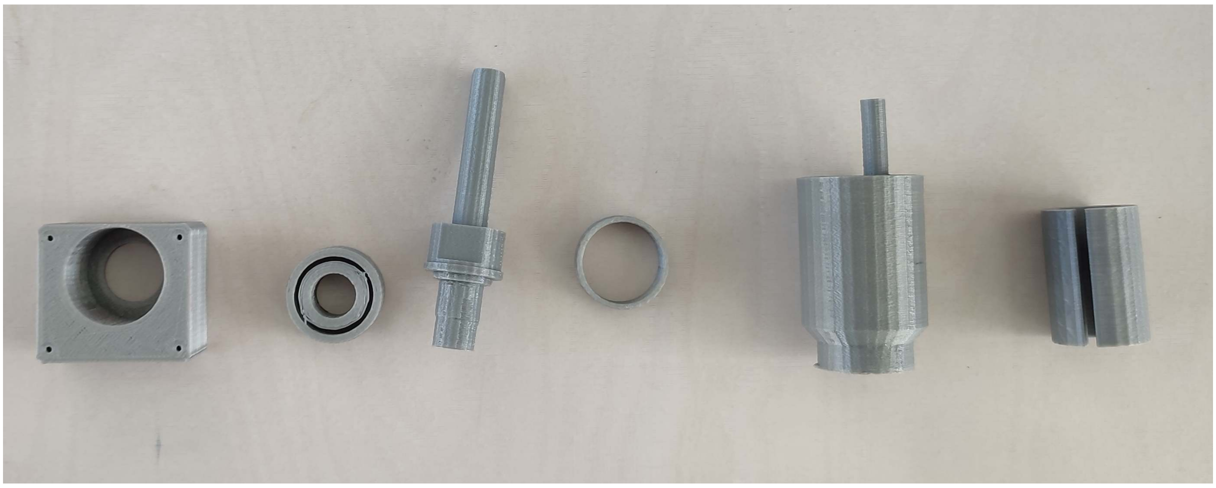
Object	Symbolic Description	Mass	Details
	Bearing_Box	102 g	Bearing box Height: 25 mm Width: 45 mm Length: 50 mm Inner diameter: 32 mm
	Bearing	42 g	Bearing Height: 13 mm Inner diameter: 15 mm Outer diameter: 32 mm
	Axis	40 g	Axis Diameter: 27 mm Length: 96 mm
	Distance_Tube	5 g	Distance tube Height: 10 mm Inner diameter: 28 mm Outer diameter: 32 mm
	Motor	20 g	Motor Diameter: 42 mm Length: 87 mm
	R20	14 g	Plastic tube Inner diameter: 20 mm Outer diameter: 30 mm Length: 45 mm

Table 3.2: RoCKIn manipulation object set.



(a)



(b)

Figure 3.11: Examplary 3D printed rocking objects (bearing box, bearing, axis, distance_tube, motor, plastic tube R20). Material: PLA silver, 2.85mm. Printer: Ultimaker 3 extended. Printer settings: fine

set of objects will be introduced. Therefore standardised mechatronic components will be used some examples are shown in Table 3.3.

3.5.3 Containers

As in many industrial settings, the RoboCup@Work environment may be equipped with several containers (see Figure 3.13). The containers are defined as industrial plastic stacking boxes size 2B, outer dimensions: 135 × 160 × 82mm, usable dimensions: 120 × 125 × 65mm in red and blue (example container from amazon). They can store any kind of manipulation object defined in Section 3.5.2. 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 3.5.1. It is also

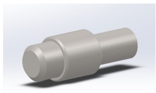
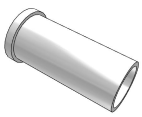
Object	Symbolic Description	Mass	Details
	`Axis2`	180 g	Steel axis Misumi: SFUB25-25-F28-P17-T15-S10-Q20 Coating/Colour: blank, black burnished Length: 68 mm Diameter: 17mm, M20 see Figure 3.12 Misumi
	`Bearing2`	100 g	Bearing SKF YAR203-2F Coating/Colour: gray Useable with housing SKF
	`Housing`	60 g	Housing SKF P40 Coating/Colour: gray Useable with bearing SKF
	`Motor2`	350g	Motor 755 Coating/Colour: gray Size: 66.7×42.0mm Diameter: $d_{axis} = 5$mm, $l_{axis} = 10$mm Amazon
	`Spacer`		Flanged Spacer Misumi CLJHJ25-30-70 Coating/Colour: white Size: 70mm Diameter: $d_{inner} = 25$mm, $d_{outer} = 30$mm Misumi

Table 3.3: RoboCup@Work New set of manipulation objects.

possible that more than one container is placed on top of a single service area. The constraints defined in Section 3.5.1 apply also to the containers.

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

3.5.4 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 object's convex hull does not touch the service area any more.

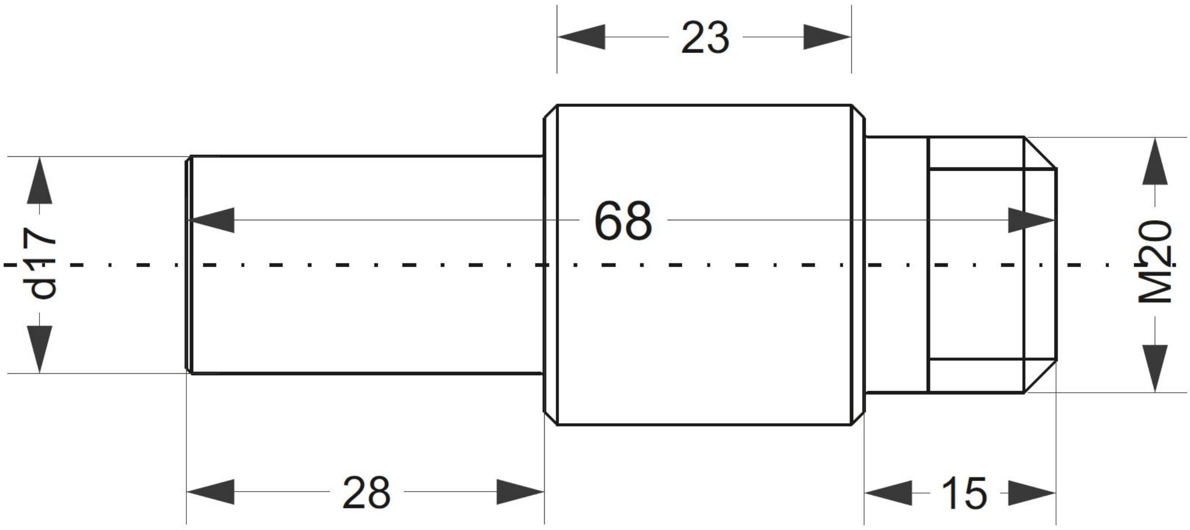


Figure 3.12: Schematic drawing of new manipulation object Axis2. Made of steel, blank or black burnished.

(a) blue

(b) red

Figure 3.13: Containers can be used for grasping objects out or placing objects into them.

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.

3.5.5 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 objects does not count as placed when it is dropped (e.g. dropped from a height above 5 cm). This is to avoid that robots throw objects and potentially harm people or property.

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

Chapter 4

Tests

The actual competition contains of 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. The test instances for 2021 are defined based on the general test description and can be seen in Section 5.1.

4.1 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.

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 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 to reach the final position.

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:

- A single robot is used.
- The robot has to start from outside the arena, enter it through the arena entrance and leave through the exit.
- 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 for the number of seconds specified by the break and does not move (very small movement of the wheels is allowed). The orientation must not deviate more than 45 degrees.
- The run is over when the robot reached the final place or the designated time has expired.

4.2 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, the number of service areas will be constraint to two, one source area and one target area, which are close to each other.

Scenario Environment Additionally to environmental elements, different manipulatable objects will be placed on the specified service areas.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.2.

Task 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. To complete the task the source and the target destination have to be reached at least once.

The task specification consists of:

– The specification of the initial place
– 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

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 service area counts as successfully reached as defined in Section 3.4.1
- A manipulation object counts as successfully grasped as defined in Section 3.5.4
- A manipulation object counts as successfully placed, if the robot has placed the object into the correct destination service area as described in Section 3.5.5.
- The run is over when the robot reached the final place or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.3 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 as well as its task planning capabilities. 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 5.2.

Task 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`).

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.

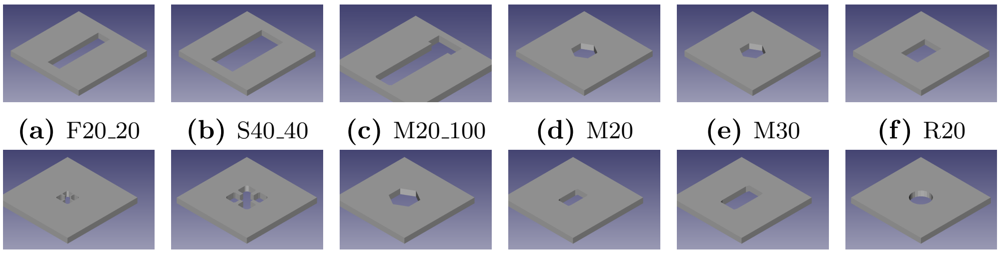
Rules The following rules have to be obeyed:

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- 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 service area counts as successfully reached as defined in Section 3.4.1
- A manipulation object counts as successfully grasped as specified in Section 3.5.4.
- A manipulation object counts as successfully placed as specified in Section 3.5.5.
- It is not allowed to place manipulation objects anywhere except for the robot itself and the correct service areas.
- A robot may carry up to three objects at the same time.
- The run is over when the robot reached the final place or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.4 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. In case that the arena does not already include a modified service area as shown in Figure 4.2, it will be added only for this particular test. The modified service arena includes object-specific cavities as shown in the Figure 4.1. 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.



(a) F20_20 **(b)** S40_40 **(c)** M20_100 **(d)** M20 **(e)** M30 **(f)** R20

(g) F20_20 **(h)** S40_40 **(i)** M20_100 **(j)** M20 **(k)** M30 **(l)** R20

Figure 4.1: 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 5.2.

Task 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 4.2).

The task consists of multiple grasp and place operations, possibly with base movement in between, which will, however, be short. 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).

Rules The following rules have to be obeyed:

- A single robot is used.

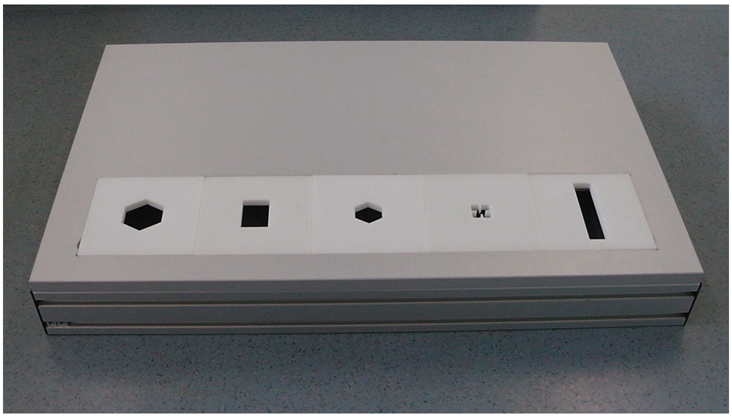


Figure 4.2: The PPT platform including five cavity tiles

- The robot has to start from outside the arena and to end in the final.
- 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 service area counts as successfully reached as defined in Section 3.4.1.
- An object counts as placed correctly if it fell through the correct cavity and touches the ground beneath. 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 run is over when the robot reached the final position or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.5 Rotating Table Test

Purpose and Focus of the Test The purpose of the *Rotating Table Test* (RTT) is to assess the robot's ability to manipulate moving objects which are placed on a 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 include such a device (see Figure 4.3), it will be added only for this particular test.

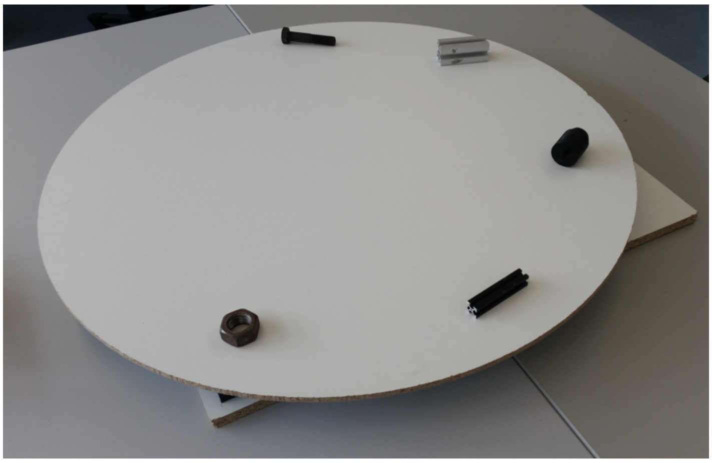


Figure 4.3: Illustration of a rotating table used in the competition.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.2.

Task The task of the robot is to navigate to the location of the rotating table and to grasp all objects from the moving table. 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.

Rules The following rules have to be obeyed:

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- The objects are placed on the rotating table before the run starts by the OC or TC.

- The speed of the rotating table is determined by the OC or TC just before the test starts.
- The robot will get the task specification from the referee box.
- A service area counts as successfully reached as defined in Section 3.4.1
- A manipulation object counts as successfully grasped as specified in Section 3.5.5.
- The objects have to be grasped actively from the moving table. The robot is not allowed to stop the items with its gripper.
- The run is over when the robot reached the final position or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.6 Final (Example)

4.6.1 Purpose and Focus of the Final

The purpose of the Final is to show what each robot can do in combination. The Final test will be a combination of the other tests. To show how the final test could look like the following is added:

4.6.2 Example Scenario

Basically the scenario is a BTT with a PPT and Navigation Complexity included, the following adjustments have been made:

- Time limit is 10 min.
- 5 objects will have to be transported in total.
- Two objects will be used twice.
- 3 service and 3 destination areas will be used. One service area is a PPT area.
- The robot will have to start at the entrance, and to complete the run exit through the exit.

4.6.3 Complexity

- Obstacle complexity (BNT)
- Barrier Tape complexity (BNT)
- Manipulation object complexity (BMT)
- Decoy object complexity (BMT)
- Orientation complexity (BMT)
- Rotation complexity (BMT)
- Position complexity (BMT)
- Speed Complexity (CBT)
- PPT Orientation Complexity (PPT)
- PPT Rotation Complexity(PPT)

4.6.4 Scoring

- 50 points for (the first time) reaching a service or destination area. An area counts as reached when any part of the robot is within 1m of the area and the robot is oriented towards the area. The robot does not have to stand still.
- 50 points for grasping a (correct) object. Grasping is defined like in BTT.
- 50 points for transporting and putting to the correct destination area.
- 50 points for placing into the correct cavity of a PPT plate.
- If an object is placed into the wrong cavity or to the wrong area no penalty points apply.
- 50 points for completing the test, + time bonus points according to rules.
- Other penalty points like losing objects etc. apply according to the BTT test, if not stated otherwise above.

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Chapter 5

Scoring and Ranking

5.1 Scoring

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

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 5.2.

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

Explanation of the terms:

- Correct navigating is defined in Section 3.4.1
- Correct grasping is defined in Section 3.5.4
- Correct placing is defined in Section 3.5.5

5.2 Simplifications

Teams may use simplifications, which will result in a reduction of scores for the given run. The simplifications may be chosen per run, but need to be announced to the referees at least one hour before the start of the 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
- Deactivation of Barrier Tape: -15% of total points of the run

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.

5.3 Penalties

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

- A manipulation object is dropped to the floor outside of a manipulation area: -100 points
- Delivering a wrong manipulation object to service area -50 points
- Minor collision (see Section 5.4): -50 points
- Major collision (see Section 5.4): -50 points and termination of the run
- Barrier Tape collision (see Section 5.4): -5% of total points of current run up till 20%

5.4 Collisions

For reasons of safety of people and property it is strictly unwanted for the robot to collide with any of the environmental objects. Only collisions of the manipulator with the upside of the service area are allowed. The different kind of collisions that can occur are defined in the following subsections.

5.4.1 Minor Collision

If the robot collides with an interaction element of the arena (RTT, PPT Cavities, upper level of Shelf) it is considered a minor collision. The only exception is the collision of the manipulator of the robot with the surface of the manipulation area.

5.4.2 Major Collision

If the robot collides with a static element of the environment it is considered a major collision.

5.4.3 Tape collisions

Yellow/Black Tape : This tape is called Barrier Tape and represents a virtual fence. If any part of the robot touches a barrier tape, it is considered a Barrier Tape Collision. Barrier Tape collision induce a point penalty proportional to the final points of the run. With each collision 5% of the final points are deducted up to a maximum of 20%. For beginner teams the option exists to opt-out of Barrier Tape and take a static deduction of 15% of the final points of the run.

Red/White Tape : This tape represents a virtual wall. This wall shall not be crossed. A robot touching this tape is considered a major collision. This tape is typically used to limit the area of the arena.

Blue/White Tape : This tape is used to indicate 0cm workstations and gates. Robot Collisions with this tape only induces a penalty if a gate is crossed twice. In this case a Major Collision occurred.

Table 5.1: Definition of minor and major collisions

Situation	Minor	Major	Barrier Tape
Collision with static elements of arena		X	
Collision with dynamic elements of arena		X	
Robot Body Collision with workstation		X	
Robot Manipulator Collision with manipulation zone			
Robot Manipulator Collision with Round Table stopping it	X		
Robot Manipulator Collision with PPT Cavity surface	X		
Robot Manipulator Collision with Shelf	X		
Yellow/Black Tape Collisions			X
Red/White Tape Collisions		X	
Blue/White Tape Collision (1st time gate)			
Blue/White Tape Collision (2nd time gate)		X	

5.5 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.
- Scores that are received after a restart are multiplied by a factor of 0.75.
- 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.

5.6 Ranking

The tests will occur in the instances shown in Table 5.2. Ranking of the teams will be based on the sum of the achieved points over all the tests.

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.

			Instances						
			1 BMT	2 BTT1	3 BTT2	4 BTT3	5 PPT	6 RTT	7 Final
Objects	RoboCup@Work & RoCKIn	RefBox	5	5	6	6	3	3	10
	Decoy	RefBox		3	3	3		3	5
	Position		Ref	Ref	Ref	Ref	Team	Ref	Ref
	Rotation		Team	Ref	Ref	Ref	Team	Team	Ref
	Orientation		Team	Team	Team	Ref	Team	Team	Ref
	Estimated Active	RefBox	2	3	4	5	2	1	8
Service area	Table height	RefBox	10 cm	10 cm	0 cm 5 cm 10 cm 15 cm	10 cm	10 cm	10 cm	0 cm 5 cm 10 cm 15 cm
	Arbitrary surface	RefBox		1	2	2			3
Arena	Obstacles (static)	Referee			2	2			2
	Barrier tape	Referee		2		1			2
Grasping	Shelf unit	RefBox				2			2
	Rotating turntable	Referee						3	1
	Rotating direction							Team	Ref
Placement	Cavity platform with decoys	RefBox					3		1
	Shelf unit	RefBox				1			1
	Red container	RefBox				2			2
	Blue container	RefBox				2			2
	Rotating turntable	RefBox			1				
	Cavities Position	RefBox					Ref		Ref
	Cavities Rotation	RefBox					Ref		Ref
	Cavities Orientation	RefBox					Team		Team
Duration		RefBox	5min	6min	10min	10min	4min	4min	13min

Table 5.2: Test specification in the instances of the RoboCup@Work 2021 competition.

	Instances						
	1 BMT	2 BTT1	3 BTT2	4 BTT3	5 PPT	6 RTT	7 Final
Correct service area reached	25	25	25	25	25	25	25
Correct object grasping standard	100	100	100	100	0		100
round table						300	200
PPT area							200
arbitrary surface		150	150	150			150
shelf upper level				150			150
shelf lower level				300			300
Correct object placing standard	75	75	75	75			75
PPT area					200		200
shelf upper level				150			150
shelf lower level				150			150
Incorrect object placing	-100	-100	-100	-100	-100		-100
Incorrect object grasping		-100	-100	-100		-100	-100
Completing whole task	75	100	150	250	50	75	300
Maximum attainable points (time bonus not included)	1000	1100	1400	2000	700	1000	3200

Table 5.3: Scoring in the instances of the RoboCup@Work 2021 competition.

Chapter 6

Virtual RoboCup

6.1 General

Due to the Covid-19 pandemic, the RoboCup 2021 will be held online. Therefore, paricipating teams must provide some infrastructure to enable the TC and OC to evaluate their performance. This is new for everyone and requires extended communication, which is why every team should join the official discord server:

https://discord.gg/z6Yn6UvhxU

Please participate in discussions and ask questions if you have any.

6.2 Arena Setup

As all teams will have different laboratory setups and some may not have the same resources (open space, workstations, etc.) as others, no fixed arena design will be used for the Robocup@work 2021. We expect that this would either exclude some teams from the competitions or limit others in their test scenario design, which is why every team can design their own arena.

However, to ensure that the different robot performances can be compared using the existing scoring system (5.2), some rules are defined to encourage teams to create challenging arena designs. In addition to the basic rules described in 3.3, teams are required to consider:

- Arena size must be atleast 4m x 2m
- The table placements should force the robot to move around the arena (not all the tables are next to each other)
- Workstations should be accessible via multiple paths, so one of them may be blocked with obstacles (6.1 orange dots). Some space must be available for non-blocking obstacles (6.1 dark green dots).
- Tables with the heights defined in (5.2) have to be provided (margin = 2cm). If a team doesn't have enough workstations of one type for a test, the TC may allow alternative table heights to be used (especially BTT3 and Final). This rule does not apply for the conveyor belt, the shelf and the precise placement station.

- PPT cavities (a)-(f) (see 4.1) must be provided. Teams may 3D print the cavities using the files in the leagues github. Standing objects are excluded. It must be possible to place $N\_PLACE + 2$ next to each other, so that atleast two decoy cavities can be used.
- Required arbitrary surfaces types: artificial grass, pvc floor / wood, mirror / aluminum foil, (plexi-)glass. These can be found in your local homedepot. (See fig. 6.2(b))
- One path blocking and one small obstacle must be available both for physical objects and barriertape. (See fig. 6.2(a))

Figure 6.1 shows one possible example of an arena configuration in a small area. Table heights are measured in cm. The orange dots mark possible path blockades, while the dark green lines mark optional obstacle placements.

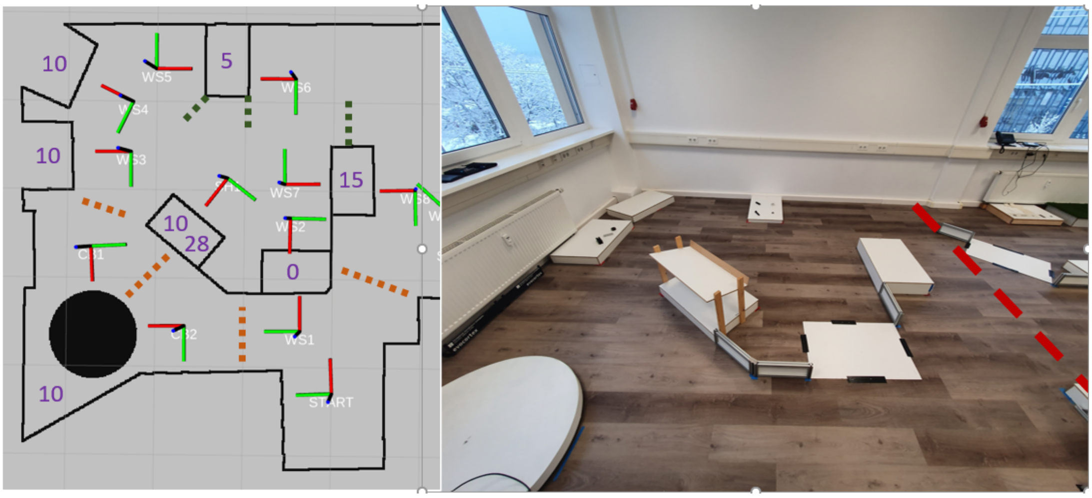


Figure 6.1: Example Arena for a small VRC Setup — Left: Annotated map - Right: Real Image

(a) Obstacle Placements

(b) Arbitrary Surfaces

Figure 6.2: Example obstacle placements and arbitrary surfaces

To enable the committee to generate fair tasks for every team, teams must provide detailed information about their arena and object inventory **1 month** prior to the first competition day. A zip-folder containing the following data must be sent via our discord server:

- Atleast two images of the arena from different perspectives. If two cannot cover the whole arena, teams must provide as many as needed.
- A map of the arena with workstations marked (name + height). Teams may use an RVIZ screenshot containing the grid (1m cell size) and the occupancy grid (your map), which may be annotated using e.g. gimp (see also 6.1).
- A list of available workstations in their arena (height and amount).
- Images of the available arbitrary surfaces
- Images of the available barriertape and obstacles
- A list of available objects and containers (amount)
- Image of the objects and containers
- Images of the robot (all sides)
- Robot dimensions in meter
- Which tests the team intends to participate in
- Refbox launchfiles

The folder must be named VRC2021-info-TEAM-NAME and shall contain the subfolders ARENA, OBSTACLES, OBJECT, ROBOT, TESTS, REFBOX. File names must contain information about the data (e.g. Arena-Image-1) and must not have default names (e.g. IMG2012).

The TC will decide if the individual arenas qualify for the tests defined in 5.2. The main requirements are already specified in 6.2, while the table describes individual task requirements more precisely.

If an arena does not qualify, the TC must notify the team **3 weeks** before competition starts, briefing the team about shortcomings and possible solutions. The team then has **1 week** to follow the TCs advice and provide a new zip-folder. If an arena does not qualify for a test, the TC may decide to exclude the associated team from those. If an arena only partly qualifies (e.g. no barriertape available), score adjustments can be made.

6.3 Camera Setup

Since the referees are not present at the arena during the Virtual RoboCup, the arena and all activities of the robot must be shown via livestream. For this purpose, cameras must be able to monitor the entire arena for the referees and the cameras should be mounted at least at head height. No blind spots are allowed when streaming the arena, so that the referees can see and evaluate every activity of the robot. Furthermore, the PC used to start the runs should also be monitored with the cameras so that the referees can observe every interaction with the PC. One or more cameras can be used to stream the arena. The OC will announce the streaming software used and the maximum number of livestreams available before the competition.

In addition to the cameras for the arena, there must be a person who follows the robot with a mobile camera and shows the robot's activities from close up. This allows the referees to detect even small mistakes. The person is allowed to enter the arena during the run. However, the person is not allowed to interact with the robot.

A camera may also be attached to the robot to better show the robot's activities to the referees and spectators. The camera on the robot is optional.

6.4 RoCKIn manipulation object set

The RoCKIn objects (see table 3.2) are no longer produced and sold. Because of this, it is allowed to create these objects with a 3D printer at the Virtual RoboCup. However, the 3D printed RoCKIn objects must not be mixed with original objects. This means that the complete RoCKIn object set is either original or 3D printed. Furthermore, the 3D printed objects must have the same color. This applies only to the RoCKIn object set and not to the RoboCup@Work object set (see table 3.1). The RoboCup@Work object set must not be 3D printed.

6.5 Task Generation

The new refbox implementation, which can be found here (https://github.com/robocup-at-work/atwork-commander), gives great opportunity to generate individual tasks for every participating team.

We advise all teams to use and test the new refbox. Teams must send configuration files for the new refbox with their arena design, so that the TC/OC can generate tasks for their arena. The config file for the arena shall contain the workstation names and heights and the available objects for a team. Teams may contact the committee via Discord if they face problems with this.

As normally the refbox would be provided by the OC onsite, no actual refbox will be used during the online competition. The OC will create the tasks for the tests using the official refbox and the parameters provided by the teams. For each test, a single bagfile (10s) will be recorded which contains all topics published by the atwork_commander.

Teams must be able to play a bagfile on an external computer, which is connected to the robot via WiFi. The bagfile then must be played to start a competition. The robot should receive the task and start with the execution phase.

To prevent incompatible bagfiles during the competition, the OC will provide test bagfiles **2 weeks** before official competitions begin. The working parameter and launchfiles will be saved and used to generate the specific task bagfiles for the competition.

6.6 Competition Test Procedure

6.6.1 Preparation

Before a test begins, the OC will announce obstacle placements, object positions and arbitrary surface application to a team **10 minutes** prior to their timeslot. Teams must prepare the arena accordingly. The task bagfile will be sent out to the team **5 minutes** before their official timeslot. Note: The durations may be modified during the competitions if they show to be unsuitable.

6.6.2 Test Start

The OC may count down before a competition (3, 2, 1, go), after which they start a timer according to the test durations in 5.2. On GO command, the active team may access the keyboard of the remote pc **only** to start the bagfile. The cameraman/-woman must show that to the audience.

6.6.3 Test Run

The audience and especially the refs watch the livestream and rate the performance. In case of a major collision or any other reason for a restart, the remote pc keyboard may be accessed to restart the robot and the bagfile. The replay of the bagfile command must be shown to the audience once again, and afterwards the keybord must not be used anymore.

6.6.4 Test End

The run ends when the timer is up, with an optional margin of five seconds due to the possible network delay. The refs then gather and discuss their performance evaluation.

6.7 Scoring

The different arena setups make time bonuses unfair and will therefore not be given in the VRC 2021. The rest of the scoring will be the same as in a normal robocup scenario, with score/runtime adjustments and/or penalty points possible to compensate for missing test elements (see 6.2). Such adjustments could be:

- The runtime for a test may be reduced if the arena is very small
- If no barriertape is available, all penalty points for crossing will be applied
- If no arbitrary surface is available, the object to pick will also be removed.

- No containers = no placement points given

Depending on the arena setups of all teams, these rules will be defined more precisely before the competitions begin.

6.8 Technical Challenges

The 2021 virtual robocup will focus on the main competition. No technical challenges will be performed during the official competitions this year. As some teams still requested technical challenges, we accept submissions for the cluttered pick test and the drawer test by video. This is because that we expect a relatively tight schedule due to the different time zones of the teams and we are unsure if the technical challenges may be performed otherwise.

As the challenges do not count into the official scoring, teams are allowed to modify their arena. They still must stick to the rules defined in 7. The bagfile for the specific challenge will be sent out to the teams on the first day of the competitions. Teams are required to record a video of their challenge with a camera setup similar to 6.3, which must be cut in a way that it is possible to see every region of interest (robot, no operator on pc, arena) at all times. The video must be rendered to mp4 format and uploaded to a cloud (e.g. onedrive). Teams must provide a link to their video via our discord server with the deadline set to last competition day, more specificly the beginning of the final runs.

The committee will review all submissions and rate the individual performances with the help of the referee team after the finals have been completed. Videos that exceed the deadline will not be reviewed and the teams participation in the challenge will be cancelled.

Chapter 7

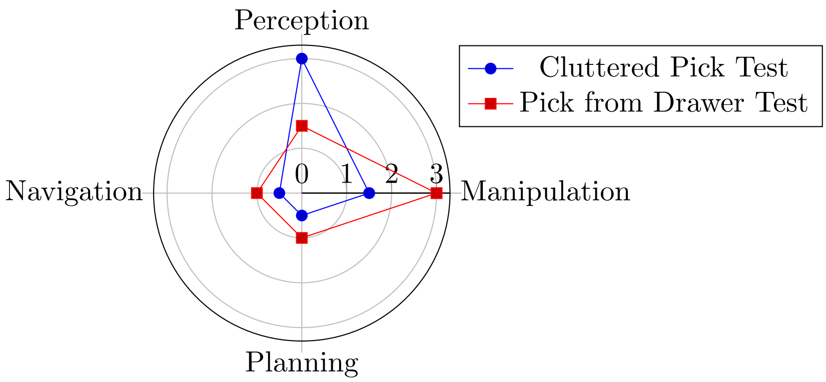
Technical Challenges

In the medium term, the RoboCup@Work aims to transfer specific aspects of industrial scenarios in the tests and to demonstrate the practical applicability of the solutions. The challenges, which are adapted or redefined annually, serve as a test platform for the further development of the competitions. Each technical challenge is separately awarded. That means, teams can participate in any number of them. Hoewever any challenge will only be awarded if at least two teams competed unless the only competing team provided an outstanding performance.

A challenge increases the level capabilities of a robot in RoboCup@Work related to:

- **Variability of the environmental conditions** ... The setup conditions of a run are designed variably including disturbances. The lighting situations in the arena are changed dynamically, the configuration of the tables (height, format) is adapted or manipulation objects are mixed with unknown decoy objects.
- **Complexity of the scenarios** ... New arena elements are involved in a scenario or its dimensions (size, duration) are increased. This includes, for example, multi-robot scenarios, assembly tasks or new interaction stations.

For a successful implementation either an existing solution has to be increased in robustness or a new approach for an additional task has to be developed. The challenges here lie in the fields of perception, manipulation, navigation and planning.



The challenges of 2021 focussing on perception and manipuation in two scenarios. While "Cluttered Pick Test" (CP) adresses the robustness of perception, the "Pick from Drawer Test" (PFD) is focused on additional complexity by including objects in a drawer. Additonally, the start of a league specific simulator, to ease entry of new teams and enable better scientific evaluation is to be established through Simulation Evaluation Test (SE).

7.1 Cluttered Pick Test

7.1.1 Purpose and Focus of the Test

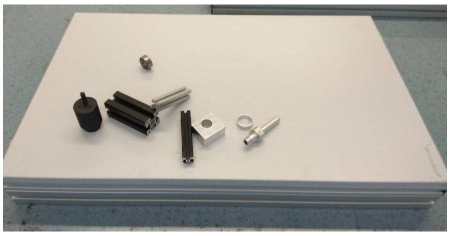
The purpose of the *Cluttered Pick Test* (CPT) is to evaluate the perception and manipulation of the robots when objects are not seperated.

The scenario is motivated by the fact that most of the objects in the factory or labs are not perfectly placed but may be stacked or cluttered across a table.

Robots should be able to successfully grasp such objects in a way that they can place them somewhere else. This ensures that they pick objects regarding potential further use.

7.1.2 Scenario Environment

The scenario is an alternated Basic Manipulation Test, with two service areas with a height of 10cm involved. All available objects must be placed randomly in a box, which then is emptied above one table. The positions of the objects must remain as they fall. Objects that end up outside of the manipulation zone may be gathered, placed in the box and dropped again. The rule for a minimum distance of 0.02m between objects does not apply for this test. They may be placed near and on top of each other (see 7.1).



(a)

Figure 7.1: objects places in cluttered environment

7.1.3 Task

The task is the same as for a BMT, with the modification that only 3 objects must be picked and placed.

7.1.4 Rules

The following rules have to be obeyed:

- A single robot is used.
- Three objects have to be picked.
- There must be atleast 5 decoy objects which must not be picked.
- The robot has to start from outside the arena and to stop in the goal area.
- A manipulation object counts as successfully grasped as specified in Section 3.5.4.
- The run is over when the robot reached the final place or the designated time has expired.
- 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.

7.1.5 Scoring

- 200 points are awarded for each correctly and successfully picked object
- 125 points are awarded for each correctly placed object.
- Standard scoring applies for all other aspects

7.2 Pick from Drawer Test

7.2.1 Purpose and Focus of the Test

The collection of freely available objects lying on a manipulation zone is the core capability of RoboCup@Work-robots. The *Pick from Drawer Test* (PFD) goes beyond this level and considers objects stored in drawers too. In this way, the challenge extends the idea of the shelf where the robot has to plan the grasping operation in a limited space but it is not necessary to interact with the environment.

7.2.2 Scenario Environment

The first version of the challenge gives much freedom to the teams. They can choose an arbitrary drawer configuration. The drawer is wholly covered in the beginning and can only be linearly moved in one direction parallel to the floor. The inside of the drawer has to have a uniform color and an uniform flat surface. The surrounding construction has to remain at its position. The inside and the handle of the drawer count as manipulation zones for collision detection purposes.

Robot's movements must open the drawer directly. Self-driven, automatic solutions integrated into the drawer system are not allowed. The rules do not define the handling mechanism itself, the teams are completely free to design an appropriate concept. Any handle, knob, hole, or connector mounted to the drawer is permitted. Based on this interaction, the drawer has to be moved at least 15cm.

7.2.3 Task

The drawer setup is located at an arbitrary position. The drawer contains 3 randomly chosen manipulation objects to be picked described in Table 5.2. They are stored directly on bottom of the drawer. Additionally, the drawer may contain three decoy objects and an arbitrary surface.

The team configures the objects and the drawer during preparation phase.

This test does not adress navigation capabilities. Hence the robot can start the run anywhere in the arena. However, the robot's starting position must be 1.5m away from the drawer. It moves directly to the drawer, opens it, grasps the objects and place them in the object inventory of the robot.

7.2.4 Rules

The following rules have to be obeyed:

- A single robot is used.

- The test runs for 5 minutes.
- The robot can start at an arbitrary position inside the arena. The position must be 1.5m away from the drawer.
- The order in which the teams have to perform will be determined by a draw.
- Each team is responsible for preparing the drawer system. The team places the randomly chosen objects in the drawer.
- The drawer is opened by at least 15cm.
- A manipulation object counts as successfully grasped as specified in Section 3.5.4. It is not necessary to place the objects at another manipulation zone. The objects should be placed in the inventory of the robot.
- The run is over when the designated time has expired or all three objects has been grasped and placed in the inventory of the robot.

7.2.5 Scoring

- 100 points for opening the drawer
- 100 points are awarded for each correctly and successfully picked object, +50 Points per object if decoys are present, +50 Points per object if the Abritrary Surface is present.
- Time bonus of one point per second after collecting 3 objects successfully.

7.3 Simulation Evaluation Test

7.3.1 Purpose and Focus of the Test

The purpose of this test is to provide the RoboCup @Work League with new capabilities. These capabilities are the option to do scientific evaluation regarding stochastic behaviour and scalability analysis. This provide the competing teams with the option of using their experimental results in scientific papers and provide a stronger link to the scientific robotic communities.

Another aspect is the option to add integration tests and continuous integration to the workflow of the teams to provide better management of software versions. Additionally, this provides the team members with the capabilities to learn state-of-the-art software development techniques.

Finally, a simulation adds the option for new teams to start with a virtual robot excluding the typical hardware problems associated with real robots. This eases the entry into the league and paves the way for a larger growth of the league in regard to participating teams in the future.

7.3.2 Scenario Environment

The scenario for this test is to enable teams using a (partial) simulation to show these to the league. Finally, the league may be able to choose a default simulation environment to provide support for this environment in the future.

Consequently, the simulation of the team competing in this challenge needs to fulfill some requirements:

Free to be used: The simulation software needs to be usable by competing teams free of charge. The software does not need to be open source.

Open-Source API: The interface of the simulation needs to be open source. Especially, the implementation of the robot specific functions and behaviours, like executing movement commandos and outputting laser scanner data etc. needs to be implemented in a way that allows for easy modification of interested teams.

Official Models: The simulated arena environment need to contain the 3D-Model of the official repository of the @Work League `https://github.com/robocup-at-work/models`. Additionally, the tasks to be executed need to be generated by the official Referee Box, see Section 3.2

Within the simulation environment one of the tasks specified in Section 4 needs to be executed.

7.3.3 Task

The task of this challenge is to show the execution of one of the tasks defined in Section 4 in the virtual environment. However, this task is not graded regarding the normal scoring scheme.

The evaluation of this task is based on the behaviour of the simulation itself. Relevant aspects that are considered in the scoring are the precision and speed of the simulation. To this end, the teams shall provide stochastic data on the precision of multiple runs of their simulation as well as the speed of the simulation expressed as a real-time-factor (Quotient between time passed in the simulation and time passed in the real world). Additionally, the teams need to indicate the API of their simulation as well as the used simulation software and its license. The task execution may either be shown in a video or live.

7.3.4 Rules

- Virtual representation based on the object and table definitions from `https://github.com/robocup-at-work/models`
- Virtual representation of the teams robot
- Free to use (for robotic teams) simulation software / environment
- Execution of a task as specified in Section 4
- Start of task by Referee Box see Section 3.2
- Task execution as video or live
- Indication of precision in form of reproduction accuracy (execute multiple times and compare results)
- Indication of simulation speed based on real-time factor (Quotient between virtual clock speed and real world time)

7.3.5 Scoring

Referees grade task execution and simulation based on the following criteria:

- Up to 100 Points for Ease of Use
- Up to 100 Points for Visualization
- Up to 200 Points for Precision
- Up to 200 Points for Speed
- Up to 300 Points for Simulation Capabilities