RoboCup@Work

Rulebook

Asadollah Norouzi
Sebastian Zug
Deebul Nair
Christoph Steup
Marco Masannek
Maximilian Hachen
Lucas Reinhart

Version: 2022
February 16, 2022

Acknowledgments

We would like to thank to previous @Work members that supported the league and advanced the rulebook over years:

Jan Carstensen
Frederik Hegger
Nico Hochgeschwender
Daniel Kaczor
Robin Kammel
Alexander Moriaty
Walter Nowak
Benjamin Schnieders
Armin Shahsavari
Jon Martin

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

If you refer to the rulebook in particular, please cite:

```
@misc{rulebook_2020,
  author = {Asadollah Norouzi, Sebastian Zug, Deebul Nair,
            Christoph Steup, Marco Masannek, Lucas Reinhart, Maximilian Hachen},
  title  = {RoboCup@Work 2022 - Rulebook},
  year   =  2022,
  howpublished = {\url{https://atwork.robocup.org/rules/}},
}
```

Contents

1 Summary of Changes **7**
1.1 Changes 2022 7
1.2 Adjustments for the virtual RoboCups 8
1.3 General Changes 8
1.4 Robot Requirements 8
1.5 Team Requirements 9
1.6 Scoring 9
1.6.1 Technical Challenges 9

2 Introduction **11**
2.1 RoboCup@Work in a Nutshell 11
2.2 Organization of the League 12
2.2.1 League Committees 12
2.2.2 League Infrastructure 14
2.3 Participation in the Competition 15
2.3.1 Steps to Participate 15
2.3.2 Qualification 16
2.3.3 Team Description Paper 16
2.3.4 Promotional Video 17
2.4 Organization of the Competition 17
2.4.1 Teams 17
2.4.2 Team Practice and Use of Arenas 17
2.4.3 Stages and Tests 18
2.4.4 Common Procedures 18
2.4.5 Referees 19
2.4.6 Meetings and Language of Communication 19
2.4.7 Code of Conduct and Disqualification 20
2.4.8 Wireless LAN 20
2.4.9 Use of External/Control Devices 20

3 General Rules **21**
3.1 Robots 21
3.1.1 Design and Constraints 21
3.1.2 Behavior and Safety 22
3.2 Arena Environment 24
3.2.1 General 24
3.2.2 Walls and Virtual Walls 25

3.2.3 Obstacles 26
3.2.4 Tapes 27
3.2.5 Tables 28
3.2.6 Shelves 29
3.2.7 Rotating Tables 29
3.2.8 Precision Placement Tables 30
3.3 Service Areas 33
3.3.1 General 33
3.3.2 Arbitrary Surfaces and Decoys 33
3.3.3 Containers 35
3.3.4 Manipulation Zone 35
3.4 Objects 37

4 Competition **41**
4.1 Time Schedule 41
4.2 Parc fermé 41
4.3 Test Procedure 42
4.4 Skipping Tests 43
4.5 Atwork Commander (AWC) 43
4.5.1 On Site 44

5 Tests **45**
5.1 General 45
5.1.1 Common Rules 45
5.1.2 Grasping Objects 45
5.1.3 Placing Objects 46
5.2 Basic Manipulation Test 48
5.3 Basic Transportation Test 49
5.4 Precision Placement Test 50
5.5 Rotating Table Test 50
5.6 Final 51
5.7 Test Specification Summary 51

6 Scoring and Ranking **53**
6.1 Scoring 53
6.2 Simplifications 53
6.3 Penalties 54
6.4 Collisions 54
6.5 Restarts 55
6.6 Ranking 56

7 Virtual RoboCup **59**
7.1 General 59
7.2 Arena Setup 59
7.3 Camera Setup 61
7.4 RoCKIn manipulation object set 62

7.5 Task Generation . . . 62
7.6 Competition Test Procedure . . . 62
7.6.1 Preparation . . . 62
7.6.2 Test Start . . . 63
7.6.3 Test Run . . . 63
7.6.4 Test End . . . 63
7.7 Scoring . . . 63
7.8 Technical Challenges . . . 64

8 Technical Challenges **65**
8.1 Master Communication Test . . . 67
8.1.1 Purpose and Focus of the Test . . . 67
8.2 Cluttered Pick Test . . . 68
8.2.1 Purpose and Focus of the Test . . . 68
8.2.2 Scenario Environment . . . 68
8.2.3 Task . . . 68
8.2.4 Rules . . . 68
8.2.5 Scoring . . . 69
8.3 Pick from Drawer Test . . . 70
8.3.1 Purpose and Focus of the Test . . . 70
8.3.2 Scenario Environment . . . 70
8.3.3 Task . . . 70
8.3.4 Rules . . . 70
8.3.5 Scoring . . . 71
8.4 Simulation Evaluation Test . . . 72
8.4.1 Purpose and Focus of the Test . . . 72
8.4.2 Scenario Environment . . . 72
8.4.3 Task . . . 72
8.4.4 Rules . . . 73
8.4.5 Scoring . . . 73
8.5 New Objects Transportation Test . . . 74
8.5.1 Purpose and Focus of the Test . . . 74
8.5.2 Scenario Environment . . . 74
8.5.3 Task . . . 74
8.5.4 Rules . . . 74
8.5.5 Scoring . . . 74
8.6 Robot-Human Interaction Test . . . 75
8.6.1 Purpose and Focus of the Test . . . 75
8.6.2 Scenario Environment . . . 75
8.6.3 Task . . . 75
8.6.4 Rules . . . 75
8.6.5 Scoring . . . 76
8.7 RoboCup Manipulation Challenge . . . 77

9 Future Changes **79**
9.1 New Objects 79

10 Special Terms **83**

11 Appendix **85**
11.1 Link list 85

Index **85**

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 (2 Lists)
- shopping list with links visited January 2022
- precision placement table in environment
- safty check procedure
- technical challeng, Robot Human Interaction with new objects

[Leander] Changes:

- **??** Markup Tape: introduce green electrical tape
- **??** Workstations: 0cm workstations are not marked with blue/white tape anymore
- 3.2.2 Walls and virtual Walls: clarifications
- 3.2.1 Start and Goal Area: add chapter

[Marco] Changes:

- Arena description
- Parc fermÃľ rules
- Detailed competition description

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 7.

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 6.1).
- 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 3.2
- The meaning of the different types of tape in the arena was modified. Please review Sections 3.2, 6.3 and 6.4

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:

```
@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},
  Volume = {8992}
}
```

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 WÃijrzburg-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/.

Discord Server The official Discord server of RoboCup@Work is

https://discord.gg/z6Yn6UvhxU

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, atWork-commander 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 âĂIJrefereeâĂİ or âĂIJteam leaderâĂİ, 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 6.1, 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

In this chapter the general rules will be explained that are valid for all tests. This chapter is seperated into the sections robot, arena environment, Service Areas and Objects.

3.1 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

TODO: Forbid flying robots (i dont want any drones here)

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 3.2. 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.

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.

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 used in the individual task. See Table 3.1, Table 3.2 and Table 9.1 as well as Table 9.2.
- The manipulator of the robot should be designed and mounted on the robot such that it can grasp Objects from different heights between 0cm and 40cm 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 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. Figure 3.1 shows three examples how a robot suitable to the competition can look like.

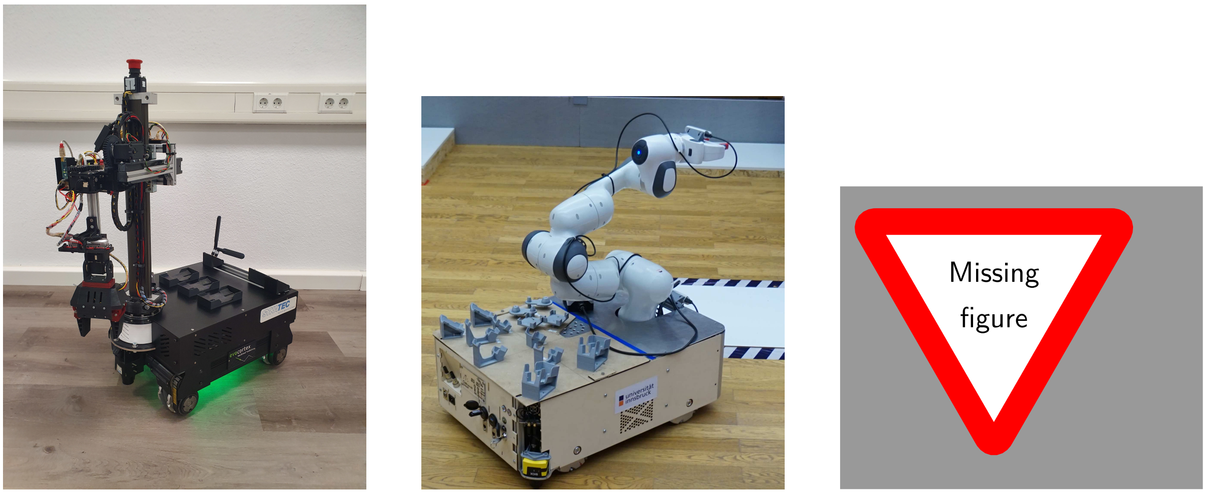


Figure 3.1: Examples mobile robot platforms that can be used for RoboCup@Work. Robots from the teams AutonOHM (Nuernberg-Germany), Tyrolics (Innsbruck-Austria) and robOTTO (Magdeburg-Germany) – from left to right.

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.

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. It has to be easy accessible from at least 3 sides of 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.

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.

Safety test procedure:

After all teams are registered and every team area is fixed. Each robot has to perform a safety test procedure. This will be included in the competition schedule given by the OC.

- Inspection of the robot platform (sharp edges and general construction)
- Description of the included safety developments by the team captain
- Test of emergency stop while standing still
- Test of emergency stop while driving
- Test of emergency stop while manipulation

3.2 Arena Environment

The competition is held in an arena resembling an example layout of industrial manufacturing facilities. In this Section different parts of the environment are explained.

3.2.1 General

The arena is a static 2D environment consisting of Walls, Tables and Obstacles etc. with a size of atleast 10 m^2 and not more than 120 m^2. An example layout is shown in fig. 3.2.

Figure 3.2: An exemplary setup of a RoboCup@Work environment.

Layouts may include rooms and hallways to create more realistic scenarios. Service Areas (see section 3.3) mark the locations for robots to perform tasks. Each requested Service Area must be accessible via atleast one path of 80cm width.

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 80cm
- Widespread Service Areas entailing robot movements
- Multiple paths between Service Areas
- START and FINISH area

START and FINISH area:

One or two parts of the arena are separated with marking Tape and considered as START and FINISH area. The START and FINISH area can be the same or two independent areas. The robot may leave the START area and enter the FINISH area only once. An area is leaved or entered when more than 50% of the robot crossed the marking Tape. In figure 3.4 an exemplary Tape configuration is shown.

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 illus-

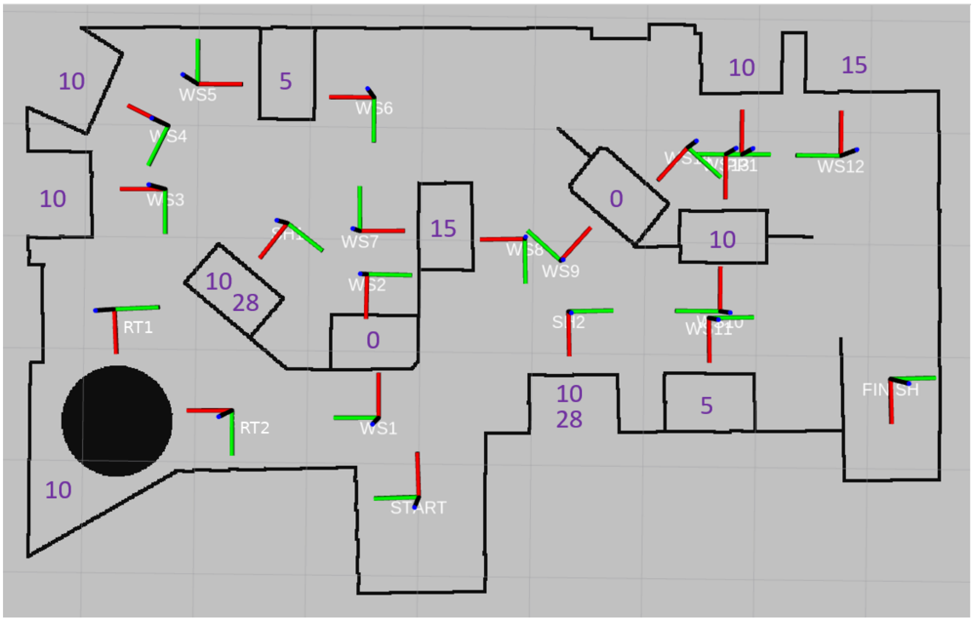


Figure 3.3: Annotated 2D map of the environment in fig. 3.2

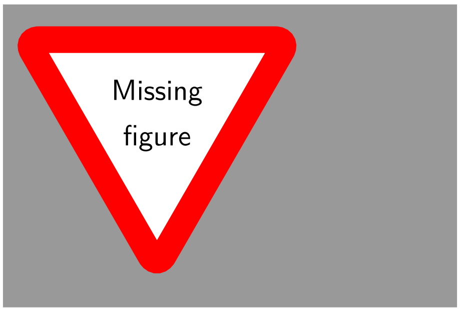


Figure 3.4: Tape configuraion, TODO...

trated in Figure 3.5. 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 1cm in any direction (clefts, rifts, ridges, etc.).

3.2.2 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 (red/white Tape). Walls have an infinitely height. The arena is completely enclosed by Walls (both types possible), meaning robots are not allowed to exit the arena during a run. All types of Walls won't be changed during the competition. If the robot touches a Wall or Virtual Wall it results in a Major

Figure 3.5: Examples of floors that can be used for RoboCup@Work arenas.

Collision.

The height of a physical Wall must be not less than 20cm and no more than 40cm. 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/white Tape and may never be crossed during a run. The arena can contain Walls and Virtual Walls inside.

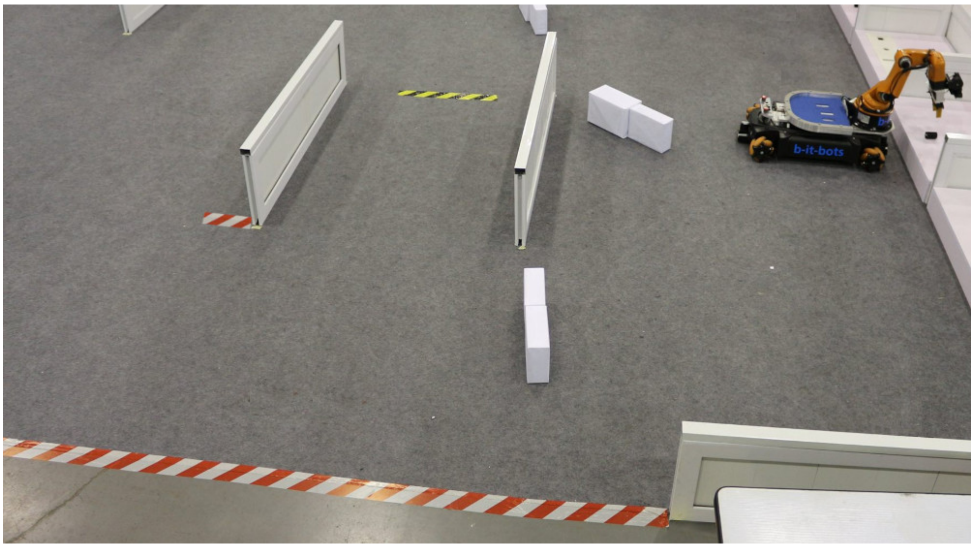


Figure 3.6: Example of a typical arena. The red/white Tape indicates a Virtual Wall. The yellow/black Tape indicates a Virtual Obstacle and the white ashlar-formed cartonages are Obstacles.

3.2.3 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 can be either physical or virtual.

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 (< 20cm).
- **Semi-Blocking:** The Obstacle reduces the distance between arena elements below the minimum width for a path (< 80cm). 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.

Physical Obstacles measure atleast 2cm x 2cm x 20cm (l x w 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 yellow/black Tape from section 3.2.4. The collisions with these Virtual Obstacles will treated different (see REF SCORING).

3.2.4 Tapes

Red/white Tape:

The red/white Tape (Tesa signal 5cm width) is considered as a Virtual Wall and has an infinite height. The red/white Tape is static and won't be changed during the whole competition. It will be used inside the arena and as an outer border of the arena. Touching the red/white Tape is considered as a Major Collision.

Yellow/black Tape:

The yellow/black Tape (Tesa signal 5cm width) is considered as a Virtual Obstacles and has an infinite height. The yellow/black Tape will be placed by the Referees before a run that contains Virtual Obstacles. Touching the yellow/black Tape is considered as a Tape Collision.

Markup Tape:

Green electrical tape is considered as markup Tape. This tape can be used everywhere, where it is useful. It is intended as a marker for the referees and teams and not for the robot. Therefore the color may deviate, but the color is not red or yellow to guarantee a clear difference to the other tapes. The tape is used to mark the START and FINISH area. Furthermore the tape can be used to mark the position of tables (especially 0cm) and Walls. The latter ones are useful for restoring the arena in case of a Major Collision.

Figure 3.7: Example red/white and yellow/black Tapes

3.2.5 Tables

The tables normally used have a width (the side the robot approaches) of 80cm and a depth of 50cm. In general terms, the table shall be big enough to contain at least one manipulation zone as described in section 3.3.4. In general two manipulation zones are included in one table (one zone on each side of the table). The used table heights are 0cm, 5cm, 10cm and 15cm. See further down in this section for more information about the 0cm-Table. See figure 3.8 for illustration. The tolerance for the heigth is ± 2cm. During a competition the table size is only fixed in the margin of ± 2cm, because of arbitrary surfaces (see 3.3.2 for an explanation of arbitrary surfaces). The table is closed between the bottom and the table top. That's why the tables can be used as a reference for navigation, when the height is sufficient for the robot. Note that the height may change slightly with arbitrary surfaces during a competition and thus the table can sometimes be visible to the laser scanners and sometimes not.

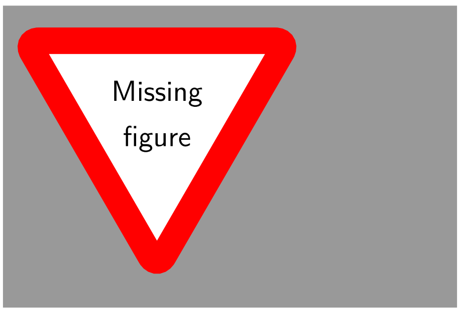


Figure 3.8: different tables... TODO Leander

If a Table has a height of 0cm, a green electrical Tape (see 3.2.4) will mark the area. A 0cm-Table can be active or inactive. Active means, that the current test (see table 5.1) includes 0cm-Tables. If the Table is active, the surrounded area may be covered by a white sheet of paper, thin wood or arbitrary surface. The material is not fixed. The OC is responsible to replace it in case of pollution or tears. To reduce the tear, it is removed when the 0cm-Table is not active. If the floor is white or the table shall have an Arbitrary Surface, no cover needs to be installed. 0cm-Table may be crossed and does not count as a collision. If the laid out white Surface is moved, it is not a collision. If the robot touches an Object while navigating, this will be handled as a collision. Examples for 0cm-Table are shown in figure 3.9.

If the service area located on a table is just used for pic and place purpose it will be referenced as *Service areas placed on* 0cm, 5cm, 10cm *and* 15cm-*tables used for pic and place operations* (workstation).

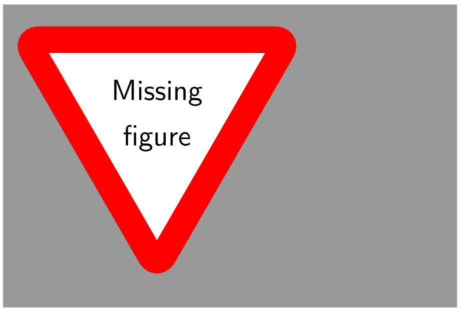


Figure 3.9: 0cm-Table, TODO Leander 3 pictures: active ws, inactive ws and with

3.2.6 Shelves

The integration of Shelves into tests is according the table 5.1. Service Areas may foresee the use of shelves and shelf units as depicted in Figure 3.10. The lower part of the shelf is a 10cm-table as specified in 3.2.5. The maximum height of the shelves should be not more than 40cm. In the example shown in Figure 3.10 the first $15\text{cm} \pm 2\text{cm}$ are not covered by the top shelf. The length of free space can be changed during competition and can not be seen as mandatory. Therefore all teams has to consider special picking behaviour to avoid collision.

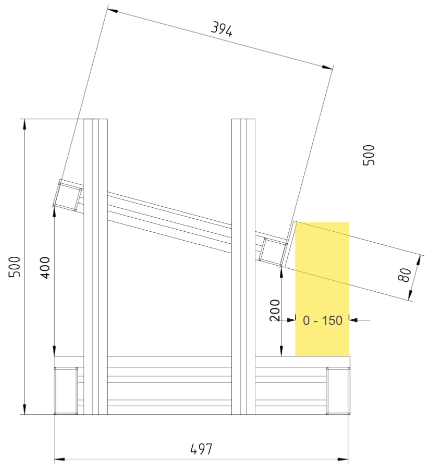
The top shelf surface may be specially designed in order to serve specific purposes, e.g. holding Objects. Objects to pic up are always placed on the bottom shelf, during the competition a placement of a delivered Object has to be done on the top shelf.

3.2.7 Rotating Tables

The integration of Rotating Tables into tests is according the table 5.1. A Rotating Table as depicted in Figure 3.11 is used for these tests. The Objects placement is the same like in section 3.3.4, so the maximal depth for Objects is 20cm and there is gap of 2cm to the border of the Rotating Table.

The height of the Rotating Table should be not lesser than 8cm and not be more than 12cm. The diameter of the Rotating Table should be not lesser than 50cm and not more than 100cm. The Rotating Table has to have a white surface colour. The rotating speed of the table depends on the diameter so that the Objects speed is able able to vary between $5\text{cm}\,\text{s}^{-1} \leq v_{object} \leq 20\text{cm}\,\text{s}^{-1}$. This has to be adjusted by the referees before a team starts its run to a fixed value (some small

(a) A shelf with two levels and uniform colored surfaces.



(b) Technical draw of shelf configuration.

Figure 3.10: Exemplary shelf and generic technical drawing.

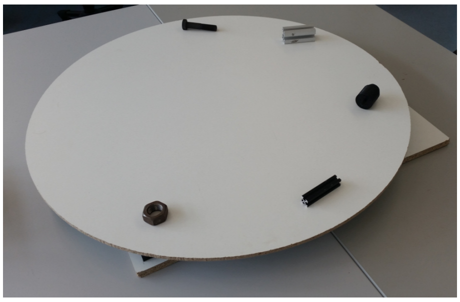
variations in boarders of technical feasibility are allowed). This is changed after each run to another random chosen value in this range. During the run of a team the speed is static. Example: For a Rotating Table with diameter $d_{table} = 1$m, Objects are placed on a grasp region with the diameter $d_{object} = 0.8$m with $\omega_{table} = \frac{2 \cdot v_{objects}}{d_{grasp}} = \frac{2 \cdot 0.2}{0.8} = 0.5$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 Rotating Table $n_{table} = 0.0796$s^{-1} (rounds per second) can be calculated.

[Martin] same speed for all teams or changed after each team??

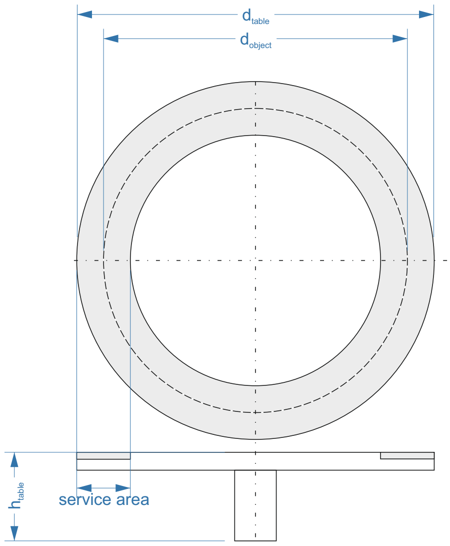
3.2.8 Precision Placement Tables

The precision placement table as shown in Figure 3.13 includes object-specific cavities tiles as shown in the Figure 3.12. It is based on a standard 10cm table described in Section 3.2.5. For each object used in the test, there will be one specific cavity. The cavity has the dimension of the object plus a 2mm offset for each dimension. At most five cavities are used in the test. The cavities are in an random order on the table and are located within the standard manipulation zone defined in Figure 3.18. One cavity tile has the dimensions of 140mm $\times$ 140mm.

Placing five cavities on a standard 10cm table leaves a boarder of 5cm on each side of the table.

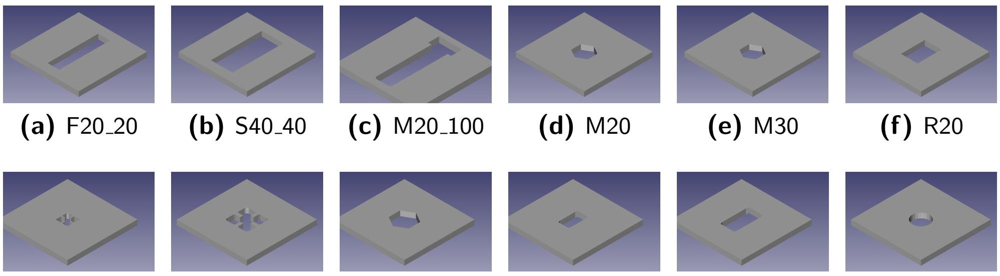


(a) A Rotationg table with some Objects.



(b) Technical draw of Rotating table.

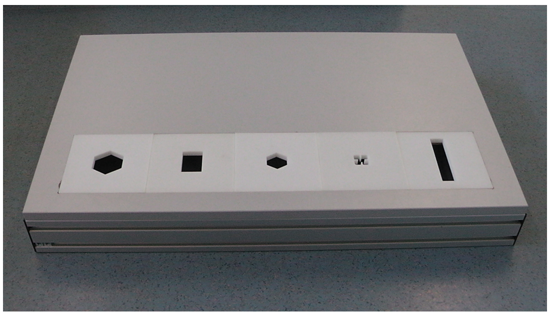
Figure 3.11: Exemplary Rotating table and generic technical drawing.



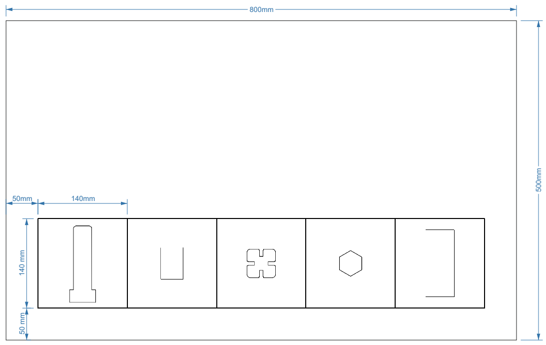
(a) F20_20 (b) S40_40 (c) M20_100 (d) M20 (e) M30 (f) R20

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

Figure 3.12: Illustration of horizontal (top row) and vertical (bottom row) cavities for the different kind of manipulation objects.



(a) The PPT platform including five cavity tile.



(b) Technical draw of Precision Placement table.

Figure 3.13: Exemplary Precision Placement table and generic technical drawing.

3.3 Service Areas

A Service Area indicates a location for a robot where tasks (e.g. picking or placing Objects) have to be performed.

3.3.1 General

Such a location is usually a Table with a flat white top (see fig. 3.2), commonly referred to as Workstation, 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 and the robot has to stand still. To enable robots to reach such a position, a rectangular area with 80cm width must be kept free of Obstacles (see fig. 3.14).

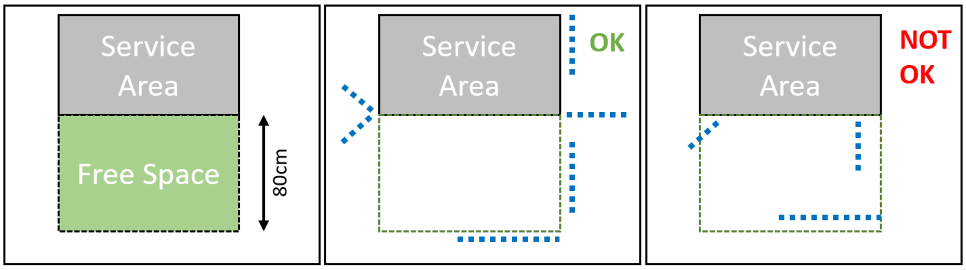


Figure 3.14: Free Space in front of a Service Area

The arena layout must define where the "front" of a table is. Figure 3.3 gives an example for the definition of the position of each Service Area, marking them as WSx (Workstation x), SHx (Shelf x), PPx (Precise Placement x)and RTx (Rotating Table 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 includes Service Areas which can be used from both sides (see fig. 3.2) are defined as two seperate workstations (e.g. WS5 & WS6). However, manipulation of theses 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 3.3.4), even though it would be physically possible.

This rule also applies to the two positions for the Rotating table (RT1 and RT2). This makes smaller physical layouts possible that still provide the ability to create complex navigation challenges due to the amount of locations to visit.

3.3.2 Arbitrary Surfaces and Decoys

In order to make the operating environment more realistic, the Service Areas may contain different kinds of Arbitrary Surfaces (Figure 3.15) with industrial items as Decoys (Figure 3.16). The Arbitrary

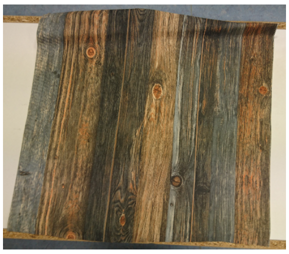
Surfaces don't have to be fixed mounted at the Service Areas. Examples of Arbitrary Surfaces can be different wood pattern, grass, alufoil, plexiglas etc. The integration of Arbitrary Surfaces and Decoys into tests is according the table 5.1.

[Lucas] I can do new photos next week with even dimensions and additional with alufoil and plexiglas

(a)

(b)

(c)



(d)

(e)

Figure 3.15: Examples of arbitrary surfaces used for Service Areas.

(a)

(b)

Figure 3.16: Examplary configuration of the working desks

[Martin] Decoys placement, surface, obstacle placement are done by referees. Decoys could also be standard objects from the rulebook.

3.3.3 Containers

As in many industrial settings, the RoboCup@Work environment may be equipped with several Containers (see Figure 3.17). The Containers are defined as industrial plastic stacking boxes size 2B, outer dimensions: $135 \times 160 \times 82$mm, usable dimensions: $120 \times 125 \times 65$mm in red ca. RAL 3020 and blue ca. RAL 5015. They can store any kind of Object defined in Section 3.4. 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 within the manipulation zone defined in Section 3.3.4. It is also possible that more than one Container is placed at a single Service Area, but not multiple Containers of the same color. The constraints defined in Section 3.3.4 apply also to the Containers. Currently, a Container itself does not need to be manipulated or transported by the robot.

(a) blue **(b)** red

Figure 3.17: Containers can be used for grasping Objects out or placing Objects into them.

3.3.4 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 20cm.
- The minimum distance between Objects to each other is 20cm.
- The minimum distance of the beginning of the manipulation zone to a Wall is 10cm.
- There as an offset of 2cm 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.

For the placement of Objects the following terms are used:

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

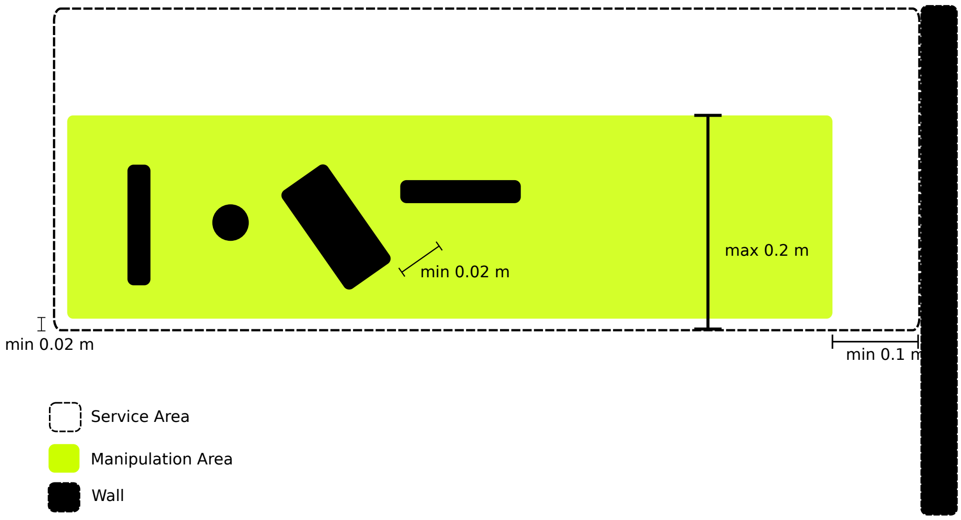


Figure 3.18: Manipulation zone: the green color indicates the area where Objects can be placed on a Service Area by the referees.

3.4 Objects

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

The intention is to start with a simple set of Objects of different shapes and colors. Every year, the spectrum shall then be widen in at least one aspect. The initial set of Objects includes basic standard screws and nuts 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 as shown in Section 11.1.

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 (ca. RAL 9006), thickness 1.75 or 2.85, not specified in detail. Figure 3.19 shows an example of all rocking Objects printed with a fused filament fabrication (FFF) 3D printer.

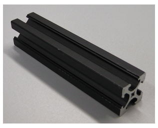
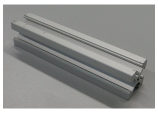
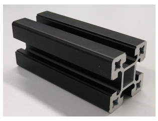
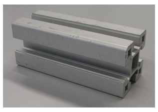
Object	Symbolic Description	Mass	Details
	F20_20_B	49 g	Small aluminium profile Coating/Colour: black anodized Height: 20 mm Width: 20 mm Length: 100 mm
	F20_20_G	49 g	Small aluminium profile Coating/Colour: gray anodized Height: 20 mm Width: 20 mm Length: 100 mm
	S40_40_B	186 g	Big aluminium profile 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 Object set.

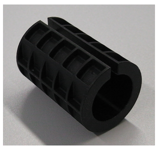
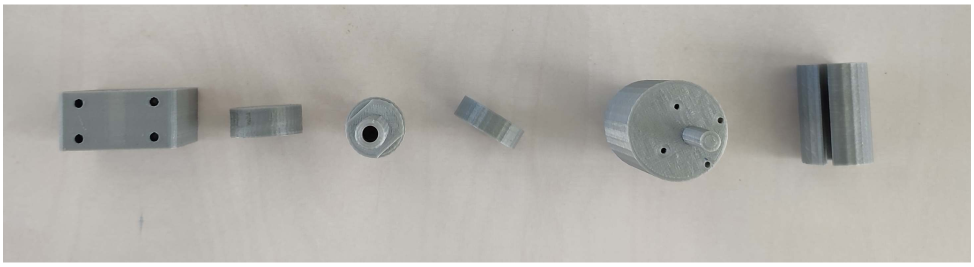
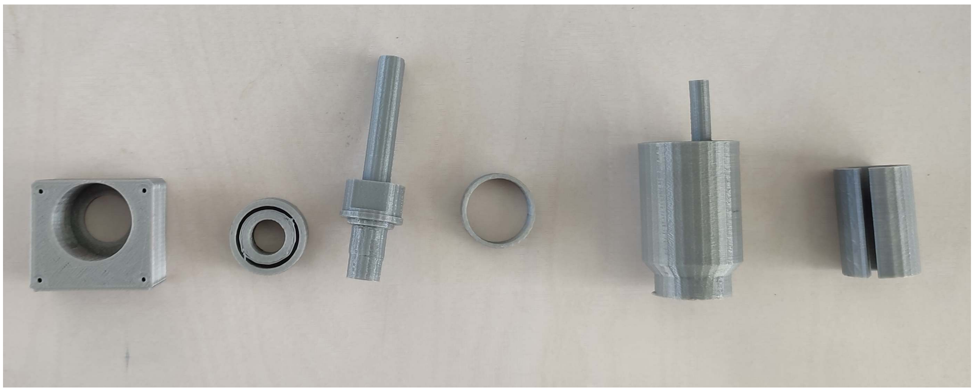
Object	Symbolic Description	Mass	Details
	Bearing_Box	102 g	Bearing box Height: 25 mm Width: 45 mm Length: 50 mm Inner diameter: 32 mm
	Bearing	42 g	Bearing Height: 13 mm Inner diameter: 15 mm Outer diameter: 32 mm
	Axis	40 g	Axis Diameter: 27 mm Length: 96 mm
	Distance_Tube	5 g	Distance tube Height: 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 Object set.



(a)



(b)

Figure 3.19: Examplary 3D printed rocking Objects (bearing box, bearing, axis, distance_tube, motor, plastic tube R20). Material: PLA silver (ca. RAL 9006), 2.85mm. Printer: Ultimaker 3 extended. Printer settings: fine

Chapter 4

Competition

The competition is held in the form of so called tests. A test requires a robot to perform various abilities, including navigation, manipulation, task planning and autonomous decision making. Different kinds of tests each have their focus a current research field, e.g. picking moving objects or efficient task execution.

All tests require a robot to autonomously navigate the arena defined in 3.2 without causing a collision. Each team can enter the arena before actual competitions to create a map of the environment and test their robot. The OC will organize time slots for each team respecting the amount of teams and available slots. Usually there will be some setup days that can be used only for training.

4.1 Time Schedule

The actual competition currently includes a total of 7 tests. These are spread across available competition days, with test having time buffers in between each other. An example for the schedule can be found here: `https://atwork.robocup.org/rc2021/`. As on site events have tighter schedules and additionally require teams to prepare everything for an unknown environment, there will usually only be two setup and four competition days, maybe even less. Teams should prepare for something like fig. 4.1.

Team leaders are required to announce wether their team likes to participate in a test 1 hour prior to the start time to allow the OC to plan the schedule and create scoring sheets.

4.2 Parc fermé

All participating teams must bring their performing robot to the parc fermé 15 minutes before a test and leave them there during the whole timeslot of the test, except when they must perform. Rules similar to motorsports apply: The robot must not be worked on or changed in any kind unless serious damage must be repaired. This intends to encourage teams to watch other performances while still give teams the chance to remain in the competition. It is allowed to attach a charger to the robot.

The location of the parc fermé will be towards the spectators for entertainment. The robots may

Figure 4.1: Example of a time schedule for a RoboCup@Work competition.

(are wished to) be turned on and ready to perform, enabling teams to set robot arm positions and illumination for the visitors.

If the power management of a robot does not enable it to be turned on during the runs of other teams, the specific team may power-on and boot their robot once the run of the previous team has ended. They may not change or modify their robot in any way during this time (hardware and software).

4.3 Test Procedure

15 minutes before a competition slot the arena is set up for the upcoming test. Therefore, the position of each static arena element is checked and objects are placed on active Service Areas. The TC will decide where dynamic arena elements are placed and which orientation an object gets to create a starting setup for the test.

[Lucas] TC or referees decide dynamic elements and only orientation?

Each team must nominate one person which acts as a referee during all tests. The job of each ref is to ensure that the arena state before each performance is the same as the setup. They also rate each performance. This ensures that the interests of every team are respected equally.

A performance slot for a team includes a preparation phase, the run phase and the end phase.

Preparation Phase

During the prep phase, teams are allowed to move their robot from the parc fermé to the defined start pose in the arena either by hand or by carefully driving manually. They should prepare their robot for their run and can therefore remote access the robot and/or make minor changes. It is explicitly forbidden to hardcode solutions for specific requirements of a test during this phase (e.g. drawing position of obstacles in the map). Also, if the robot passes and detects obstacles during this phase, they must be erased from the memory (e.g. clear costmap) unless they can be detected from the START location.

Run Phase

The run phase begins once the start time is up or when the teamleader announces that the team is ready. The task is then sent to the robot and from there on, the robot must act fully autonomously. It is forbidden to interact or control the robot in any human kind (keyboard/mouse actions, gestures, voice). The unplugging of a LAN cable to ensure that the task was send to the robot at bad WLAN connections is the only interaction with the robot that is allowed. The run phase ends once the robot has stopped at the FINISH location of the arena, when the run time is up, when the teamleader says 'stop' or the robot caused a second Major Collision.

End Phase

In the resulting end phase the team is expected to move their robot back to parc fermé. Referees gather and discuss their performance rating afterwards. Once they agree on the performing team's result, the teamleader is required to accept this score. Teams are allowed to make their case if they do not agree with the refs decision, but cannot force changes and are expected to be understanding. Special cases will be decided by the TC if the rulebook leaves room for interpretation.

Once the score has been accepted by a team, the arena must be set up for the next run if necessary. The prep time of the next team begins once the arena state is declared as ready by all refs.

TODO ADD TABLE

4.4 Skipping Tests

If a team decides not to participate in a test during the official time slot, this test type may be repeated once during a following time slot. This should enable struggling teams to do the more simpler tests later in the competition. This option should only be used by teams if really necessary to keep the structure of the overall competition. Also, teams are only allowed to perform a test with a lower potential total score than the current test.

4.5 Atwork Commander (AWC)

All specific test configurations are being generated using the atwork-commander.

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

The purpose of the atwork-commander is to create randomized test configurations for any given arena configuration. It thereby essentially functions as a master control, creating and sending current tasks to robots. It may also keep time during the prep, run and end phase. Robots must connect to the atwork-commander using one of the following interfaces:

Object Scoped The commander generates transportation tasks for each individual object that must be transported. This includes the object class and the initial and target service area. The exact pose of the object is not specified and the order of all transportation tasks is random.

Arena Scoped The commander transmits the initial and the target state of the arena. Service areas each contain the respective objects according to the individual test configuration, meaning robots must figure out the transportation tasks by themselves.

Robots should remain connected to the AWC during their whole test run. It may be required (optional) to send feedback to the AWC (heartbeat, completed tasks). Please access the github for detailed interface desciptions.

4.5.1 On Site

During a robocup, one unique test configuration is created and being used for each individual test. All teams must perform this (the same) test configuration in their assigned competition slot. For training purposes, other configurations may be created and sent to a robot during a test slot of the team.

Depending on the organization and possibilities on site, the TC must either provide all teams with atleast one "public" PC with a running refbox to allow them to test their connection setup, or decide before the first competition day if only bagfiles are being used.

In this case, robots do not have to connect to the atwork commander during a run, but may rather process the contents of the rosbag and start the task execution. The run phase of a team then starts once the robot operator announces his starting action (executing a 'rosbag play NAME' command.

Chapter 5

Tests

5.1 General

5.1.1 Common Rules

Unless stated other, the following rules apply to all test types:

- The order in which the teams have to perform will be determined by a draw from the OC.
- Teams must not hardcode information gained from runs of previous teams.
- A single robot is used.
- The robot must not leave the arena.
- The maximum objects a robot is allowed to carry is 3.
- The robot has to start and end at the respective arena location (START, FINISH).
- The robot will get the task specification from the referee box.
- Reaching succesfully a Service Area is rewarded as defined in 6.2.
- The reward for reaching a Service Area will be only rewared once for a Service Area.
- Service Areas count as succesfully reached as defined in section 3.2.
- Manipulation tasks count as successful as defined in 5.1.2 and 5.1.3.
- The score for this test will be calculated as defined in 6.1.
- Exact test specification is displayed in table 5.1.

5.1.2 Grasping Objects

An Object counts as successfully grasped, if the robot grasps the correct Object of the correct Service Area and transport it out of the corresponding Service Area. In that case the Service Area has an infinite height.

A robot is allowed to grasps an incorrect Object as long as the Object don't leave the Service Area with his complete form. This enables a robot to grasp an Object to examine the Object with a camera. If an incorrect Object grasped and moved out of the Manipulation Zone it is counted as an incorrect Object Grasping.

If the Objects falls down from the platform, the robot drops the Object to the floor after leaving the

Service Area or the Object falls on top of the Service Area from a height higher than 5cm while the grasping process it is counted as an Object Loss.

5.1.3 Placing Objects

General

An Object counts as successfully placed, if the robot places an correct Object to a Manipulation Zone of the correct Service Area. The robot has to place the Object so that the Object is lying with his complete form inside the Manipulation Zone. The pose of the Object on the Manipulation Zone can be chosen freely by the robot.

There is a Placement Deduction that will be subtracted from the points of the successfull Grasping. The Placement Deduction will be applied at the following situations, if multiple situations happen while the same placing process the Placement Deduction will applied only once:

- If the placed Object or the Manipulator touches another Object, Container or Decoy while the placing process at the Manipulation Zone
- If the placed Object is not lying with his complete form within the Manipulation Zone at the end of the placement process

The placement process starts when the Manipulator with the Object enters the Manipulation Zone and ends when the placed Object doesn't move anymore and the Manipulator has left the Manipulation Zone. In these cases the Manipulation Zone has an infinte height.

If an Object is placed from a height higher than 5cm to the top of the Manipulation Zone it is considered as an Object Loss and no points are given for a successfull Placing.

If a placed Object is either incorrect or the corresponding Service Area is incorrect, the Placement is considered as an Incorrect Placement. If at this Incorrect Placement a Placement Deductions occurs then no additional penalty points will be added to the Incorrect Placement penalty.

Shelf

The Placement at the upper part of the Shelf has to be in the Manipulation Zone of the upper part of the shelf and it is allowed that the Object is moving down to the lower area of the upper part of the shelf after the placement.

Precision Placement

A successfull Placement of the Object into the cavity will rewarded with a successfull Precision Placement. A successfull Precions Placement is if a correct Object falls thorugh the correct cavity tile. If the Object is not falling down through the cavity but is lying at the end of the run at the correct cavity it will be rewarded with an successfull Cavity Tile Placement. However The Object has to be lying with his complete form within the correct cavity.

If an Object is placed on the wrong cavity tile then no points are given and in this case there is also no incorrect Object Placing penalty as long as the Object has to be placed at this Precision Table.

If an Object is placed on a Precision Table that shouldn't be placed there, then the incorrect Object Placement penalty will be apllied.

There are recovery stragedies allowed at the Precion Table to put the Objects into the cavity. For example it is allowed to poke with the Object in the Gripper to place the Object into the cavity. This allows the use of a force sensor for placing the Object into the cavity. It is also allowed to move the Object on the cavity as long as the Object stays on the same cavity. This ensures that a movement of a Object over the complete Table is not allowed.

5.2 Basic Manipulation Test

The *Basic Manipulation Test* (BMT) is the initial test for all robots in RoboCup@Work. The main focus is to demonstrate basic object recognition and manipulation capabilities of robots.

Therefore only two service areas will be used. Those service areas will be located near to each other, e.g. WS3 and WS4 in fig. 3.2 and 3.3. One service area is used as the source location and one as the target location, meaning that all objects are initially placed on the source service area and have to be delivered to the target service area.

This test involves no arbitrary surfaces, decoy objects or obstacles. However, a total number of 5 objects are placed on the source table. This means that the robot has to visit each service area atleast twice to complete the test successfully (transportation limit = 3, see 5.1.1).

5.3 Basic Transportation Test

The *Basic Transportation Test* (BTT) targets both navigation and manipulation, aswell as logistical optimization. Objects are initially placed on randomly selected service areas and must be transported to their specific target location. As some paths may be blocked by obstacles (see section 3.2.3), robots must choose alternative routes and optionally replan the order in which they want to perform tasks.

As such requirements for autonomous robots are hard to meet perfectly, a total of three BTT's are performed during a competition, each with a different degree of difficulty. They also slowly introduce the more challenging elements of RoboCup@Work. The following paragraphs explain the different levels but DO NOT override the test specification in table 5.1.

BTT1

- Five objects have to be transported.
- There will be three estimated active service areas.
- Only tables with a height of 10cm are used.
- Virtual Obstacles (Barriertapes) are placed inside the arena (one blocking, one non-blocking).
- One service area will have an arbitrary surface.

BTT2

- Six objects have to be transported.
- There will be four estimated active service areas.
- All table heights are used (0-15 cm).
- Physical Obstacles are placed inside the arena (one blocking, one semi-blocking).
- Two service areas will have an arbitrary surface.

BTT3

- Six objects have to be transported.
- There will be five estimated active service areas.
- Only tables with a height of 10cm and shelfs are used.
- Both physical and virtual Obstacles (Barriertapes) are placed inside the arena (one blocking, one semi-blocking, one non-blocking).
- Two service areas will have an arbitrary surface.
- Two objects must be grasped from the shelf (bottom-part).
- Four objects must be placed inside of a container (two red, two blue).
- One object must be placed on a shelf (top-part).

5.4 Precision Placement Test

The *Precision Placement Test* (PPT) requires high precision while detecting, grasping, transporting and placing objects. Three objects are initially placed on a 10cm service area and must be placed into the respective cavity on a precision placement table as described in Section 3.2.8. The position of the cavities on the table is random, meaning robots must recognize the correct cavity for an object class. Objects must completely pass the table surface to count as placed successfully.

Reduced placement points will be awarded if an object gets stuck in the correct cavity hole or lying on the correct cavity tile. It is allowed to perform recovery strategies if a robot can detect objects that have not fallen through (e.g. force fitting, swiping, unstuck), but only if the respective object is already on the correct tile. It is not allowed to move or damage the cavities during this process. See section 5.1.3 for more detailed placing information.

As navigation is not the focus of this test, the source location will be close to the precise placement table and no obstacles are placed inside the arena. The robot does not have to move to the FINISH location. The run ends once the third object has been successfully placed or a rule violation has been called by the referees.

5.5 Rotating Table Test

The *Rotating Table Test* (RTT) introduces moving objects to the competition. A total of six objects are placed on the rotating table (see Section 3.2.7), of which three must be picked and three are decoy objects.

This requires robots to detect objects and estimate their trajectory in order to grasp them successfully. To lower the difficulty of this task, the table continously spins with a constant speed, enabling robots to use data from multiple rotations to calculate the optimal grasping position and move their manipulator in time.

It is explicitly NOT allowed to stop the table (e.g. by pushing the gripper into the table surface).

It is also explicitly NOT allowed to position the gripper in a way that blocks the objects unless it is during the grasping process of a target object and does not affect the table rotation or other objects.

The table starts spinning once the runtime of each team has started. The initial table rotation is the same for each team to ensure comparability.

As navigation is not the focus of this test, robots only have to travel to the rotating table and do not have to move to the FINISH location. The run ends once all three objects have been picked or a rule violation has been called by the referees.

5.6 Final

The *Final Run* (Final) acts as the full benchmark for robots, including all previous test types in a single run. Basically it is a BTT with both PPT and RTT included. As the total amount of target Objects is higher than in all previous tests, task order optimization plays a major role in this test.

Final

- Ten objects have to be transported.
- There will be eight estimated active service areas.
- All table types are used.
- Both physical and virtual Obstacles (Barriertapes) are placed inside the arena (two blocking, one semi-blocking, one non-blocking).
- Three service areas will have an arbitrary surface.
- Two objects must be grasped from the shelf.
- One object must be grasped from the rotating table.
- Four objects must be placed inside of a container (two red, two blue).
- One object must be placed on a shelf.
- One object must be placed inside of the corresponding ppt cavity.

5.7 Test Specification Summary

			Instances						
			1 BMT	2 BTT1	3 BTT2	4 BTT3	5 PPT	6 RTT	7 Final
Objects	RoboCup@Work & RoCKIn	atwork-commander	5	5	6	6	3	3	10
Objects	Decoy	atwork-commander		3	3	3		3	5
Objects	Position		Ref	Ref	Ref	Ref	Team	Ref	Ref
Objects	Rotation		Team	Ref	Ref	Ref	Team	Team	Ref
Objects	Orientation		Team	Team	Team	Ref	Team	Team	Ref
	Estimated Active	atwork-commander	2	3	4	5	2	1	8
Service area	Table height	atwork-commander	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
Service area	Arbitrary surface	TC		1	2	2			3
Arena	Physical Obstacles	TC			2	2			2
Arena	Virtual Obstacles	TC		2		1			2
Arena									
Grasping	Shelf unit	atwork-commander				2			2
Grasping	Rotating table	Referee						3	1
Grasping	Rotating direction							Team	Ref
Placement	Preisicon placement table	atwork-commander					3		1
Placement	Shelf unit	atwork-commander				1			1
Placement	Red container	atwork-commander				2			2
Placement	Blue container	atwork-commander				2			2
Placement	Rotating turntable	atwork-commander			1				
Placement	Cavities Position						Ref		Ref
Placement	Cavities Rotation						Ref		Ref
Placement	Cavities Orientation						Team		Team
Duration		atwork-commander	5min	6min	10min	10min	4min	4min	13min

Table 5.1: Test specification in the instances of the RoboCup@Work 2022 competition.

Chapter 6

Scoring and Ranking

6.1 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 5.1.

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

Explanation of the terms:

- Correct navigating is defined in Section **??**
- Correct grasping is defined in Section 5.1.2
- Correct placing is defined in Section 5.1.3

6.2 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.

6.3 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 6.4): -50 points
- Major collision (see Section 6.4): -50 points and termination of the run
- Barrier Tape collision (see Section 6.4): -5% of total points of current run up till 20%

[Leander] add penalties for not successful place or at least a reference

[Lucas] add/rename penalties : Object Loss, incorrect Object Placement, Placement Deductions,

6.4 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. Any Collisions cause a point penalty that is explained in section 6.1.

Major Collision:

If the robot (platform and arm) collides with a static element of the environment or touches a red/white barrier tape it is considered as a major collision. If the manipulator cause a fundemental change of the environment at the service area it is counted as a major collision, this could be for example moving an arbitrary surface off the workspace. A major collision results in the termination of the run and the arena can be restored.

Minor Collision:

If the manipulator 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.

Tape Collision:

Red/White Tape : This tape represents a Virtual Wall with an infinitely height. This wall shall not be crossed. If any part of the robot (including the manipulator) is above the tape, it is considered a major collision.

Yellow/Black Tape : This tape is called Barrier Tape and represents a Virtual Obstacle. 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.

Marking Tape : This tape is used as an universal marker for several purposes and therefore a collision does not matter.

Table 6.1: 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	
Marking Tape			

6.5 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.

[Lucas] add/rename points : correct Object Placement, successfull Precision Placement, successfull Cavity Tile Placement

6.6 Ranking

The tests will occur in the instances shown in Table 5.1. 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
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 (tbdiscussed... reduce points)		150	150	150			150
shelf upper level				150			150
shelf lower level				300			300
Correct object placing standard (tbdiscussed... increase, more than grasping to motivate the teams to implement placement with collision avoidance?)	75	75	75	75			75
PPT area					200		200
shelf upper level				150			150
shelf lower level				150			150
Incorrect object placing tbdiscussed... (wrong service area?)	-100	-100	-100	-100	-100		-100
Incorrect object placing tbdiscussed... (outside manipulation zone and/or touching other objects)	50	50	50	50	50		50
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 6.2: Scoring in the instances of the RoboCup@Work 2022 competition.

Chapter 7

Virtual RoboCup

7.1 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.

7.2 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 (5.1), some rules are defined to encourage teams to create challenging arena designs. In addition to the basic rules described in 3.2, 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 (7.1 orange dots). Some space must be available for non-blocking obstacles (7.1 dark green dots).
- Tables with the heights defined in (5.1) 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 3.12) 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. 7.2(b))
- One path blocking and one small obstacle must be available both for physical objects and barriertape. (See fig. 7.2(a))

Figure 7.1 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.

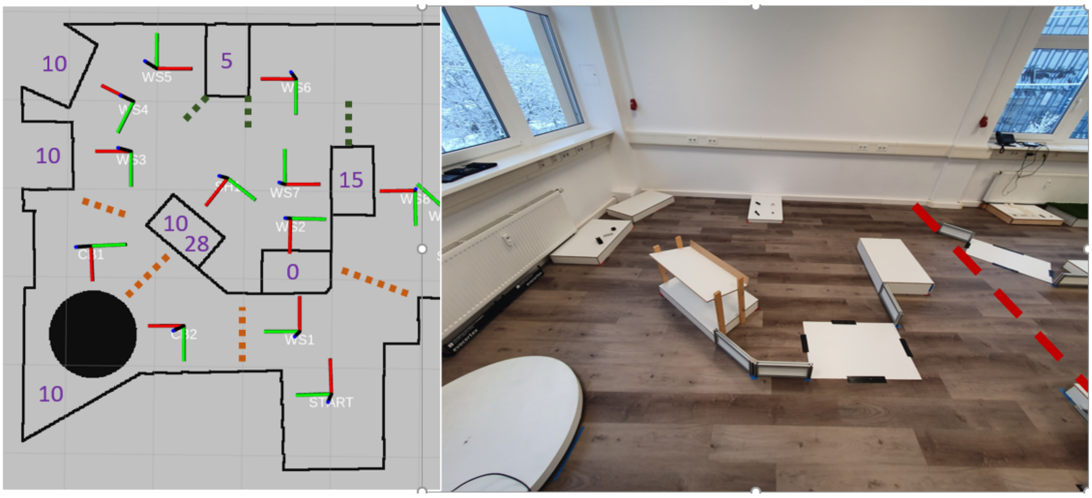


Figure 7.1: Example Arena for a small VRC Setup — Left: Annotated map - Right: Real Image

(a) Obstacle Placements

(b) Arbitrary Surfaces

Figure 7.2: 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 7.1).
- 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
- atWork-commande 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 5.1. The main requirements are already specified in 7.2, 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.

7.3 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.

7.4 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.

7.5 Task Generation

The new atWork-commander 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 atWork-commander would be provided by the OC onsite, no actual atWork-commander will be used during the online competition. The OC will create the tasks for the tests using the official atWork-commander 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.

7.6 Competition Test Procedure

7.6.1 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.

7.6.2 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 5.1. 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.

7.6.3 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.

7.6.4 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.

7.7 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 7.2). 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.

7.8 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 8. 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 7.3, 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 8

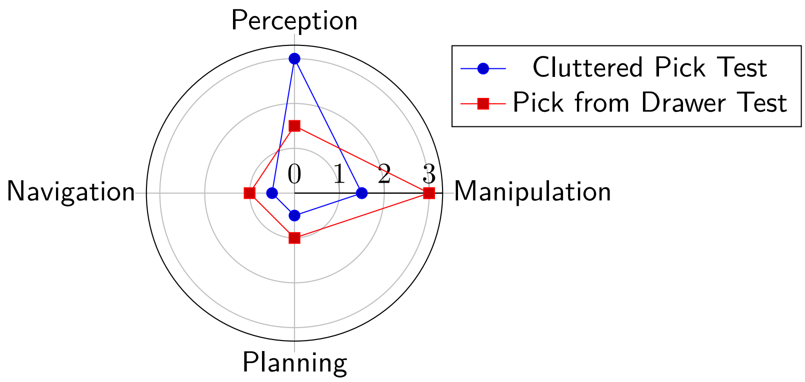
Technical Challenges

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).

8.1 Master Communication Test

8.1.1 Purpose and Focus of the Test

The purpose of the *Master Communication Test* (MCT) is to introduce the atwork-commander to all (espeically new) teams and encourage them to implement reliable communications. Therefore, a BTT1 test configuration is created but not sent as whole, but rather as individual transportation tasks. Robots must confirm a successfully completet task before receiving the next one, meaning they can only perform one task if they do not have logging / feedback implemented.

8.2 Cluttered Pick Test

8.2.1 Purpose and Focus of the Test

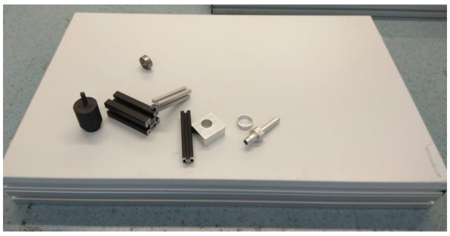
The purpose of the *Cluttered Pick Test* (CPT) is to evaluate the perception and manipulation of the robots when objects are not seperated.

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.

8.2.2 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 8.1).



(a)

Figure 8.1: objects places in cluttered environment

8.2.3 Task

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

8.2.4 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 5.1.2.
- 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.

8.2.5 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

8.3 Pick from Drawer Test

8.3.1 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.

8.3.2 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.

8.3.3 Task

The drawer setup is located at an arbitrary position. The drawer contains 3 randomly chosen manipulation objects to be picked described in Table 5.1. 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 robotâĂŹs 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.

8.3.4 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 5.1.2. 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.

8.3.5 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.

8.4 Simulation Evaluation Test

8.4.1 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.

8.4.2 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 **??**

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

8.4.3 Task

The task of this challenge is to show the execution of one of the tasks defined in Section **??** 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.

8.4.4 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 **??**
- Start of task by Referee Box see Section **??**
- 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)

8.4.5 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

8.5 New Objects Transportation Test

8.5.1 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 *New Objects Transportation Test* (NOT) includes a new and realistic objects set to grasp. The challenge extends the standard Basic Transportation Test 5.3 where the robot has transport only basic objects.

8.5.2 Scenario Environment

Basically the BTT2 scenario will be used but with the objects defined in section 11.1. This includes all basic manipulation objects from Table **??** and future objects from Table 9.1 and Table 9.2.

8.5.3 Task

The task is the same as for a BTT2, with the modification that rocking objects will be replaced by the objects from section 11.1.

8.5.4 Rules

The following rules have to be obeyed:

- A single robot is used.
- Six objects have to be picked.
- There must be at least 3 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 5.1.2.
- The run is over when the robot reached the final place and the human worker successfully assembled the components 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.

8.5.5 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

8.6 Robot-Human Interaction Test

8.6.1 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 *Robot Human Interaction Test* (RHI) includes not only a new and realistic objects set to grasp but also includes human workers into the scenario. In this way, the challenge extends the standard Basic Transportation Test 5.3 where the robot has transport only basic objects without any further interaction.

8.6.2 Scenario Environment

Basically the BTT2 scenario will be used but with the objects defined in section 11.1. This includes all basic manipulation objects from Table **??** and future objects from Table 9.1 and Table 9.2.

8.6.3 Task

The task is the same as for a BTT2, with the modification that rocking objects will be replaced by the objects from section 11.1. Furthermore a human worker has to be selected which has to assemble suitable parts together. The human worker has to stand outside the arena and has to be able to collect items from goal workspaces. Additional tools, screws, nuts and washers needed can be carried and prepared by the human worker. Objects which can be assemble:

- Screw M20_100 and Spacer and Nut M20
- Bearing2 and Housing
- Axis2 and Nut M20

After successfully reassembling of the objects the human worker has to place the objects on the table and the robot has to recognize the new assembled objects and has to transport those to a final goal destination.

8.6.4 Rules

The following rules have to be obeyed:

- A single robot is used.
- Six objects have to be picked.
- There must be at least 3 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 5.1.2.
- The run is over when the robot reached the final place and the human worker successfully assembled the components 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.

8.6.5 Scoring

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

8.7 RoboCup Manipulation Challenge

This challenge is not part of the @work technical challenges. It's a RoboCup challenge sponsored and supported by MathWorks, Franka-Emika and P&G. Because it is about manipulation, all @work teams are invited to participate. The challenge took place the first time in 2021 as a simulation competition. In 2022 it will be simulation again, but in 2023 it should become real. The idea is to provide a real industrial use case via industrial partners.

TODO: add ref to 2022 edition, brief description, price money

Chapter 9

Future Changes

9.1 New Objects

In the year 2023 there will be new objects introduced to the rulebook this is due to the fact that the RockIn Objects (see Table 3.2) are no longer sold and available. The RoCKIn Objects and the R20 will be removed from the object set and the following new standardised mechatronic objects will be introduced (see Table **??**)

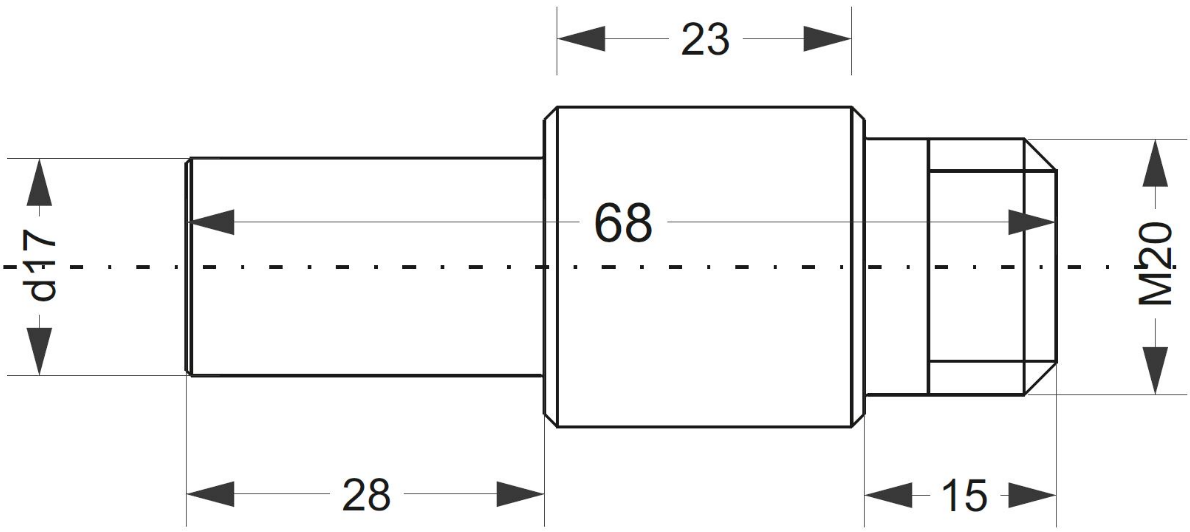


Figure 9.1: Schematic drawing of new manipulation object Axis2. Made of steel, blank or black burnished.

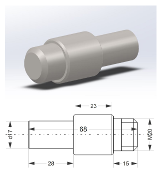
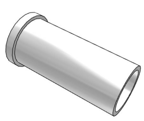
Object	Symbolic Description	Mass	Details
	`Axis2`	180 g	Steel axis Misumi: SFUB25-25-F28-P17-T15-S10-Q20 Coating/Colour: blank, black burnished Length: 68 mm Diameter: 17mm, M20 see Figure 9.1 Misumi (visited Januar 2022)
	`Bearing2`	100 g	Bearing SKF YAR203-2F Coating/Colour: gray Useable with housing SKF (visited Januar 2022)
	`Housing`	60 g	Housing SKF P40 Coating/Colour: gray Useable with bearing **Remark:** needs two hex socket screw M8x10 (DIN EN ISO 4762, DIN 912, CSN 021143, PN 82302, UNI 5931) and two M8 nuts (ISO 4032, DIN 934) SKF (visited Januar 2022)
	`Motor2`	350g	Motor 755 Coating/Colour: gray Size: 66.7×42.0mm Diameter: $d_{axis} = 5$mm, $l_{axis} = 10$mm Amazon (visited Januar 2022)
	`Spacer`		Flanged Spacer Misumi CLJHJ25-30-70 Coating/Colour: white Size: 70mm Diameter: $d_{inner} = 25$mm, $d_{outer} = 30$mm Misumi (visited Januar 2022)

Table 9.1: RoboCup@Work New set of manipulation objects (components set).

Object	Symbolic Description	Mass	Details
	`Screwdriver`	19g	WERA 352 Ball end screwdriver,hexagon socket screws Coating/Colour: black/green Size: 181mm Diameter: $d_{tip} = 2.5$mm Code: 05138070001 Amazon (visited Januar 2022)
	`Wrench`	ca. 72g	WERA Jocker 6000, 8mm Ratcheting combination wrenches Coating/Colour: silver/grey/pink Size: ca. 144mm Diameter: $d_{max} = 20$mm Code: 05073268001 Amazon (visited Januar 2022)
	`Drill`	ca. 10g	Bosch Drill HSS-Co DIN338 Drill Coating/Colour: gold/ Cobalt alloy Length: ca. 151mm Diameter: $d_{max} = 13$mm Code: 3165140382724 Amazon (visited Januar 2022)
	`AllenKey`	ca. 10g	Wera Allen Key 8mm, 3950 PKL L-key, metric, stainless Coating/Colour: silver Length: ca. 195mm $\times$ 37mm Diameter: $d_{max} = 8$mm Code: 05022708001 Amazon (visited Januar 2022)

Table 9.2: RoboCup@Work New set of manipulation objects (tool set).

Chapter 10

Special Terms

Arbitrary Surface
Arbitrary Surface is defined as an surface that has not the standard white color. Examples are wood pattern, grass, alufoil etc.

Arm
Arm is defined as only the robot arm without the gripper.

Container
Container is defined as a red or blue industrial plastic stacking boxe with the size 2B

Decoy
Decoy is defined as an Object that don't belong to the standard Objects.

EC
Executive Committee

FINISH
FINISH is defined as the area where the platform ends his run.

Gripper
Gripper is defined as only the gripper without the arm.

Manipulation Zone
Manipulation Zone is defined as the area at a Service Area in which the Objects has to be grasped or placed by the robot.

Manipulator
Manipulator is defined as the combination of arm and gripper.

Object
Object is defined as a standard object that has to be grasped or placed by the robot.

Obstacle
Obstacle is defined as a semi-static physical obstacle in the arena.

OC
Organization Committee

Parc ferme
Parc ferme is defined as...

Referee Box
Referee Box is defined as...

Service Area
Service Area is defined as an area where the robot has to perform tasks. This can be at a Table, Rotating Table, Shelf or Precision Placement Table.

START
: START is defined as the area where the platform starts his run.

TC
: Technical Committee

TDP
: Team Description Paper

Virtual Obstacle
: Virtual Obstacle is defined as a semi-static yellow/black Tape in the arena.

Virtual Wall
: Virtual Wall is defined as a static red/white Tape in the arena and is static for the whole competition.

Wall
: Wall is defined as physical wall in the arena and is static for the whole competition.

Chapter 11

Appendix

11.1 Link list

Due to have a somehow standardised set of objects for each team. In Table 11.1 an example shopping list, including some links of different items needed is given.

Item	Symbolic Description	Shop	Details
Metal Axis	`Axis2`	Mitsumi	Misumi: SFUB25-25-F28-P17-T15-S10-Q20 Misumi (visited January 2022)
Bearing	`Bearing2`	SKF	SKF YAR203-2F SKF (visited January 2022)
Bearing housing	`Housing`	SKF	SKF P40 SKF (visited January 2022)
Motor	`Motor2`	Amazon	Motor 755 Amazon (visited January 2022)
Plastic Spacer	`Spacer`		Misumi CLJHJ25-30-70 Misumi (visited Januar 2022)
Screwdriver	`Screwdriver`	Amazon	WERA 352 Code: 05138070001 Amazon (visited January 2022)
Wrench	`Wrench`	Amazon	WERA Jocker 6000, 8mm Code: 05073268001 Amazon (visited January 2022)
Drill	`Drill`	Amazon	Bosch Metal Drill Bit HSS-Co 13 x 101 x 151 mm Code: 3165140382724 Amazon (visited January 2022)
AllenKey	`Allen Key`	Amazon	3950 PKL L-key, metric, stainless, 8mm Code: 05022708001 Amazon (visited January 2022)
Containers	`Containers`	Amazon	Allit Box Size 2B Amazon (visited January 2022)
Printing Material	`PLA Material`	Amazon	Basic PLA filament Amazon (visited Januar 2022)

Table 11.1: Example shopping list of required items.