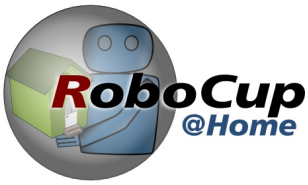

RoboCup@Home

Rules & Regulations

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About this rulebook

This is the official rulebook of the RoboCup@Home competition 2016. It has been written by the 2015/2016 RoboCup@Home Technical Committee (in alphabetical order): Loy van Beek, Kai Chen, Dirk Holz, Loreto Martinez Luz Sanchez, Mauricio Matamoros, Hideoki Nagano, Caleb Rascon, Josemar Rodrigues de Souza, Maja Rudinac, Javier Ruiz des Solar, and Sven Wachsmuth.

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                  Martinez Luz Sanchez AND Mauricio Matamoros AND
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People that have been working on this rulebook as member of one of the league's committees (in alphabetical order):

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Chapter 1

Introduction

1.1. RoboCup

RoboCup is an international joint project to promote AI, robotics, and related fields. It is an attempt to foster AI and intelligent robotics research by providing standard problems where a wide range of technologies can be integrated and examined. More information can be found at http://www.robocup.org/.

1.2. RoboCup@Home

The *RoboCup@Home* league aims to develop service and assistive robot technology with high relevance for future personal domestic applications. It is the largest international annual competition for autonomous service robots and is part of the RoboCup initiative. A set of benchmark tests is used to evaluate the robots abilities and performance in a realistic non-standardized home environment setting. Focus lies on the following domains but is not limited to: Human-Robot-Interaction and Cooperation, Navigation and Mapping in dynamic environments, Computer Vision and Object Recognition under natural light conditions, Object Manipulation, Adaptive Behaviors, Behavior Integration, Ambient Intelligence, Standardization and System Integration. It is collocated with the RoboCup symposium.

1.3. Organization

1.3.1. Executive Committee — ec@robocupathome.org

The *Executive Committee* (EC) consists of members of the board of trustees, and representatives of each activity area. Members representing the @Home league:

- Dirk Holz (University of Bonn, Germany)
- Maja Rudinac (Delft University of Technology, Netherlands)
- Sven Wachsmuth (Bielefeld University, Germany)

1.3.2. Technical Committee — tc@robocupathome.org

The *Technical Committee* (TC) is responsible for the rules of each league. Members of the RoboCup@Home Technical Committee for 2016:

- Kai Chen (University of Science and Technology of China, China)

- Caleb Rascon (Universidad Nacional Autónoma de México, Mexico)
- Loy Van Beek (Eindhoven University of Technology, The Netherlands)
- Mauricio Matamoros (Delft University of Technology, The Netherlands)
- Josemar Rodrigues de Souza (Bahia State University, Brazil)
- Hideoki Nagano (Tokyo City University, Japan)
- Loreto Martinez Luz Sanchez (University of Chile, Chile)

The Technical Committee also includes the members of the Executive Committee.

1.3.3. Organizing Committee — oc@robocupathome.org

The *Organizing Committee* (OC) is responsible for the organization of the competition. Members of the RoboCup@Home Organizing Committee for 2016:

- (chair) Sebastian Meyer zu Borgsen (Bielefeld University, Germany)
- Krit Chaiso (Kasetsart University, Thailand)
- Fagner Pimentel (Bahia State University, Brazil)
- Raphael Memmesheimer (University of Koblenz, Germany)
- He Chauncey (Beijing Information Science & Technology University, China)
- Local chairs:
  - Paul G. Ploeger (Bonn-Rhein-Sieg University of Applied Sciences, Germany)
  - Dirk Holz (University of Bonn, Germany)

1.4. Infrastructure

1.4.1. RoboCup@Home Mailinglist

The official *RoboCup@Home mailing list* can be reached at

`robocup-athome@lists.robocup.org`

You can register to the email list at:

http://lists.robocup.org/listinfo.cgi/robocup-athome-robocup.org

1.4.2. RoboCup@Home Web Page

The official *RoboCup@Home website* that also hosts this RuleBook can be found at

http://www.robocupathome.org/

1.5. Competition

The competition consists of 2 *Stages* and the *Finals*. Each stage consists of a series of *Tests* that are being held in a daily life environment. The best teams from *Stage I* advance to *Stage II* which consists of more difficult tests. The competition ends with the *Finals* where only the five highest ranked teams compete to become the winner.

1.6. Awards

The RoboCup@Home league features the following *awards*.

1.6.1. Winner of the competition

There will be a 1st, 2nd, and 3rd place award.

1.6.2. Innovation award

To honour outstanding technical and scientific achievements as well as applicable solutions in the @Home league, a special *innovation award* may be given to one of the participating teams. Special attention is being paid to making usable robot components and technology available to the @Home community.

The *Executive Committee* (EC) members from the RoboCup@Home league nominate a set of candidates for the award. The *Technical Committee* (TC) elects the winner. A TC member whose team is among the nominees is not allowed to vote.

There is no innovation award in case no outstanding innovation and no nominees, respectively.

1.6.3. Skill Certificates

The @Home league features certificates for the robots best at a the skills below:

- Navigation
- Manipulation
- Speech Recognition
- Person Recognition

A team is given the certificate if it scored at least 75% of the attainable points for that skill. This is counted over all challenges, so e.g. if the robot scores manipulation points during the navigation test to open the door, that will count for the Manipulation-certificate. The certificate will only be handed out if the team is *not* the overall winner of the competition.

Chapter 2

Concepts behind the competition

A set of conceptual key criteria builds the basis for the RoboCup@Home Competitions. These criteria are to be understood as a common agreement on the general concept of the competition. The concrete rules are listed in Chapter Section 3.

2.1. Lean set of rules

To allow for different, general and transmissible approaches in the RoboCup@Home competitions, the rule set should be as lean as possible. Still, to avoid rule discussions during the competition itself, it should be very concrete leaving no room for diverse interpretation.

If, during a competition, there are any discrepancies or multiple interpretations, a decision will be made by the *Technical Committee* (TC) and the referees on site.

Note: Once the test scoresheet has been signed or the scores has been published, the TC decision is irrevocable.

2.2. Autonomy & mobility

All robots participating in the RoboCup@Home competition have to be *autonomous* and *mobile*.

An aim of RoboCup@Home is to foster mobile autonomous service robotics and natural human-robot interaction. As a consequence humans are not allowed to directly (remote) control the robot. This also includes verbally remote controlling the robot.

Furthermore, the specific tasks must not be solved using *open loop control*.

2.3. Aiming for applications

To foster advance in technology and to keep the competition interesting, the scenario and the tests will steadily increase in complexity. While in the beginning necessary abilities are being tested, tests will focus more and more on real applications with a rising level of uncertainty. Useful, robust, general, cost effective, and applicable solutions are rewarded in RoboCup@Home.

2.4. *Social relevance*

The competition and the included tests should produce socially relevant results. The aim is to convince the public about the usefulness of autonomous robotic applications. This should

be done by showing applications where robots directly help or assist humans in everyday life situations. Examples are: Personal robot assistant, guide robot for the blind, robot care for elderly people, etc. Such socially relevant results are rewarded in RoboCup@Home.

2.5. Scientific value

RoboCup@Home should not only show what can be put into practice today, but should also present new approaches, even if they are not yet fully applicable or demand a very special configuration or setup. Therefore high scientific value of an approach is rewarded.

2.6. Time constraints

Setup time as well as time for the accomplishment of the tests is very limited, to allow for many participating teams and tests, and to foster simple setup procedures.

2.7. No standardized scenario

The *scenario* for the competition should be simple but effective, available world-wide and low in costs. As uncertainty is part of the concept, no standard scenario will be provided in the RoboCup@Home League. One can expect that the scenario will look typical for the country where the games are hosted.

The scenario is something that people encounter in daily life. It can be a home environment, such as a living room and a kitchen, but also an office space, supermarket, restaurant etc. The scenario should change from year to year, as long as the desired tests can still be executed.

Furthermore, tests may take place outside of the scenario, i.e., in an previously unknown environment like, for example, a public space nearby.

2.8. Attractiveness

The competition should be attractive for the audience and the public. Therefore high attractiveness and originality of an approach should be rewarded.

2.9. *Community*

Though having to compete against each other during the competition, the members of the RoboCup@Home league are expected to cooperate and exchange knowledge to advance technology together. The *RoboCup@Home mailing list* can be used to get in contact with other teams and to discuss league specific issues such as rule changes, proposals for new tests, etc. Every team is expected to share relevant technical, scientific (and team related) information there and in its *team description paper* (see Section 3.1.4) through the team's website.

All teams are invited to submit papers on related research to the RoboCup Symposium which accompanies the annual RoboCup World Championship.

2.10. Desired abilities

This is a list of the current desired technical abilities which the tests in RoboCup@Home will focus on.

- Navigation in dynamic environments
- Fast and easy calibration and setup
  The ultimate goal is to have a robot up and running out of the box.
- Object recognition
- Object manipulation
- Detection and Recognition of Humans
- Natural human-robot interaction
- Speech recognition
- Gesture recognition
- Robot applications
  RoboCup@Home is aiming for applications of robots in daily life.
- Ambient intelligence, e.g., communicating with surrounding devices, getting information from the internet etc.

Chapter 3

General Rules & Regulations

These are the general rules and regulations for the competition in the RoboCup@Home league. Every rule in this section can be considered to implicitly include the term *"unless stated otherwise"*, meaning that additional or contrary rules in particular test specifications have a higher priority than those mentioned herein in the general rules and regulations.

3.1. Team Registration and Qualification

3.1.1. Registration and Qualification Process

Each year there are four phases in the process toward participation:

1. *Intention of Participation* (optional)
2. *Preregistration*
3. *Qualification* announcements
4. Final *Registration* for qualified teams

Positions 1 and 2 will be announced by a call on the *RoboCup@Home mailing list*. Preregistration requires a *team description paper*, a *video* and a *website*.

3.1.2. Qualification Video

As a proof of running hardware, each team has to provide a *qualification video* showing at least all from following abilities (minimum requirement):

- Human-Robot interaction
- Navigation (safe, indoors with obstacle avoidance).
- Object detection & manipulation.
- People detection
- Speech recognition.
- speech synthesis (clear and loud).

Showing some of the following abilities is recommended:

- Activity recognition
- Complex speech recognition
- Complex action planning
- Gesture recognition

For qualification, we consider showing the robot(s) successfully solving at least one test of the last year's or current rulebook (excluding ability tests).

For robots moving slowly, it is much appreciated speed-up videos. When doing so, please specify the speed factor being used (e.g. 2x, 5X, 10X). The same is applied for slow motion scenes.

We encourage teams to produce self-explicative videos for a general audience where complex tasks are solved

Please notice that the videos should not last longer than the average time for a test (max. 30 min).

3.1.3. Team Website

The *Team Website* should be designed for a broader audience, but also including scientific material and access to open source code being developed. Requirements are as follows:

1. **Multimedia:** Please include as many photos and videos of the robot(s) as possible.
2. **Language:** The team website has to be in English. Other languages may be also available, but English must be default language.
3. **Team:** List of the team members including brief profiles.
4. **RoboCup:** Link to the league website and previous participation of the team in RoboCup.
5. **Scientific approach:** The team website has to include research lines, description of the approaches, and information on scientific achievements.
6. **Publications:** Relevant *publications* from 5 years up to date. Downloadable publications are scored higher during the qualification process.
7. **Open source material:** Blueprints, designs, repositories or any kind of contribution to the league is highly scored during qualification process.

3.1.4. Team Description Paper

The *team description paper* (TDP) must have a explained description of your main research, including the scientific contribution, goals, scope, and results.

Preferably, it should also contain the following:

- the focus of research and the contributions in the respective fields,
- innovative technology (if any),
- re-usability of the system for other research groups
- applicability of the robot in the real world
- photo(s) of the robot(s)

On the last page, after references, please include:

- Name of the team
- contact information
- website
- team members
- photo(s) of the robot(s), unless included before.
- description of the hardware used

  - Provide a brief compact list (2DOF head, 2x7DOF anthropomorphic arms, Pioneer base, etc.).
  - Avoid explaining how your hardware works unless it is part of your research (e.g. we already know what a Hokuyo Laser or Kinect are used for).
- description of the software
  - Provide a brief compact list (ROS, ROS nav2d, Object Recognition Kitchen, OpenCV, etc.).
  - Avoid explaining how your software works unless it is part of your research.
  - List the *external computing resources* (See Section 3.6), if any. State their purpose and URL/IP-address.

The TDP has to be in English, up to eight pages in length and formatted according to the guidelines of the RoboCup International Symposium. It goes into detail about the technical and scientific approach.

Please notice that, during qualification process, TDP will be scored by its scientific value, novelty and contributions.

3.1.5. Qualification

During the *qualification process* a selection will be made by the *Organizing Committee* (OC) Taken into account and evaluated in this decision process are:

- The content on the team website, scoring higher publications and open content;
- the number of abilities shown in the qualification video,
- the complexity of the tasks shown in the qualification video, and
- the scientific value, novelty and contributions in the *team description paper*.

(Additional) evaluation criteria are:

- the performance in previous competitions,
- the relevant scientific contributions and publications, and
- the contributions to the RoboCup@Home league.

3.2. Scenario

The tests take place in the *RoboCup@Home arena*. In addition, particular tests are situated outside the arena, e.g., in a previously unknown public place. The following rules are related to the *RoboCup@Home arena* and its contents.

3.2.1. RoboCup@Home arena

The *RoboCup@Home arena* is a realistic home setting (apartment) consisting of inter-connected rooms like, for instance, a living room, a kitchen, a bath room, and a bed room. Depending on the Local Organization, there may be multiple apartments which may be different to each other. Robot must be prepared to perform any challenge in any arena, not the same arena every time.

3.2.2. Walls, doors and floor

The indoor home setting will be surrounded by high and low *walls*. These walls will be built up using standard fair construction material.

1. **Walls:** Walls have a minimum height of 60 cm. A maximum height is not specified, but should be chosen so that the audience is able to watch the competition.
   Walls will be fixed and are likely to be not modified during the competition (see Section 3.2.4).
2. **Doors:** There will be at least two entry/exit *doors* connecting the outside of the scenario. These doors are used as starting points for the robots (see Section 3.8.8). There will be also another door inside the scenario with a handle (not a knob) between any two rooms. Doors with handle (not a knob) may be closed at any time, it is expected robots be able to open them.
3. **Floor:** The floor of the arena as well as the doorways of the arena are even. That is, there will be no significant steps or even stairways. However, minor unevenness such as carpets, transitions in floor covering between different areas, and minor gaps (especially at doorways) must be expected.
4. **Appearance:** Floor and walls are mainly uni-colored but can contain texture, e.g., a carpet on the floor, or a poster or picture on the wall.
   Although being unlikely at the moment, transparent elements are also possible.

3.2.3. Furniture

The arena will be equipped with typical objects (furniture) that are not specified in quantity and kind. The minimal configuration consists of

- a small dinner table with two chairs,
- a couch,
- an open cupboard or small table with a television and remote control,
- a cupboard or shelf (with some books inside), and
- a refrigerator in the kitchen (with some cans and plastic bottles inside).

A typical arena setup is shown in Figure 3.1a.

3.2.4. Changes to the arena

Since the robots should be able to function in the real world the scenario is not fixed and might change without further notice.

1. **Major changes:** The arena is meant to be a simulated apartment. The furniture might be moved around between challenges. This includes furniture that is a named location (see Section 3.2.8). As in a normal home, furniture is not very likely to move from one room to another and is unlikely to be moved to the other side of a room. However, a couch or table may be rotated, moved to its side etc. Walls will stay in place and rooms will not change function. Passages might be blocked and cleared. One hour before a test slot begins no *major changes* will be made. This time will be shortened in the future.
2. **Minor changes:** In contrast to major changes, *minor changes* like, for instance, slightly moved chairs cannot be avoided and may happen at any time (even during a test).

(a) Typical arena **(b)** Typical objects

Figure 3.1.: Scenario examples: (a) a typical arena, and (b) typical objects.

3.2.5. Objects

Some tests in the RoboCup@Home league involve object manipulation and recognition. These *objects* resemble items usually found in household environments like, for instance, soda cans, coffee mugs or books. An example of objects used in a previous competition can be seen in Figure 3.1b.

Objects are divided in five main groups:

1. ***Known objects*:** Objects with no noticeable difference among peers. *Known objects* tend to be artificial and regular shaped, such as coke cans, beer bottles, cereal boxes, etc. A set of copies of these objects is provided before the competition for training.
2. ***Alike objects*:** Objects with slight differences among peers (e.g. color, size, shape). *Alike objects* tend to be natural and similar to each other, but not equal; for example: apples, bananas, rags, etc. A specimen of these objects is provided before the competition for training.
3. ***Containers*:** Objects which can contain, transport or be filled with other objects or their content, such as trays, baskets, bowls, etc. . As with *known objects*, *containers* are known beforehand with no noticeable difference among peers, and a copy is provided before the competition for training.
4. ***Special objects*:** Objects require a proper identification and special handling (not necessarily grasping), operation or interaction for accomplishing a particular task. Examples of special objects are: door handles, chairs, walking sticks, poles, etc. Notice that a copy of these objects may not be available beforehand for previous training.
5. ***Unknown objects*:** Any other object that is not known beforehand but can be grasped or handled.

The following general rules for objects apply:

1. **Object category:** Each object will be assigned to an *object category*. The objects "apple" and "banana" may be of class "fruits" for example.
2. **Object (category) locations:** An *object location* object will be assigned to each *object category*. For example, Objects categorized as "fruits" may be usually found on the

"kitchen table", and unknown objects "unknown" may be usually found on the "trash bin".

3. **Announcement:** The TC makes the set of *objects*, including their names, categories, and usual locations; available during the setup days.
4. **Placement:** Unless stated otherwise, in manipulation tasks, the objects will be positioned at *manipulation locations* and less than 15 cm away from the border of the surface they are located at. There will be at least 5 cm space around each object.

Important note: It is not allowed to modify any of the objects provided for training. Also, teams are not allowed to keep more than 5 the objects provided for training at a time nor retaining it for more than one hour.

Containers

The TC will provide at least two containers (a transport container such as a tray and a pouring container such as a bowl) which will be available for training during the setup days.

There are no restrictions on a container size, appearance or weight; however, it can be expected that the selected containers be lightweight, with handles, and easily manipulable by a human using both hands.

Custom containers. The goal of containers is to encourage **bi-hand manipulation**. However, it is allowed that a team provide a *custom container* adapted to be used by the robot, considering the following:

1. Custom containers must be approved by the TC during during the *Robot Inspection* (see Section 4.4).
2. Custom containers must *not* have any kind of artificial marks, sensors, or electronic devices.
3. Penalties may apply for the use of custom containers. The TC may establish special penalties during the *Robot Inspection*. The default penalties applicable to any task involving a container are as follows.
   - Special color on an otherwise unmodified two-hand manipulable container: 75% of the points.
   - Special color on an otherwise unmodified single-hand manipulable container: 50% of the points.
   - Specially designed or adapted two-hand manipulable container (e.g. special handles): 50% of the points.
   - Specially designed or adapted single-hand manipulable container (e.g. special handle): 25% of the points.
   - Two-hand manipulable container adapted to be used *single-handed*: 25% of the points.
   - On-robot mounted container: 0 points.

   Notes: Trays are considered two-hand manipulable containers, while most bowls and dishes are considered single-hand manipulable container unless they are too big. Color patterns are allowed as long as they look natural (e.g. *barber sign colored* handles are allowed, but black and white bar-code like handles are not). Penalties does not stack, the most meaningful modification is considered.

Predefined objects

The TC will compile a list of at least 10 objects (including both *known objects* and *alike objects*) which will be available for training. There are no restrictions on an object size, appearance or weight; however, it can be expected that the selected objects are easily manipulable by a human using a single hand.

Note that, any object not previously announced by the TC is automatically considered an unknown object for scoring purposes (e.g. ornamentation).

3.2.6. Predefined locations

Some tests in the RoboCup@Home league involve *predefined locations*. These may include places like a "bookshelf" or a "dining table", as well as certain objects such as a "television", or the "front door".

1. **Definition:** The TC will compile a list of predefined locations. There are no restrictions on which parts of the arena will be selected as a predefined location.
2. **Location classes:** Each location will be assigned to a *location class*. The objects "couch" and "arm chair" may be of class "seat" for example.
3. **Announcement:** The TC makes the set of locations (and their names and classes) available during the setup days.
4. **Position:** The positions of locations are *not* necessarily fixed (see Section 3.2.4).
5. **Manipulation locations:** The TC will mark at least 20 locations out of the set of predefined locations as being *manipulation locations*. Whenever a test involves manipulation, the object to manipulate will be placed at one of the manipulation locations.

3.2.7. Predefined rooms

Some tests in the RoboCup@Home league involve *predefined rooms*.

1. **Definition:** The TC will compile a list of room names.
2. **Announcement:** The TC makes the set of rooms available during the setup days.

3.2.8. Predefined (person) names

Some tests in the RoboCup@Home league involve *predefined names* of people.

1. **Definition:** The TC will compile a list of 20 predefined names. The names are 50 % male and 50 % female, and taken from the (current) most common first names in the United States.
   In order to ease speech recognition, it is tried to select names to be phonetically different from each other.
2. **Announcement:** The TC makes the set of names available during the setup days.
3. **Assignment:** When a test involves interacting with persons (using a person's name), all involved persons are assigned names by the referees before the test.

Typical names are, for example, James, John, Robert, Michael and William as male names; Mary, Patricia, Linda, Barbara and Elizabeth as female names.

3.2.9. Wireless network

For wireless communication, an *arena network* is provided. The actual infrastructure depends on the local organization.

- To avoid interference with other leagues, this WiFi has to be used for communication only. It is not allowed to use the above or any other WiFi network for personal use at the venue.
- During the competitions, only the active team is allowed to use the *arena network*.
- The organizers cannot guarantee reliability and performance of wireless communication. Therefore, teams are required to be ready to setup, start their robots and run the tests even if, for any reason, network is not working properly.

Preferably the organizers will try to provide one LAN cable on the desk of each participating team for Internet connection. However, this cannot be guaranteed. If multiple LAN connections are needed, each team has to bring its own LAN hub/switch and cables.

Important note: Any unapproved wireless device may be removed by the TC at any time.

3.2.10. Smart Home Devices

The Organizing and Technical Committees in coordination with the Local Organization will compile a list of *Smart Home* official devices that will be available in the arena and can be used in some tests for additional score.

At any time, only the Smart Home devices provided by the Local Organization and approved by the Technical Committee may be used during competition.

Smart Home devices list announcement

The list if Smart Home devices will be provided to teams as soon as it becomes available and has been granted by the Local Organization and approved by the Technical Committee.

This list must be announced at least one month prior the competition. In case that this list does not become available for that date, Smart Home devices may still be present at the arena for testing, but no additional score can be achieved for its use. This is to maintain fair conditions among all teams.

Technical specifications

The list of *Smart Home* official devices will include as much technical information as possible. However, before it becomes available you may assume the following considerations:

1. **Interface:** Most Smart Home devices interface wireless, often via R/F transmitters. When possible, the OC will provide an official interface via the *arena network*.
2. **Operating voltage:** The operating voltage used will be the standard for the place of the competition (e.g.120V/60Hz for North America and 220V/50Hz for Europe). Please note that devices designed for other voltages/frecuencies may burn when plugged to the outlet.
3. **Type of devices:** Mostly Smart Home switches will be used (set on/off, read can not be guaranteed). For high bandwidth devices such as microphones or video cameras, an official interface (such as a ROS topic or web service) will be provided via the *arena network*.

Availability & Scoring

All test has been designed to optionally allow the use of Smart Home devices and even grant bonus scoring for using this option. However, robots must be able to continue operating normally when there are no Smart Home devices available. Therefore, it is unacceptable that a robot gets stuck or in some sort of deadlock while trying to operate those devices.

As stated in Section 3.2.9, organizers cannot guarantee reliability and performance of wireless communication. Therefore, in case of malfunction or communication problems with the Smart Home devices, or any other issue which may affect scoring, no claims will be accepted by the EC/TC/OC, nor test will be repeated. The decision on if a team given points for using *Smart Home* devices, is conducted by the *Technical Committee* (TC), and it reserves the rights of discarding Smart Home related scoring.

3.3. Robots

3.3.1. Autonomy & Mobility

Robots that participate in the RoboCup@Home league need to be *autonomous* and *mobile*. Any deviations reported to the TC, may result in a penalty for the team (see Section 3.9.2).

3.3.2. Number of robots

1. **Registration:** The maximum *number of robots* per team that can be registered for the competitions is *two* (2).
2. **Regular Tests:** Only one robot is allowed per test. For different tests different robots can be used.
3. **Open Demonstrations:** In the *Open Challenge* and the *Finals* both robots can be used simultaneously.

3.3.3. Size and weight of robots

1. **Dimensions:** The dimensions of a robot should not exceed the limits of an average door, which is 200 cm by 70 cm in most countries.
   The TC may allow the qualification and registration of larger robots, but due to the international character of the competition it cannot be guaranteed that the robots can actually enter the arena. In case of doubt, contact the local organization.
2. **Weight:** There is no specific weight restriction. However, the weight of the robot and the pressure it exerts on the floor should not exceed local regulations for the construction of buildings which are used for living and/or offices in the country where the competitions is being held.
3. **Transportation:** Team members are responsible for quickly moving the robot out of the arena. If the robot cannot move by itself (for any reason), the team members must be able to transport the robot away with an easy and fast procedure.

3.3.4. Emergency stop button

1. **Accessibility and visibility:** Every robot has to provide an easily accessible and visible *emergency stop* button.
2. **Color:** It must be coloured red, and preferably be the only red button on the robot. If it is not the only red button, the TC may ask the team to tape over or remove the other red button.
3. **Robot behavior:** When pressing this button, the robot and all parts of it have to stop moving immediately.
4. **Inspection:** The emergency stop button is tested during the *Robot Inspection* test (see Section 4.4).

3.3.5. Start button

1. **Requirements:** As stated in Section 3.8.7, teams that aren't able to carry out the default start signal (opening the door) have to provide a *start button* that can be used to start tests. The team needs to announce this to the TC before every test that involves a start signal, including *Robot Inspection*.
2. **Definition:** The start button can be any "one-button procedure" that can be easily executed by a referee. This includes, for example, the release of the *emergency button* (Section 3.3.4), a hardware button different from the *emergency button* (e.g., a green button), or a software button in a Graphical User Interface.
3. **Inspection:** It is during the the *Robot Inspection* test (see Section 4.4) that the procedure for the start button, if needed, is announced to the TC and inspected. The start button for a robot should be the same for all the tests.
4. **Penalty for using start button:** If a team needs to use the start button in a test where opening the door is the start signal, it may receive a penalty (see Section 3.8.7).

3.3.6. Appearance and safety

Robots should have a nice product-like appearance, be safe to operate & be around and should not annoy its human users. The following rules apply to all robots and are part of the *Robot Inspection* test (see Section 4.4).

1. **Cover:** The robot's internal hardware (electronics and cables) should be covered in an appealing way. The use of (visible) duct tape is strictly prohibited.
2. **Loose cables:** There may not be any loose cables hanging out of the robot.
3. **Safety:** The robot may not have sharp edges or other things that could severe people.
4. **Annoyance:** The robot should not permanently make loud noises or use blinding lights.
5. **Driving:** To be safe, the robots should be careful when driving in a direction it cannot sense for example.

3.3.7. Audio output plug

1. **Mandatory plug:** Either the robot or some external device connected to it *must* have a *speaker output plug*. It is used to connect the robot to the sound system so that the audience and the referees can hear and follow the robot's speech output.

2. **Inspection:** The output plug needs to be presented to the TC during the *Robot Inspection* test (see Section 4.4).
3. **Audio during tests:** Audio (and speech) output of the robot during a test have to be understood at least by the referees and the operators.
   - It is the responsibility of the teams to plug in the transmitter before a test, to check the sound system, and to hand over the transmitter to next team.
   - Do not rely on the sound system! For fail-safe operation and interacting with operators make sure that the sound system is not needed, e.g., by having additional speakers directly on the robot.

3.4. Data Recording

In order to benchmark robots and software outside the RoboCup@Home arena, the teams are asked to contribute to a public dataset. This will consist of audio, imagery and other data obtained and generated by the robots during RoboCup@Home challenges. Contributing to this dataset gives a small bonus as an incentive. The bonus will be proportional to the points gathered normally: if 50% of points are gathered, 50% of the data collection points are awarded.

3.4.1. Collected data

During a challenge, specific data is to be gathered and stored on a USB stick. After all attempts at a challenge are made, the USB stick must be given to the TC, which will copy the data to the public dataset. The recordings themselves are not used for scoring and may be post-processed manually to be more useful, before handing over to the TC. Not all types of data are interesting for each challenge and thus each challenge will list which data to record.

- **Audio:** A .wav file of conversation or commands given by any operator and the result of the automatic speech recognition, if applicable. The recording must be made of the same signals that are input to the automatic speech recognition software.
  - **Format:** TeamName_SensorName_Timestamp.wav
  - **Format:** PCM Wav 44.1 kHz 16 bit stereo
- **Commands:** A text file with the commands as received by the robot. This may be the output of speech recognition or the outcome of any form of the continue rule. Include a timestamp and then the command.
  - **Format:** TeamName_commands_Timestamp.csv
  - **Format:** csv-file. First column has command timestamp, second column the command in “quotes”.
- **Images:** 2D and/or 3D RGB(D) images from the robot’s camera(s) while doing any sort of recognition task. Record the full field of view.
  - **Color images:**
    - **Filename:** TeamName_SensorName_Timestamp_rgb.png
    - **Format:** Standard PNG 24bit
  - **Depth images:**

    - ∗ **Filename:** TeamName_SensorName_Timestamp_depth.png
    - ∗ **Format:** Standard PNG 16bit grayscale
- **Mapping data:** Record the data the robot uses for mapping its surroundings and obstacle avoidance plus the resulting map. For many robots this will be 2D laser scans of an Laser Range Finder but other means are possible.
- **Plans:** Any plan generated by the robot. This includes navigation paths, arm trajectories and action plans. If possible, plans are preferably annoted with whether is was succesfully executed or not.

For ROS-based robots, the most convenient data format for mapping data (laser scans, occupancy grids etc.) and motion plans are their ROS messages recorded into a ROS Bag file. This ROSBag should then contain:

- **Laser scans:** sensor_msgs/LaserScan
- **Path(s):** nav_msgs/Path
- **Map(s):** nav_msgs/OccupancyGrid
- **Robot pose:** geometry_msgs/PoseStamped
- **Transformation tree:** tf2_msgs/TFMessage or equivalent
- **Odometry:** nav_msgs/Odometry

Although not all robots use ROS, this serves as a guideline of the type of data that may be interesting for others. The RoCKIn robot competition provides a conversion tool that converts to ROS Bag files: http://rockinrobotchallenge.eu/rockin_d2.1.3.pdf, section 3.4 and https://github.com/rockin-robot-challenge/benchmark_and_scoring_converter

3.5. External devices

1. **Definition:** Everything which is not part of the robot is considered an *external device*.
2. **Inspection:** In general, external devices are not allowed unless presented and explained to the *Technical Committee* (TC) during the *Robot Inspection* test (see Section 4.4).
3. **Supervision:** In regular tests, external devices may only be used under supervision by referees and after approval by the TC. The devices have to be brought to the arena for every test, and removed quickly after the test.
4. **Open demonstrations:** For the *Open Challenge* and the *Finals*, external devices are allowed, still their use needs to be announced beforehand.
5. **Wireless devices:** All *wireless devices* including bluetooth devices, walkie-talkies, and anything else that uses an RF signal to operate need to be announced to the *Organizing Committee* (OC). The use of any wireless device not approved by the TC is strictly prohibited.
6. **Artificial landmarks:** *Artificial landmarks* and *markers* are not allowed.
7. **Computing devices:** External computers for decentralized computations are allowed, please see Section 3.6.
8. **Wireless LAN:** The use of networks other than the *arena network* (see Section 3.2.9) is strictly prohibited.
9. **External microphones:** *External microphones*, hand microphones, and headsets are not allowed. Using an *on-board microphone* is mandatory for communication with the robot.

3.6. External computing

Robots are allowed to use some form of external computing, for example in the form of so-called "Cloud services" and/or "Internet API's" etc.

1. **Definition:** Computing resources that are not physical part of the robot are *external computing resources*.
2. **Inspection:** In general, external computers are not allowed unless explained to and allowed by the *Technical Committee* (TC). A team must announce to the TC at least 1 month in advance the external computing resources they want to use, for what purpose and how to reach the resources. E.g. specify the URL or IP-address. This must be specified in the team description paper.
3. **Connection:** The robot may connect to *external computing resources* via a network connection, e.g. the Internet. The competition organisation cannot make any guarantees concerning availability, connectivity and performance of the connection. The robot should still be functional (albeit limited perhaps) if the *external computing resources* cannot be used for some reason. This is the team's responsibility.
4. **Autonomy:** The robot has to maintain full autonomy when using *external computing resources*, meaning there may not be a human giving the robot any kind of instructions via *external computing resources*. It is up to the team to prove to the *Technical Committee* (TC) that there was no cheating introduced via the *external computing resources*. For example, the use of Amazon Mechanical Turk to classify and recognize objects during a competition will be considered cheating, since effectively a human will do the classification. Remote control or tele-operation is also considered cheating.
5. **Availability:** The resources must be publicly available, for use by robots of other teams, well before and after the competition.
6. **Recognition:** In case the resources are not developed by the team itself, the creators must be properly credited in the Team Description Paper (See Section 3.1.4).
7. **Limit:** A robot is limited to use up to 5 *external computing resources*.

3.7. Organization of the competition

3.7.1. Stage system

The competition features a *stage system*. It is organized in two stages each consisting of a number of specific tests. It ends with the *Finals*.

1. **Stage I:** The first days of the competition will be called *Stage I*. All qualified teams can participate in *Stage I*. Stage I comprehends a set of *Ability Tests*, an *Integration Test*, and an audience demonstration called *Following & Guiding*. Those *Proficency Tests* (*Ability Tests*, and *Integration Test*) are performed multiple times (See Section 3.7.4).
2. **Stage II:** The best *50% of teams with full integrated capabilities*[1] (after Stage I) advance to *Stage II*. Here, more complex abilities or combinations of abilities are tested. In order to advance to Stage II a team must successfully solve 3 out of *Proficency Tests* in Stage I. The *Open Challenge* is the open demonstration in Stage II.

[1] If the total number of teams is less than 20, up to 10 teams may advance to Stage II

3. **Final demonstration:** The best *five teams* (after Stage I and Stage II) advance to the final round. The final round features only a single open demonstration.

In case of having no considerable score deviation between a team advancing to the next stage and a team dropping out, the TC may announce additional teams advancing to the next stage.

3.7.2. Number of tests

1. In *Stage I*, the *maximum number of tests* that a team can participate in is *six (6)*.
2. In *Stage II*, the *maximum number of tests* that a team can participate in is *three (3)*.
3. None of the tests is mandatory, except for the *Robot Inspection* test (see Section 4.4).

3.7.3. Schedule

1. **Tests:** The *Organizing Committee* (OC) provides schedules for all tests and teams.
2. **Participation is default:** Teams have to indicate to the *Organizing Committee* (OC) in which tests they are *not* going to participate. Without such indication, they are automatically added to all test schedules and may receive a penalty when not attending (see Section 3.9.1).
3. **Slots:** The tests will be held in *test slots* of approximately two hours.
4. **Preparation:** The *Organizing Committee* (OC) provides schedules for all teams to organize the access to the arena between test slots. In these *preparation slots* the teams may conduct calibration procedures, remap the arena if necessary, or conduct test runs. Preparation slots are inserted whenever possible, but may not be available before all test slots.
5. **Arena access:** One hour before a test slot, only the teams participating in that slot are allowed in the arena. This rule only applies when not having organized *preparation slots*.

3.7.4. Score system

1. **Stage I:** The maximum total score (excluding special penalties and bonuses) in *Stage I* is *1150 points*.
   1.1. ***Proficency Tests*:** Each proficiency test is attempted three times. The maximum total score is calculated as the average of the best two attempts for that test.
2. **Stage II:** Test in *Stage II* are rewarded on a task-solved scoring basis.
   2.1. Each test but the *Open Challenge* has a main task. The base score for solving the main task is *250 points*.
   2.2. The maximum score for *Open Challenge* is *250 points*.
   2.3. Optionals and subtasks add bonus points to the main task score.
3. ***Finals*:** Final score is normalized and special evaluation is used
4. **Special tests:** Tests may specify a maximum total score deviating from the general maximum total scores.
5. **Minimum score:** The minimum total score per test in *Stage I* and *Stage II* is *0 points*. That is, if the total score for a test is below zero, the team does not receive any points.

6. **Penalties:** An exception to the *minimum score* rule are penalties. Both penalties for not attending (see Section 3.9.1) and extraordinary penalties (see Section 3.9.2) can cause a total negative score.
7. **Partial scores:** All tests—except for the open demonstrations—are rewarded on a partial scoring basis.
   7.1. Tests are split into designated parts.
   7.2. Each part is assigned a certain number of points.
   7.3. A team that successfully passes a designated part of the test receives points for that part.
   7.4. In case of partial success, referees (and TC members) may decide to only award a percentage instead of the full partial score.
   7.5. The total score for a test is the sum of partial scores.
   7.6. Partial scores can be negative (e.g. to penalize failures etc.).

3.7.5. Open Demonstrations

1. **Stage II:** The *Open Challenge* is the open demonstration in *Stage II*.
   1.1. To participate in the *Open Challenge*, a team needs to participate in at least one regular *Stage II* test.
   1.2. Teams can demonstrate freely chosen abilities.
   1.3. The performance is evaluated by a jury consisting of the *Technical Committee* (TC).
   1.4. The *Open Challenge* is described in Section 6.2.
2. ***Finals*:** The competition ends with a final demonstration.
   2.1. The concept of the final demonstration is the same as that of the *Open Challenge*, but the performance evaluation is different.
   2.2. The are two juries—an *external* consisting of three or more people not from the RoboCup @Home league, and an *internal* formed by the *Executive Committee* (EC). Both juries have different sets of evaluation criteria.
   2.3. Members of the external jury are selected by the *Executive Committee* (EC) on site.
   2.4. The demonstration in the *Finals* does not have to be different from the one shown in the *Open Challenge*. It does not have to be the same either.

3.8. Procedure during Tests

3.8.1. Safety First!

1. **Emergency Stop:** At any time when operating the robot inside and outside the scenario the owners have to stop the robot immediately if there is a remote possibility of dangerous behavior towards people and/or objects.
2. **Stopping on request:** If a referee, member of the Technical or Organizational committee, an Executive or Trustee of the federation tells the team to stop the robot, there will be no discussion and the robot has to be stopped *immediately*.
3. **Penalties:** If the team does not comply, the team and its members will be excluded from the ongoing competition immediately by a decision of the RoboCup@Home *Technical*

Committee (TC). Furthermore, the team and its members may be banned from future competitions for a period not less than a year by a decision of the RoboCup Federation Trustee Board.

3.8.2. Maximum number of team members

1. **Regular Tests:** During a regular test, the maximum number of team members allowed inside the arena is *one* (1). The only exceptions are tests that require for more team members in the arena.
2. **Setup:** During the setup of a test, the number of team members inside the arena is not limited.
3. **Open Demonstrations:** During the *Open Challenge*, and the *final demonstration* (Finals), the number of team members inside the arena is not limited.
4. **Moderation:** During a regular test, one team member *must* be available to host and comment the event (see Section 3.8.12).

3.8.3. Fair play

Fair Play and cooperative behavior is expected from all teams during the entire competition, in particular:

- while evaluating other teams,
- while refereeing, and
- when having to interact with other teams' robots.

This also includes:

- not trying to cheat (e.g. pretending autonomous behavior where there is none),
- not trying to exploit the rules (e.g. not trying to solve the task but trying to score), and
- not trying to make other robots fail on purpose.

Disregard of this rule can lead to penalties in the form of negative scores, and disqualification for a test or even for the entire competition.

3.8.4. Robot Autonomy and Remote Control

1. **No touching:** During a test, the participants are not allowed to make contact with the robot(s), unless it is in a "natural" way and/or required by the test specification.
2. **Natural interaction:** The only allowed means to interact with the robot(s) are gestures and speech.
3. **Natural commands:** Only general instructions are allowed. Anything that resembles direct control is prohibited.
4. **Remote Control:** Remotely controlling the robot(s) is strictly prohibited. This also includes pressing buttons, or influencing sensors on purpose.
5. **Penalties:** Disregard of these rules can lead to penalties in the form of negative scores, and disqualification for a test or even for the entire competition.

3.8.5. Collisions

1. ***Touching*:** Robots are allowed to gently *touch* objects, items and humans. They are not allowed to crash into something. The "safety first" rule (Section 3.8.1) supercedes all other rules.
   - It *is* allowed however to *functionally* touch an item with e.g. the base.

   The OC/TC/EC and the RoboCup Trustees all have the right to immediately stop a robot, and to disqualify a team for the duration of the competition, or longer, in case of *dangerous* behavior. Furthermore, referees can recommend to disqualify a team in which case EC/TC decides.
2. ***Major collisions*:** If a robot crushes into something during a test, the robot is immediately stopped. Additional penalties may apply.
3. **Robot-Robot avoidance:** If two robots encounter each other, they both have to actively try to avoid the other robot.
   3.1. A robot which is not going for a different route within a reasonable amount of time (e.g., 30 s) is removed.
   3.2. A non-moving robot blocking the path of another robot for longer than a reasonable amount of time (e.g., 30 s) is removed. In this context, "moving" refers to any kind of motion or action required in the test. For example, a robot standing still but manipulating an object does not need to stop manipulating and move away, even when blocking the way of another robot for the duration of the manipulation.

3.8.6. Removal of robots

Robots not obeying the rules are stopped and removed from the arena.

1. It is the decision of the referees and the TC member monitoring the test if and when to remove a robot.
2. When told to do so by the referees or the TC member monitoring the test, the team has to immediately stop the robot, and remove it from the arena without disturbing the ongoing test.

3.8.7. Start signal

1. **Opening the door:** Unless stated otherwise, the cue for the robot to enter the arena and start the test is the opening of the door by a referee.
2. **Start button:** If the robot is not able to automatically start after opening the door, the team may start the robot using a start button.
   2.1. Using a start button needs to be announced to the referees. It is the responsibility of the team to do so before the test starts.
   2.2. There may be penalties for using a start button in some tests

3.8.8. Entering and leaving the arena

1. **Start position:** Unless stated otherwise, the robot starts outside of the arena.
2. **Entering:** The robot has to autonomously enter the arena.

3. **Success:** The robot is said to *have entered* when the door used to enter can be closed again, and the robot is not blocking the passage.

3.8.9. Gestures

Hand gestures may be used to control the robot in the following way:

1. **Definition:** The teams define the hand gestures by themselves.
2. **Approval:** Gestures need to be approved by the referees and TC member monitoring the test. Gestures should not involve more than the movement of both arms. This includes e.g. expressions of sign language or pointing gestures.
3. **Instructing operators:** It is the responsibility of the team to instruct operators.
   3.1. The team may only instruct the operator when told to so by a referee.
   3.2. The team may only instruct the operator in the presence of a referee.
   3.3. The team may only instruct the robot for as long as allowed by the referee.
   3.4. When the robot has to instruct the operator, it is the robot that instructs the operator and *not* the team. The team is not allowed to additionally guide the operator, e.g., tell the operator to come closer, speak louder, or to repeat a command.
   3.5. The robot is allows to instruct the operator at any time.
4. **Receiving gestures:** Unless stated otherwise, it is not allowed to use a speech command to set the robot into a special mode for receiving gestures.

3.8.10. Referees

1. **Setup:** Unless stated otherwise, each test is monitored by two referees and one member of the *Technical Committee* (TC).
2. **Selection:** The two referees
   - are chosen by EC/TC/OC,
   - are announced together with the schedule for the test slot,
   - and have to referee all teams in that slot.
   - Referees may not be from one of the teams in the slot.
3. **Not showing up:** Not showing up for refereeing (on time) will result in a penalty (see Section 3.9.2).
4. **TC monitoring:** The referee from the TC acts as a main referee.
5. **Referee instructions:** Right before each test, referee instructions are conducted by the TC. The referees for all slots need to be present at the arena where the referee instructions are taking place.When and where referee instructions are taking place is announced together with the schedule for the slots.

3.8.11. Operator

1. **Default operator:** Unless stated otherwise, robots are operated by the monitoring TC member, a referee, or by a person selected by the TC.
2. **Fallback/custom operator:** If the robot fails to understand the command given by the default operator, the team may continue with a custom operator.

- The custom operator may be any person chosen by the team (and willing to do so); including the referees or the monitoring TC member.
- A penalty may be involved when using a custom operator.

3.8.12. Moderator

1. **Providing a moderator:** For each regular test (i.e., not for the open demonstrations), all participating teams need to provide a team member as moderator for the duration of their performance.
2. **Responsibilities:** The moderators have to:
   - explain the rules of the test,
   - comment on the performance of their team,
   - not interfere with the performance,
   - speak in English,
   - and obey the instructions by the monitoring TC member.
3. **Competitive tests:** In competitive tests (tests in which two teams directly compete against each other), the moderation has to be done by the two teams together.

3.8.13. Time limits

1. **Stage I:** Unless stated otherwise, the time limit for each test in *Stage I* is *5 minutes*.
2. **Stage II:** Unless stated otherwise, the time limit for each test in *Stage II* is *10 minutes*.
3. **Setup time:** Unless stated otherwise, all time specifications, e.g., setup time and time for instructing operators, are within the total test time.
4. **Scores:** When the time is up, the team has to immediately remove their robot(s) from the arena; no more points can be scored. In special cases, the monitoring TC member may ask the team to continue the test for demonstration purposes (after time is up, points cannot be scored).

3.8.14. Restart

1. **Stage 1** has no restarts but features multiple attempts at a challenge. If a robot fails during an attempt, the attempt ends. A robot has several (ideally 3, depending on available time in the scheduele) attempts for each challenge. An attempt cannot be restarted. E.g. if a robot fails halfway through an attempt at the navigation challenge, the attempt is over, the robot is moved out of the test area and may prepare for the remaining attempts at the challenge.
2. **Stage 2** does have restarts for challenges:
   2.1. **Number of restarts:** A team may request one (1) restart during a test, unless stated in otherwise. There are tests in which a restart is not allowed.
   2.2. **Procedure:** In case a restart is allowed, the team may request the restart only before 50% of the time alloted to the test. The complete test is then restarted from the beginning (e.g., with entering the arena). The referees may rearrange the locations of objects/persons if necessary.

2.3. **Time:** The time is neither restarted nor stopped. The team has 1 minute to restart the test (the same time to start the test); if the team is not able to do so in the allotted time, the test is called as finished by the TC.
2.4. **Score:** The score of the second run (after the restart) counts. If it is lower than the score of the first run (before the restart), the average score of first and second run is taken.
2.5. **Forced restart:** The referees and the monitoring TC member may force the team to do a restart:
- if the robot is doing nothing or nothing reasonable for *one minute*, or
- when the robot fails to understand a command for *five times*, or
- after a minor collision

3.8.15. Continue rule: Bypassing Automatic Speech Recognition

Giving commands to the robot is an important part of many tests. RoboCup@Home fosters natural human-robot interaction through gestures and speech, such that speech is the primary modality to give complex commands to the robot. Automatic speech recognition (ASR) however can be very difficult in the international competition environment of RoboCup. Because active robots are preferred over robots that are passive due to failing ASR, the team is allowed to provide means to bypass ASR. The robot can then still continue to a next part of a test, but with a penalty for needing a bypass. The penalty for using such a bypass will be more severe in future competitions.

All robots are **highly recommended to use QR-codes as a standardized alternative** to ASR. These QR-codes will be generated by the TC to encode the spoken command/sentence as-is. Any punctuation like commas, questionmarks, apostrophes and dots in the (generated) spoken command will also be present in the QR-code.

Non-standardized alternative means should be approved by and demonstrated to the TC during the *Robot Inspection* test (see Section 4.4).

Procedure

Automatic Speech Recognition is preferred and any command given to the robot will given by voice first.

1. **Default:** When the referee generates a command for the robot, it will be read out loud by the operator to the robot. 100% of the points for getting the command will be awarded, if not stated otherwise.
2. **team member:** If this fails, a team member may speak the command to the robot if this was not the case already. 75% of the points for getting the command will be awarded, if not stated otherwise.
3. **QR-code:** If this fails as well, as a last resort, a QR-code will be generated that encodes the command as plain text and shown to the robot, displayed on either a piece of paper or a computer screen. 50% of the points for getting the command will be awarded, if not stated otherwise. For some example QR codes, see Appendix C.

1. **Number of Continue's:** Unless stated otherwise, the referee chooses to apply and initate the steps of the procedure listed above.

2. **Time:** The time is neither restarted nor stopped while the Continue rule is applied.
3. **Multiple Continue's:** The Continue rule will applied by the referee as often as required to make the robot be active. The penalty involved makes this unpreferable to the team and the usage should not be preferred, incentivizing the team to provide a proper means of ASR.

Alternative methods

Below are some suggested alternatives for ASR besides the QR-code as specified above:

- Any custom alternative that MUST be intuitive and intended for users with no technological expertise.
- Other types of natural interaction such as gestures.
- A touch-sensitive designed interface.
- The robot hosts a website/app on which some text can be entered.

The default penalties for ASR alternative methods will be decided on by the TC, during the *Robot Inspection* test (see Section 4.4). Operating the robot in a very user-friendly way via whatever manner may yield a significant amount of points more than using an user-unfriendly way such as the QR codes.

What a good custom ASR alternative is loosely defined on purpose: be creative. Consider who may use a service robot, why they might want/need such a robot and what this means for how they might operate a service robot.

Remark: Plug-in external devices (keyboard/computer), typing commands in terminal (ssh, rostopic), and complex interfaces will not be allowed. User interfaces MUST be in English (multi-language GUI are allowed).

3.9. Special penalties and bonuses

3.9.1. Penalty for not attending

1. **Automatic schedule:** All teams are automatically scheduled for all tests.
2. **Announcement:** If a team cannot participate in a test (for any reason), the team leader has to announce this to the OC at least *60 minutes* before the test slot begins.
3. **Penalties:** A team that is not present at the start position when their scheduled test starts, the team is not allowed to participate in the test anymore. If the team has not announced that it is not going to participate, it gets a penalty of *150 points*.

3.9.2. Extraordinary penalties

1. **Penalty for inoperative robots:** If a team starts a test, but it does not solve any of the partial tasks (and is obviously not trying to do so), a penalty of *50 points* is handed out. The decision is made by the referees and the monitoring TC member.
2. **Extra penalty for collision:** In case of major, (grossly) negligent collisions the *Technical Committee* (TC) may disqualify the team for a test (the team receives *0 points*), or for the entire competition.

3. **Not showing up as referee or jury member:** If a team does not provide a referee or jury member (being at the arena on time), the team receives a penalty of *150 points*, and will be remembered for qualification decisions in future competitions.
   Jury members missing a performance to evaluate are excluded from the jury, and the team is disqualified from the challenge (receives *0 points*).

3.9.3. Bonus for outstanding performance

1. For every regular test in *Stage I* and *Stage II*, the @Home *Technical Committee* (TC) can decide to give an extra bonus for *outstanding performance* of up to 10% of the maximum test score.
2. This is to reward teams that do more than what is needed to solely score points in a test but show innovative and general approaches to enhance the scope of @Home.
3. If a team thinks that it deserves this bonus, it should announce (and briefly explain) this to the *Technical Committee* (TC) beforehand.
4. It is the decision of the *Technical Committee* (TC) if (and to which degree) the bonus score is granted.

3.10. General Instructions for Organizing Committee

Although there are instructions for the OC are specified per test, there are several aspects that the OC requires to carry out for competition in general:

During competition:

- Provide TC and referees with scoring sheets, pens, clipboards, stopwatches and other material relevant of carrying out the scoring.
- Post time schedules in the allotted spaces for the team's knowledge.

1h before each test:

- Organize referees.

Chapter 4

Setup and Preparation

Prior to the RoboCup@Home competition, all arriving teams will have the opportunity to setup their robots and prepare for the competition in a *Setup & Preparation* phase. This phase is scheduled to start on the first day of the competition, i.e., when the venue opens and the teams arrive. During the setup phase, teams can assemble and test their robots. On the last setup day, a *welcome reception* will be held. To foster the knowledge exchange between teams a conference-like *poster session* takes place during the reception. All teams have to get their robots inspected by members of the TC to be allowed to participate in the competition.

Regular tests are not conducted during setup & preparation. The competition starts with Stage I (Section Section 5).

Table 4.1.: Stage System and Schedule (distribution of tests and stages over days may vary)

Setup & Preparation	*Stage I*	*Stage II*	*Finals*
	advance → All teams that passed Inspection	*advance* → Best 10 (<20) or best 50% (≥ 20)	*advance* → Best 5 teams

4.1. General Setup

Depending on the schedule, the *Setup & Preparation* phase lasts for one or two days.

1. **Start:** Setup & Preparation starts when the venue opens for the first time.
2. **Intention:** During Setup & Preparation, teams arrive, bring or receive their robots, and assemble and test them.
3. **Tables:** The local organization will setup and randomly assign team tables.
4. **Groups:** Depending on the number of teams, the *Organizing Committee* (OC) may form multiple groups of teams (usually two) for the first (and second stage). The OC will assign teams to groups and announce the assignment to the teams.
5. **Arena:** The arena is available to all teams during Setup & Preparation. The OC may schedule special test or mapping slots in which arena access is limited to one or more teams exclusively (all teams get slots). Note, however, that the arena may not yet be complete and that last works are conducted in the arena during the setup days.

6. **Objects:** The delegation of EC, TC, OC and local organizers will buy the objects (see Section Section 3.2.5). Note, however, that the objects may not be available at all times and not from the beginning of Setup & Preparation.

4.2. Welcome Reception

Traditionally –since Eindhoven 2013– the RoboCup@Home holds an own *welcome reception* in addition to the official opening ceremony. During the welcome reception, a *poster session* is held in which teams present their research foci and latest results (see Section Section 4.3).

1. **Time:** The welcome reception is held in the evening of the last setup day.
2. **Place:** The welcome reception takes place in the @Home arena and/or in the RoboCup@Home team area.
3. **Snacks & drinks:** During the welcome reception snacks and beverages (beers, sodas, etc.) are served.
4. **Organization:** It is the responsibility of the OC and the local organizers to organize the welcome reception & poster session including
   4.1. organizing poster stands (one per team) or alternative to present the posters,
   4.2. organizing the snacks and drinks,
   4.3. inviting officials, sponsors, local organization and the trustees of the RoboCup Federation to the event.
5. **Poster presentation:** During the welcome reception, the teams give a poster presentation on their research focus, recent results, and their scientific contribution. Both the poster and the teaser talk are evaluated by a jury (see 4.3).

4.3. Poster Teaser Session

Before the welcome reception & poster session, a *poster teaser session* is held. In this teaser session, each team can give a short presentation of their research and the poster being presented at the poster session.

4.3.1. Poster teaser session

1. **Presentation:** Each team has a maximum of three minutes to give a short presentation of their poster.
2. **Time:** The poster teaser session is to be held before the welcome reception & poster session (see Section Section 4.2).
3. **Place:** The poster session may be held in or around the arena, but should not interfere with the robot inspection (see Section Section 4.4).
4. **Evaluation:** The teaser presentation and the poster presentation are evaluated by a jury consisting of members of the other teams. Each team has to provide one person (preferably the team-leader) to follow and evaluate the entire poster teaser session and the poster session. Not providing a person results in no score for this team in the *Open Challenge*.

5. **Criteria:** For each of the following evaluation criteria, a maximum of 10 points is given per jury member:
   5.1. Novelty and scientific contribution
   5.2. Relevance for RoboCup@Home
   5.3. Presentation (Quality of poster, teaser talk and discussion during poster session)
6. **Score:** The points given by each jury member are scaled to obtain a maximum of 50 points. The total score for each team is the mean of the jury member scores. To neglect outliers, the N best and worst scores are left out:

$$score = \frac{\sum \text{team-leader-score}}{\text{number-of-teams} - (2N+1)}, N = \begin{cases} 1, & \text{number-of-teams} \geq 10 \\ 2, & \text{number-of-teams} < 10 \end{cases}$$

7. **Sheet collection:** Evaluation sheets are collected by the OC at a later time (announced beforehand by the OC), allowing teams to continue knowledge exchange during the first days of the competition (Stage I).
8. **OC Instructions:**
   - Prepare and distribute evaluation sheets (before the poster teaser session.)
   - Collect evaluation sheets.
   - Organize and manage the poster teaser presentations and the poster session.

4.4. Robot Inspection

Safety is the most important issue when interacting with humans and operating in the same physical workspace. Because of that all participating robots are inspected before participating in RoboCup@Home. Every team needs to get its robot(s) inspected and approved for participation.

1. **Procedure:** The *robot inspection* is conducted like a regular test, i.e., starts with the opening of the door (see Section Section 3.8.7). One team after another (and one robot after another) has to enter the arena through a designated entry door, move to a designated intermediate way-point in the arena, and then leave the arena to the designated exit door. In between entering and leaving the robot is inspected.
2. **Inspectors:** The robots are inspected by the *Technical Committee* (TC).
3. **Checked aspects:** It is checked if the robots comply with the rules (see Section Section 3.3), checking in particular:
   - size of the robot
   - emergency button(s)
   - start button (if the team is going to require it)
   - collision avoidance (a TC member steps in front of the robot)
   - voice of the robot (it must be loud and clear)
   - robot speaker system (plug for RF Transmission)
   - use of custom containers
   - use of external devices (including wireless network)
   - usage of (standardized) continue rule (Section 3.8.15). The robot must stop anywhere between the entry and exit and wait for someone to show a QR-code encoding the text “Continue” as per the standardized Continue-rule. If the team has a custom

alternative to ASR for the Continue Rule, this must also be demonstrated so the TC. The TC will decide after deliberation what (reduced) penalty will be given when the alternative is used.
- other safety issues (cables hanging loose etc.)

4. **Re-inspection:** If the robot is not approved in the inspection, it is the responsibility of the team to get the approval (later). Robots are not allowed to participate in any test before passing the inspection by the TC.
5. **Time limit:** The robot inspection is interrupted after three minutes (per robot). When told to so by the TC (in case of time interrupt or failure), the team has to move the robot out of the arena through the designated exit door.
6. **Appearance Evaluation:** In addition to the inspection, the TC evaluates the appearance of the robots. Robots are expected to look nice (no duct tape, no cables hanging loose etc.). In case of objection, the TC may penalize the team with a penalty of maximum 50 points.
7. **Accompanying team member:** Each robot is accompanied by only one team member (team leader is advised).
8. **OC instructions (at least 2h before the Robot Inspection):**
   - Specify and announce which doors will be used as entry door and exit door.
   - Specify and announce the location where the robot should drive to in the arena.
   - Specify and announce where and when the poster teaser and the poster presentation session take place.

Chapter 5

Tests in Stage I

*Stage I comprehends five **ability tests** and an **integration test** along with an open demonstration for the audience. Each ability test is designed to evaluate the average performance of the robot in one particular skill, providing data for benchmarking. Meanwhile, the integration test has been designed to evaluate how this abilities work together while solving a common task.*

The total score for ability and integration tests is the average of the best two performances out of preferably three performances (given the time constraints of a competition). The point of this is the both elimate good and bad luck for the robots/teams and to get a more objective view of the performance, not to give teams time to tweak the robot between test performances.

Following and Guiding (demonstration for the audience) goes out of the arena and into the venue between the audience.

Scheduling

For maximal efficiency, teams will be scheduled interleaved: Team A does an attempt while team B sets up their robot. When A is done, it moves out the way for team B, then B attempts while A sets up the robot again etc.

The preparing team should prepare their robot close to the place of the test, but not interfere with the performing robot. Prepared robots must wait at this preparation location until commanded to start the test. When commanded to start, the robot must move automatically beyond this point.

Robot should be ready to start the next attempt to the same test as fast as possible: when the performing robot is done with a attempt, the next robot must be ready to go with the start of a button or a voice command.

5.1. Manipulation and Object Recognition

The robot must reach a bookcase in which there are 10 objects at different shelves in the bookcase. The robot must then identify and grasp and identity 5 of those objects and put those into a new, easy-to-reach shelve that the team/robot may choose.

Optionally, the robot may open a little door or drawer for additional points.

5.1.1. Goal

The robot has to identify, grasp and correctly place several objects at different heights or positions. Opening drawers and/or doors is optional.

5.1.2. Focus

This test focuses on object detection, and manipulation; as well as object recognition.

5.1.3. Setup

This test may also be held outside the arena. This is in order to have the possibility to run multiple robots in parallel and reduce the total time needed to test all robots.

1. **Location:** One of the bookcases in or around the apartment is used for this test. The robot will start at a random distance between 1.0m and 1.5m from the bookcase. The bookcase has at least 5 shelves between 0.30m and 1.80m from the ground. One of the shelves is empty or will be made empty when the team chooses a shelve.
2. **Objects:** The bookcase contains 10 objects from the Scenario Objects 3.2.5. The robot may grasp 5 objects and may identify 5 objects.
3. **Object distribution:** The objects are located as follows:
   - 3.1. Known object in an upper shelf.
   - 3.2. Known object in a middle shelf.
   - 3.3. Known object in a lower shelf.
   - 3.4. Alike object in a middle shelf.
   - 3.5. Cloth/tray/bowl in a middle shelf

   Optional An occluded or hidden object on a middle shelf (e.g. behind another object or inside a bowl).
4. **Door/drawer:** The bookcase contains a door and a drawer, in which an additional object is placed. Opening the door or drawer gives a bonus.

Please note that there may be more than one object in each shelf to fit all objects in.

5.1.4. Task

1. **Searching for objects:** When told so by an operator, the robot approaches to the shelf from its nearby starting position and starts searching for objects.
2. **Grasping objects:** Any object found by the robot may be grasped by it. Before or right after grasping the object, the robot may announce which object it has found. The scoring only takes the classifications in the report into account.

3. **Placing objects:** After grasping the object, the robot has to safely place it (Section Section 3.2.5) on the empty shelf. The object must stay there for at least 10 seconds.
4. **Handling objects multiple times:** Scores can only be gained a single time for each specific object.
5. **Optional: Opening door or drawer:** The robot may open the door or drawer in the bookcase. An additional item is located behind/in it.

5.1.5. Additional rules and remarks

1. **No setup:** The robot must be ready to start the test with a voice command or start button when requested by the referee. There is no setup time.
2. **Startup:** The robot must be started with a single voice command or via a start button (Section Section 3.8.7). If the robot is unable to start it must be removed immediately.
3. **Single try:** The robot must be able to start from the first attempt. 'There is no restart for this test. If the robot is unable to start it must be removed immediately.
4. **Collisions:** Slightly touching the shelves or the bookcase is tolerated. Driving over the objects or any other form of a major collision is not allowed, and the referees directly stop the robot (Section Section 3.8.1).
5. **Object types:** The objects selected from the *Standard Objects Set* will be chosen to be easily detectable and contrasting with the shelf (ex. red or black objects on a white shelf).
6. **Recognition report:** Robots must create a PDF report file including the list of recognized objects with a picture showing the object and the object name/label. This file may be stored on a USB-stick on the robot which is given to the TC after the test. The PDF file name should include the team name and a timestamp. Furthermore, it must be unmistakeable which label belongs to which object. Objects must also be recognizable in the report by a human (TC) so that it can be scored. An overview of the shelf with bounding boxes and labels attached to the bounding boxes is handy for the TC to score. False positives in the report (labeling an object which is not an object but e.g. the edge of the shelf) are penalized.
7. **Clear area:** The robot may assume that the direct vicinity of the bookcase is clear and that the robot can move slightly backwards for its task.

5.1.6. Data recording

Please record the following data (See Section 3.4):

- Images
- Plans

5.1.7. Referee instructions

The referee needs to

- Place the objects in the bookcase
- Make sure there is one empty shelf in the middle of the bookcase. Ask the team which shelve they want to be empty.
- Put an item in the drawer or behind a door, and close them.

- 5 of the object in the shelf should be unknown objects, in order to have 5 recognizable objects for scoring.

5.1.8. Score sheet

The maximum time for this test is 3 minutes.

Action	Score
Grasping objects	
For each successful grasp of any object (lifting it up to at least 5 cm for more than 10 seconds)	*5 × 10*
Placing objects	
For each successful placement of any object (safely stands still for more than 10 seconds)	*5 × 10*
Recognizing objects	
Every correctly recognized object in the report file	*5 × 10*
False positive label	*5 × -5*
Hidden object optional	
Finding a hidden or occluded object	*20*
Successful grasp of hidden or occluded object	*20*
Bonus	
Open the drawer or door	*50*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*24*
Total score (excluding penalties and bonuses)	*240*

5.2. Navigation

The robot must visit a set of waypoints while avoiding obstacles on its path and finally follow a person outside the arena.

5.2.1. Focus

This test focuses on tracking and recognizing a previously unknown person, obstacle avoidance, obstacle interaction, and safe navigation in dynamic environments in general.

5.2.2. Setup

1. **Doors:** All doors in the apartment are open, except for the entry door.
2. **Location:** One of the arenas (apartment) and its surroundings. The apartment is in its normal state. Part of the test is performed outside the arena in a public space. The arena will likely contain another door that may be used for this test.
3. **Operator:** A "professional" operator is selected by the TC to test the robot during the guiding phases.
4. **Other people:** There are no restrictions on other people walking by or standing around throughout the complete task.
5. **Path:** A path is setup beforehand and announced, except for Waypoint 4 (later explained).

5.2.3. Task

1. **Entering:** The robot enters the arena.
2. **Waypoint 1 (path planning):** After entering the arena, the robot must navigate to *Waypoint 1* that is reachable via, at least, two paths, each one requiring the robot to go through a door which will be shut as the robot approaches. The robot may:
   - Take a different path.
   - Open the closed internal door.
3. **Waypoint 2 (obstacle interaction):** Immediately after reaching *Waypoint 1*, the robot must go to and reach at grasp (or place) distance *Waypoint 2*, a placement location (e.g. a shelf). A large obstacle will prevent the robot from getting close to its destination, having the robot to identify it and interact with it. Possible actions include:
   - Gently move the obstacle (e.g. if the obstacle is an object).
   - Gently ask the obstacle to move away (e.g. if the obstacle is a human).
   - Wait for the object to move away by itself (e.g. if it is unable to identify the type of obstacle). The obstacle will clear or be cleared after roughly a minute.

   It must be clear to the referee that the robot has correctly identified the type of obstacle to score points for "state the nature of the obstacle".
4. **Waypoint 3 (following a human):** After reaching *Waypoint 2*, the robot must navigate to *Waypoint 3*, a landmark or beacon, where a *Professional Walker* will be waiting. The robot must memorize the *Professional Walker* and follow them outside the arena to *Waypoint 4* which location is unknown.

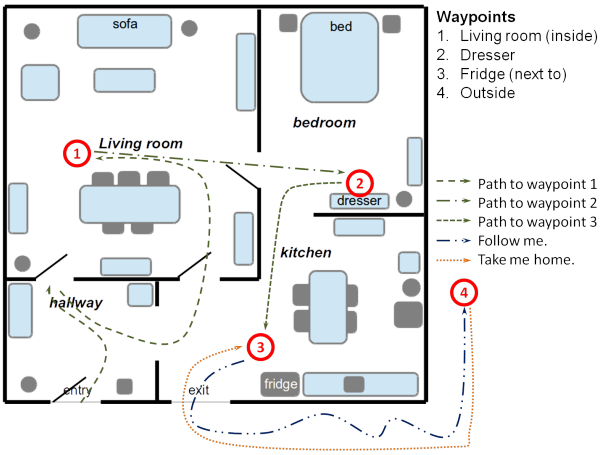


Figure 5.1.: Navigation test: setup and execution example.

- **Training phase:** The robot has to memorize the operator. During this phase, the robot may instruct the operator to follow a certain setup procedure and instruct the operator on what to do when the robot needs to stop following.
- **Following phase:** When the robot signals that it is ready to start following, the operator starts walking –in a natural way– through a designated path outside the arena. The robot needs to follow the operator until the operator asks the robot to stop doing so (when *Waypoint 4* has been reached).
- **Resuming:** If the robot loses the *Professional Walker*, it can ask him/her to signal it by waving to resume following, but will be penalized for doing so.
- **Stop following:** Upon reaching *Waypoint 4*, the *Professional Walker* will command the robot to stop following him, using the instructions given by the robot in the training phase.

5. **Go back home:** After reaching *Waypoint 4* the robot must go back to *Waypoint 3*. After the human left the apartment to guide the robot to *Waypoint 4*, the external doors of the apartment will be closed (as one would when leaving the house). The robot must open a door of the appartment before it can enter and collect the point for reaching *Waypoint 3*.
   - Reach the external door it left the appartment from.
   - Open that door. The latch of the door will be fixed so that it can't lock into the door frame. This means the door can be pushed open, as the external doors open to the inside of the apartment and the robot comes from the outside. The robot is allowed to use its base to push the door further open, but only after it used a manipulator to initially open the door by the handle. It also has to announce it will use "functional touching" to open the door. Rotating the handle is not needed but the robot must show it knows where the door handle is. The door must be opened gently, not by bumping into it without stopping first. The door is considered open only if the robot is able to drive through it to the next waypoint.
   - Reach waypoint 3 again. The door must be ale to be shut behind the robot.
6. **Leaving the arena:** The robot must finally leave the arena through the indicated door.

Remarks:

1. Depending on the layout of the arena, waypoint 1 and 2 may be swapped.
2. Reaching a waypoint also includes the direction in which the robot should be looking when it reaches, which will be announced by the TC during the setup of the path.
3. The distance between Waypoints 3 and 4 is about 10-20 meters.

5.2.4. Obstacles

While navigating to waypoints 1, 2, and 3 the robot will find one of the following obstacles on its path:

- **Small object:** Box sized object (between 5 and 15 cm per edge).
- **3D Object:** A bar table, normal table, rolling chair: some object that is wider at its top than on its bottom, thus requiring more than just a laser scanner mounted near the ground to avoid obstacles.
- **Smart obstacle:** A person to whom the robot may speak to and kindly ask to move away. When interacting with people, the robot must look at the person and make clear is speaking with him/her.

5.2.5. Additional rules and remarks

1. **Waypoints:** Waypoints may be rooms, placement locations, furniture, beacons, landmarks, etc. The robot must clearly state when it has reached a waypoint or if it was not able to reach the waypoint.
2. **Show must go on:** If a robot is unable to reach a waypoint, it must say it and proceed to the next one.
3. **Closing internal doors:** The internal door that will be shut will be the door on the route the robot has committed to. It will be shut right after the robot starts driving towards the door, but granting enough time to notice that the door is now closed.
4. **Moving objects:** If the robot finds on its way a *static movable obstacle* (chair, cubes, toys, etc.) which is capable to move, it must announce is going to move an obstacle and then proceed to move the object apart with its manipulator, or by **gently** pushing it with its body.
5. **Asking people to move away:** If the robot finds on its way a person blocking its path, it must announce it has found a person, *gently* ask that person to move away and wait for the path to be clear. **Robots are not allowed to touch people**.
6. **Following people:**
   - 6.1. **Instruction:** The robot interacts with the operator, *not* the team. That is, the team is not allowed to instruct the operator.
   - 6.2. **Natural walking:** The operator has to walk "naturally", i.e., move forward facing forward. The operator is not allowed to walk back, stand still, signal the robot or follow any re-calibration procedure.
   - 6.3. **Asking for passage:** The robot is allowed to (gently) ask people to step aside.

5.2.6. Data recording

Please record the following data (See Section 3.4):

- Mapping data
- Plans

5.2.7. Referee instructions

The referee needs to

- Instruct the OC and volunteers on when and where locate objects.
- Instruct the OC and volunteers on when and which doors must be closed.
- Stop the robot immediately when it is about to collide.

5.2.8. OC instructions

2 hours before the test

- Announce the entry and exit doors.
- Announce the locations for waypoints 1, 2, and 3.
- Establish location for waypoint 4 and the path for the *follow me* phase.

During the test

- Open and close the doors when instructed by the referee.
- Place the obstacles (or act as an obstacle) when instructed by the referee.

5.2.9. Score sheet

The maximum time for this test is 5 minutes.

Action	Score
Waypoint 1: Path planning	
Planning new trajectory after the door has been shut	*5*
Reaching waypoint 1	*5*
Waypoint 2: Obstacle interaction	
Correctly state the nature of the obstacle blocking its path	*10*
Reaching waypoint 2 (to grasp/place distance)	*5*
Waypoint 3-4: Follow me	
Leaving the arena while following the *Professional Walker*	*10*
Reaching waypoint 4	*20*
Penalty for asking *Professional Walker* to wave to resume following.	*10* × *-2*
Waypoint 4-3: Go back back home	
Reaching the door via which the robot went out the appartment again. The handle must be within manipulator reach	*5*
Pushing the door handle/knob/lever with manipulator	*20*
Opening the door far enough to drive in	*20*
Reaching waypoint 3 after reentering the arena	*5*
Obstacle avoidance	
Avoiding box-sized object	*5*
Avoiding 3D object (Difficult-to-see object)	*10*
Asking a person to step aside	*5*
Moving away movable object	*30*
Leaving the arena	
Leaving the arena	*5*
Bonus	
Opening the door and continue instead of planning a new trajectory	*40*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*20*

Total score (excluding penalties and bonuses) *200*

5.3. Person Recognition

An Operator is introduced to the robot, which needs to learn what the Operator looks like. Once the robot has gathered enough information about the Operator, the Operator mixes within a crowd and the robot needs to find the Operator. Once the robot has found its Operator, it must state some information about the Operator and the crowd, such as genders.

5.3.1. Goal

The robot has to identify the Operator within a crowd and state information about the Operator and the crowd.

5.3.2. Focus

This test focuses on people detection and recognition; as well as pose recognition and human-robot interaction with unknown people.

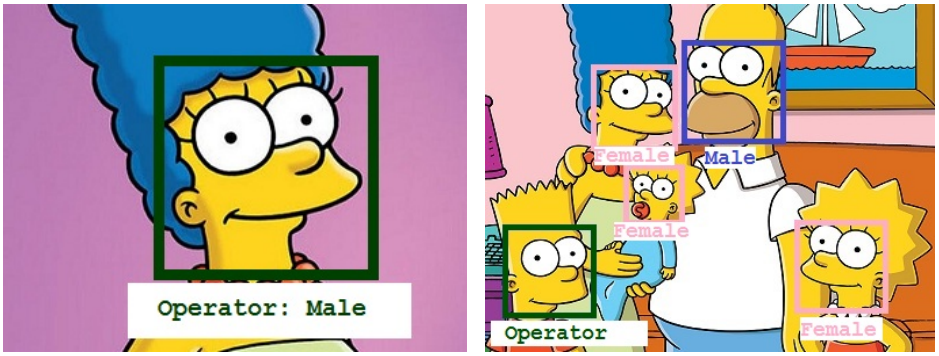
5.3.3. Setup

1. **Operator:** A "professional" operator is selected by the TC to test the robot. This person may a different be drafted from the crowd in each run.
2. **Other people** There are no restrictions on other people walking by or standing around throughout the complete task.

5.3.4. Task

This test may also be held outside the arena This is in order to have the possibility to run multiple robots in parallel and reduce the total time needed to test all robots.

1. **Start:** The robot starts at a designated starting position, and waits for the "professional" operator.
2. **Memorizing the operator:** The robot has to memorize the operator. During this phase, the robot may instruct the operator to follow a certain setup procedure.
3. **Learning operator name:** Optionally, the robot may ask the operator for his/her name and make the interaction after finding the operator again more natural.
4. **Waiting 10 seconds:** Once the robot states it has finished memorizing the operator, it must wait 10 seconds while the operator walks around and mixes with the crowd.
5. **Find the crowd:** After the time elapses, the robot must turn around about 180°, find the crowd, and start looking for the operator.
   - **Crowd size:** The crowd may contain between 5 and 10 people, standing or sitting or lying within an area of 5 meters (diameter).
   - **Crowd position:** The crowd will be located behind the robot at a distance between 2 and 3 meters apart.
6. **Finding the operator:** Once the crowd has been located, the robot must greet the operator (optionally by name) and state their gender, pose (sitting, standing, raised arm), and relative position within the crowd. Alternatively to state the relative position of the



(a) Operator **(b)** Crowd

Figure 5.2.: Report picture examples: The operator's gender was incorrectly labeled and wasn't found in the crowd, however four out of four genders are specified correctly. No pose is stated.

operator, the robot may point or approach to the operator. In any case, it must be clear to the referees that the robot has found the operator, unambiguously. Examples include:

- My operator is the girl sitting left most of the crowd.
- Mary, you are standing behind the bearded man with black shirt wearing glasses.
- Adam is the blond guy standing in the center between two female people.

Remark: In the case of the slightest ambiguity, no points will be granted.This includes the referees not being able to understand or hear the robot.

7. **Describing the crowd**: Finally, robot must tell the size of the crowd and how many men, women and unidentified people are (even including children).
8. **Delivering report file**: Immediately after the test, an USB pen-drive will be collected by the referees from the robot. The pen-drive must contain a report file as described further.

5.3.5. Report file:

Robots must create a PDF report file stored in a USB-stick attached to the robot to be given to the TC after the test, which will be used for scoring. The report must be as follows:

- **File name:** The name of the file must be: `TeamName-Try-Timestamp.pdf`
- **Team name:** The report file **must contain the name of the team**.
- **Operator's picture:** The report file must include a picture of the operator with a caption stating operator's gender and, if given, the operator's name. Drawing a frame enclosing the region(s) used for recognition is advised.
- **Crowd's picture:** Under the operators information, the report file must include a picture of the crowd with a labeled frame enclosing each detected person, and a set of captions stating their genders and, in the case of the operator, the pose.

5.3.6. Additional rules and remarks

1. **Waiting & Continue Rule:** Instead of waiting 10 seconds the robot may wait for a spoken command. Since this test is not concerned with audio and speech recognition,

therefore there is no penalty when using the Continue Rule (see Section Section 3.8.15). A single key press used as start command is also allowed.
2. **Disturbances from outside:** If a person from the audience (severely) interferes with the robot in a way that makes it impossible to solve the task, the team may repeat the test immediately.
3. **Children:** Note that the operator and crowd may be members of the audience as well, which may include children. A robot only looking up may look over a child operator.
4. **Preparation:** The robot needs to wait for about 1 min before the operator appears in front of the robot. During this waiting time the team is not allowed to touch the robot.
5. **Instructing the operator:** The robot interacts with the operator, not the team. The team is not allowed to instruct the operator.

5.3.7. Data recording

Please record the following data (See Section 3.4):

- Images These will not be publicly available due to privacy concerns of the operator and crowd.

5.3.8. OC instructions

2 hours before the test

- Select the "professional" operator(s).
- Select the crowd.

During the test

- Check safe operation of the robot; the robot needs to be stopped immediately if a person is going to be touched by the robot

5.3.9. Score sheet

The maximum time for this test is 5 minutes.

Scoring in this test requires a report in PDF format to be delivered to the TC for further statement validation. Scoring for stating the people gender in the crowd is normalized to the crowd size.

Action	Score
Operator	
State operator's gender	*20*
State operator pose	*20*
Unambiguously indicate operator position (approching, pointing at or describing relative position)	*20*
Crowd (requires report validation)	
State crowd's size (with no false positives)	*10*
Reporting gender of people in the crowd	*80*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*15*
Total score (excluding penalties and bonuses)	*150*

Normalization: Let N be the total amount of people in the crowd counting the operator, and c, i the **c**orrectly and **i**ncorrectly labeled gender count respectively, excluding the operator. Scoring for *reporting gender of people in the crowd* is calculated by following the next formula:

$$score = 80 \times \frac{max(c - i, 0)}{N - 1}$$

A perfect score is when $C = N - 1$ meaning all people in the crowd were correctly identified, but in case most people were incorrectly identified, the score is set to zero.

5.4. Speech Recognition & Audio Detection Test

This test is divided in two phases. First the robot must answer a set of questions to an operator at the first attempt without asking for confirmation. The operator is not allowed to move to the robot or shout to the robot.

For the second phase, the focus is to carry out Sound Source Localization (SSL) and Automatic Speech Recognition (ASR) at the same time. To this effect, volunteers will stand around the robot and a randomly chosen volunteer will ask a question. The robot is expected to turn towards that volunteer and answer the question. If the robot is NOT able to carry out SSL and ASR at the same time (e.g. it needs to turn towards the speaking volunteer using SSL before doing ASR), the robot is allowed to request to repeat the question (with a penalty). In addition, if SSL cannot be carried out, the robot may still answer the question without turning, but no points will be provided for SSL.

5.4.1. Goal

The robot must be able to properly recognize and answer to a specific set of questions without ask for confirmation. Also, the robot shall be able to react to a speaking operator which is not facing towards to.

5.4.2. Focus

This test focuses on voice recognition and audio-source localization in a noisy environment, with moving sound sources[1].

5.4.3. Setup

1. The apartment is in its normal state.
2. All doors of the apartment are open, except for the entry door.

5.4.4. Task

1. **Direct speech recognition:** The robot should move (or be moved) to a previously specified point inside the arena. A TC member will ask 5 questions from the set of 50 predefined questions in front of the robot. The robot should answer the question without asking confirmation. A question will only be asked once; there are no repetitions of a question.
   - The operator shall be standing still and facing to the robot.
   - The operator shall be between 0.75 and 1.0 meters away from the robot position.
   - The operator shall be between -60° and 60° from the robot's center (front range).
2. **Indirect speech recognition:** A group of several volunteers will stand around the robot as in Figure 5.3, standing still, facing the robot, and between 0.75 to 1.0 meters away from it. The number of volunteers may change from the Figure. A random person of this group will ask a question of the same set described in the first part of the test. Before

[1] This test may also be held outside the arena

answering, the robot can do one or both of the following (each providing different amount of points):

- Answer the question,
- Turn towards the person that asked the question,
- Ask for only one repetition of the question, if needed (penalty).

This process will repeat 5 times. No attempt may receive negative points. When the robot provides an answer it should not ask for confirmation.

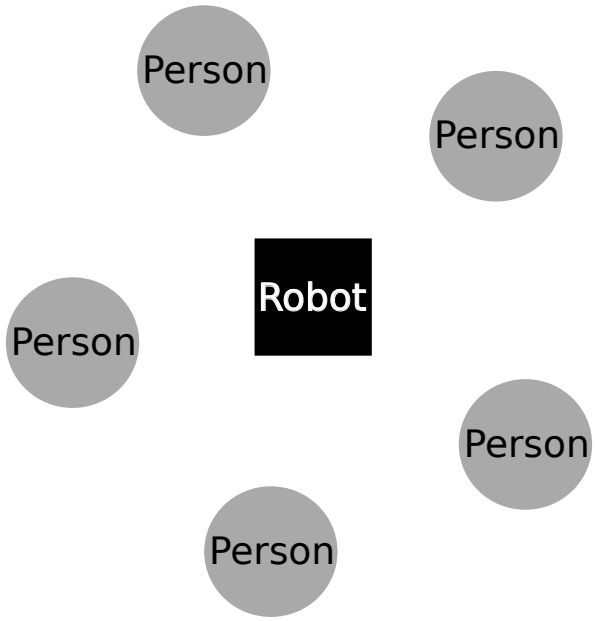


Figure 5.3.: Speech recognition test: person setup around the robot for 2nd part.

5.4.5. Additional rules and remarks

- **Continue rule:** Continue rule (Section Section 3.8.15) can not be used during this test.
- **Question timeout:** If the robot does not answer within 10 seconds, the question is considered as *missed*, and the TC member will proceed with the next question.
- **Understanding the answer:** If the robot's answer is not understood by the operator, it is considered as *incorrect*, and the TC member will proceed with the next question. It is thus advised that the robot provide answers such that it is clear that the robot understood the question. For example, if the question is "What is the capital of Germany?", instead of just answering "Berlin", it is advised that the robot answers something to the effect of "The capital of Germany is Berlin".
- **Question repetition:** In the second phase, if the robot turns towards the operator to be asked once again, it should clearly state that it requires a repetition of the question once it finishes turning, so as to cue the operator to do so.

5.4.6. Data recording

Please record the following data (See Section 3.4):

- Audio
- Commands

5.4.7. Referee instructions

The referee needs to

- Avoid shouting to the robot.
- Avoid getting closer to the robot.
- Speak to the robot loud and clear with plain standard English.
- Avoid repeating questions for the same robot.
- Choose the volunteers for the second part of the test, and describe this requirements to them.

5.4.8. OC instructions

1 day before the test

- Provide the set of 50 predefined questions

2 hours before the test

- Announce the placement of the robots

5.4.9. Score sheet

The maximum time for this test is 5 minutes.

Action	Score
Direct speech recognition	
Correctly answered a question	*5 × 10*
Indirect speech recognition	
Correctly answered a question	*5 × 10*
Turned towards person	*5 × 10*
Penalty for asking for repetition	*5 × -5*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*15*
Total score (excluding penalties and bonuses)	*150*

5.5. Following & Guiding

The robot must follow a person out of the arena and through unknown, dynamic, and crowded regions of the venue. After reaching the destination, the robot must guide the person back to the arena.

5.5.1. Goal

The goal of this test is mostly an audience outreach, in the tradition of the RoboZoo test series in the previous years. Spectators can take (flash photography) pictures of the robots up close and maybe even interact with the robot themselves. This is achieved by taking the robots out of the arena, into the RoboCup venue and performing in that dynamic environment.

5.5.2. Focus

This test focuses on tracking, recognizing, following and guiding a previously unknown person as well as safe navigation in dynamic environments.

5.5.3. Setup

1. **Doors:** All doors in the apartment are open.
2. **Location:** The test starts and ends in one of the arenas (apartment). During the test, the robots have to safely operate outside the arena in a public space.
3. **Operator:** An operator is selected by the technical committee (TC)to test the robot during the following and guiding phases.
4. **Other people:** There are no restrictions on other people walking by or standing around throughout the complete task.
5. **Path:** A path is setup but not announced beforehand. The path includes check points and a destination location.
6. **Disturbances:** The path includes defined disturbances during following and guiding (not announced before the test). In addition, this test will take place in the RoboCup venue where some unpredicted disturbances will manifest themselves.

5.5.4. Task

1. **Initialization:** The robot starts at a predefined *starting location*. The designated *operator* will step in front of the robot and tell the robot to start.
2. **Training phase & operator instructions:** The robot must memorize the *operator* and follow the *operator* to a designated *goal location* outside the arena. Neither the path taken nor the goal location are announced beforehand. During the training phase, the robot may instruct the operator to follow a certain setup procedure and what to do when the robot stops following (or ask for help).
3. **Following phase:** When the robot signals that it is ready to start following, the operator starts walking—in a natural way—along the designated path. The robot needs to follow the operator until the operator asks the robot to stop doing so, at the *goal location* or some intermediate location chosen by the operator. It could be that the operator has to stop walking for some reason. When the operator continues, the robot should continue

to follow as well. The robot can ask for confirmation on whether to continue following or start the next phase.

4. **Guiding phase:** Upon reaching the *goal location*, the *operator* will command the robot to stop following and to start guiding the *operator* back to the arena. This may be a single command and can be specified by the team and included in the operator instructions in the training phase. When the robot signals that it is ready to start guiding, the operator starts walking—in a natural way—following the robot and its instructions. If the robot is unable to guide a human, it may go back to the *starting location* without an operator.
5. **End of the test:** Once back at *starting location*, the robot has to announce that it is back in the arena. After the announcement, the robot has to leave through the exit door.

Remarks:

1. The waypoints and the goal location are reached once the robot passes a marker.
2. The starting location (guiding phase) is reached once the robot is back in the arena.

5.5.5. Obstacles and Disturbances

During following and guiding, some *disturbances* will occur, quite possibly multiple times. Disturbances may include:

- A person crosses in between operator and robot (following and guiding),
- A person stops for ca. 3 seconds in between operator and robot (following and guiding),
- The operator disappears behind a group of people (following),
- The operator becomes slower (guiding),
- The operator stops following,
- Audience taking pictures of the robot and its operator,
- Operator walking a different direction than (s)he is guided,

In case of disturbances it is expected that the robot continues following or guiding the operator and to find the operator again in case the operator got out of sight.

5.5.6. Additional rules and remarks

1. **Safety**: Robots must not touch people and operate safely! The technical committee (TC)may stop the robot and the test at any time in case the robot is not longer safely operating or shows problems with continuing the test (e.g., loosing the operator or moving randomly). The robots are accompanied by referees, organizing committee (OC)members, or technical committee (TC)members at all times. At least one technical committee (TC)member is always in sight to stop the robot (or tell others to do so).
2. **Asking people to move away:** If the robot finds on its way a person blocking its path, it may *gently* ask that person to move away and wait for the path to be clear. This is prefered over robots waiting indefinitely while standing still.
3. **Instructions:** The robot interacts with the operator, *not* the team. That is, the team is not allowed to instruct the follower.
4. **Natural walking:** The operator has to walk "naturally", i.e., move forward facing forward. The operator is not allowed during the following phase to walk back, stand still, signal the robot or follow any re-calibration procedure. During the guiding, the operator

follows with constant pace besides the defined disturbances. The operator is not allowed to move faster to catch up with the robot.

5. **Going back home early:** If the robot is not able to follow or guide the operator all the way to the goal or starting location and looses the operator before that, it may drive back to the starting location alone. The robot must announce it lost the operator and that it will drive back. The robot can only score points for going back before a waypoint after it passed the waypoint after that. E.g. if the robot looses the operator shortly after waypoint 3, it cannot score points for waypoint 3 (which it was already close to), only for waypoints 2, 1 and the starting location.
6. **Going back to known position:** If the robot lost the operator during following or guiding, it may go back to a previous position where it still had the operator. It must announce that it is doing so, as to not confuse the referees between this case and the case "Going back early".
7. **Calling the robot:** If the robot lost the operator during following or guiding, the operator may call the robot by e.g. waving or as instructed by the robot to the operator during the training phase.

5.5.7. Data recording

Please record the following data (See Section 3.4):

- Mapping data
- Trajectories and planned paths

5.5.8. TC & OC instructions

2 hours before the test

- Define the path, locations and check points (same for all teams).
- Define the types and locations of disturbances (same for all teams).
- Announce the *starting locations* for the teams.

During the test

- Let a person cross between robot and operator before entering the public.
- Let a person stop for 3 seconds between robot and operator before entering the public.

5.5.9. Score sheet

The maximum time for this test is 5 minutes, 5 more for the optional guiding-phase.

Action	Score
Following	
Reaching checkpoint 1	*10*
Reaching checkpoint 2	*10*
Reaching checkpoint 3	*10*
Reaching the *goal location*	*10*
Guiding	
Reaching checkpoint 3 without operator	*5*
Reaching checkpoint 3 with operator	*10*
Reaching checkpoint 2 without operator	*5*
Reaching checkpoint 2 with operator	*10*
Reaching checkpoint 1 without operator	*5*
Reaching checkpoint 1 with operator	*10*
Reaching the *starting location*	*5*
Reaching the *starting location* with operator	*10*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*10*
Total score (excluding penalties and bonuses)	*100*

5.6. General Purpose Service Robot

This test evaluates Human-Robot Interaction and the integration of the abilities of the robot tested in stage I. In this test the robot has to solve a task upon request. That is, the test is not incorporated into a (predefined) story and there is neither a predefined set of actions. The task that is to be carried out by the robot is randomly generated by the referees and is composed by 3 subtasks which include navigation, human-robot interaction and robot-object interaction.

The task given by a speech command is composed of three actions, which the robot has to show it has recognized. The robot may repeat the understood command and ask for confirmation. If it can't recognize the command correctly, it can also ask the speaker to repeat the complete command, or ask for further information. The actual command text may directly reference two actions while a third is inferred by either of the two directly stated commands. Often, this concerns navigation to the place a command must be carried out.

5.6.1. Focus

This test particularly focuses on the following aspects:

- No predefined order of actions to carry out (to get away from state machine-like behavior programming).
- Increased complexity in speech recognition (possible commands are less restricted in both actions/operators and arguments/objects, commands can include multiple objects, e.g., "put the apple on the kitchen table")

5.6.2. Task

1. **Entering and command retrieval:** The robot enters the arena and drives to a designated position where it has to wait for further commands.
2. **Command generation:** A command is generated randomly, depending on the command category chosen by the team (see below).

3. **Command categories:** All possible actions has been classified previously by the TC according to their difficulty level. The team may choose from the following three categories:
   - 3.1. **Category I:** Tasks with a low degree of difficulty (easy to solve). This category includes indoor navigation, grasping known objects, answering questions (from the predefined set of questions), etc.
   - 3.2. **Category II:** Tasks with a moderate degree of difficulty. This category includes following a human, indoor navigation in crowded environments, recognizing & grasping alike objects, find a calling person (waving or shouting), etc.
   - 3.3. **Category III:** The same tasks as in category II. However, the information given to the robot will be incomplete or incorrect, meaning that the command as it is specified exactly is not possible. The robot must come up with an appropriate solution to meet the operators' command. Please see the Command examples below.
4. **Task assignment:** The robot is given the command by the operator and may directly start to work on the task assignment. The robot must must prove it has understood the given command by repeating it (Please see the remarks about this in section 5.6.4).

5. **Exiting the arena:** After accomplishing the assigned task, the robot has to leave the arena.

5.6.3. Tasks and actions

The task is composed of three actions, which the robot has to show it has recognized. The robot may repeat the understood command and ask for confirmation. If it can't recognize the command correctly, it can also ask the speaker to repeat the complete command. If the robot fails to understand the given commands, it may ask to the operator to repeat them up to three times, if it fails the team may opt to use the Continue rule (Section Section 3.8.15). In case the robot has understood the command only partially, it may ask the operator for additional information (e.g. "did you say apple juice or pineapple juice?"). The robot is certainly not required to repeat the command word by word; reprasing the command is allowed.

Required in this test are:

1. abilities from stage I forming a set of actions A (e.g., following a person, finding a random person, finding a person after memorizing her; finding, recognizing, grasping, and delivering objects, etc.),
2. a set of people P,
3. a set of questions Q,
4. a set of objects O (the same set as used as in the other tests),
5. a set of locations L (the same set as used as in the other tests).

Each task assignment contains an action $a \in A$ and, depending on the respective action an object $o \in O$, a location $l \in L$, a question $q \in Q$, a person $p \in P$ to interact with, or a combination of those. The set of actions is not given beforehand, instead, teams should identify the abilities from Stage I by themselves (and find synonyms for that). That is, L, O and Q are known in advance (provided during setup days), but A has to be "found out" by the teams (e.g. taken from freely available ontologies, synonym searches etc.). For the actions A are going to be used common synonyms (like "go to", "move to", "drive to", and "navigate to" to describe navigation). For the people P, any person willing to operate the robot in a natural way can be expected, however, "Professional Operators" are more likely to be used.

Command examples

1. **Category I**
   - Go to the bedroom, find a person and tell the time (there is only one person in the bedroom).
   - Go to the dinner-table, grasp the crackers, and take them to the side-table.
   - Bring a coke to the person in the living room and answer him a question (there is only one person in the bedroom).
   - Go to the door, ask the person there for her name and tell it to me.
2. **Category II**
   - Go to the bedroom, find the waving person and tell the time (there is more than two people in the bedroom, only one waving).

- Go to the kitchen, find a person and follow her (there is only one person in the kitchen).
- Go to the side-table, grasp the coke, and take it to the dinner table (the way to the bedroom is crowded and the access to the side-table may be blocked by a human).
- Go to the dinner-table, grasp the banana, and take it to the side-table.

3. **Category III**
   - Take the apple from the sink and carry it to me. (There may no apple in the sink, but maybe another fruit the operator might want, an apple may be found somewhere else, etc.)
   - Go to the kitchen, grasp the coke, and take it to the side-table. (There may no coke in the kitchen but some other drink.)
   - Go to the bathroom, grasp the soap, and take it to the side-table. (The door to the bathroom may be closed. The robot must open the door, find a soap somewhere else or ask someone to open the door for it.)
   - Grasp the fanta from the small table and carry it to me. (When the robot comes back with the drink, I have moved somewhere else and the robot must find me again.)

5.6.4. Additional rules and remarks

1. **Referees:** Since the score system in this test involves a subjective evaluation of the robot's behavior, the referees are EC/TC members.
2. **Operator:**
   - The person operating the robot is one of the referees (default operator).
   - If the robot appears to consistently not be able to understand the operator, the referees may ask the team to apply the CONTINUE rule (Section 3.8.15).
   - With the custom operator, the team can only score 50% of the points for the respective command.
3. **Repeating the given command:** The robot must show it has understood the given command by stating all the required information to accomplish the task. This doesn't mean the robot must repeat exactly the same given command. For instance, if the robot is instructed to *"deliver a coke to Mary in the kitchen"*, the robot may ask: *"do you want me to go to the kitchen, find Mary and deliver a coke to her?"* or *"do you want me to find Mary at the kitchen and give her a coke?"* since both sentences involve all given information.
4. **Asking reasonable questions** The robot is allowed to ask a (one) reasonable question. This is to prevent 'phone dialog' style commanding of the robot.
   4.1. **Misunderstood information:** When the robot did not understood part of a command or it is unsure of what has been told, it may ask the operator to repeat or clarify without fall into a new attempt. For instance, if the robot is instructed to *"bring me the apple juice from the kitchen table"*, a valid question for the robot to ask is *"did you say apple juice or pineapple juice?"* without considering it as a new attempt for giving the command.
   4.2. **Missing information:** When a given command lacks of information required for accomplishing the task, the robot should request for that missing part. For instance,

if the robot is instructed to *"offer a drink to the person at the door"*, a proper question for the robot to ask is *"which drink should I deliver to the person at the door?"* It is also possible that the robot simply confirms the command and fetch a random drink at drinks' location.

5. **Following people**
   - 5.1. **Instruction:** The robot interacts with the operator, *not* the team. That is, the team is not allowed to briefly instruct the operator.
   - 5.2. **Natural walking:** The operator has to walk "naturally", i.e., move forward facing forward. The operator is not allowed to walk back, stand still, signal the robot or follow some re-calibration procedure.
   - 5.3. **Asking for passage:** The robot is allowed to (gently) ask people to step aside.
   - 5.4. **Stopping:** The robot must decide when to stop following a person, either because it was instructed to follow her to a certain location, because it was asked to stop by the operator or because the test time is running out. In any case, the robot should state the reason why it changes its behavior.

5.6.5. Data recording

Please record the following data (See Section 3.4):

- Audio
- Commands
- Images
- Plans

5.6.6. Referee and OC instructions

2h before test:

- Specify and announce the entrance and exit door

During the test:

- Generate a set of commands beforehand, so that and even distribution of skills and points can be obtained by all teams.

5.6.7. Score sheet

The maximum time for this test is 6 minutes.

Action	Score
Getting instructions	
Understanding the set of actions on the 1^{st} attempt	*40*
Understanding the set of actions on the 2^{nd} attempt	*20*
Understanding the set of actions on the 3^{rd} attempt	*10*
Reduction of points for every command provided by a team member	*0.5* × *-1*
Performing the task: Category I	
Performing the first task correctly	*10*
Performing the second task correctly	*10*
Successfully solving the complete command	*30*
Performing the task: Category II	
Performing the first task correctly	*20*
Performing the second task correctly	*30*
Successfully solving the complete command	*50*
Performing the task: Category III	
Asking reasonable questions to obtain missing information	*10*
Performing the first task correctly	*30*
Performing the second task correctly	*60*
Successfully solving the complete command	*80*
Explaining how the original command was not possible in it's (incorrect) statement and how this was solved	*30*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*25*
Total score (excluding penalties and bonuses)	*250*

Chapter 6

Tests in Stage II

All ability and integration tests in Stage II grants 250 points (but the Open Challenge which grants 250) and are performed only once. Some tests have optional tasks that grant additional points when performed correctly, clean and fast. The Technical Committee (TC) must be informed if a team is planning to perform any of the optional tasks. Unless explicitly stated otherwise, no additional time is given while performing optional tasks.

In the Open Challenge the robot must be able to show to the Technical Committee (TC) the achievements on the main research line of its own team. This test grants up to 200 points.

6.1. Robot & team cooperation

We encourage robots and teams to work together when performing challenges. For scoring, points are awarded per subtask. The robot (and thus team) performing the subtask gets the points. For example, in the Restaurant-challenge, if one robot of team A can take the order and another robot of team B delivers the order, then the points for taking the order go to team A, while the points for delivering go to team B. Of course, team A & B can both perform the challenge in their own turn.

6.2. Open Challenge

During the Open Challenge teams are encouraged to demonstrate recent research results and the best of the robots' abilities. It focuses on the demonstration of new approaches/applications, human-robot interaction and scientific value.

6.2.1. Task

The Open Challenge consists of a demonstration and an interview part. It is an open demonstration which means that the teams may demonstrate anything they like. The performance of the teams is evaluated by a jury consisting of all team leaders, TC and EC.

1. **Setup and demonstration:** The team has a maximum of *seven minutes* for setup, presentation and demonstration.
2. **Interview and cleanup:** After the demonstration, there is another *three minutes* where the team answers questions by the jury members.
   During the interview time, the team has to undo its changes to the environment.

6.2.2. Presentation

During the demonstration, the team can present the addressed problem and the demonstrated approach.

- A video projector or screen, if available, may be used to present a brief (max. 1 minute) introduction to what will be shown.
- The team can also visualize robot's internals, e.g., percepts.

It is important to note that the jury may decide to end the demonstration if there is nothing happening or nothing *new* is happening.

6.2.3. Changes to the environment

1. **Making changes:** As in the other open demonstrations, teams are allowed to make modifications to the arena as they like, but under the condition that they are reversible.
2. **Undoing changes:** In the interview and cleanup team, changes need to be made undone by the team. The team has to leave the arena in the *very same* condition they entered it.

6.2.4. Jury evaluation

1. **Jury of team leaders:** All teams have to provide *one* person (preferably the team-leader) to follow and evaluate the entire Open Challenge.
2. **Evaluation:** Both the demonstration of the robot(s), and the answers of the team in the interview part are evaluated.
   For each of the following *evaluation criteria*, a maximum of *10 points* is given per jury member:
   2.1. Overall demonstration
   2.2. Human-robot interaction in the demonstration
   2.3. Robot autonomy in the demonstration

2.4. Realism and *usefulness for daily life* (Can this robot become a product?)
2.5. Novelty and (scientific) contribution (+contribution to the community)
2.6. Difficulty and success of the demonstration

A jury member is not allowed to evaluate and give points for the own team.

3. Normalization and outliers:

3.1. The points given by each jury member are scaled to obtain a maximum of *250 points* (i.e., multiplied by $^{25}/_{6}$).
3.2. The total score for each team is the mean of the jury member scores. To neglect outliers, the N best and worst scores are left out:

$$\text{score} = \frac{\sum \text{team-leader-score}}{\text{number-of-teams} - (2N+1)}, \quad N = \begin{cases} 2, & \text{number-of-teams} \geq 10 \\ 1, & \text{number-of-teams} < 10 \end{cases}$$

6.2.5. Additional rules and remarks

1. **Start signal:** There is no standard start-signal for this test.
2. **Abort on request:** At any time during the demonstration, the jury may interrupt and abort the demonstration:
   2.1. if nothing is shown: in case of longer delays (more than one minute), e.g., when the robot does not start or when it got stuck;
   2.2. if nothing new is shown: the demonstrated abilities were already shown in previous tests (to avoid dull demonstrations and push teams to present novel ideas).
3. **Team-team-interaction:** An extra bonus of up to 50 points can be earned if robots from two teams (4 robots maximum, 2 from each team) successfully collaborate (robot-robot interaction).
   3.1. This bonus is earned for both teams.
   3.2. The robot(s) of the other team must only play a minor role in the total demonstration.
   3.3. It must be made clear that the demonstrations from the two teams are not similar, otherwise the points cannot be awarded.
   3.4. In case a team receives two (or more) bonuses, the maximum bonus will be taken.
   3.5. The collaboration is possible even if one of the two teams has not reached Stage 2.
   3.6. The team which does not participate in Stage 2 receives no points for this test.

6.3. Restaurant

The robot is tested in a real environment such as a real restaurant or a shopping mall.

6.3.1. Focus

This test focuses on online mapping, safe navigation in previously unknown environments, gesture detection, human-robot interaction, and manipulation in a real environment.

The robot will need to create its own map from the environment and then move into it to handle human requests, such as delivering drinks or snacks, while people are walking around.

6.3.2. Setup

1. **Location:** A real restaurant fully equipped with a "Professional Waiter" i.e. the operator and at least three tables with "Professional Clients".

6.3.3. Task

1. **Instruction:** In case the robot can work with a "Professional Waiter", the team should very briefly instruct the waiter how to command the robot, e.g. what to say when a table location must be memorized etc.
2. **Start:** The robot starts at a designated starting position, and waits for an operator: the "Professional Waiter". When the referees start the time, the team is allowed to (briefly) instruct the operator. After the instruction, the operator steps in front of the robot and tells it to follow (no start signal).
3. **Memorizing the operator:** The robot has to memorize the operator. During this phase, the robot may instruct the operator to follow a certain setup procedure.
4. **Guide phase:** Starting from the *Kitchen*, the robot is guided through the environment by a "Professional Waiter" which shows to the robot the location of each of the tables, its number, and on which side the table is (there is a total of 3 tables). After visiting all the tables, the robot must be guided again to the *Kitchen*, to the same place where the guide phase started.

   - **Own *Professional Waiter* [Optional]:** Team Leader may choose to use their own custom *Professional Waiter* for this test instead of the one provided by the committee.
   - **Finding the tables [Optional]:** Team Leader may choose not to tell the robot on which side (left or right) is the table, and let the robot find the tables by itself. When using this option, the robot must state where the table is (e.g. by telling: *the table is to my right*).

   Remark: When using a custom *Professional Waiter*, no points are earned for state the side of the table.
5. **Ordering phase:**

   5.1. **Which table to attend:** Once back in the kitchen, the robot shall ask to the *Professional Waiter* to which table go first to take an order from. The robot has to

go to the indicated table and ask for an order there. This interaction of telling the robot which table to attend should be natural.

5.2. **First order (Table A)**: The robot must aks the person what he or she wants to order. See Orders below for details about ordering.

5.3. **Detecting a call (Table B or C):** At any time while attending Table A's guests (going to fetch an order, asking the client, or returning to the kitchen with the order), a guest at Table B or C will ask for the robot's attention by waving *and* calling it out using voice. The robot must state out loud that it has detected the call and that it will attend as soon as possible. If the robot does not detect such a call, it may be given a command to go to the next table when it is back at the kitchen after finishing table A's order.

5.4. **Second order (Table B or C):** After taking the Table A client's order, and if the request was detected, the robot must go to the table of the waving/calling person and ask for an order.

5.5. **Avoiding random citizen:** At any time while going to any of the tables or to the *Kitchen*, a person may step on the robot's path. It is expected the robot to avoid that person or stop and wait for it to move away.

Orders: The menu offers Beverages and Combos. An order may be a Beverage or Combo. One guest will order a Combo while the other will order a Beverage. A Combo is a combination of two of the food items from the set of objects 3.2.5, e.g. "noodles with peanuts" or "noodles and peanuts". Guests also prefere to state their order in a natural way, as their would in a restaurant operated by humans.
Note: Table A, B and C may be any of Table 1, 2, 3, . . . , N in any order.

6. **Delivering phase:**

6.1. **Repeating the order:** Once again in the kitchen, the robot recites the orders for each table, including the table number (e.g. *Hamburger with fries for table 1 and Orange juice for table 2*), to the *Professional Barman*. This includes determining the table number of the waving/calling person. The *Professional Barman* will serve the order and place it into a tray on the Kitchen-bar. If the barman cannot understand the order that the robot repeats, he cannot hand out the order and no points can be awarded for reciting the order.

6.2. **Delivering Beverage:** The robot must grab a can of the appropriate drink from a set of cans on the Kitchen-bar and deliver it to the correct table.

6.3. **Delivering Combo:** The robot must carry a tray with the ordering to the table the food was ordered from. Teams must indicate beforehand whether the robot is able to grasp the plate itself, whether it needs a tray or whether the plate needs to be handed to the robot.

7. **Next customer, please:** The task is finished when the robot has delivered both orders and is back at the kitchen.

6.3.4. Additional rules and remarks

- **Safety!** This test takes place in a public area. That is, there may be people standing, sitting or walking around the area throughout the test. The robot is expected to not even

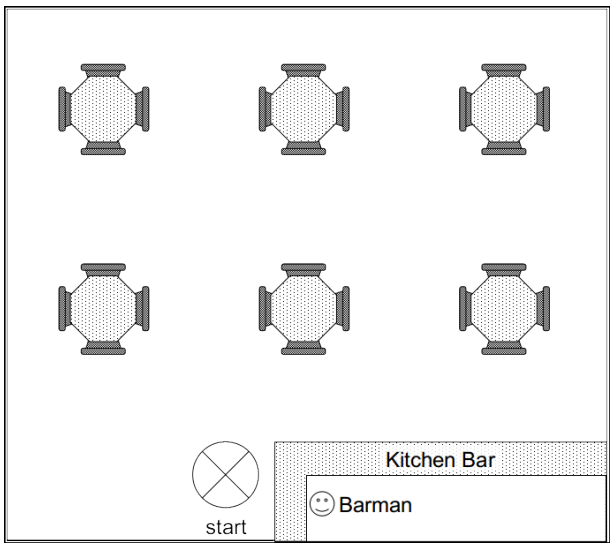


Figure 6.1.: Restaurant test: example setup.

slightly touch anything and is immediately stopped in case of danger.

- **Referees and guidance:** For safety reasons, the referees in this test are TC members. One of the referees follows the robot and is always in reach of the emergency button.
- **Start:** There is no fixed start signal in this test.
- **Order:** The way the user provides information to the robot is up to the robot's team. A natural interaction is preferred.
- **Location:** This test can be arranged in any real restaurant or shopping mall. If this is not possible, the test can be conducted in an arbitrary room containing the appropriate locations. The only requirement is that this room is not part of the arena and that the teams do not know the room beforehand. The exact location, including the object and delivery locations, will be defined by the technical committee on site (and in corporation with the local organization). In addition, to avoid unnecessary time investment for navigation, the distances between tables and the "Kitchen Bar" will be minimal.
- **Natural walking:** The operator has to walk "naturally", i.e., move forward facing forward. If not mentioned otherwise, the operator is not allowed to walk back, stand still, signal the robot or follow some recalibration procedure.
- **Disturbances from outside:** If a person from the audience (severely) interferes with the robot in a way that makes it impossible to solve the task, the team may repeat the test immediately.
- **Learning tables:** Of course, it can only be sure that a robot correctly learned a table when it is able to go there after being commanded so.
- **Instruction:** The robot interacts with the operators, not the team. That is, the team is only allowed to (very!) briefly instruct the *Professional Waiter* and *Professional Barman*
  - how to the tell the robot to follow,
  - how to visually/acoustically indicate table names and position (e.g., pointing or telling "Table 1 is on your left"),
  - how to the tell the robot the *Guide Phase* has ended, and

  - how to the tell the robot the order has been served

  It is not allowed to the team to instruct the clients on how to get robot's attention. It shall be done in a natural way like when interacting with a human waiter.
- **Kitchen-bar:** The *Kitchen-bar* will be a table located at the restaurant's kitchen, next to the place where the *Guide Phase* started and ended. The robot may ask on which side of the robot the Kitchen-bar is, e.g. on its left or right side. It may ask this at the beginning or the end of the guide phase. It has the following setup.
  - **Barman:** A *Professional Barman* (member of the TC) will be at the other side of the Kitchen-bar to take the order provided by the robot and serve it in the official tray.
  - **Beverages:** Beverages will be located on the Kitchen-bar next to the *Professional Barman*.

6.3.5. Data recording

Please record the following data (See Section 3.4):

- Audio
- Commands
- Mapping data
- Images
- Plans

6.3.6. Score sheet

The maximum time for this test is 15 minutes.

Action	Score
Training phase	
Learning the location of a table (Professional Waiter)	*3 × 10*
Learning the location of a table (Custom Waiter)	*3 × 5*
Inferring the side on which a table is (Professional Waiter only)	*3 × 10*
Ordering phase	
Understanding which table to take an order from	*5*
Going to the designated table	*15*
Taking an order from the designated table	*10*
Noticing a waving/calling person from distance	*20*
Going to the table of the waving/calling person	*20*
Taking an order from the waving/calling person	*10*
Avoiding a person crossing the robots' path	*10*
Delivering phase	
Reciting both the order and table number for both tables	*2 × 5*
Grasping the correct drink	*10*
Getting close to the correct table with the drink	*15*
Delivering the drink by placing it on the correct table	*15*
Picking up the plate	*15*
Getting close to the correct table with the plate	*15*
Delivering the plate by placing it on the correct table	*20*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*25*
Total score (excluding penalties and bonuses)	*250*

6.4. E²GPSR

(Enhanced Endurance General Purpose Service Robot)

This test evaluates the required robot abilities throughout the Stage I & II tests this (2016) and previous years' rulebook. In EEGPSR the robot has to solve multiple tasks that are chosen randomly by the referees from a larger set of actions, over an extended period of time (30-45 minutes). In other words, tasks are not incorporated into a (predefined) story and there is neither a predefined order of tasks nor a predefined set of actions. The actions to be carried out by the robot are organized in several categories with equivalent complexity but targeting different abilities. It is upto the teams to choose how to execute the command and solving the involved tasks according to robot capabilities. Scoring thereby depends on the complexity of the abilities shown.

6.4.1. Focus

This test particularly focuses on the following aspects:

- No predefined order of actions to carry out.
- Increased complexity in speech recognition.
- More advanced capabilities
- Environmental (high-level) reasoning
- Robust long-term operation.

6.4.2. Task

1. **Entering and command retrieval:** The robot enters the arena and drives to a designated position where it has to wait for further commands.

2. **Command generation:** A command is generated randomly depending on the category chosen by the team (see below). All commands are composed by up to three actions that the robot has to show it has recognized. The robot may repeat the understood command and ask for confirmation. If it can't recognize the command correctly, it can also ask the speaker to repeat the whole command again.

   2.1. **Category I:** The command is focused in **Advanced Manipulation**.
   2.2. **Category II:** The command is focused in **Advanced Object Recognition**.
   2.3. **Category III:** The robot gets a command focused in Human-Robot Interaction (**HRI**) that does not include all the necessary information to accomplish the task.
   2.4. **Category IV:** The command is focused in **Memory and Awareness**. This category can only be chosen after the team has successfully accomplished another command.
   2.5. **Category V:** The command is focused in **People Recognition** and **Navigation**.
   2.6. **Category VI:** The command is focused in **simple tasks** involving Manipulation, Object Recognition, and Person Recognition.

3. **Task assignment:** The robot is given a command by the operator and may directly start to work on the task assignment. If a robot is unable to perform a command, it should get back to the operator, and clearly state **why** it wasn't able to accomplish the task.

4. **Task execution:** The robot must stop the execution of a task and return to its designated position within 5 minutes. Otherwise the robot must be moved to its designated position immediately. If a restart is still available to the team, it can be restarted at the designated position.

5. **Returning:** After accomplishing the assigned task, the robot has to move back to its designated position to wait and retrieve the next command (i.e., go back to 1. without the need of re-entering the arena). The robot can work on at most 3 commands.

6. **Timing:** The total time allotted to the robot for command retrieval and task execution is 3 $\times$5 minutes. If the robot is not at its designated position after the time has expired, it must be moved at its designated position immediately. See the section on scheduling below as well.

7. **Exiting the arena:** When commanded to do so, a robot should leave the arena.

6.4.3. Additional rules and remarks

1. **CONTINUE rule:** Teams are able to use the CONTINUE rule in this test, with all the standard penalties it involves as described in section Section 3.8.15.

2. **Number of Teams and Scheduling:** In each test slot multiple teams (preferably 2 teams) may be competing in the arena concurrently. The robots will be tested in an interleaved fashion: The robots will retrieve commands and execute the task one after the other. As stated above, each robot will have a maximum amount of 5 minutes per command (including time for retrieving the command and executing it).

3. **Returning to designated position:** To facilitate a fluent and untroubled performance of the robots, they must return (or being returned) to their designated position before the 5 minutes command time elapses. **If a robot moves from its designated position while another robot is working on a command, it must be immediately disabled** and moved to its designated position. If a restart is still available to the team, it can be restarted at its designated position.

4. **Carrying robots:** To carry the robot, at most two team members are allowed in the arena, and the robot must be moved as quickly as possible. To start or restart the robot, at most one team member may operate the robot. The team members moving and operating the robots must leave the arena immediately after the robot is placed or started.

5. **Referees:** Since the score system in this test involves a subjective evaluation of the robot's behavior, the referees are EC/TC members. One referee is assigned to each team to judge performance, to measure the time for working on a command, and to keep track of the overall operating time of the robot.

6. **Category selection:** For every of the three commands given to the robot, the team chooses the desired command category. Please do note that points for showing an ability can only be scored once, as also detailed in the next point.

7. **Scoring:** Points are scored per ability with the total score of the test being the sum of the points scored in each successfully demonstrated ability while solving the tasks (see score sheet). Abilities will be scored considering the best execution only (e.g. successfully grasping scores for *grasping*), with the single exception of collision-free navigation.

8. **Operator:**
   - The person operating the robot is one of the referees (default operator).
   - If the robot appears to consistently not be able to understand the operator, the referees ask the team to apply the CONTINUE rule (Section 3.8.15).

9. **Inoperative robots:** If a robot gets stuck while trying to accomplish a task during a reasonable amount of time (e.g. 30 seconds), the referee may ask the team to move back the robot to its designated position, proceeding with the next robot.

10. **Restart:** The number of commands to be given to a robot is three regardless if the restart were used or not. If a restart is required during before the first half of the total time allowed for execute a command elapses, a new command will be generated for the robot to perform. If the first half of the time has elapsed, the team may proceed with the restart but no new command will be generated and the robot must wait for the remaining commands (if any). Robots will be restarted at their designated position, **it won't be allowed to start outside the arena.**

11. **Changing/Charging batteries:** The team may install a charging station at the designated position of the robot, if it does not hinder the other robots. However, the robot must connect itself with the charging station after carrying out a command. Changing batteries or manually connecting the robot with the charging station is allowed during a restart.

12. **Scoring:** Robots are scored by successfully performed ability and full command completion within time.

6.4.4. OC instructions

2h before test:

- Specify and announce the entrance/exit door for each robot.
- Specify and announce the waiting position for each robot.

During the test:

- Help placing items and arranging people upon referee request.

6.4.5. Referee instructions

During the test:

- Generate random sentences.
- Take the command and total time per team.

6.4.6. Score sheet

Given commands:

Command 1:

Category: 1 2 3 4 5 6 Restart? Custom Operator? Continue? ASR attempts: 1 2 3

Command 1 · 2:

Category: 1 2 3 4 5 6 Restart? Custom Operator? Continue? ASR attempts: □□□

Command 1 · 2 · 3 :

Category: 1 2 3 4 5 6 Restart? Custom Operator? Continue? ASR attempts: □□□

Command 1 · 2 · 3 :

Category: 1 2 3 4 5 6 Restart? Custom Operator? Continue? ASR attempts: □□□

Remark: Abilities marked with * are subjectively evaluated by EC/TC members. Scoring is granted proportionally based on robot performance.

The maximum time for this test is 40 minutes.

Action	Score
Getting instructions	
Understanding the set of actions on the 1^{st} attempt	*40*
Understanding the set of actions on the 2^{nd} attempt	*20*
Understanding the set of actions on the 3^{rd} attempt	*10*
Command given by custom operator (point reduction to ASR)	*0.50* × *-1*
HRI	
Answering a predefined question	*05*
Ask for missing information	*10*
Ask for command after detecting an event	*05*
Explain in detail why the robot could not accomplish a task *	*20*
Natural handover (give or take)	*10*
Manipulation	
Grab an item	*10*
Open door/drawer *	*50*
Place an item	*10*
Pour into a bowl *	*30*
Two-handed transport of tray/bowl *	*20*
Memory & Awareness	
Detect an expected event (within a reasonable amount of time) *	*15*
Detecting an unexpected event*	*25*
Provide information about changes in the environment and/or given commands*	*25*
Navigation	
Follow operator until stopped	*15*
Guide a human to location without loosing him or colliding	*20*
Object recognition	
Describing a set of unknown objects at a location	*25*
Find (and grasp) an object from a description *	*40*
Recognize an object's class correctly	*10*
Search for item at location	*15*
People, pose and activity recognition	
Detect a calling/waving person	*10*
Find a person in a given room	*10*
Recognize a newly learned face correctly	*30*
State the gender of a person	*10*
State the number of people in a group	*10*
State the pose of a person *	*10*
Special penalties & standard bonuses	
Contributing with recorded data ($\frac{\sum gathered\ points}{max\ points}\times$) (see sec. 3.4)	*10*
Not attending (see sec. 3.9.1)	*-50*
Outstanding performance (see sec. 3.9.3)	*44*

Total score (excluding penalties and bonuses) *440*

Chapter 7

Finals

The competition ends with the Finals on the last day, where the five teams with the highest total score compete. The *Finals* are conducted as a final open demonstration. This demonstration does not have to be different from the other open demonstrations—open challenge and demo challenge. It does not have to be the same either.

7.1. Final Demonstration

In the final demonstration, every team qualified for the Finals can choose freely what to demonstrate. The demonstration is evaluated by both a league-internal and a league-external jury.

7.1.1. Task

The procedure for the demonstration and the timing of slots is as follows:

1. **Setup and demonstration:** The team has a maximum of *ten minutes* for setup, presentation and demonstration.
2. **Interview and cleanup:** After the demonstration, there is another *five minutes* where the team answers questions by the jury members.
   During the interview time, the team has to undo its changes to the environment.

7.1.2. Evaluation and Score System

The demonstration is evaluated by both a league-internal and a league-external jury. The final score and ranking are determined by the two jury evaluations and by the previous performance (in Stages I and II) of the team.

1. **League-internal jury:** The league-internal jury is formed by the Executive Committee. The evaluation of the league-internal jury is based on the following criteria:
   1.1. Scientific contribution
   1.2. Contribution to @Home
   1.3. Relevance for @Home / Novelty of approaches
   1.4. Presentation and performance in the finals.
   It is expected that teams present their scientific and technical contributions in both *team description paper* and the *RoboCup@Home Wiki*. In addition, finalist teams may provide a printed document to the jury (max 2 pages) that summarizes the demonstrated robot capabilities and contributions. The influence of the league-internal jury to the final ranking is 25 %.
2. **League-external jury:** The league-external jury consists of people not being involved in the RoboCup@Home league, but having a related background (not necessarily robotics). They are appointed by the Executive Committee. The evaluation of the league-external jury is based on the following criteria:
   2.1. Originality and Presentation (story-telling is to be rewarded)

2.2. Usability / Human-robot interaction
2.3. Multi-modality / System integration
2.4. Difficulty and success of the performance
2.5. Relevance / Usefulness for daily life

The influence of the league-external jury to the final ranking is 25 %.

3. **Previous performance:** 50 % of the final score are determined by the team's previous performance during the competition, i.e., the sum of points scored in Stage I and Stage II.

7.1.3. Changes to the environment

1. **Making changes:** As in the other open demonstrations, teams are allowed to make modifications to the arena as they like, but under the condition that they are reversible.
2. **Undoing changes:** In the interview and cleanup team, changes need to be made undone by the team. The team has to leave the arena in the *very same* condition they entered it.

7.2. Final Ranking and Winner

The winner of the competition is the team that gets the highest ranking in the finals.

There will be an award for 1st, 2nd and 3rd place. All teams in the Finals receive a certificate stating that they made it into the Finals of the RoboCup@Home competition.

Appendix A

Example Skills

The following section presents a list of *Example Skills* with an high degree of difficulty which can be exploited during the *Open Demonstrations* (See Section 3.7.5. Other skills not on this list (yet) may be added as well. If you want to do so, please let the TC know via email (tc@robocupathome.org) for their inclusion on the RuleBook so all teams may also show this skill.

Please note that these examples are to illustrate the level of complexity and applicability that should be shown. For instance, "Handle a pan" is listed in the category of *Complex manipulation*, but it is extensive to handling pans, pots, woks and any other cookware with handles.

A.1. Skills by category

A.1.1. Complex manipulation

- Cook a meal.
- Manipulating panels/switches/knobs.
- Use/open a fridge/stove/blender/microwave/washing machine.
- Iron clothes.
- Move a movable object (pole, chair, table).
- Pouring liquids/powders.
- Operate a water tap.
- Handle a pan.

A.1.2. Complex vision

- Read text from a newspaper.
- Handle glass/shiny-metallic objects.
- Recognize moods, activities, age, gender.
- Label unknown objects.

A.1.3. Complex navigation

- Navigate in (very) crowded environments.
- Navigate difficult terrain.
- Climb stairs.
- Push a wheelchair.

A.1.4. Robot-Human Interaction

- Collaborative robot-human manipulation.
- Maintaining a conversation.
- Learning actions on-the-fly.

- Learning objects from humans e.g. “This object is a ...” with an open vocabulary.
- Following a human by grasping its hand.
- Explain the robot abstract concepts (why people love sunny days).
- Arrange unknown random people for a nice photo (no occlusions).

A.1.5. Complex action planning

- Separate clothes for laundry (e.g. by color)
- Arrange a dish-washer.
- Take a cup from the cupboard whose location has changed, is closed, or the path to it is blocked (e.g. by a chair).
- Light the way out with a lamp during a general power off.
- Arrange unknown random people for a nice photo (no occlusions).
-

A.1.6. Mapping

- Learn/create a (3D) map on the fly.
- Semantically annotate a map on the fly
- The robot enters a completely changed arena (furniture moved or even changed), explores it and is told to go to e.g. a table that is moved or added.

Appendix B

E^2GPSR in detail.

B.1. Focus explained

This test particularly focuses on the following aspects:

- No predefined order of actions to carry out (to get away from state machine-like behavior programming).
- Increased complexity in speech recognition (possible commands are less restricted in both actions/operators and arguments/objects, and can include multiple targets, e.g., "put **an apple, a banana, and the milk** on the kitchen table" or "Ask **Mary** in the kitchen where is **John**").
- More advanced capabilities (e.g. pose and activity detection, unknown object description, door opening, pouring, manipulating a tray, following people in crowded environments etc.).
- Environmental (high-level) reasoning, including:
  - Memory (robot should be able to remember performed actions and their effects).
  - Awareness (unexpected events may occur while the robot is waiting for a command).
- Robust long-term operation.

B.2. Categories explained

This section explain each of the categories of the test and provides examples on how the abilities are scored.

It is important to remark that there is no script or predefined way to solve the tasks, being most of them of ambiguous nature. It is up to the team to choose how to solve each tasks according with robot capabilities and skills. For instance, consider that the robot is asked to ***serve breakfast***. A simple approach might be to pick up and deliver a single object in the *food* category (scoring for grasp and place only). A more complex approach would be to ask the operator how breakfast must be served, navigating to the kitchen, pouring cereal into a bowl, put the bowl, a fruit and some milk on a tray, and deliver the tray to the operator himself right after closing the kitchen's door (scoring for requesting additional information, grasping, placing, pouring, two-hand transporting, operating a door, and performing natural handover).

B.2.1. Category I: Advanced Manipulation

Advanced Manipulation involves two-hand manipulation, eye-hand coordination, and operating knobs, handles, buttons, etc. Most of these tasks require a closed control loop between what the robot sees and its manipulators.

Some advanced manipulation examples are:

- Arranging cutlery.
- Opening a bottle (twist, uncap, etc.).
- Opening a door.

- Placing objects inside a box.
- Pouring cereal in a bowl.
- Transporting a tray.

Remark: Teams are allowed (and encouraged) to demonstrate the robot's manipulation skills during this test by performing tasks not mentioned on the rulebook. Such demonstrations, when successfully executed, will be evaluated and scored proportionally by the TC. Please inform a member of such abilities the Technical Committee in advance.

Category I command examples

Below, examples of commands involving advanced manipulation are shown:

- Bring me something for breakfast.
- Bring me some oat, banana and milk in a tray.
- Open the entrance door.
- Put all the beverages in the dinner table.
- Pour the flakes into the bowl and bring it to me.

B.2.2. Category II: Advanced Object Recognition

Advanced Object Recognition involves affordance/feature detection and classification, untrained object recognition, and far-distance recognition. Feature detection for description and detection may involve color, shape, relative size, relative position, and special characteristics of the object such as text, logos, patterns, etc.

Some advanced object recognition examples are:

- Counting objects.
- Describing unknown objects.
- Finding object from far distance.
- Finding objects from a description.
- Infer object's class (category) from features.
- Object detection and recognition of occluded or hidden objects (behind of, inside of, etc.).

Category II command examples

Below, examples of commands involving advanced object recognition are shown:

- Bring me the biggest pill bottle from the kitchen counter.
- Bring me the bookcase's right-most object.
- Describe the objects on the drawer to me.
- Tell me how many red apples are in the basket on the kitchen table.
- Count the snacks in the shelf and tell me how many there are.

B.2.3. Category III: HRI & Incomplete Information

This category focuses in commands not including all required information necessary to accomplish the task, making necessary for the robot to interact with the operator.

- **Retrieving missing information:** The robot can ask questions to retrieve the missing information about the task. In the questions, the robot has to make clear what it has already understood and precisely which information is asking for. It is important to remark that several questions may be necessary to fill the gaps in a command.

- **Bypassing ASR:** This category depends heavily in establishing a natural dialog between the robot and the operator, for this reason is highly advised to change of category instead of using the CONTINUE rule Section 3.8.15.
- **Commands difficulty:** Although incomplete, commands involve solving **simple tasks** such as Manipulation, Object Recognition, and Person Recognition.

Remark: Robots may also attempt to solve the command on their own without asking for additional information. For instance, if the operator asks for a beverage but not stating which, the robot may proceed to search for a random drink from the drinks location.

Category III command examples

Below, examples of commands involving HRI & Incomplete Information are shown:

Example Scenario 1 The robot is asked to *Follow Elizabeth and tell the time.* Robot may:

- Ask where is Elizabeth and execute the command.
- Look for Elizabeth and, once she has been found, follow her for later telling the time.

Example Scenario 2 The robot is asked to *Offer a drink to Ana.* Robot may:

- Ask where is Ana, go there, ask Ana which drink does she want, and deliver it.
- Ask where is Ana and which drink must be delivered.
- Ask where is Ana, fetch a random drink and deliver it.
- Find a random drink and start looking for Ana.

Example Scenario 3 The robot is asked to *Guide James to the table.* Robot may:

- Ask where is James, to which table should the robot guide him, and execute the command.
- Ask where is James, go there, and guide him to the dinner table.
- Look for James and, once he has been found, guide him to the dinner table.

B.2.4. Category IV: Memory and Awareness

Memory refers to the robot's ability to remember previous executed tasks and its effects. Directly related with memory, Awareness requires the robot to be aware of changes in the environment as consequence of its actions, as well as being able to detect unexpected events either while idle or during the execution of a task.

Memory and questions on past commands: Unlike other categories, this category cannot be chosen by a team until a command from another category has been (partially) executed. It is up to the referees to decide when a robot is eligible for solving this category. After the first command has been (partially) accomplished, the operator may ask the robot to provide information about its actions and the environment.

Some Memory and Awareness examples are:

- Answering questions about the environment status and changes.
- Approaching a calling (shouting, waving, etc.) operator while idle.
- Detecting the operators fell while guiding the robot.
- Detecting the requested object is taken by another person while grasping.
- Noticing a door has been shut.
- Noticing the operator is not at the designated position.
- Noticing a sleeping person wakes up.

Remark: Teams are allowed (and encouraged) to demonstrate the robot's XXXXX skills during this test by performing tasks not mentioned on the rulebook. Such demonstrations, when successfully executed, will be evaluated and scored proportionally by the Technical Committee. Please inform a member of such abilities the Technical Committee in advance.

Category IV command examples

Below, example scenarios involving Memory and Awareness are shown:

Example Scenario 1 Consider that the robot just delivered the newspaper to John in the living room, possible commands may include:

- Go to the *dinner table*, find *Anna* and tell her who has the newspaper.
- Go to the *coach*, find *James* and answer a *question*.

  Q: The question may be "where is the newspaper?"
  A: A valid answer is "The newspaper is in the living room".
  A: Another valid answer is "I gave it to John in the living room".

Example Scenario 2 The robot has been asked to *Go with the waving person in the dinning room and ask for their name*, which is *Jessica*. Possible commands may include:

- Bring an *apple* to *Jessica*.
- Go to the *coach*, find *James* and answer a *question*.

  Q: The question may be "where is Jessica?"
  A: A valid answer is "Jessica is in the dinning room".

Example Scenario 3 The robot has been asked to *Take the biggest flask from the shelf and put it on the kitchen table*. Possible commands may include:

- Bring me the flask.
- Find John standing next to the *lamp* and answer a *question*.

  Q: The question may be "How many objects there are in the shelf?" (Assume there were 4 before the robot took one).
  A: A valid answer is "There are 3 objects in the shelf".

B.2.5. Category V: People Recognition and Navigation

This category focuses mostly in People Recognition, but considering that guiding and following people involves navigation skills, this ability is also considered. People Recognition involves detecting, remembering, and recognizing people and their characteristics such as gender, age, clothing, size, pose, gestures and activities.

Some People Recognition examples are:

- Counting people in a crowd.
- Counting people in a crowd with an specific pose, gender, age, etc.
- Detecting people pose and gestures.
- Finding and recognizing people from far distance.
- Finding people matching a description (tallest, sitting, wearing specific color, etc.).
- Detecting and recognizing occluded people (behind of, wearing sun glasses, etc.).
- Remembering and later recognizing new people.

Remark: Teams are allowed (and encouraged) to demonstrate the robot's People Recognition skills during this test by performing tasks not mentioned on the rulebook. Such demonstrations, when successfully executed, will be evaluated and scored proportionally by the Technical Committee. Please inform a member of such abilities the Technical Committee in advance.

Category V command examples

Below, examples of commands involving People Recognition are shown:

- Bring a coke to the person with black T-shirt in the couch.
- Go to the living room and follow the waving person.
- Offer something to drink to all the girls in the living room.
- Tell me how many girls are in the living room.
- Tell me how many standing men are in the dinning room.

B.2.6. Category VI: Mastering simple skills

This category, instead of requiring advanced skills, requires mastering the simple ones, for simple task must be solved as quick as possible. In this category, speed is the key.

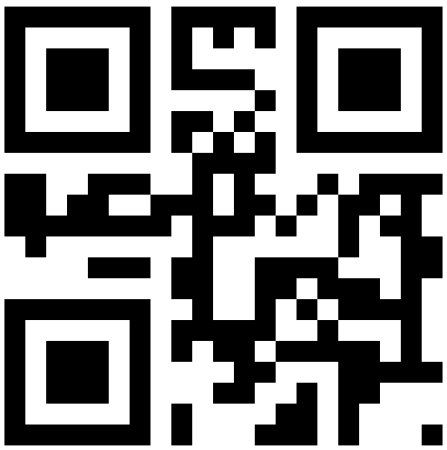
Category VI command examples

Below, examples of commands involving XXXX are shown:

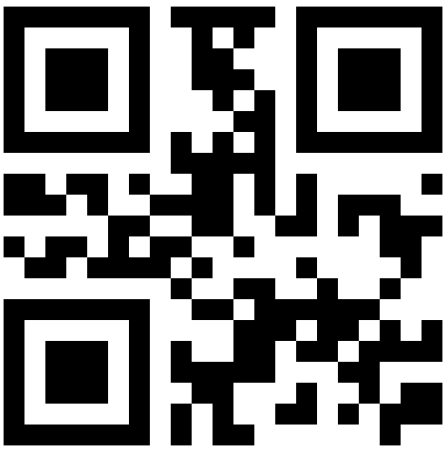
- Look for Jennifer in the couch and tell her how many apples are in the kitchen counter.
- Find James in the living room, tell the time, and guide him to the Exit.
- Put the chips on the dinner table, go to the entrance, and guide Samantha to the dinning room.
- Take the milk, look for a person in the corridor and answer a question.
- Grasp the coke from the shelf, bring it to the kitchen table, and follow the person in front of you.
- Get the coke from the dinner table and deliver it to Luis at the bathroom.

Appendix C

QR code examples



(a) "continue"



(b) "yes"

(a) "no"

(b) "Go to the coach, find James and answer a question."

Figure C.1.: Various QR codes

Abbreviations

EC	Executive Committee	11, 13, 33
Finals	final demonstration	34
OC	Organizing Committee	12, 21, 30, 32, 41
TC	Technical Committee	71
TC	Technical Committee	11, 13, 15, 27, 30, 31, 33, 34, 36, 39, 40, 43
TDP	team description paper	20

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