RoboCup@Work

Rulebook

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Chapter 1

Summary of Changes

1.1 Season 2023

1.1.1 Restructuring of Benachmark Tests

The specialized tasks Precise Placement and Rotating Table have been integrated into the new Advanced Transportation Tasks and the Final. The standalone tests have therefore been removed from the competition schedule, effectively reducing the number of total tests by one.

1.1.2 Linear Increase of Complexity

The elements included in the different tests have been adjusted to form a more linear increase of overall task complexity over the course of the competition. This should allow teams to participate in the tests more successful for longer while still setting benchmarks in the advanced tests.

1.1.3 Replacement of the RoCKIn Object Set with the new Advanced Set

The objects from previous years technical challenge "Real Object Test" have been added to the new Advanced Object set. This replaces the outdated RoCKIn object set for this season and onwards.

1.1.4 Introduction of April Tagged Objects

With increasing requirements for object recognition due to the introduction of arbitrary surfaces and more difficult objects, the object detection is very critical for teams to being able to perform tasks in the league. To relax the initial boundary of this task, an option to replace the real objects with April tagged cubes has been introduced. Teams can then focus on other aspects of the league (navigation, task optimization, etc.) while being able to participate in the league successfully. As the final benchmark still foresees actual detection and recognition of real objects, a penalty is applied when a team uses this simplification.

1.1.5 Clarifications for successful manipulation

Some unclear situations were adressed with some clarifications regarding successful object placement on the table, in containers and on precise placement tiles.

1.1.6 Referee Briefing

An additional organization slot was added to the schedule that shall be used to brief the referees of each team for the upcoming competition tests. Only briefed refs are allowed to judge the future runs. Teams are asked to send at least two members to the briefing, if possible.

1.1.7 Minimum Ref Number

A lower boundary of 4 for the amount of refs required for "fair" judgement was added. In case of only a few attending teams and therefore lower referee numbers, TC members will assist in the judging process.

1.1.8 Technical Challenges

The technical challenge "Real Object Test" has been removed as the new object set is used in the benchmark tests.

1.2 Season 2022

1.2.1 General Changes for 2022

In 2021, the first virtual robocup was held online via discord, zoom and youtube live. As a lot of new teams came into the league which never experienced a in-person robocup, it came clear that the rulebook was missing out on specific information and rule definitions. A lot of the rules have been habit and spoken agreements during the years, which included crucial elements such as handling of robot collisions, repeating runs, on-site competition organization and more.

This years rulebook tries to clarify all these rules, while also releasing some constraints while enforcing more robot safety. In the following, some rule summaries are being made about the following chapters. Please carefully read the paragraphs anyways.

1.2.2 Chapter 2: League Organization

Discord has proven to be a very useful tool to organize robocups as it allows teams to communicate. All participating teams should join our Discord to keep up on news and announcements.

1.2.3 Chapter 3: Robot Rules

The size constraints were relaxed to allow more chassis types. However, certain safety requirements must be met to participate in the competition.

1.2.4 Chapter 3: Environment Specification

The requirements for a robot to autonomously navigate the arena have been specified. Robots must fit those specs to participate.

The arena elements and their role in the competition are defined, declaring a task location a service area. Robots must perform various manipulation tasks at service areas, mostly by handling a set of objects.

1.2.5 Chapter 4: The Competition

The on-site process is defined and explained, most importantly the rules and schedule of runs. Robots must autonomously perform a set of tasks at different service areas, where the exact task definition is defined by so called tests.

Each team has one performance slot for each test type (currently 7+1), with the option to repeat a lower-scoring test once in a later timeslot if possible. A performance slot consists of a prep phase, a run phase and the end phase, where the performing team prepares and executes their run and then gets their performance then evaluated by the refs.

1.2.6 Chapter 5: Test Definition

Clarification of the basic manipulation, basic transportation, precise placement and rotating table test.

1.2.7 Chapter 6: Scoring Adjustments

The scoring for successful task execution and errors has been updated to ease the competition for newer teams while keeping the ambitions for more difficult tasks with boni.

1.2.8 Chapter 7: Virtual Cups

Taking the rules from 2021s virtual cup, requirements for arena setups at home are defined to allow teams to participate in their own laboratory. They must livestream their test performance with a professional camera setup to allow refs worldwide to evaluate the performance.

1.2.9 Chapter 8: Technical Challenges

Three new technical challenges have been introduced to help evolve the league and the scientific challenges. The exact specification of the individual tests is yet to be made.

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.

2.2 Organization of the League

2.2.1 League Committees

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

2.2.1.1 Executive Committee

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

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

2.2.1.2 Technical Committee

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

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

2.2.1.3 Organizing Committee

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

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

2.2.2 League Infrastructure

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

2.2.2.1 Infrastructure Maintained by the League

Website The official website of RoboCup@Work is at

`https://atwork.robocup.org/`.

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

Discord Server The official Discord server of RoboCup@Work is

https://discord.gg/z6Yn6UvhxU

Teams are asked to join the server, as it is a place for exchange in the league. Things as Questions, Announcements and Discussions are usually held here.

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:

https://lists.robocup.org/cgi-bin/mailman/listinfo/rc-work.

`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.

https://lists.robocup.org/cgi-bin/mailman/listinfo/rc-work-tc

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.

Team Description Paper Template All TDPs must be written using the following template:

https://www.overleaf.com/latex/templates/springer-lecture-notes-in-computer-science/kzwwpvhwnvfj#.WtR5Hy5ua71

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 safety systems used on the robot, including emergency stop procedure
- 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. All TDPs must be written using the following template: Overleave TDP template

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.

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

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. The maximum voltage that is allowed on the robotic system is 60 V DC.

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 stop within a reasonable distance 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. Aerial robots are not allowed in this competition.

- 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 **??** and Table 3.2 as well as Table 3.3.
- 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.

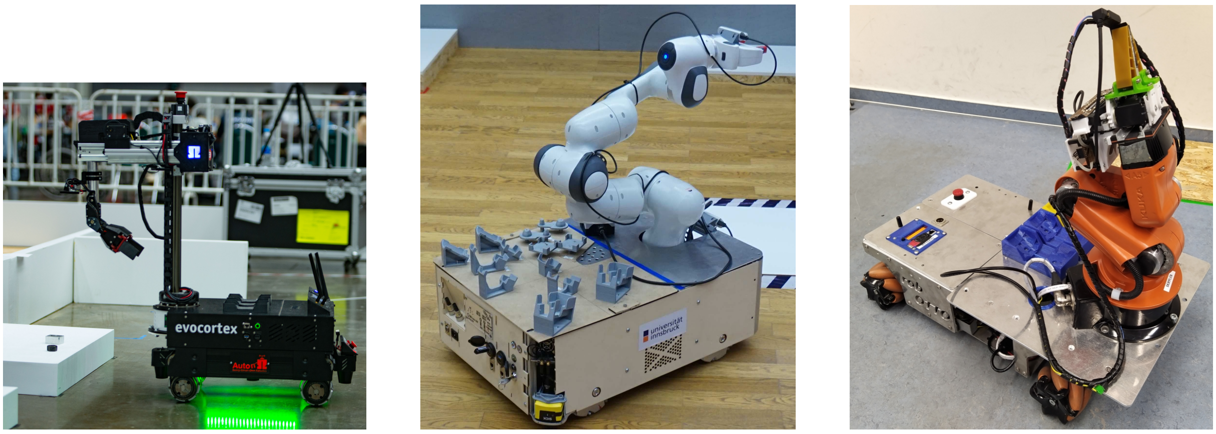


Figure 3.1: Examples mobile robot platforms that can be used for RoboCup@Work. Robots from the teams AutonOHM (Nuernberg-Germany), Tyrolics (Innsbruck-Austria) and robOTTO (Magdeburg-Germany) – from left to right.

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:

Before the competition starts 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 systems 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.

Between the area where the robot is and where the spectators stand is the referee zone. The referee zone should allow the referees to move freely around the arena.

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 at least 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

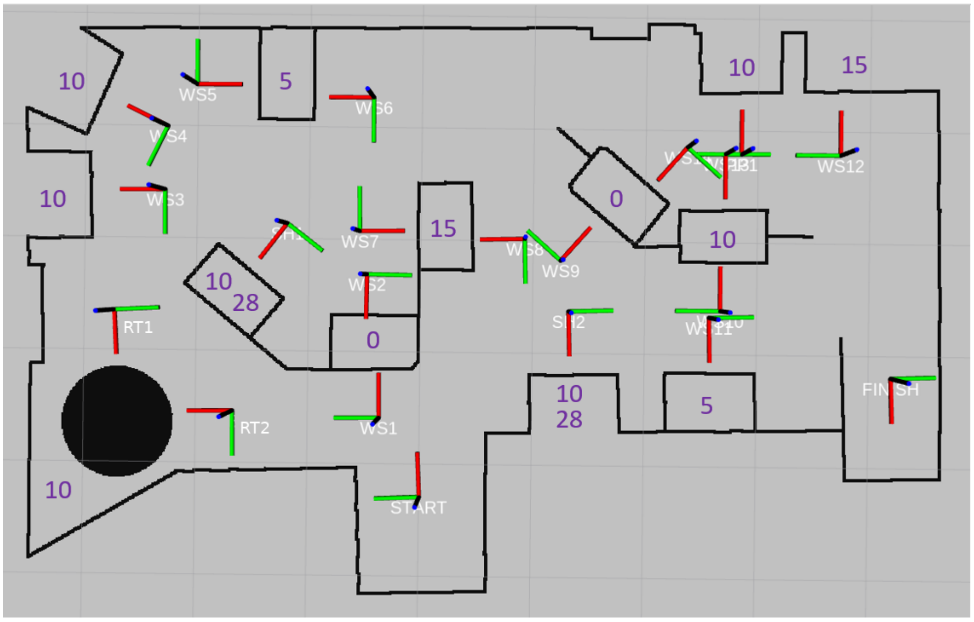


Figure 3.3: Annotated 2D map of the environment in fig. 3.2

the START area and enter the FINISH area only once. The START/FINISH area is leaved/entered when the robot completely cross the corresponding Marking Tape. In figure 3.4 an exemplary Tape configuration is shown. As soon as the robot enters the FINISH area or re-enters the START area the run ends. The FINISH area counts as a Service Area and reaching the FINISH area gives additional points.

Floor

The floor is made of some firm material. This includes among others floors made of concrete, screed, timber, plywood, chipboard, laminated boards, linoleum, PVC flooring, or carpet. Some examples are illustrated 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). All walls (physical and virtual) 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 Collision.

The height of a physical Wall must be not less than 20cm and not more than 40cm (but will be

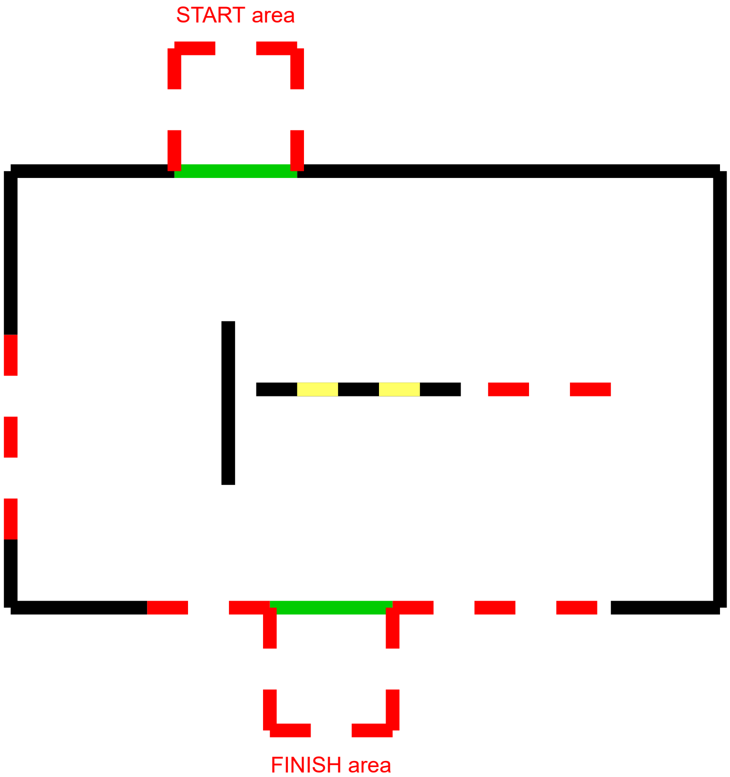


Figure 3.4: Exemplary tape configuration: black lines are physical walls, red white dashed lines are virtual walls, yellow black dashed lines are barrier tape and green lines are marking tape

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

seen as infinite high). 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.

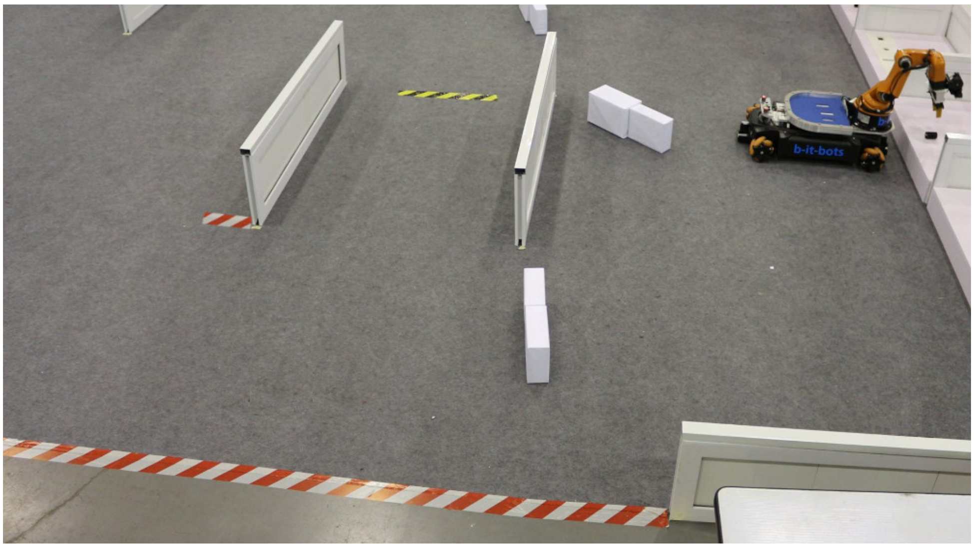


Figure 3.6: Example of a typical arena. The red/white Tape indicates a Virtual Wall. The yellow/black Tape indicates a Virtual Obstacle and the white ashlar-formed cartonages are Obstacles.

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 TC 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. The gap width is fixed and its value is calculated using the width of the biggest robot in the competition plus 10cm. This usually adds up to around 60cm, but might be higher or lower, depending on the participating robots.
- **Non-Blocking:** The Obstacle adds or enlarges an arena element but keeps all paths intact.

Physical Obstacles (see figure 3.6) 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 (Major Collision).

Virtual Obstacles are marked using the yellow/black Tape from section 3.2.4. The collisions with these Virtual Obstacles will treated as Tape Collision (see 6.4).

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 TC before a run that contains Virtual Obstacles. Touching the yellow/black Tape is considered as a Tape Collision.

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

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.

3.2.5 Tables

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 on 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 Table 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: left: 0cm-Table with arbitrary surface (approx. 1cm thick); right: PPT-Table which is a standard 10cm-Table with cavities

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 **??**) includes 0cm-Tables. If the table is active, the surrounded area may be covered by a white sheet of paper 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 Minor Collision. Examples for 0cm-Table are shown in figure 3.9.

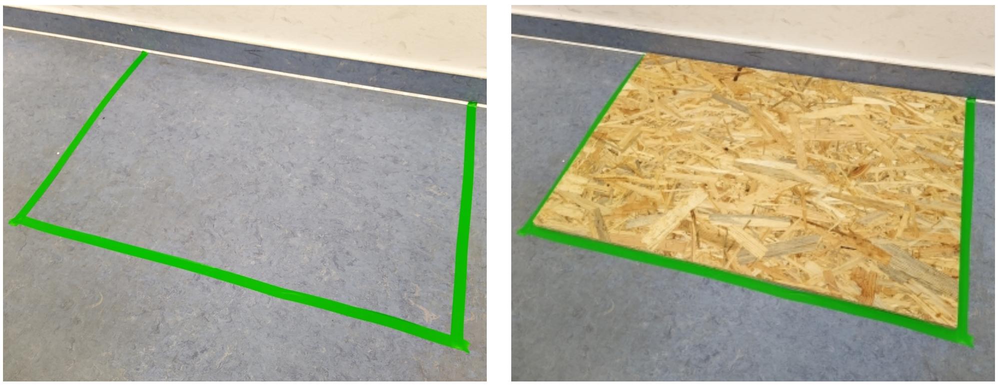


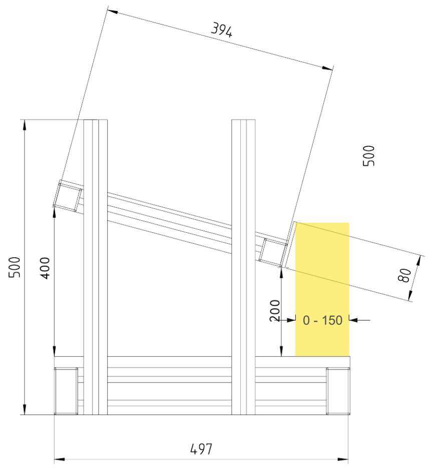
Figure 3.9: left: 0cm-Table which is considered as inactive or as an active table with arbitrary surface; right: 0cm-Table which is considered as active with an arbitrary surface

3.2.6 Shelves

The integration of Shelves into tests is according the table **??**. 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 15cm $\pm$ 2cm 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 behavior to avoid collision.

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

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



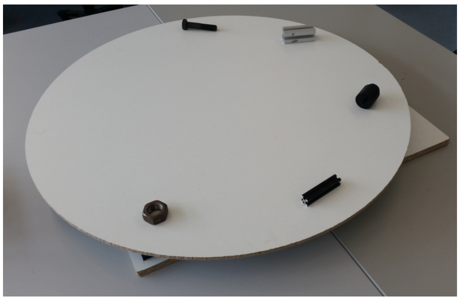
(b) Technical draw of shelf configuration.

Figure 3.10: Exemplary shelf and generic technical drawing.

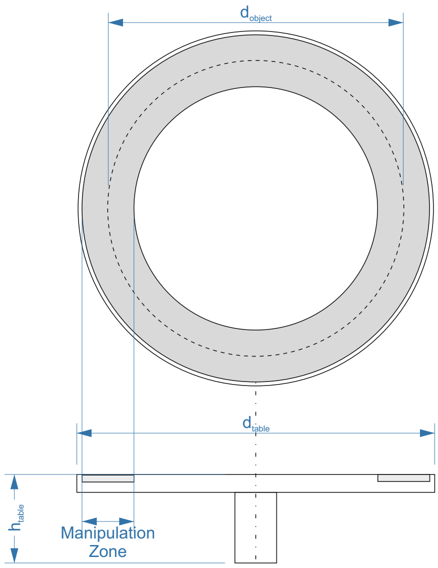
3.2.7 Rotating Tables

The integration of Rotating Tables into tests is according the table **??**. 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 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 variations in boarders of technical feasibility are allowed). This is changed after each run type to another random chosen value in this range. During the run of a team the speed is static and each team will have the same table speed. 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 $\omega_{table} = \frac{2 \cdot v_{objects}}{d_{grasp}} = \frac{2 \cdot 0.2}{0.8} = 0.5 \text{rad s}^{-1}$ and with $n_{table} = \frac{\omega_{table}}{2 \cdot \pi} = \frac{0.5}{2 \cdot \pi}$ the minimum rotational speed of the Rotating Table $n_{table} = 0.0796 \text{s}^{-1}$ (rounds per second) can be calculated.



(a) A Rotationg table with some Objects.

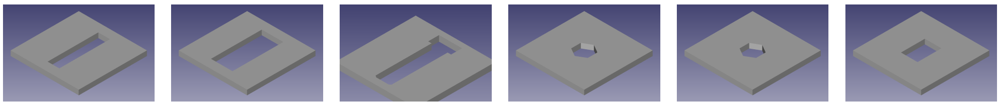


(b) Technical draw of Rotating table.

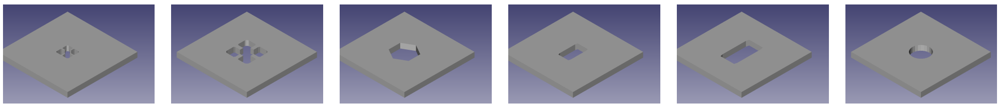
Figure 3.11: Exemplary Rotating table and generic technical drawing.

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. The additional decoy cavity tiles will be chosen by the referees. For the Precision Placement Table only the RoboCup@Work Object Set will be used.

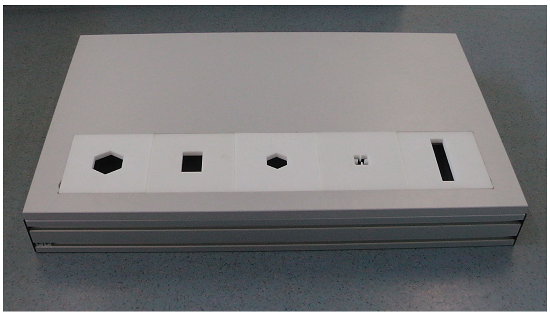


(a) F20_20 **(b)** S40_40 **(c)** M20_100 **(d)** M20 **(e)** M30 **(f)** R20

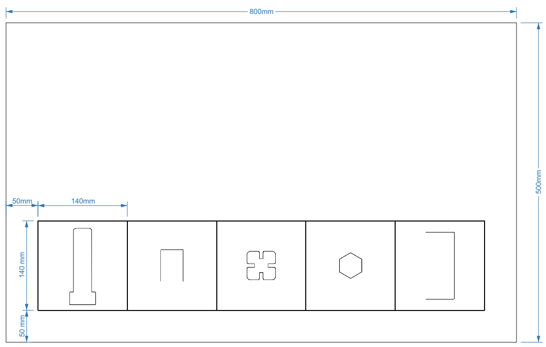


(g) F20_20 **(h)** S40_40 **(i)** M20_100 **(j)** M20 **(k)** M30 **(l)** R20

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 (only in a case of a normal Table), 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).

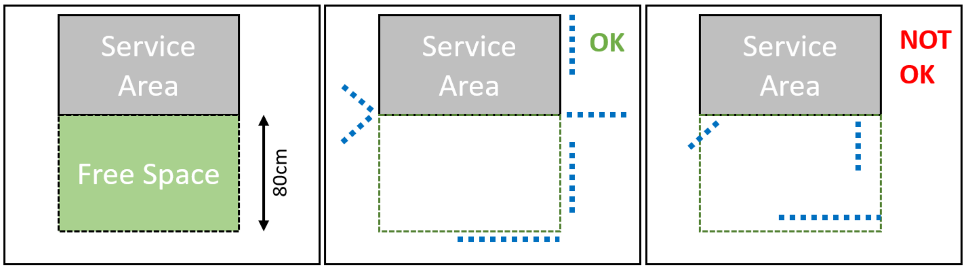


Figure 3.14: Free Space in front of a Service Area

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.

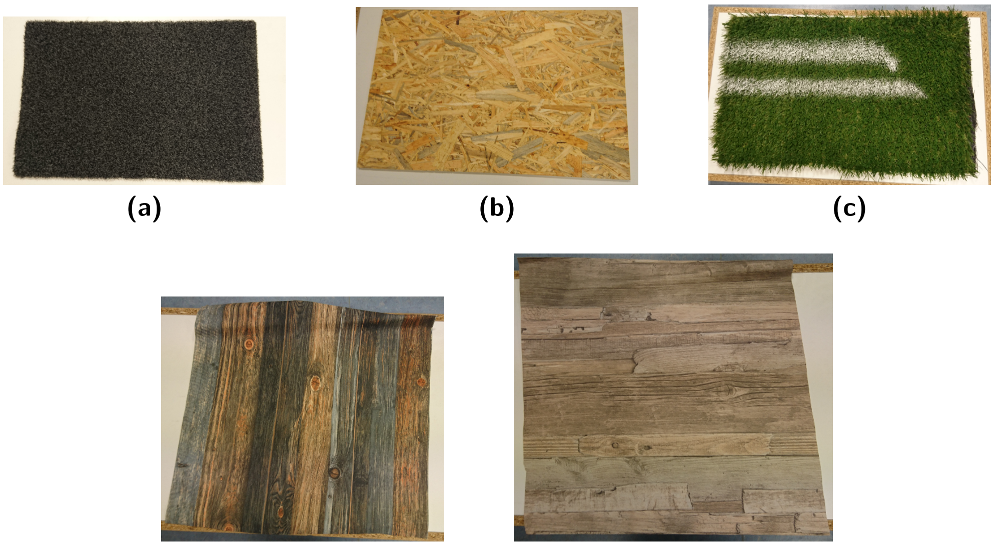
Tables that includes Service Areas which can be used from both sides (see fig. 3.2) are defined as two seperate workstations (e.g. WS5 & WS6). However, manipulation of theses Service Area requires the robot to have its center in the rectangular area defined in fig. 3.14. This means that manipulation 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 **??**.



(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 including objects and decoys.

Placement of Decoys and arbitrary surfaces are done by the referees. Decoys could be any kind of object (tools, hardware, small electrical devices) but also standard objects from the rule book defined in section 3.4 can be used. Figure 3.16 shows some examples.

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. The position of the Containers will be decided by the referees before every run type.

(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 2cm.
- 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.

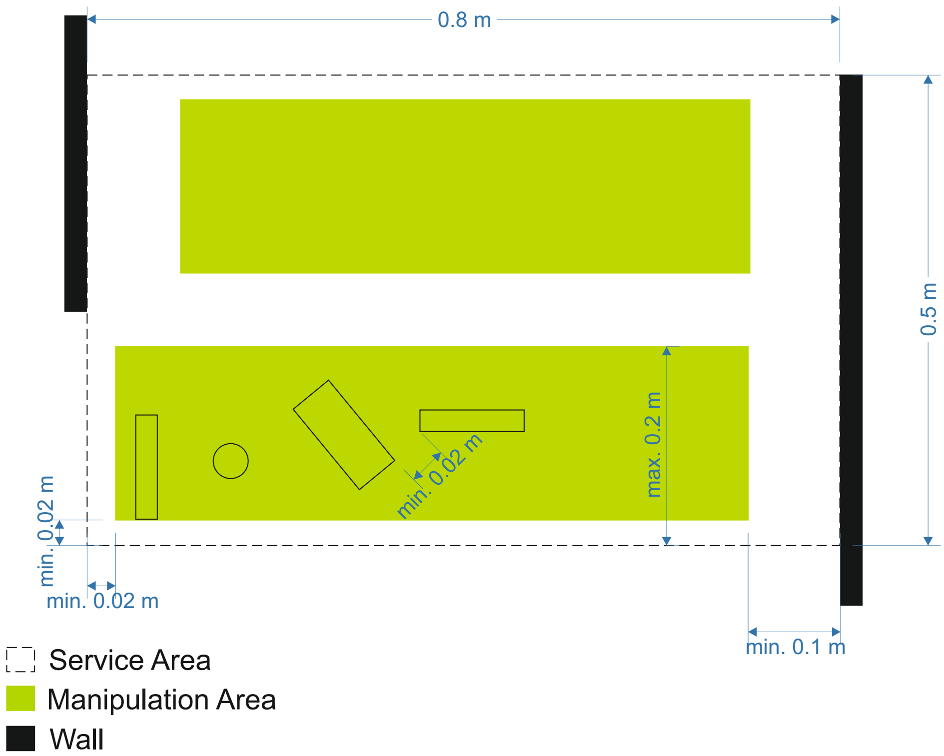


Figure 3.18: Manipulation zone: the green color indicates the area where Objects can be placed on a Service Area by the referees.

3.4 Objects

The Objects in RoboCup@Work 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. Object types are selected by the TC and shall vary in complexity due to different shapes, colors and uses of objects.

The basic set of Objects (called @work Object Set) includes standard profile rails, screws and nuts with various sizes and masses (see table 3.1).

In 2023, the RoCKIn object set (see 2022 rulebook or previous ones) is finally replaced by a selection of better available parts for a drive train, as well as some tools (see Section 9.1). The new object set was introduced in a technical challenge in 2022 and is called Advanced Object Set.

The exact appearance of the object used in the competition can slightly vary, e.g. different coating colors for some standard parts.

3.4.1 Basic Object Set

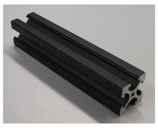
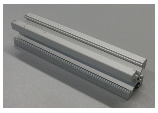
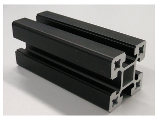
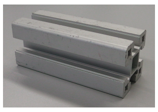
ID	Object	Symbolic Description	Mass	Details
1		`F20_20_B`	49 g	Small aluminium profile Coating/Colour: black anodized Height: 20 mm Width: 20 mm Length: 100 mm
2		`F20_20_G`	49 g	Small aluminium profile Coating/Colour: gray anodized Height: 20 mm Width: 20 mm Length: 100 mm
3		`S40_40_B`	186 g	Big aluminium profile Coating/Colour: black anodized Height: 40 mm Width: 40 mm Length: 100 mm
4		`S40_40_G`	186 g	Big aluminium profile Coating/Colour: gray anodized Height: 40 mm Width: 40 mm Length: 100 mm
5		`M20_100`	296 g	Screw ISO4014, DIN 931, CSN 021101, PN 82101, UNI 5737, EU 24014 Coating/Colour: blank, black burnished Size: $\mathrm{M}20 \times 100$
6		`M20`	56 g	Small nut ISO4032, DIN934, CSN 021401, PN 82144, UNI 5588, EU 24032 Coating/Colour: blank, black burnished Size: M20
7		`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.

3.4.2 Advanced Object Set

A new object set was introduced in 2022 as a technical challenge that is intended to introduce objects that are closer to a real-life scenario. The set includes different tools and an updated drive shaft to replace the RoCKIn set. Links for purchase can be found in 9.1.

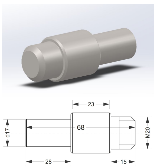
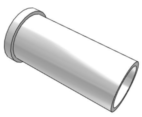
ID	Object	Symbolic Description	Mass	Details
20		`Axis2`	180 g	Steel axis Misumi: SFUB25-25-F28-P17-T15-S10-Q20 Coating/Colour: blank, black burnished Length: 68 mm Diameter: 17mm, M20 see Figure **??** Misumi (visited Januar 2022)
21		`Bearing2`	100 g	Bearing SKF YAR203-2F Coating/Colour: gray Useable with housing SKF (visited Januar 2022)
22		`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)
23		`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)
24		`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 3.2: Advanced Object Set

Object	Symbolic Description	Mass	Details	
24		`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)
25		`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)
26		`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)
27		`AllenKey`	ca. 10g	Wera Allen Key 8mm, 3950 PKL L-key, metric, stainless Coating/Colour: silver Length: ca. 195mm × 37mm Diameter: $d_{max} = 8$mm Code: 05022708001 Amazon (visited Januar 2022)

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

3.4.3 April Tagged Object Set

For the season 2023 and onwards, 3D printed cubes marked with April tags might be used in the competition. Further on this cubes will be called April Tag Tagged Cubes (ATTC). This shall prepare the possibility to design tasks that focus on other areas than object recognition by simplifying the detection. All April Tags will be $40\text{mm} \times 40\text{mm}$ and out of the *36h11* April Tag Family, including 1bit black, 1bit white boarder as shown in fig. 3.19.

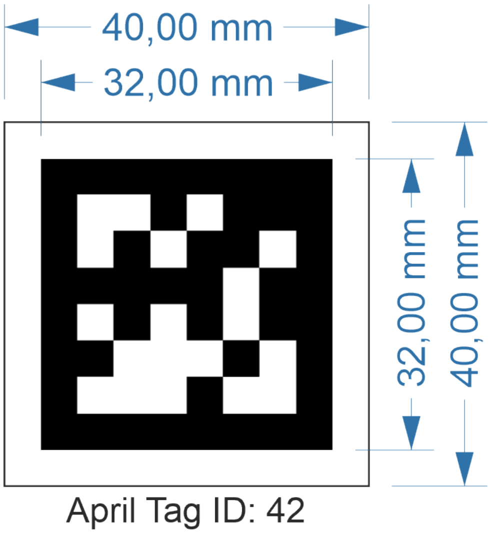


Figure 3.19: Example of an April Tag with the ID: 42 out of the 36h11-April Tag Family.

All the used April Tag ID numbers will fit to the ID numbers used by the AtWork Commander.

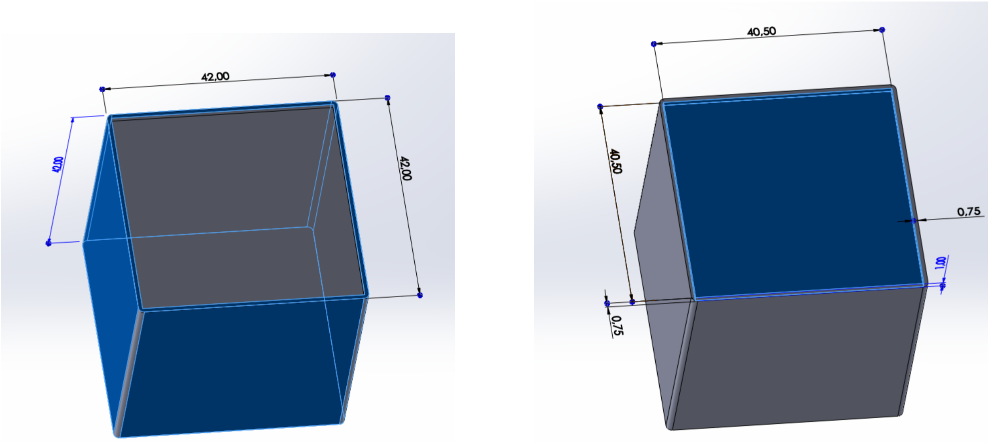
3.4.3.1 ATTC as Manipulation Objects

The standard ATTC measures $42\text{mm} \times 42\text{mm} \times 42\text{mm}$ and has slightly rounded edges, similar to the shape of aluminum profile rails. On the top there is a 1mm deep cavatie ($40.5\text{mm} \times 40.5\text{mm}$) to place the individual April Tag. It is manufactured by 3D printing using PLA filament of any color. The april tag is glued to the top side of the ATTC and is encoded with an ID matching one of the objects. The exact design and size is specified in fig. 3.20 and can be downloaded from the official league repository: 3D STL file of manipulation Cube. The sides are marked with the ID in numeric numbers to make the cubes also identifyable by humans.

3.4.3.2 Tagged Targets

Target objects, such as a precise placement cavity or a container, might also be marked with an April Tag.

For the PP cavaty tiles, one design will be used for all ATTC with any object ID. The design foresees a matching hole and two square cut-outs where tagged plates can be inserted. Additional to the

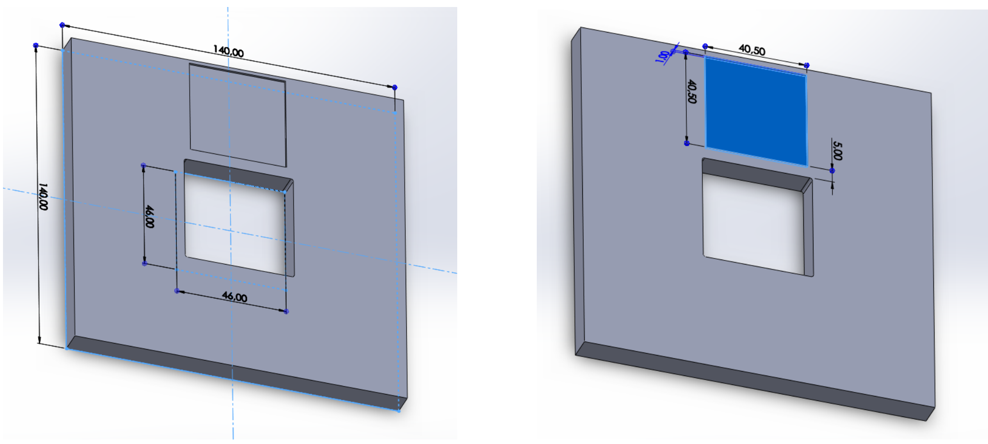


(a) April Tag Tagged Cube (ATTC), including overall dimensions.

(b) Detailed dimensions of the ATTC cavaty to fix a certain April Tag.

Figure 3.20: 3D construction of the ATTC as manipulation object.

April Tag also the April Tag ID will be shown on the tile. The ID used matches the ID used in the Atwork Commander so it should also mach with the correct ATTC. See the schematics shown in fig. 3.21 for details.



(a) ATTC cavity tile, including overall dimensions.

(b) Detailed dimensions of the ATTC tile April Tag cavatie.

Figure 3.21: 3D construction of the ATTC Precision Placement cavaty tile.

Containers get an April tag glued onto the inside of the bottom surface with centric placement as shown in fig. 3.22.

Figure 3.22: Example of a red container, tagged with the April Tag ID: "31".

3.4.3.3 April Tags

April Tags can be easy generated. The usage of any ROS package to identify the April Tag is allowed. For example the April Tag ROS package can easy be adapted to be used within the competition. Example April Tags out of the April Tag Family 36h11 are shown in fig. 3.23.

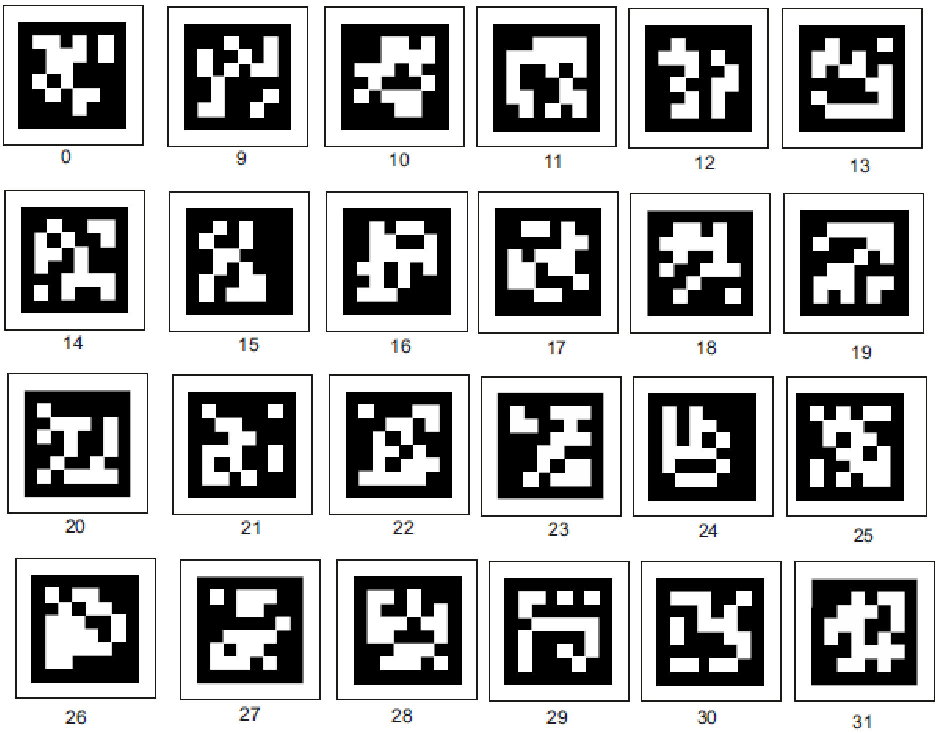


Figure 3.23: Examples of April Tags with $0 \leq AprilTagID \leq 31$.

Chapter 4

Competition

4.1 Teams and Roles

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 teamleader. A change of the teamleader must be communicated to the OC. The teamleader is the only person who can officially communicate with the referees during the competition, e.g. aborting a run, to call a restart, etc. The teamleader may ask the OC to accept additional teammembers for these tasks.

Each team must also nominate one person which acts as a referee during all tests. The job of each referee is to ensure that the arena state before each performance is the same as the initial run setup. They also rate the robot performances during a run. This ensures that the interests of every team are respected equally. It also involves the refs in discussions with other teams and the league officials, which helps getting to know each other. Each referee gets a referee sheet from the OC which is used to evaluate the performance. An additional referee is the head referee which measures the time and organizes the referees. If less than 4 referees without the head referee are available (so less than 4 teams participate), TC members can also be referees to fill this up to 4. 4 referees are beneficial, because there is at least one on each side of the arena. A referee briefing is held before a competition by the TC and OC. The goal is to discuss questions and to sensitize the referees for their task. Only briefed refs are allowed to judge the future runs. Teams are asked to send at least two members to the briefing, if possible.

Teams are asked (and wished) to comment their robots performance during their run. This makes the competition more entertaining while also sharing knowledge about robots, the challenges of a task and smart solutions. The commentator may be any teammember and is optional during competitions.

4.2 Meetings and Language of Communication

Both the TC and the OC may organize several special meetings during a competition, such as referee meetings, teamleader meetings, etc. The meetings are held in english and will be planned and announced locally. They are used to clarify rules, assign timeslots, request test participation or for any other exchange of information between teams and commitee members. It is the responsibility of each team to inform themselves about the organization and scheduling of such meetings. Each team is expected to send at least one representative to such meetings. If the meeting refers to specific roles, such as 'referee' or 'team leader', the person designated by the team to fill this role is expected to participate.

4.3 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.

4.4 Competition Procedure

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 through 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.

4.5 Time Schedule

The actual competition currently includes a total of 7 tests. These are spread across available competition days with 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.

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

4.6 Practice Slots

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.

4.7 Qualification for a Test

Depending on the amount of participating teams and available timeslots, the competition **may be** seperated into different stages. Starting with the rather easy tests including all teams, only high performing teams might be allowed to participate in later (more difficult) tests.

The OC must create an onsite schedule during the setup days and announce it before the first competition day. The schedule should include all teams in all tests if possible, but might introduce special stages in the following order:

1. Stage One: limit the maximum amount of teams in the final test, only the X best teams may participate
2. Stage Two: limit the maximum amount of teams in the Advanced Transportation and later tests, only the X best teams may participate

Teamleaders of qualified teams are required to announce 1 hour before the respective time slot wether their team likes to participate in a test or not. This enables the OC to plan the schedule and create scoring sheets.

4.8 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 (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).

4.9 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. See table **??** for the different responsibilities of placing arena elements, Objects (Pose), Decoys, Containers etc.

A competition slot consists of multiple performance slots (one for each team), including 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. The TC might disqualify teams that try to gain unfair advantages from the current or even the following tests.

Run Phase

The run phase begins once the preparation 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 only interaction allowed is the unplugging of a LAN cable connecting the robot and the controlling pc when relying on wired communication due to onsite WiFi jams.

During the run phase, the robot must not leave, nor may any person enter the arena. Teammembers of the performing team are allowed to enter the arena to prevent damage in case of an error (e.g. remove a dropped object from the robots path), but receive a penalty for each interaction. If a robot behaves uncontrolled and poses a potential threat to the environment, any person may approach the robot and press the emergency stop. However, it is requested and strongly advised that only the developers touch their robot.

The run phase regularly ends when:

- The robot has reached the FINISH location of the arena
- The run time is up
- The teamleader says 'stop'

The run phase ends early when:

- The robot has caused a second major collision
- The emergency stop button had to be pressed before a restart call
- A team was identified to be cheating

The end of a run phase must be announced by the OC by saying 'end'. Once this happened, the team may touch and control their robot to bring it to a full stop.

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.

Performance Slot Example

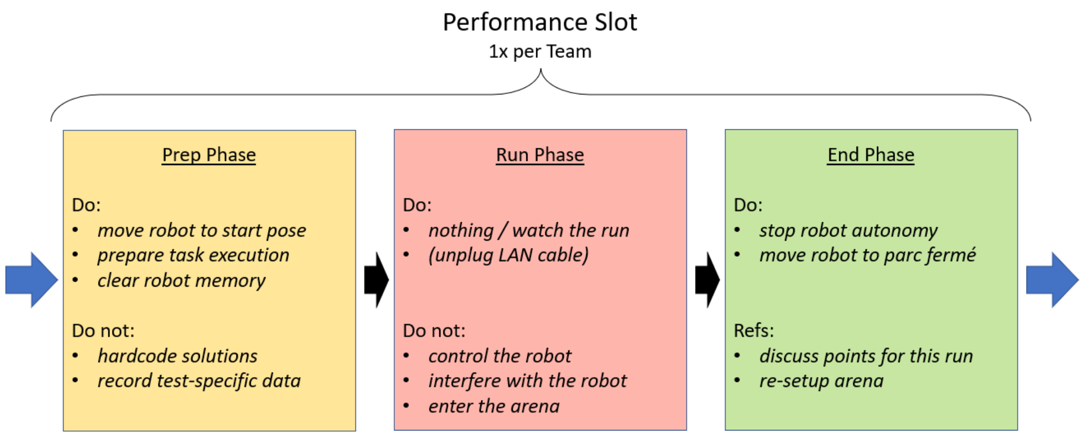


Figure 4.2: Performance Slot Example: each team gets one per test, following the random team order

4.10 Restarting a Run

During a run, the teamleader can restart the test execution once. Therefore he/she must say 'restart', which stops the current run phase. The robot must be stopped using the emergency switches, which then allows the refs to reset the arena state. The remaining run time will be noted and used after the restart. Once the refs have finished resetting the arena, the performing team is brought back to their prep phase, which allows them to move the robot back to the start area and prepare it for the restarted run. A so called tactical call of a restart (e.g. to prevent a major collision) is allowed, because this rewards the teams knowledge about the robot. Note: When the first major collision occurs, the team can decide whether they stop the run or they restart the run (see section 6.5).

4.11 Skipping Tests

If a team decides not to participate in a test during the official time slot, they may repeat that test type once in one of the following competition slots. Their performance slot for the later test type is then replaced by one that suits the previously skipped test type, and they then can perform that test type instead of the originally scheduled one.

This should enable struggling teams to do the more simpler tests later in the competition, but should only be used by teams if really necessary to keep the structure of the overall competition. Therefore it is not allowed to repeat a test that has been replaced with this option.

Please note that this option might not be available at all if the schedule is too tight otherwise.

4.12 Atwork Commander (AC)

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

4.12.1 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 performance 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 AC 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.
- The prep phase has a time limit of 3 minutes.
- 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 AC.
- Reaching each active Service Area successfully is rewarded once with points defined in **??**.
- 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 **??**.

5.1.2 Grasping Objects

General

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 Manipulation Zone. In that case the Manipulation Zone has an infinite height.

A robot is allowed to grasps an incorrect Object as long as the Object don't leave the Manipulation Zone 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 Service Area it is counted as an **Incorrect Object Manipulation**.

The grasping process starts when the Manipulator enters the Manipulation Zone und ends when it leaves the Manipulation Zone. In these cases the Manipulation Zone has an infinite height.

If the Objects falls down from the robot platform, the robot drops the Object to the floor after leaving the Manipulation Zone, the Object falls from the Manipulation Zone to the floor 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**.

If the robot collides with an Object, Decoy or Container at the Manipulation Zone while the grasping process it is considered as a **Manipulation Deduction**.

Rotating Table

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.

If one of these both situations happen while a grasping process then no points are rewarded for the following successful grasping of the Object.

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.

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 infinite height.

If one (or more) of the following situations occur the fixed **Manipulation Deduction** will be applied. The fixed **Manipulation Deduction** is not depending on the type of the manipulation (RT, SH, arbitrary surface etc):

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

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 Object Manipulation**.

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. If the placed Object collides with an already placed object it is considered as a fixed **Manipulation Deduction**.

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 through the correct cavity tile. If the Object is not falling down through the cavity but is stuck in the cavity or is lying with his complete form at the correct cavity at the end of the run it will be rewarded with an successfull **Cavity Placement**.

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 Manipulation 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 Manipulation** penalty will be apllied.

There are recovery stragedies allowed at the Precision 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 an Object over the complete Table is not allowed and will be considered as zero points.

Place examples

Here some valid (fig. 5.1) and some wrong (fig. 5.2) container placements are shown. On the ruelbook github page even more pictures can be found.

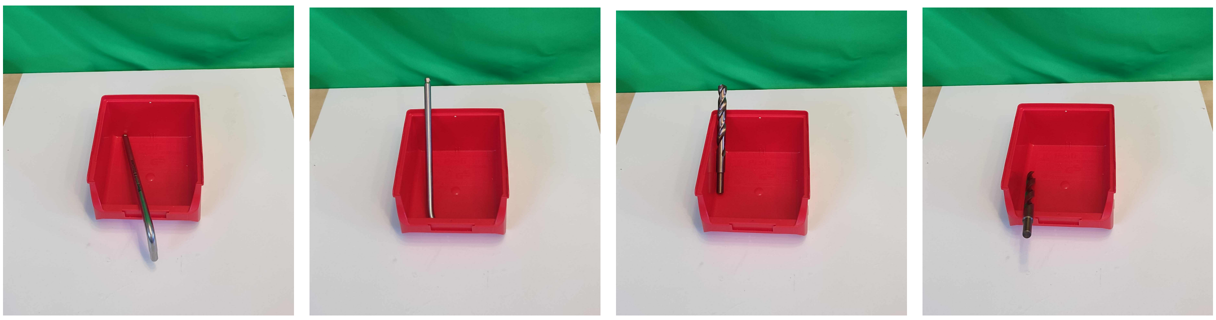


Figure 5.1: Examples of correct AllenKey and Drill in container placement.

Especially with the new advanced object set it is important to not produce an object loss during placement. The object has to be placed so that the fingers are not more than 5cm above the ground (here the bottom of the red container). That means the gripper finger has to be below the container edge (inside the container).

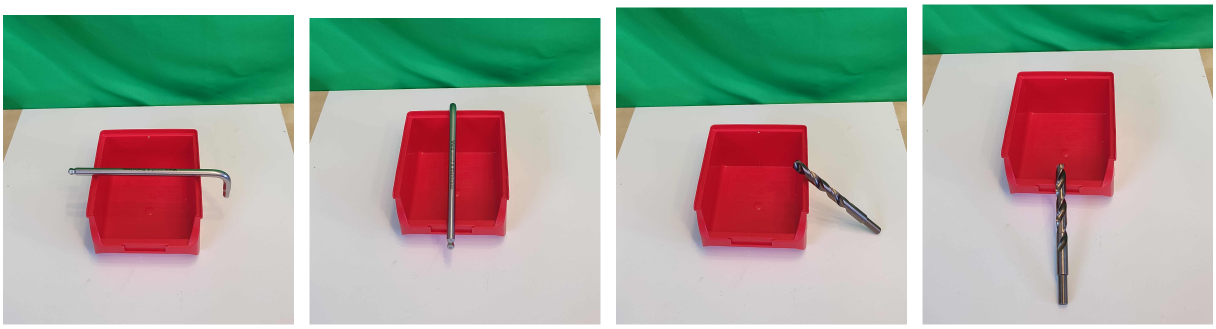


Figure 5.2: Examples of not correct AllenKey and Drill in container placement.

5.2 New Test Structure

For the 2023 season, the TC decided to restructure the benchmark tests. The main changes include:

- The dedicated test slots for "Precise Placement" and "Rotating Table" were removed. PP and RT were included in the more advanced tests.
- As this removes two competition slots from the schedule and therefore leaves some "free time", one additional transportation task was added.
- The now four total transportation tasks were split into two categories: "basic" and "advanced".
- The requirements for all "basic" tasks (BMT, BTT1 & BTT2) were relaxed in order for them to suit the naming.

We think that this had the following effects:

- The complexity of each test now increases more linear over the competition.
- Teams with less experience should be able to successfully participate in the competition for longer rather than coming out of a test with no points.
- Perfect runs are more achievable (for experienced teams) in the beginner tasks, bringing back more relevance to bonus points for reliable and consistent performance.

5.3 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. The objects that have to be manipulated are pre-selected and will include one small grey alu (f20_20_g), one small nut (M20) and the bolt (M20x100). The placement and orientation of the objects will be random.

5.4 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 their total number now exceeds the inventory size, robots will have to manage their inventory content and optimize their payload. The object pool consists of the complete Basic Object Set.

There are currently two versions of the BTT. They gradually introduce more elements of the league to the competition, including the randomness of the used objects, the increase of active Service Areas and them not being next to each other anymore, using different table heights and the placement of physical obstacles.

The following paragraphs summarize the two different levels but DO NOT override the test specification in table **??**.

BTT1

- Four randomly selected objects have to be transported.
- There will be three active service areas and they are not next to each other.
- Only tables with a height of 10cm are used.

BTT2

- Five randomly selected objects have to be transported.
- Two randomly selected decoy objects are placed onto one or more randomly selected service areas.
- There will be four active service areas with each covering one of the four table heights (0, 5, 10, 15 cm).
- Physical Obstacles are placed inside the arena (one blocking, one semi-blocking).

5.5 Advanced Transportation Test

The *Advanced Transportation Test* (ATT) has its origins as a BTT, but greatly increases the difficulty of the tasks to perform by introducing more random elements.

This includes the introduction of arbitrary surfaces, shelfs and precise placement tables, barriertape as visual obstacles and the containers as target objects. With the object count further increasing, task optimization and replanning in case of failure also becomes more relevant. In addition, the Advanced Object set is introduced into the object pool.

As with the BTTs, there are two versions of the ATT, which gradually introduce the more challenging elements of RoboCup@Work. The following paragraphs summarize the two different levels but DO NOT override the test specification in table **??**.

ATT1

- Six randomly selected objects have to be transported.
- Three randomly selected decoy objects are placed onto one or more randomly selected (active) service areas
- There will be five active service areas (four tables and one shelf)
- All table heights are used (0-15 cm).
- Two Objects must be placed on a shelf (top part).
- Virtual Obstacles (Barriertapes) are placed inside the arena (one blocking, one non-blocking).
- Two service areas will have an arbitrary surface.

ATT2

- Seven randomly selected objects have to be transported.
- Five randomly selected decoy objects are placed onto one or more randomly selected (active) service areas
- There will be six active service areas (four tables, one shelf and one Precise Placement table)
- All table heights are used (0-15 cm).
- One object must be picked from a shelf (lower part).
- One object must be Precise Placed.
- Two objects must be placed into a container (preferably one to each color).
- One visual and one physical obstacle is placed inside the arena (both semi-blocking).
- Three service areas will have an arbitrary surface.

5.6 Final

The *Final Run* (Final) acts as the full benchmark for robots, including all elements of RoboCup@Work. With the number of objects and active service areas at its peak, task planning and execution speed may become a limiting factor for competing robots.

Final

- Ten randomly selected objects have to be transported.
- Seven randomly selected decoy objects are placed onto one or more randomly selected (active) service areas

- There will be eight active service areas (four tables, two shelfs, one Rotating Table and one Precise Placement table)
- All table heights are used (0-15 cm).
- Two objects must be picked from a shelf (lower part).
- Two objects must be picked from the Rotating Table.
- Two objects must be placed on a shelf (top part).
- Two objects must be Precise Placed.
- Four objects must be placed into a container (preferably two to each color).
- Two visual and two physical obstacles are placed inside the arena (two blocking, one semi-blocking, one non-blocking).
- Four service areas will have an arbitrary surface.

5.7 Test Specification Summary

Environment

	ITEM	Environment Decisions						
		BMT1	*BTT1*	*BTT2*	*BTT3*	*PPT*	*RTT*	*FINAL*
Objects Decoys	Position	REF	REF	REF	REF	TEAM	REF	REF
Objects Decoys	Rotation	TEAM	REF	REF	REF	TEAM	TEAM	REF
Objects Decoys	Orientation	TEAM	TEAM	TEAM	TEAM	TEAM	TEAM	REF
Service Area	Table height	10cm	10cm	0cm, 5cm, 10cm, 15cm	10cm	10cm	10cm	0cm, 5cm, 10cm, 15cm
RTT	Rotation direction						REF	REF
PPT	Cavaties Position						REF	REF
PPT	Cavaties Rotation						REF	REF
PPT	Cavaties Decoy Type						TC	TC

Figure 5.3: Test specification in the environment of the RoboCup@Work 2023 competition.

Instance

	Item	Object Type	Number of Appearance					
			BMT1	BTT1	BTT2	ATT1	ATT2	FINAL
Objects	RoboCup@Work And RoCKIn num	AC	3	4	5	6	7	10
	Decoys	TC			2	3	5	8
Service Area	Active Service Areas (incl. SH, PPT	AC	2	3	4	5	6	8
	Arbitrary surface	TC				2	3	4
	Table Heights	AC	10	10	0,5,10,15	0,5,10,15	0,5,10,15	0,5,10,15
Arena	Physical Obstacles	TC			2		1	2
	Virtual Obstacles	TC				2	1	2
Object Grasping	from Shelf	AC					1	2
	from RTT	AC					1	2
	from Arbitrary surface	AC						
Object Placement	on PPT	AC				1		2
	on Shelf	AC				1		2
	in Red container	AC					1	2
	in Blue container	AC					1	2
	on Arbitrary surface	AC						
	Duration	AC	4min	6min	8min	10min	12min	14min

Figure 5.4: Test specification in the instances of the RoboCup@Work 2023 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 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 5.4.

For example in a **perfect** BMT run (perfect means all tasks fulfilled and no penalties given) a team could achieve TODO:Add points (without time bonus). This points are calculated using the values out of table 6.1.

- 2 Service areas reached: $2 \times 25 = 50$ points
- Finish reached: $1 \times 50 = 50$ points
- 3 Objects grasped: $3 \times 100 = 300$ points
- 3 Objects placed: $3 \times 100 = 300$ points
- perfect run bonus: $1 \times 100 = 100$ points

6.2 Time Bonus

If a team finishes a test in the required time frame, the left over time will be added as time bonus to the points. Time bonus is calculated using the left over time in seconds multiplied by 1.

6.3 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 before the start of the run.

6.3.1 Deactivation of Obstacles

TODO? Barriertape is now only in ATTs. Do we want to allow that ppl ignore it? Physical Obstacles aswell.

6.3.2 Using April Tag Tagged Cubes as Objects

Real objects are replaced by the April Tag tagged cubes (ATTC) described in 3.4.3. Each ATTC is encoded with the matching object ID as defined in the Atwork Commander. Manipulation tasks count as successful if an atc with a matching object ID is handled correctly. Using this option adds a penalty factor of 50% to all manipulation points gained.

6.4 Penalties

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

- Object Loss: -100 points
- Incorrect Object Manipulation (see Section 5.1.3): -50 points
- Manipulation Deduction (see Section 5.1.3): fixed 50 points (in any Manipulation szenarios)
- Minor collision (see Section 6.5): -50 points
- Major collision (see Section 6.5): restart or -50% penalty
- Tape collision (see Section 6.5): -5% of total points of current run up till 20%
- Human interaction during the run: -100 points
- Cheating: reset all points to 0

Manipulation Deduction:

The Manipulation Deduction is a fixed point reward (50) if one or more Deductions happen while a grasping or placing process. The type of manipulation (like PP, SH, RT, arbitrary surface etc) when the Deductions happens doesn't affect the fixed points of 50.

6.5 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 gripper with the upside of the service areas are allowed while a Grasping or Placing process. In all collision cases the Virtual Walls/Obstacles have an infinite height. The different kind of collisions that can occur are defined in the following section and the table 6.1 gives an overview. Any Collisions cause a point penalty that is explained in section 6.4.

Major Collision:

If the robot (platform and manipulator) collides with a static element of the environment or touches a Virtual Wall it is considered as a major collision. An exception of this rule is when the cables of the manipulator touches the environment while the Grasping or Placing process. As stated before a collision with the gripper with the upside of the service areas is allowed as long as there is no fundamental change of the environment at the service area. In this case it would be considered as a major collision. This could be for example moving an arbitrary surface off the workspace.

If a major collision occurs the first time, the team can decide between the following two options:

- stop the run and get 50% of the already reached points
- restart the run (the normal restart rules apply)

The decision will most likely depend on the remaining run time. If a second major collision occurs, the run is stopped and the team get 50% of the points reached in the second try.

Since the impact of a major collision on the scoring is very high, the declaration of a major collision is clarified in the following. A major collision is declared by shouting through authorized persons. Nobody is allowed to call a major collision, except the following persons depending on the number of available referees:

- only referees, when at least 4 referees (and 1 additional head referee) are available
- referees and TC members, when less than 4 referees (without the additional head referee) are available

The idea of the two cases is to guarantee a proper number of observers (at least one on each side of the arena). This topic should be highlighted in the referee briefing prior the competition. If a team stops or restarts the run just before the major collision, the major collision is ignored. In this case, the teams knowledge about there robot is rewarded.

Minor Collision:

If the Robot collides with (Manipulation) Objects, Decoys or Containers while moving through the arena. Collisions with Objects, Decoys or Containers while grasping or placing process is considered as Manipulation Deduction.

Tape Collision:

The yellow/black tape is called Barrier Tape and represents a Virtual Obstacle. If any part of the robot touches a barrier tape, it is considered a Tape Collision. 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.

A Collions with the Marking Tape will not be penalized.

Table 6.1: Definition of minor and major collisions

Situation	Minor	Major	Tape
Collision with static elements of arena		X	
Collision with dynamic elements of arena		X	
Body Collision with WS, SH, RT, PP		X	
Manipulator Collision with top surface of manipulation zone			
Robot Collision with Objecht, Decoy or Container (platform movement)	X		
Manipulator Collision with Shelf		X	
Virtual Obstacle (Yellow/Black Tape) Collisions			X
Virtual Wall (Red/White Tape) Collisions		X	
Marking Tape			

6.6 Restarts

Teams might use one so-called restart in a run. Scores achieved before the restart are set to zero.

6.7 Ranking

The tests will occur in the instances shown in Table **??**. 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. If it is necessary to divide the competition into two stages (see section 4.7), the scores of the first stage tests are summed up, and the teams with the highest sums proceed to the next stage (depending on overall number of teams). Depending on the number of teams and if there is enough time, all teams are allowed to enter the second stage.

In case of a tie of the first three places a deciding run will be scheduled. A point tie down from 4th place will result in to sharing the achieved place.

	Action	Points	BMT	Max.	BTT1	Max.	BTT2	Max.	ATT1	Max.	ATT2	Max.	Final	Max.	Total
	Navigation														
	Service Area reached	100	2	200	3	300	4	400	5	500	6	600	8	800	2800
	FINISH reached	100	1	100	1	100	1	100	1	100	1	50	1	100	550
	Grasping														
	Object Grasped	100	3	300	4	400	5	500	6	600	7	700	10	1000	3500
Bonus	from Shelf	100									1	100	2	200	300
Bonus	from RT	200									1	200	2	400	600
Bonus	from arbitrary	75													
	Placement														
	Object placed	100	3	300	4	400	5	500	6	600	7	700	10	1000	3500
Bonus	Cavity Placement	100							1	100			2	200	300
Bonus	Precision Placement	100							1	100			2	200	300
Bonus	on shelf	50							1	50			2	100	150
Bonus	in red container	100									1	100	2	200	300
Bonus	in blue container	100									1	100	2	200	300
Bonus	on arbitrary	50													
	Sum of possible points without perfect run:			900		1200		1500		2050		2550		4400	12600
	Sum of possible points with perfect run:			960		1280		1600		2170		2690		4600	13300
	Bonus														
	Perfect run	+ (n_picks + n_places) *10		60		80		100		120		140		200	700
	Time Bonus	seconds left													

Error	Penalty
General	
Object Loss	-100
Incorrect Object Manip	-50
Manip Deduction	Fixed 50
Human Interaction	-100
Cheating	*0
Collision	
Major	*0 . *0.5
Minor	-50
Tape	x * 0.05

Note: A successful **Precision Placement** includes a **Cavity Placement**
-> A successful **Cavity Placement** = 200 points
-> A successful **Precision Placement** = 300 points

Figure 6.1: Scoring in the instances of the RoboCup@Work 2023 competition.

Chapter 7

Virtual RoboCup

7.1 General

Since the start of the the Covid-19 pandemic, the RoboCups could not take place in person. In 2021, the first virtual RoboCup was hosted online, requiring teams to livestream their robots performance in their own laboratory. A ruleset was created that made a fair competition possible. Paricipating teams have to follow a guideline to provide some infrastructure that enable the TC and OC to evaluate their performance and to communicate during the competitions. As the organisation of such an online event is rather new for everyone and requires extended communication, every team should join the official RoboCup@Work discord server:

https://discord.gg/z6Yn6UvhxU

Announcements will be made via specific channels on this server. 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 a virtual RoboCup@Work. 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 (**??**), 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 (**??**) 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.

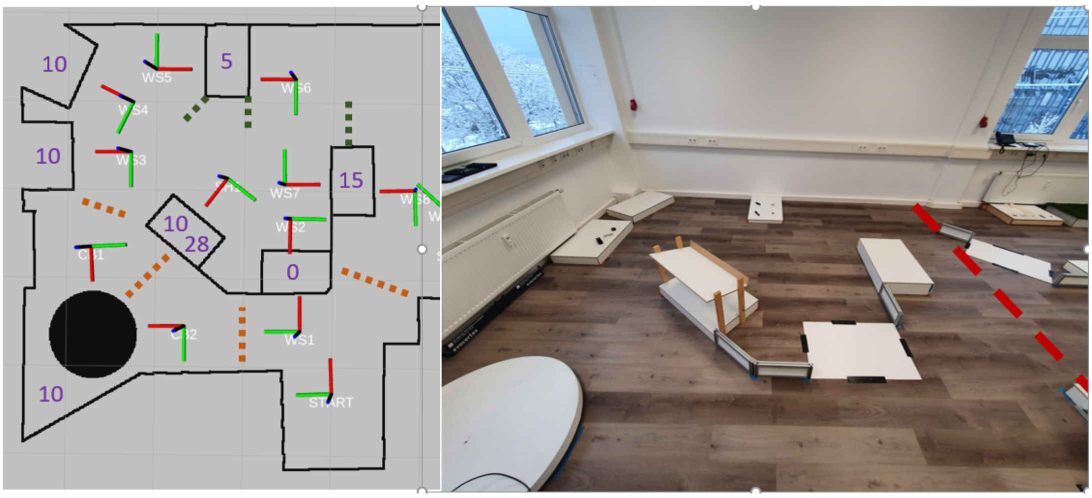


Figure 7.1: Example Arena for a small VRC Setup — Left: Annotated map - Right: Real Image

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

(a) Obstacle Placements

(b) Arbitrary Surfaces

Figure 7.2: Example obstacle placements and arbitrary surfaces

- 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 VRC-YEAR-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 **??**. 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 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 Atwork Commander. Teams must send configuration files for the new Atwork Commander 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.

7.5 Competition Test Procedure

7.5.1 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.

7.5.2 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 **??**. 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.

7.5.3 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.

7.5.4 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.

7.6 Scoring

The different arena setups make time bonuses unfair and therefore they wont be awarded. 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.

7.7 Technical Challenges

A virtual robocup will focus on the main competition. No technical challenges will be performed during the official competitions. As some teams still requested technical challenges, we accept submissions 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.

This years challenges try to introduce the relatively new atwork-commander and the planned set of new objects (see 9.1). These changes seem highly important for the participation of new teams, which is why we encourage every team to participate in atleast one technical challenge.

The exact test definition is still missing at the moment, but as the challenges are not part of the main scoring system, some of the rules may be adjusted to the requirements of the teams.

8.1 Master Communication 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 Coworker Assembly Test

In the *Coworker Assembly Test* (COT), the goal is for a robot to produce a product while cooperating with a human worker.

Therefore, the robot has to collect three components scattered in the arena and bring them to a single workstation where the human worker waits on the other side of the table. The robot has to place the objects and then wait for the human to assemble the objects to a product. Once the human worker (a teammember of the performing team) has assembled the product, he/she must place the product back onto the table and give the robot a completion signal. This may be done via sign (visual) or voice (acoustic). It is not allowed to use controller or keyboard input.

Once the robot has recognized the signal, it must detect the assembled product, grasp it and then deliver it to another workstation. This step concludes the assembly process by imitating the transport of the product to a warehouse.

Three object sets can be assembled during the COT:

- Set 1: Screw M20_100 and Spacer and Nut M20
- Set 2: Bearing2 and Housing
- Set 3: Axis2 and Nut M20

Chapter 9

Appendix

9.1 Link list

Due to have a somehow standardised set of objects for each team. In Table 9.1 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 9.1: Example shopping list of required items.