Funded by the European Union

Robot Competitions Kick Innovation
in Cognitive Systems and Robotics
FP7-ICT-601012

RoCKIn@Home

– A Competition for Domestic Service Robots –

II: RoCKIn@Home Rule Book

Revision: 5.0
Date: September 18, 2014

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1 Introduction to RoCKIn@Home

RoCKIn@Home is a competition that aims at bringing together the benefits of scientific benchmarking with the attraction of scientific competitions in the realm of domestic service robotics. The following ***user story*** is the basis upon which the RoCKIn@Home competition is built:

> *An elderly person, named "Granny Annie", lives in her own apartment together with some pets. Granny Annie is suffering from typical problems of aging people: She has some mobility constraints. She tires fast. She needs to have some physical exercise, though. She needs to take her medicine regularly. She must drink enough. She must obey her diet. She needs to observe her blood pressure and blood sugar regularly. She needs to take care of her pets. She wants to have a vivid social life and welcome friends in her apartment regularly. Sometimes she has days where she is not feeling so well and needs to stay in bed. She still enjoys intellectual challenges and reads books, solves puzzles, and socializes a lot with friends.*

For all these activities, RoCKIn@Home is looking into ways to support Granny Annie in mastering her life. A more detailed account of RoCKIn@Home, but still targeted towards a general audience, is given in the RoCKIn@Home in a Nutshell document (see [1]), which gives a brief introduction to the very idea of RoCKIn and RoCKIn@Home, the underlying user story, and surveys the scenario, including the environment for user story, the tasks to be performed, and the robots targeted. Furthermore, this document already gives general descriptions of the task benchmarks and the functional benchmarks that make up RoCKIn@Home.

The document on hand is the rule book for RoCKIn@Home, and it is assumed that the reader has already read the nutshell document. The audience for the current document are teams who want to participate in the competition, the organizers of events where the RoCKIn-@Home competition is supposed to be executed, and the developers of simulation software, who want to provide their customers and users with ready-to-use models of the environment. They all need to know more details on the competition than the nutshell document provides.

This remainder of this document is structured as follows: The ***test bed*** for RoCKIn@Home competitions is described in some detail in the next section (Section 2). Subsections are devoted to the specification of the structure of the environment and its properties (2.1), to the objects in the environment relevant to the tasks on hand (2.2), to other objects not directly related to tasks but possible affecting the robot's behavior in other ways (e.g. need to avoid them in navigation, distractions and perceptual noise caused by them in robot vision) (2.3), to the networked devices embedded in the environment and accessible to the robot (2.4), and to the benchmarking equipment which we plan to install in the environment and which may impose additional constraints to the robot's behavior (equipment presenting obstacles to avoid) or add further perceptual noise (visible equipment) (2.5). Next (Section 3), we provide some specifications and constraints applying to the ***robots and teams*** permitted to participate in RoCKIn@Home. The RoCKIn consortium is striving to minimize such constraints, but for reasons of safety and practicality such constraints are required. After that, the next two sections describe in detail the ***task benchmarks*** (Section 4) and the ***functionality benchmarks*** (Section 5) comprising the RoCKIn@Home competition. Section 6 on ***competition structure*** provides information on how the competition is organized, in particular, in which order the benchmarks are executed, whether and how often they are repeated, and when. While information on scoring and ranking the performance of participating teams on each benchmark is already provided in the benchmark descriptions, Section 7, ***award categories*** surveys the number and kind of awards that will be awarded and how the ranking of the award categories is determined based on individual benchmark results. Last but not least, Section 8 provides details on ***organizational issues***, like the committees involved, the media to communicate with teams, qualification and setup procedures, competition schedules, and post-competition activities.

2 The RoCKIn@Home Test Bed

The test bed for RoCKIn@Home consists of the environment in which the competition will happen, including all the objects and artefacts in the environment, and the equipment brought into the environment for benchmarking purposes. An aspect that is comparatively new in robot competitions is that RoCKIn@Home is, to the best of our knowledge, the first open competition targeting an *environment with ambient intelligence*, i.e. the environment is equipped with networked electronic devices the robot can communicate and interact with, and which allow the robot to exert control on certain environment artefacts.

An environment fitting quite well the user story is depicted by Figure 1.

Figure 1: Granny Annie's apartment.

Note: There is considerable discussion in the community, as to how specific and precise the description of the environment should be, especially in the light of benchmarking. In order to require teams to develop robots which can be easily and flexibly adapted to a wide range of different environments, can deal with a wide variety of objects, etc., and to avoid overengineering of solutions, it would be highly advisable to keep the description as flexible as possible. We reflect this in the specifications below by providing comparatively generous *boundary conditions*, e.g. on room sizes, and by complementing them by a *recommendation*, which should be understood as a default size and the size we target to use at least for the first iteration of the competition. Competition organizers should plan with this recommended sizes and objects. while the developers of simulation software should provide means to easily modify models, e.g. by resizing rooms or by changing the properties of the environment or replacing objects, etc.

The *recommended* environment for the 2014 RoCKIn@Home competition is illustrated in Figure 2. Participating teams should assume the competition environment to be as illustrated; deviations should only occur if on-site constraints (space available, safety regulations) enforce them.

Figure 2: The test bed for the 2014 RoCKIn@Home competition (Patio and Bathroom will not be accessible to the robots in this edition).

Figure 3: The test bed for the 2014 RoCKIn@Home competition with dimensions.

2.1 Environment Structure and Properties

The following set of scenario specifications must be met by the RoCKIn@Home environment.

Environment Specification 2.1 (*Structured Environment*)

The environment consist of an ensemble of five spatial areas.

Two additional areas are foreseen for future extensions; they may be provided as part of a test bed, but they are not foreseen and not accessible to the robots for 2014. We do not further consider them in the following specifications.

Environment Specification 2.2 (*Flat Environment*)

All spatial areas all located on the same level, except where specified otherwise. There are no stairs in the environment.

Environment Specification 2.3 (*Spatial Areas and Rooms*)

Spatial areas completely enclosed by walls are referred to as rooms. The appartment follows an open plan architecture, i.e. several spatial areas are connected to each other by open space ("openly connected") and are only jointly surrounded by walls. In human-robot interaction, such spatial areas may still referred to as rooms.

Environment Specification 2.4 (*List of Rooms*)

The environment features the following five spatial areas: hallway, living room, dining room, kitchen, and bedroom.

Environment Specification 2.5 (*Sizes of Spatial Areas*)

Robots are expected to cope with rooms and spatial areas of different sizes.

The minimum sizes of the spatial areas are as follows: hallway $120cm \times 200cm$*, bedroom* $400cm \times 300cm$*, kitchen* $200cm \times 240cm$*, dining room* $300cm \times 300cm$*, living room* $400cm \times 400cm$*.*

The whole apartment should fit into bounding rectangular box having a minimum area of $50m^2$ *and a maximum area of* $200m^2$*.*

The ***recommended sizes*** *of the spatial areas are as follows: hallway* $120cm \times 200cm$*, bedroom* $400cm \times 300cm$*, kitchen* $300cm \times 260cm$*, dining room* $300cm \times 300cm$*, living room* $400cm \times 580cm$*.*

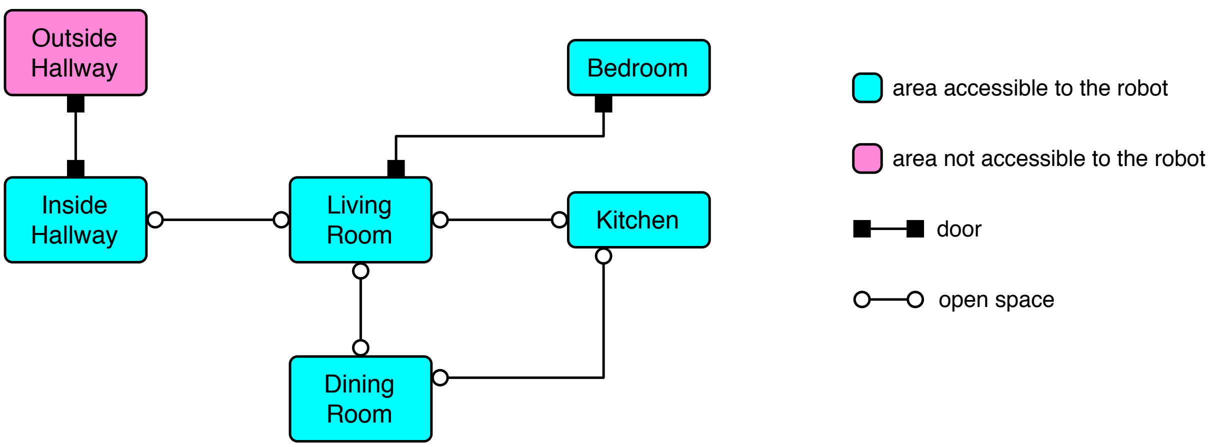


Figure 4: Graph showing the topological structure of environment.

Environment Specification 2.6 (*Connectivity of Spatial Areas*)

The environment is accessible from outside through a front door to the hall way. The hallway is openly connected to the living room by a portal. The living room is connected to the bedroom by a door. The living room is openly connected to the kitchen. The living room is openly connected to the dining room. The dining room is openly connected to the kitchen.

The connectivity of the spatial areas is illustrated by the topological graph depicted in Figure 4.

Environment Specification 2.7 (*Floors*)

The floor of each spatial area must be such that safe operation of robots meeting the specifications laid down in Section 3 is possible. The following criteria must be met:

Material features: *The floor is either carpet or parquet floor. No constraints exist with respect to the colors or patterns used.*

Slope: *The floor should be well-leveled, but slopes of up to* $2°$ *and unevenness of up to* $5mm$ *are acceptable.*

Uniqueness: *The floor may be unique or not, i.e. a floor in a room be the same as in other room, or it may be different.*

Environment Specification 2.8 (*Walls*)

The walls of the environment must meet the following criteria:

Material features: *The bedroom walls have to be made of some stiff material, such as wood, wood-based materials (chipboards), stone, concrete, or metal. For competition arenas, walls will usually be made of chipboards in combination with wood or metallic frames. The color of the walls will usually be some light color (such as white, ivory, yellow, light green, to name a few examples). One or two walls per room may be painted with some darker color (such dark red, aubergine, mocca, dark grey, dark brown, to name a few examples) for decorative purposes. Patterned wallpaper may be used for finishing the walls. The walls are not translucent. If some kind of translucent material, such as glass, Plexiglass®, Perspec®, or Lucite®is used, then these wall areas are defined as windows.*

Shape/form: *The walls are upright. No slanted walls will be used. Offsets up to* $5cm$ *are allowed to ease construction of testbeds.*

Size: *The minimum height of the walls is* $80cm$*. The recommended wall height is* $240cm$*. Exceptions may be made for up to two connecting walls of each room in order to allow better visibility for the audience at competitions. The length of the walls is defined by the connecting floor shapes and Figure 3, a version of Figure 2 containing measures. The width (thickness) of the walls must be large enough to ensure sufficient stability. The drawings assume a wall thickness of* $20cm$*. If the construction of an environment foresees inside walls with less thickness, then the space of the connecting spatial areas will grow accordingly.*

Uniqueness: *The walls may be unique or not, i.e. the wall colors and patterns may be the same as in other spatial areas of the appartment or they may be different.*

Environment Specification 2.9 (*Ceilings*)

The rooms may or may not be covered by a ceiling. If it is not covered by a ceiling, then special constructions may be foreseen for fixing lamps, sensors, or other objects. If it is covered by a ceiling, the following specifications apply:

Material features: *The ceiling can be of any material.*

Slope: *The ceiling may be (partially or completely) sloped.*

Uniqueness: *The ceiling is not unique.*

Environment Specification 2.10 (*Bedroom*)

The bedroom has a window, which can be opened and tilted. It has a rolling shutter that is operated electrically. The furniture includes a double bed, two bedside tables, a large wardrobe, a large mirror, a dressing table, and a carpet. The lighting includes ceiling lights and two bedside lamps.

An example configuration of the bedroom is depicted in Figure 5.

Figure 5: An example bedroom created with the IKEA bedroom planner.

Environment Specification 2.11 (*Living Room*)

The living room has a large window front side to the patio. These windows cannot be opened. These windows have inside blinds that are operated electrically. The furniture includes a large carpet, a coffee table, a couch, two armchairs, a low-height sideboard, and a bookshelf. A TV set is mounted on the wall above the sideboard. The lighting includes central ceiling lights, a band of dimmable ceiling spots, and a large floor light.

Environment Specification 2.12 (*Dining Room*)

The dining room has a window, which can be opened and tilted. It has a rolling shutter that is operated electrically. The furniture includes a dining table seating four, and four chairs. The lighting consists of ceiling lights above the dining table.

Environment Specification 2.13 (*Kitchen*)

The kitchen has no window and no door. The furniture includes several cupboards with drawers and doors. The installation include a fridge/freezer combination, a sink, a dishwasher, a stove, a baking oven, and an exhaust hood. Two rows of ceiling lights make for the lighting.

(Details of the kitchen will be specified in more detail as needed.)

Environment Specification 2.14 (*Hallway*)

The hallway has no windows. The furniture consists of a coat rack. The lighting consists of three ceiling spotlights.

2.2 Task-Relevant Objects in the Environment

The test bed environment will contain numerous objects, some of which are explicitly relevant for one or more of the *task benchmarks* or *functionality benchmarks* described in sections 4 and 5, respectively. We distinguish three major categories of task relevance:

Navigation-Relevant Objects: This class of objects comprises of all objects which have extent in physical space and do (or may) intersect (in 3D) with the robot's navigation space. All such objects must be avoided during navigation, i.e. whenever the robot moves, it may not bump into these objects or touch them, unless otherwise specified by a task. Navigation-relevant objects may be known by name or not. If these objects have a unique name, then the object may occur as a destination, e.g. for a navigation or manipulation operation.

Manipulation-Relevant Objects: This class contains all objects that the robot may have manipulative interactions with, which may include touching (a switch), grasping (a glass), lifting (a book), holding (a cup), placing (a parcel), dropping (waste), carrying (a glass), pushing (a drawer), pulling (a drawer), turning (a book), filling (a glass), pouring (from a cup), etc. For these objects, the most comprehensive information will be provided.

Perception-Relevant Objects: These are objects that the robot must "only" be able to perceive. By "perceive" we mean that the robot should be able to recognize if such an object is in its view, that it should be able to identify the object if it is unique or to classify it if not (e.g. an instance of a cup, if several non-unique instances exist), and that it should be able to localize the object. Objects that are only perception-relevant usually occur in tasks where the robot is supposed to find and localize these objects, but is not required to manipulate them.

Subsequently, we describe a complete collection of all objects relevant for the task benchmarks and functionality benhchmarks.

2.2.1 Navigation-Relevant Objects

Environment Specification 2.15 (*Navigation-Relevant Object Types*)

The navigation-relevant objects that may be present in the environment include the following types of objects:

- *Rugs, which may be placed on top of floors, covering the floor usually only partially.*
- *Furniture, which is placed in the environment.*
- *Doors, which connect rooms and may be in various different states.*
- *Any other kind of object, task-relevant or not, and including networked embedded devices and benchmarking equipment, if placed in the environment such that the object occupies space in the robot's workspace.*

Object Specification 2.1 (*Rugs*)

The 2014 RoCKIn@Home competition does not foresee any rugs in the environment.

Object Specification 2.2 (*Furniture*)

The furniture placed in each room or spatial area for the 2014 RoCKIn@Home competition is listed in the environment specifications 2.10 to 2.14. Further details on the furniture will be provided in due time and will be added as an appendix to this document.

Object Specification 2.3 (*Doors*)

The doors used in the environment have a door handle on both sides. Doors are dynamic objects that can be in different states at different times. At any time, a door may be in one of the following four states: open, ajar, closed, locked. A door is considered open if its opening angle is 80° or more. A door is considered closed, if its opening angle is 0° and the door is latched but not locked. In case the door is locked as well, the door state obviously is locked. In all other cases, the door is considered to be ajar.

2.2.2 Manipulation-Relevant Objects

Environment Specification 2.16 (*Manipulation-Relevant Object Types*)

The manipulation-relevant objects that may be present in the environment include the following types of objects:

- *Personal items, like keys connected by key rings, mobile phones, tablet computers, MP3 players, eyeglasses/spectacles and their cases, wallets/purses and billfolds, watches, bracelets and rings.*
- *Mail items, like letters and parcels, and print material, like newspapers, magazines, journals, paperbacks and books.*
- *Household items, such as glasses, cups, plates, knifeware, and such.*
- *Groceries in containers of various forms, like cartons, cans, bottles, tubes, bags.*
- *Switches for lighting and electronic appliances.*
- *Handles of doors, includings handles of wardrobe doors and drawers.*
- *Any other kind of object provided that it meets all of the object constraints 2.1 to 2.4.*

Object Specification 2.4 (*Personal Items*)

The personal items to be used in the 2014 RoCKIn@Home competition include:

- *One key with key ring and lanyard.*
- *One mobile phone.*
- *One iPad tablet computer*
- *Three pairs of eyeglasses with cases; one pair of rimless eyeglasses, one pair of horn-rimmed spectacle, one one pair of sunglasses.*
- *Two purses with different colors.*
- *Two wristwatches; one Swatch model and one with metal frame and wrist.*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.5 (*Mail Items and Print Material*)

The mail items to be used in the 2014 RoCKIn@Home competition include:

- *Three postcards, size A6 according to EN ISO 216.*
- *Three letters, using brown envelopes, one each in size B6, B5, and B4 (EN ISO 216).*

- *Five parcels, all of them DHL packsets [2], two of size XS ($225mm \times 145mm \times 35mm$) two of size S ($250mm \times 175mm \times 100mm$) one of size M ($375mm \times 300mm \times 135mm$)*

The print material items to be used in the 2014 RoCKIn@Home competition include:

- *three newspapers*
- *fifteen journals and magazines*
- *fifteen paperbacks*
- *seven books*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.6 (*Household Items*)

The household items to be used in the 2014 RoCKIn@Home competition include:

- *Six coffee mugs, each in a differnet color or pattern*
- *Six coffee cups with saucers, all identical.*
- *Six dessert plates*
- *A cake plate*
- *Six small glasses*
- *Six large glasses*
- *A water jug*
- *A coffee machine*
- *An electric kettle*

Further details on these objects (including images) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.7 (*Groceries*)

The grocery items to be used in the 2014 RoCKIn@Home competition include:

- *Eight cartons of different size and coloring, containing food items such as cornflakes, cereal, pasta, salt, cornstarch,*
- *Eight tin cans in at least three different sizes, containing tinned food such as tomato paste, sauerkraut, tuna, and fruits such as pears, peaches, and pineapples*
- *Eight tin cans, all of the same size, but differently colored, containing soft drinks. Four cans each of two different soft drinks are to be used.*
- *Eight glass jars in at least two different sizes, containing food such as pickled vegetables like cucumber, onions, corn, and beetroot, or pasta sauces, mustard, mayonaise, or jams and jellies.*
- *Six PET bottles, containing water, soft drinks, or juices.*
- *No tubes or bags are foreseen for 2014.*

Further details on these objects (including images) will be provided in due time and will be added as an appendix to this document.

The next two object specifications concern objects relevant for manipulation, which themselves are embedded either directly into the environment or into objects placed into the environment, like furniture.

Object Specification 2.8 (*Switches*)

Switches are either buttons, knobs (e.g. dimmer of a lamp), sliders (e.g. lock switch of portable devices) or rocker switches (e.g. light switch). A rocker switch and button has the two states ON and OFF. A button may be be a latching (e.g. power button of a washing machine) or non-latching (e.g. power button of a PC). Digital switches are connected to either lamps or shutters.
Switches are used in the 2014 RoCKIn@Home competition as follows:

- *Switches embedded into walls for operating ceiling lighting. These may be simple on/off switches, changeover switches, or intermediate switches.*
- *Switches embedded into walls for operating blinds or shutters. These switches come as a pair of pushbuttons, one for each direction of operation, and require to remain pushed for the duration of the operation.*

Further details on these objects (including images) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.9 (*Door Handles*)

The door handles to be used in the 2014 RoCKIn@Home competition include:

- *Each of the doors in the environment has a door handle on each side of the door.*
- *Furniture features some handles, but they will not be relevant for manipulation in 2014.*

Further details on these objects (including images) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.10 (*Other Objects*)

As a special challenge, the competition organizers will bring five previously unspecified objects to the competition, which will be shown to teams only during the competition. All these objects will, of course, satisfy the object constraints 2.1 to 2.4.

Object Constraint 2.1 (*Object Weight*)

The objects foreseen for manipulation can have a maximum weight of $1kg$.

Object Constraint 2.2 (*Object Size*)

The default minimum width/length/depth/diameter/thickness (henceforth: size) of an object foreseen for manipulation is $2cm$, *and the default sum of the length, width, and height of the smallest bounding box around the object (henceforth: box sum) is* $6cm$. *An object may have a lower size than* $2cm$, *down to* $5mm$, *in up to two dimensions, if the other dimensions compensate for it, i.e. if the box sum is still at least* $6cm$.

Object Constraint 2.3 (*Object Consistency, Rigidity, Stiffness*)

Any objects foreseen for manipulation tasks must be sufficiently rigid such that grasping by a robot is possible. There may be constraints on where objects can or may be grasped. Some objects may be foreseen which can appear in different shapes, e.g. glasses or a bunch of keys.

Object Constraint 2.4 (*Object Content*)

Objects may not consist of or contain any kind of hazardous material. The content of objects may be solid matter (e.g. paper, nutrition), fluids (e.g. water or juices), or gases (e.g. air). If the object contains fluids or solid matter in the form of loose material (e.g. cornflakes or chips), the object must have a lid or other kind of fixture which ensures that the content is properly contained in the object and not spilled.

2.2.3 Perception-Relevant Objects

This section provides some clarifications with respect to perception.

Environment Specification 2.17 (*Perception-Relevant Object Types*)

The perception-relevant objects in the environment include the following types of objects:

- *The basic environment structure including floors, walls, and ceilings.*
- *All navigation-relevant objects, including rugs, furniture, and any other physical object in the workspace.*
- *All dynamic navigation-relevant objects, i.e. objects with changeable state, like doors, windows, and some furniture.*
- *All manipulation-relevant objects, some of which may be uniquely identifiable while others are not (identical copies present)*
- *Target locations for navigation and manipulation may require the capability to identify objects (such as furniture items) that are not manipulation-relevant. Examples include objects the robot is supposed to move nearby (e.g. the bedside table) or objects the robot is supposed to grasp or place objects (e.g. the kitchen counter)*
- *Non-task-relevant objects (see Section 2.3) will not have to be perceived as part of task benchmarks or functionality benchmarks, but due to their presence in the environment, they will present **perceptual noise**.*

The perception-relevant objects are already specified in various other sections. Further details on the target locations (and respective objects) will be provided in due time and will be added as an appendix to this document.

2.3 Non-Task-Relevant Objects in the Environment

The test bed environment for RoCKIn@Home is supposed to resemble a realistic appartment inhabited by an elderly person.Aside of the already listed and specified objects, which make up the environment itself, and objects relavant for navigation and manipulation, as well as networked embbedded devices (see Section 2.4) and benchmakring equipment (see Section 2.5), the environment will contain numerous other objects, mostly for decoration and providing the required realism.

Environment Specification 2.18 (*Non-Task-Relevant Object Types*)

The non-task-relevant objects that may be present in the environment include the following types of objects:

- *Textile objects, like curtains, tablecloth, placesets, napkins, and pillows, either affixed to walls/ceilings or sitting on top of furniture.*
- *Mirrors, usually fixed to walls or furniture.*
- *Lamps, on the floor or on top of furniture.*
- *Floristic objects, like flowers and plants, and associated objects like flower pots and vases, which may be on the floor, on window sills, or on top of furniture.*
- *Pictorial objects, like posters, photographs, drawings, and paintings, either affixed to walls or sitting on furniture.*
- *Other decorative objects, like plates and bowls, candles, and miniatures, usually sitting on top of furniture items.*

Object Specification 2.11 (*Textile Objects*)

The textile objects to be used in the 2014 RoCKIn@Home competition include:

- *Curtains for the bedroom windows.*
- *Two different tablecloths for the dining table.*
- *Two differently colored sets of textile placesets, each set consisting of four items.*
- *Two differently colored sets of textile napkins, each set consisting of four items.*
- *Five pillows for couch and chairs in the living room.*
- *Linens, pillows, and coverlets for the bed in the bedroom.*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.12 (*Mirrors*)

The mirror objects to be used in the 2014 RoCKIn@Home competition include:

- *One tall mirror in the hallway.*
- *One large mirror in the bedroom*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.13 (*Lamps*)

The lamps to be used in the 2014 RoCKIn@Home competition include:

- *Two small lamps on top of the bedside tables.*
- *One floor lamp in the living room.*
- *One floor uplighter in the living room.*

Note that ceiling lamps are already specified with the environment. Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.14 (*Floristic Objects*)

The floristic objects to be used in the 2014 RoCKIn@Home competition include:

- *Three small plants in pots on the bedroom window sill.*
- *Two herbal plants in pots on the kitchen window sill.*
- *One large plant in a pot in the living room.*
- *One large plant in the dining room.*
- *One small vase with flowers on the kitchen counter.*
- *One large vase with xerophytes on the floor of the living room.*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.15 (*Pictorial Objects*)

The pictorial objects to be used in the 2014 RoCKIn@Home competition include:

- *20 small framed pieces of photographs or drawings, each sized less than A4.*
- *10 medium-sized pieces of posters or prints, each sized about A3.*
- *6 large pieces of paintings or posters, each sized about A1.*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

Object Specification 2.16 (*Decoration Objects*)

The decoration objects to be used in the 2014 RoCKIn@Home competition include:

- *Two different plates*
- *Three different bowls*
- *Two different triplets of candles.*
- *Five different miniatures or other decorartive objects.*

Further details on these objects (including images and procurement details) will be provided in due time and will be added as an appendix to this document.

2.4 Networked Devices in the Environment

In order to facilitate certain aspects of the tasks that need to be performed by the robot, networked sensors and actuators will be provided as a part of the environment. These devices are as enumerated and described below.

Home automation controller: This device will run as a server on the local area network within the testbed. It will be accessible from all 'permitted' devices (wifi-enabled laptops/single board computers, etc. on the robots) on the same network. Using this controller, devices such as motorized window blinds/shutters, some of the room lights, motorized tilt-able windows, etc. can be controlled. The controller will be able to receive messages (in a specific format provided to the teams) from the 'permitted' devices in order to control all the aforementioned devices. An example of such a controller can be found here[1].

Ethernet Camera: This camera will be installed on the outside of the apartment's main door, facing forward, and will be running on the local area network withing the testbed. It will be accessible from all 'permitted' devices (wifi-enabled laptops/single board computers, etc. on the robots) on the same network. During the camera access over the network it can not only be used to stream the images but can also be used to switch on/off the camera and change camera acquisition parameters (frame rate, shutter speed, etc.) However, the camera will not be motor-controlled (no pan-tilt). The projection model (e.g., fisheye, pinhole) of the camera, as well as its intrinsic parameters will be provided to the teams beforehand. However, the teams are free to perform their own calibration for the intrinsic/extrinsic parameters during the setup days of the competition and without physically disturbing the camera installation. An example of such a camera is provided here[2].

Tablet Computer: The tablet computer has a screen size between 7- and 10-inches and hosts an Android operating system. The device is connected via WLAN to the network of the environment which the robots can also access.

The above mentioned devices will be accessible to all participating teams only during the following time periods:

- To all teams during the setup days.
- To a particular team, during its time-slot for the actual run of a task or functionality benchmark on each of the competition days.

[1] `http://rollertrol.com/store/en/vera-home-automation-control/87-vera-v3.html`
[2] `http://www.vivotek.com/web/product/productdetail.aspx?Model=FD7132`

2.5 Benchmarking Equipment

RoCKIn benchmarking is based on the processing of data collected in two ways:

- **internal benchmarking data**, collected by the robot system under test (see Section 3);
- **external benchmarking data**, collected by the equipment embedded into the test bed.

External benchmarking data is generated by the RoCKIn test bed with a multitude of methods, depending on their nature.

One of the types of external benchmarking data used by RoCKIn are pose data about robots and/or their constituent parts. To acquire these, RoCKIn uses a camera-based commercial motion capture system (NaturalPoint OptiTrack), composed of dedicated hardware and software. Benchmarking data has the form of a time series of poses of rigid elements of the robot (such as the base or the wrist). Once generated by the OptiTrack system, pose data are acquired and logged by a customized external software system based on ROS (Robot Operating System): more precisely, logged data is saved as *bagfiles* created with the *rosbag* utility provided by ROS.

Pose data is especially significant because it is used for multiple benchmarks. There are other types of external benchmarking data that RoCKIn acquires: however, these are usually collected using devices that are specific to the benchmark. For this reason, such devices (such as the test panels used for the Object Manipulation functionality benchmark: see Section 5.2) are described in the context of the associated benchmark, rather than here.

Finally, equipment to collect external benchmarking data includes any *server* which is part of the test bed and that the robot subjected to a benchmark has to access as part of the benchmark. Communication between servers and robot is performed via the test bed's own wireless network (see Section 3.2).

3 Robots and Teams

The purpose of this section is twofold:

1. It specifies information about various robot features that can be derived from the environment and the targeted tasks. These features are to be considered at least as desirable, if not required for a proper solution of the task. Nevertheless, we will try to leave the design space for solutions as large as possible and to avoid premature and unjustified constraints.
2. The robot features specified here should be supplied in detail for any robot participating in the competition. This is necessary in order to allow better assessment of competition and benchmark results later on.

3.1 General Specifications and Constraints on Robots and Teams

Robot Specification 3.1 (*Type/Class*)

A competition entry may use a single robot or multiple robots acting as a team.

Robot Specification 3.2 (*Mobility Subsystems*)

At least one of the robots entered by a team must be mobile and able to visit different task-relevant locations by autonomous navigation. Teleoperation (using touch screens, tablets, mouse, keyboard, etc.) of robots for navigation is not permitted (except when otherwise specified, e.g., in particular instances of task and functional benchmarks). The robot mobility must work in the kind of environments specified for RoCKIn@Home and on the kind of floors defined in the RoCKIn@Home environment specifications.

Robot Specification 3.3 (*Sensor Subsystems*)

Any robot used by a team may use any kind of ***onboard*** *sensor subsystem, provided that the sensor system is admitted for use in the general public, its operation is safe at all times, and it does not interfere with other teams or the environment infrastructure.*

A team may use any kind of sensor system ***provided as part of the environment****, e.g. the networked camera specified in Section 2.4, by correctly using a wireless communication protocol specified for such purpose and provided as part of the scenario. Sensor systems used for benchmarking and any other systems intended for exclusive use of the organisers are not accessible by the robot system.*

Robot Specification 3.4 (*Communication Subsystems*)

Any robot used by a team may ***internally*** *use any kind of communication subsystem, provided that the communication system is admitted for use in the general public, its operation is safe at all times, and it does not interfere with other teams or the environment infrastructure.*

A robot team must be able to use the communication system provided ***as part of the environment*** *by correctly using a protocol specified for such purpose and provided as part of the scenario.*

Robot Specification 3.5 (*Power Supply*)

Any mobile device (esp. robots) must be designed to be usable with an onboard power supply (e.g. a battery). The power supply should be sufficient to guarantee electrical autonomy for a duration exceeding the periods foreseen in the various benchmarks, before recharging of batteries is necessary.

Charging of robot batteries must be done outside of the competition environment. The team members are responsible for safe recharging of batteries. If a team plans to use inductive power transmission devices for charging the robots, they need to request permission from the event organizers in advance and at least 3 months before the competition. Detailed specifications about the inductive device need to be supplied with the request for permission.

Robot Constraint 3.1 (*Computational Subsystems*)

Any robot or device used by a team as part of their solution approach must be suitably equipped with computational devices (such as onboard PCs, microcontrollers, or similar) with sufficient computational power to ensure safe autonomous operation. Robots and other devices may use external computational facilities, including Internet services and cloud computing to provide richer functionalities, but the safe operation of robots and devices may not depend on the availability of communication bandwidth and the status of external services.

Robot Constraint 3.2 (*Safety and Security Aspects*)

For any device a team brings into the environment and/or the team area, and which features at least one actuator of any kind (mobility subsystems, robot manipulators, grasping devices, actuated sensors, signal-emitting devices, etc.), a mechanisms must be provided to immediately stop its operation in case of an emergency (emergency stop). For any device a team brings into the environment and/or the team area, it must guarantee safe and secure operation at all times. Event officials must be instructed about the means to stop such devices operating and how to switch them off in case of emergency situations.

Robot Constraint 3.3 (*Environmental Aspects*)

Robots, devices, and apparatus causing pollution of air, such as combustion engines, or other mechanisms using chemical processes impacting the air, are not allowed.

Robots, devices, and any apparatus used should minimize noise pollution. In particular, very loud noise as well as well-audible constant noises (humming, etc.) should be avoided.

The regulations of the country in which a competition or benchmark is taking place must be obeyed at all times. The event organizers will provide specific information in advance, if applicable.

Robots, devices, and any apparatus used should not be the cause of effects that are perceived as a nuisance to the humans in the environment. Examples of such effects include causing wind and drafts, strong heat sources or sinks, stenches, or sources for allergic reactions.

3.2 Benchmarking Equipment in the Robots

Preliminary Remark: Whenever teams are required to install some element provided by RoCKIn on (or in) their robots, such element will be carefully chosen in order to minimize the work required from teams and the impact on robot performance.

Hardware As a general rule, RoCKIn does not require that teams install additional robotic hardware on their robots. Moreover, permanent change to the robot's hardware is never required. However, RoCKIn may require that additional standard PC hardware (such as an external, USB-connected hard disk for logging) is temporarily added to the robot in order to collect internal benchmarking data. When this is the case, the additional hardware is provided by RoCKIn during the Competition, and its configuration for use is either automatically performed by the operating system, or very simple.

To allow the acquisition of external benchmarking data about their pose, robots need to be fitted with special reflective markers, mounted in known positions. The teams will be required to prepare their robots so to ease the mounting of the markers. Teams will also be required to provide the geometric transformation from the position the marker to the odometric center of the robot[3].

Software RoCKIn may require that robots run RoCKIn-provided (or publicly available) software during benchmarks. A typical example of such software is a package that logs data provided by the robot, or a client that interfaces with a RoCKIn server via the wireless network of the test bed. Whenever a team is required to install and run such a package, it will be provided as source code, its usage will be most simple, and complete instruction for installation and use will be provided along with it. All RoCKIn software is written to have a minimal impact on the performance of a robot, both in terms of required processing power and in terms of (lack of) interaction with other modules. When required by a benchmark, the relevant RoCKIn software to be run by participating robots is provided well in advance with respect to the Competition.

RoCKIn will make any effort to avoid imposing constraints on the teams participating to the Competition in terms of software architecture of their robots. This means that any provided piece of software will be designed to have the widest generality of application. However, this does not mean that the difficulty of incorporating such software into the software architecture of a robot will be independent from such architecture: for technical reasons, differences may emerge. A significant example is that of software for data logging. At the moment, it appears likely that any such software by RoCKIn will be based on the established *rosbag* software tool, library and file format. As rosbag is part of ROS (Robot Operating System), robots based on ROS can use it to log data without any modification; on the contrary, robots not using ROS will be required to employ the rosbag library to create rosbag files (*bagfiles*) or to develop ad-hoc code to convert their well established logging format into the rosbag one by using the rosbag API. If this will be the case, RoCKIn will provide tools to ease the introduction of software modules for creation of

[3]Benchmarking data related to poses will refer to the marker position: this is why additional information is required to know the position of the base.

bagfiles into any software architecture; yet, teams not using ROS will probably have to perform some additional work to use such tools.

3.3 Communication between Benchmarking Equipment and Robots

For some types of internal benchmarking data (i.e. provided by the robot), logging is done on board the robot, and data are collected after the benchmark (for instance, via USB stick). Other types of internal benchmarking data, instead, are communicated by the robot to the test bed during the benchmark. In such cases, communication is done by interfacing the robot with standard wireless network devices (IEEE 802.11n) that are part of the testbed, and which therefore become a part of the benchmarking equipment of the test bed. However, it must be noted that network equipment is not strictly dedicated to benchmarking: for some benchmarks, in fact, the WLAN may be also (or exclusively) used to perform interaction between the robot and the test bed.

Due to the need to communicate with the test bed via the WLAN, all robots participating to the RoCKIn Competition are required to:

1. possess a fully functional IEEE 802.11n network interface[4];
2. be able to keep the wireless network interface permanently connected to the test bed WLAN for the whole duration of the benchmarks

4 Task Benchmarks

Details concerning rules, procedures, as well as scoring and benchmarking methods, are common to all task benchmarks.

Rules and Procedures Every run of each of the task benchmark will be preceded by a safety-check, outlined as follows:

1. The team members must ensure and inform at least one of the organizing committee (OC) member, present during the execution of the task, that they have an emergency stop button on the robot which is fully functional. Any member of the OC can ask the team to stop their robot at any time which must be done immediately.
2. A member of the OC present during the execution of the task will make sure if the robot complies with the other safety-related rules and robot specifications presented in Section 3.

All teams are required to perform each task according to the steps mentioned in the rules and procedures sections for the tasks. During the first two days of the competition, all teams are required to repeat the task (twice on day 1 and twice on day 2). On the third day, only a selected number of top teams will be allowed to perform the task. Maximum time allowed for one task run is 10 minutes.

Scoring and Ranking Evaluation of the performance of a robot according to task benchmarks is based on performance equivalence classes. Classes are related to the fact that the robot has executed or not the task required by the benchmark.

[4] It must be stressed that full functionality also requires that the network interface must not be hampered by electromagnetic obstacles, for instance by mounting it within a metal structure and/or by employing inadequate antenna arrangements. Network spectrum in the Competition area is typically very crowded, and network equipment with impaired radio capabilities may not be capable of accessing the test bed WLAN, even if correctly working in less critical conditions.

The criterion defining the performance equivalence class of robots is based on the concept of *tasks required achievements*. While the ranking of the robot within each equivalence class is obtained by looking at the performance criteria. In particular:

- The performance of any robot belonging to performance class N is considered as better than the performance of any robot belonging to performance class M whenever $M < N$
- Considering two robots belonging to the same class, then a penalization criterion (penalties are defined according to task performance criteria) is used and the performance of the one which received less penalizations is considered as better
- If the two robots received the same amount of penalizations, the performance of the one which finished the task more quickly is considered as better (unless not being able to reach a given achievement within a given time is explicitly considered as a penalty).

Performance equivalence classes and in-class ranking of the robots are determined according to three sets:

- A set A of **achievements**, i.e. things that should happen (what the robot is expected to do).
- A set PB of **penalized behaviors**, i.e. robot behaviors that are penalized, if they happen, (e.g., hitting furniture).
- A set DB of **disqualifying behaviors**, i.e. robot behaviors that absolutely must not happen (e.g. hitting people).

Scoring is implemented with the following 3-step sorting algorithm:

1. If one or more of the elements of set DB occur during task execution, the robot gets disqualified (i.e. assigned to the lowest possible performance class, called class 0), and no further scoring procedures are performed.
2. Performance equivalence class X is assigned to the robot, where X corresponds to the number of achievements in set A that have been accomplished.
3. Whenever an element of set PB occurs, a penalization is assigned to the robot (without changing its performance class).

One key property of this scoring system is that a robot that executes the required task completely will always be placed into a higher performance class than a robot that executes the task partially. Moreover the penalties do not make a robot change class (also in the case of incomplete task).

One further common issue concerns all (task or functionality) benchmark runs in which a spoken sentence from a human to the robot is expected, and is specified as follows. RoCKIn will provide to the teams at least eight weeks before the competition date:

- the lexicon that will be used, i.e., verbs, nouns referring to objects/locations/people, and terms for spatial relations
- a set of audio files and/or strings of text with examples of sentences

More precisely, RoCKIn will define a large set of sentences for each phase of a test in which such sentences are needed. Then the complete lexicon will be extracted from this set and the Organizing Committee will select and publish a subset of it. In the actual runs a randomly chosen sentence in the remaining part of the data set will be used.

4.1 Task *Catering for Granny Annie's Comfort*

This benchmark aims at assessing the robot's performance of executing requests about the user's comfort in the apartment.

4.1.1 Task Description

The robot provides little kinds of help for Granny Annie throughout the day. After waking up in the morning, Granny Annie calls the attention of the service robot by touching a button on her tablet computer. After the robot has come close to her, Granny Annie gives subsequent task orders by spoken commands: She wants the robot to "*lift the shutters*", "*tilt the window*", and "*switch off the lights*". Granny Annie may give any subset of a set of possible commands in any order. Other comfort duties include lowering the shutters to block bright sunshine, bringing Annie a book, a cup of tea, or a glass of water.

Task Specification 4.1 (*Comfort Providing Task*)

The comfort providing task involves the following activities:

1. *The user initiates the task by calling the robot's attention.*
2. *The robot confirms the contact.*
3. *The robot moves nearby the user, such that speech communication is possible.*
4. *The user requests the robot to perform a sequence of activities by giving a list of natural language commands.*
5. *The robot confirms it has understood the subtasks.*
6. *The robot executes the subtasks in any order. The performance of some of the subtasks may require further interaction with the user.*
7. *The robot informs the user that all subtasks have been performed.*

The next section provides details on each of these activities, including the specification of relevant features and their variations.

4.1.2 Feature Specifications and Variation

The first activity in need of clarification is how the robot's attention can be called by the user. In order to avoid unpredictable and possibly lengthy procedures like the robot having to search for the user, a standardized mechanism will be applied:

Feature Specification 4.1 (*Calling the Robot for Attention*)

The user is given a tablet computer which runs an app provided by the consortium. On the tablet's screen, the app presents a small set of large icons to the user. One such icon will be used for calling the robot's attention. Upon touching the icon, the app will send a message in a standardized format to the robot.

If the robot does not know the current location of the user, it may send back a message to the app requesting the user to help. The app will present a plan of the appartment on the screen. By touching a particular spot on the screen, the app will send the user's location to the robot.

For the 2014 RoCKIn competition, there is no variation of this feature planned.

One of the outstanding features of domestic robots is their ability to converse with users in natural language. The next few specs provide some detail.

Feature Specification 4.2 (*Language for Speech-Based Interaction*)

The language used for speech-based interaction between user and robot is a constrained subset of English.

Feature Specification 4.3 (*Order of User Commands*)

The user commands are either specified in a pre-defined order, or in an arbitrary order.

Feature Specification 4.4 (*Restriction of User Commands*)

The user commands are either not restricted (i.e. all possible user commands can be specified) or restricted to one class (e.g. operating the shutters).

Feature Specification 4.5 (*Task Constraints*)

The user command may contain constraints which the robot has to take into account during the execution of the desired task. These (possible) constraints are:

Task	*Constraint*
Open/close shutters	*completely; half; so that Annie is not blinded by the sun*
Dim the light	*completely; for watching TV*

Feature Specification 4.6 (*Object Locations*)

The objects can be placed either in any of the pre-defined locations or arbitrary locations within the test bed.

Feature Specification 4.7 (*Object Types*)

Either of the following different types of object sets can be located in the test bed:

- *All relevant objects and no unknown objects.*
- *A subset of the relevant objects and no unknown objects.*
- *A subset of the relevant objects and unknown objects.*

Feature Specification 4.8 (*Dynamic Selection of Objects*)

Two options for the selection of object types are possible:

1. *All teams must handle exactly the same objects.*
2. *Each team must handle a set of randomly chosen objects.*

4.1.3 Input Provided

A list of relevant objects (including Annie's comfort devices) and rooms (according to the specifications in Section 2) will be specified before the runs of this task. Examples of comfort devices are lights and window shutters. Each of these devices can be operated with a predefined interface that will be known to the team before-hand. Examples of objects relevant for this task are: glasses, cups, books, etc. For each of these classes of objects, one particular object instance will be denoted as the target one (i.e., the one that Annie is looking for), while other objects may be used in the task runs as well. Teams can calibrate their system during the set-up days using these objects.

Input Specification 4.1 (*Device Operation*)

A list which associates rooms with possible user requests is provided. An example of such a list is given below.

Room	*Possible user requests*
Bedroom	*"Dim the light", "Lift the shutters"*
Kitchen	*"Open the drawer", "Switch on the light", "Switch off the light"*
Living room	*"Open the door", "Close the door", "Tilt the window"*

Input Specification 4.2 (*Likely locations*)

A list of "likely" locations for task-relevant objects will be provided. The locations are described as text fragments such as "`on the kitchen counter`", "`on the bedside table`", and "`in the third row from the bottom of the cupboard`". The "likelihood" for a location is specified as a number between 0 and 100. It does not relate to probabilities, but may be understood such that if two places A and B have likelihoods 40 and 80, then the chance of finding the item at B is roughly twice as good. An example of such a list is given below.

Object	*Location*	*Likelihood*
Reading glasses	*on the bedside table*	*80*
	on the kitchen counter	*40*
	in the third row from the bottom of the cupboard	*20*
Cup	*on the lowest shelf of the cupboard*	*90*
	in the dish washer	*57*
	on the kitchen counter	*42*

Input Specification 4.3 (*Manual controls of comfort devices*)

The teams are provided with complete specifications of the manual controls (type, location, make and model) of comfort devices as part of the specifications for the RoCKIn@Home test bed.

Input Specification 4.4 (*Remote controls of comfort devices*)

Protocols and interfaces for the remote controls of comfort devices are provided to the teams well in advance of the competition date.

4.1.4 Expected Robot Behavior or Output

The robot is expected to reach the room where Granny Annie is located when she calls upon the robot's service. The robot should ask for orders in English language as speech output, and receive such orders as spoken commands in English. The robot should confirm orders in an appropriate way. The orders should be executed as expected.

When given the task to search for the glasses or some other object, the robot should acknowledge the order first. Then it may ask Granny Annie right away whether she remembers where she has used the glasses last. If Annie specifies a location, the robot will look there first, otherwise the robot will visit the likely locations in the order of their likelihood. The robot may deviate from this order if it can opportunistically shorten the overall search time of all locations.

When the robot receives the task to operate a device (e.g., opening and closing the shutters or dimming a light), it can decide to either use the networked test bed or the manual interface to access the requested device. Then the robot executes the task, which Annie has specified.

This task benchmark ends when the robot accomplished the request or the available time for the benchmark expires.

4.1.5 Procedures and Rules

Step 1 Grannie Annie (played by a member of the OC) will send the 'call' signal to the robot through a tablet computer by touching an icon on the tablet screen. The robot has to enter the room where Grannie Annie is waiting for it.

Step 2 (Assuming that the robot is in the same room with Grannie Annie) Grannie Annie will give the robot a set of possible commands (as mentioned in the feature specifications) which the robot must execute. Such voice commands can be related to any of the comfort-related tasks mentioned earlier in the task description sub-subsection of this task. If the robot fails to understand and/or perform a command, it may proceed to the next command.

Step 3 (Assuming that the robot has either finished the task requested in Step 2, or has shown its incapability to do so and is physically idle) Grannie Annie will give voice commands to the robot to look for one of her possessions (e.g., keys, reading glasses, mobile phones, and others as mentioned in the above task description) which the robot must search, pick and bring back to her.

In Step 3, each team must handle a set of randomly chosen objects from the same class (e.g., glasses, mobile phones). The class selected may vary from day to day of the competition. Note that, during the execution of this task, there can be several objects from the different classes of Annie's possessed objects, lying at different locations in the environment, none of which will be pre-specified to teams.

4.1.6 Acquisition of Benchmarking Data

During the execution of the benchmark, the following data will be collected[5]

- On the robot, the audio signals of the conversations between Annie and the robot[6]. [offline]
- The final command produced during the natural language analysis process. [online]
- The pose of the robot while moving in the environment.
- The pose of the robot while moving in the environment, as perceived by the robot. [offline]
- The sensorial data of the robot when recognizing the object to be operated. [offline]
- The results of the robot's attempts to execute Annie's commands.

Formats and interfaces for the transmission of internal robot data will be provided to the teams well in advance of the Competitions.

4.1.7 Scoring and Ranking

The set A of *achievements* for this task are:

- The robot enters the room where Granny Annie is waiting.
- The robot understands Annie's command(s).
- The robot operates correctly the right device(s).
- The robot finds the right object(s).

[5] In the following, 'offline' identifies data produced by the robot that will be collected by the referees when the execution of the benchmark ends (e.g., as files on a USB stick), while 'online' identifies data that the robot has to transmit to the testbed during the execution of the benchmark. Data marked neither with 'offline' nor with 'online' is generated outside the robot. NOTE: the online data should also be displayed by the robot on its computer screen, for redundancy purposes, in case problems with wireless communications arise.

[6] Speech files from all teams and all benchmarks (both Task benchmarks and Functional benchmarks) will be collected and used to build a public dataset. The audio files in the dataset will therefore include all the defects of real-world audio capture using robot hardware (e.g., electrical and mechanical noise, limited bandwidth, harmonic distortion). Such files will be usable to test speech recognition software, or (possibly) to act as input during the execution of speech recognition benchmarks.

- The robot brings to Annie the right object(s).

The set PB of *penalized behaviors* for this task are:

- The robot bumps into the furniture.
- The robot drops an object.
- The robot stops working.

Additional penalized behaviors may be identified and added to this list if deemed necessary. The set DB of *disqualifying behaviors* for this task are:

- The robot hits Annie or another person in the environment.
- The robot damages or destroys the objects requested to manipulate.
- The robot damages the test bed.

Additional disqualifying behaviors may be identified and added to this list if deemed necessary. These sets will be completed in later rule revisions.

4.2 Task *Welcoming visitors*

This task assesses the robot's capability to interact effectively with humans and to demonstrate different behaviors when dealing with known and unknown people.

4.2.1 Task Description

Granny Annie stays in bed because she is not feeling well. The robot will handle visitors, who arrive and ring the door bell, as follows (doors are assumed to be always open):

- Dr. Kimble is her doctor stopping by to see after her. He is a known acquaintance; the robot lets him in and guides him to the bedroom.
- The Deli Man delivers the breakfast; the actual person is changing almost daily, but they all have a Deli Man uniform. The robot guides the Deli Man to the kitchen, then guides him out again. The robot is supposed to always observe the stranger.
- The Postman rings the door bell and delivers mail and a parcel; the actual person is changing almost daily, but they all have a Postman uniform. The robot just receives the deliveries, and farewells him.
- An unknown person, trying to sell magazine subscription is ringing. The robot will tell him good-bye without letting the person in.

The task involves handling several visitors arriving in any sequence, but separately from each other. The robot must be able to handle/interact with a video intercom (see Section 2.4). If a visitor has been admitted, either by the face or the kind of uniform, the robot guides him out after the visit.

4.2.2 Feature Variation

In all the runs of this task the four persons indicated above will ring the door bell. The robot is thus required to deal with all the situations described above. However, the order in which the people will appear will be randomized for each run/participant. Every visit will terminate before the next one.

4.2.3 Input Provided

The following information about the people that will act as visitors will be provided to the team during the set-up days, as specified below.

- Dr. Kimble (i.e., a person of the Technical or Organizing Committee running all the runs): images with the person's face; teams may ask the Technical Committee to calibrate their system during the set-up days with the actual person who will perform the test as Dr. Kimble.
- Deli Man (the actual person will change in every run, but s/he will always wear a known uniform): images of the uniform and of some people wearing this uniform (not the people used in the test); teams may ask the Technical Committee to calibrate their system during the set-up days with the actual uniform used in the tests.
- Postman (the actual person may change in every run, but s/he will always wear a known uniform): images of the uniform and of some people wearing this uniform (not the people used in the test); teams may ask the Technical Committee to calibrate their system during the set-up days with the actual uniform used in the tests.
- Unknown person: no information is provided.

Some privileges are given to the four different kinds of people, as reported in the following table, and the robot has to act accordingly.

Privileges	Dr. Kimble	Deli Man	Postman	Unknown
Allow to enter	Yes	Yes	Yes	No
Allow to deliver objects	No	Yes	Yes	No
Allow access to kitchen	Yes	Yes	No	No
Allow access to bedroom	Yes	No	No	No

Moreover, the robot is required to verify that, after the visit, if a person was allowed to enter, s/he must have exited.

4.2.4 Expected Robot Behavior or Output

Start of the test

The test starts with the robot in the bedroom or in any room in which it can use the video intercom. Then for each visiting person, the following three phases are expected.

Phase 1: detection and recognition of the visitor.

Whenever a person rings the door bell, the robot can use its own on-board audio system to detect the bell ring(s). The robot has to understand who is the person asking for a visit, according to the descriptions given above, including using the intercom camera. If the robot does not detect the ring call through the intercom after three times, then the person will leave and the task will continue with the next person after a while.

If the robot is not able to recognize the person, it should use speech output for asking the person to look at the camera and to say his/her name and the reason of the visit. Examples of possible answers are given below:

Visitor	Visitor's Greeting message
Dr. Kimble	"Hi. This is Dr. Kimble."
Deli Man	"I am the Deli Men with the breakfast."
Postman	"Hello, I am George, the PostMan."
Unknown	"Good morning, are you interested in the local newspaper?"

If the robot is still not able to detect the person after three speech sentences, the person will leave. If the robot is not able to detect the person within 3 minutes, the person will leave.

Phase 2: greeting of the visitor.

For each detected visitor, the robot has to use the intercom and greet the visitor. In this spoken sentence, the robot has to demonstrate that it understood the category of the person. For example, these sentences spoken by the robot will be considered adequate.

Visitor	Robot's Greeting message
Dr. Kimble	"Hi Dr. Kimble, I am coming to open the door."
Deli Man	"Hello, I am coming to get the breakfast."
Postman	"Hello, I am coming to get the post mail."
Unknown	"Sorry, I don't know you. I cannot open the door."

Phase 3: executing the visitor-specific behavior.

The following behaviors are expected depending on the visitor (doors are assumed to be open).

Dr. Kimble: the robot goes to the entrance door allows the Doctor to enter and guides the Doctor to Annie's bedroom; then it waits until the Doctor exits the bedroom, follows him/her to the entrance door, and allows the Doctor to exit.

Deli Man: the robot goes to the entrance door, allows the Deli Man to enter, guides the Deli Man to the kitchen, asking him/her to deliver the breakfast box on the table; then it guides the Deli Man back to the entrance door, and allows the Deli Man to exit.

PostMan: the robot goes to the entrance door, allows the PostMan to enter, receives the postal mail (or ask the Postman to put it in the table in the hall), and allows the PostMan to exit.

Unknown person: do nothing.

After the execution of the visitor-specific behavior, the robot can return to the initial position where it can receive the next visit.

4.2.5 Procedures and Rules

The visitors will be from all the four categories mentioned previously (including the unknown person). The following three steps will be repeated for each visitor (in a random order).

Step 1 The door-bell will be rung by the visitor, played by a member of the OC. At this point in time, the robot must recognize the sound of the door bell and reach to the apartment's main door in the environment.

Step 2 (Assuming that the robot has reached the above-mentioned position) the robot must activate the video intercom so that the visitor on the other side is aware of *somebody's* presence at the door.

Step 3 The visitor can be either a known person or a completely unknown person. The robot must correctly identify the person first as known or unknown and then proceed as follows. If the person is known according to his/her face and/or uniform, the robot must proceed to do the rest of the actions as per mentioned in the task description. If the person is unknown, the robot just says goodbye to him/her.

4.2.6 Acquisition of Benchmarking Data

During the execution of the benchmark, the following data will be collected[7]

- The event/command causing the activation of the robot. [online]
- The video signal from the door camera.
- The pose of the robot during the execution of the task.
- The pose of the robot while moving in the environment, as perceived by the robot. [offline]
- The results of any attempts by the robot to detect and classify a visitor. [online]
- The audio signals of the conversations with the visitors[8]. [offline]
- Any notifications from the robot (e.g., alarm if a visitor shows anomalous behavior). [online]
- The results of any actions taken by the robot, including opening or closing the front door, guiding visitors into and around the apartment, manipulating objects, etc.

Formats and interfaces for the transmission of internal robot data will be provided to the teams well in advance of the Competitions.

4.2.7 Scoring and Ranking

The set A of *achievements* for this task are:

- The robot reaches the door when the door bell is rung by Dr. Kimble and correctly identifies him.
- The robot reaches the door when the door bell is rung by the Deli Man and correctly identifies him.
- The robot reaches the door when the door bell is rung by the PostMan and correctly identifies him.
- The robot reaches the door when the door bell is rung by an unknown person and correctly identifies the person as such.
- The robot exhibits the expected behavior for interacting with Dr. Kimble.
- The robot exhibits the expected behavior for interacting with the Deli Man.
- The robot exhibits the expected behavior for interacting with the PostMan.
- The robot exhibits the expected behavior for interacting with an unknown person.

The set PB of *penalized behaviors* for this task are:

- The robot fails in making the visitor respect the proper rights.

[7]In the following, 'offline' identifies data produced by the robot that will be collected by the referees when the execution of the benchmark ends (e.g., as files on a USB stick), while 'online' identifies data that the robot has to transmit to the testbed during the execution of the benchmark. Data marked neither with 'offline' nor with 'online' is generated outside the robot. NOTE: the online data should also be displayed by the robot on its computer screen, for redundancy purposes, in case problems with wireless communications arise.

[8]Speech files from all teams and all benchmarks (both Task benchmarks and Functional benchmarks) will be collected and used to build a public dataset. The audio files in the dataset will therefore include all the defects of real-world audio capture using robot hardware (e.g., electrical and mechanical noise, limited bandwidth, harmonic distortion). Such files will be usable to test speech recognition software, or (possibly) to act as input during the execution of speech recognition benchmarks.

- The robot generates false alarms.
- The robot fails in maintaining the original state of the environment.
- The robot requires extra repetitions of speech.
- The robot bumps into the furniture.
- The robot stops working.

Additional penalized behaviors may be identified and added to this list if deemed necessary. The set DB of *disqualifying behaviors* for this task are:

- The robot hits Annie or one of the visitors.
- The robot damages the test bed.

Additional disqualifying behaviors may be identified and added to this list if deemed necessary. These sets will be completed in later rule revisions.

4.3 Task *Getting to know my home*

This task is focused on acquiring knowledge about the environment and on its explicit representation. The robot is required to understand the changes in the environment either through user interaction or automatically or with a mixed approach.

4.3.1 Task Description

Before each task run, some random changes in the environment are made with respect to the nominal configuration given to the teams during the set-up days. These changes involve one door, and perception-relevant objects (two pieces of furniture and three, task-relevant or not, objects). The robot has to detect these changes, either automatically or with the help of a user (a team member), and provide an explicit representation of them referred to the map of the environment (that can be either acquired on-line during the task run, off-line before the run, or merge off-line and on-line acquisition).

4.3.2 Feature Variation

For each task run, the door, the two pieces of furniture and the three objects that implement the changes are randomly chosen.

4.3.3 Input Provided

The teams must create a map of the environment and label it with pieces of furniture and objects in there during the set-up days. This information will be used for this task, together with the topological map, rooms and objects specifications described in Section 2.

4.3.4 Expected Robot Behavior or Output

Phase 1: knowledge acquisition.

The robot in any way (human-robot interaction (HRI) or autonomously or mixed) has to detect these changes and represent them in an explicit format (see Expected Output below). In case of an HRI-based approach, a team member can guide the robot in the environment and show the changes with only natural interactions (speech and gesture). No input devices are allowed (e.g., touch screens, tablets, mouse, keyboard, etc.). In this phase, the robot has to provide an output containing an explicit representation of the acquired knowledge. At any time the teams can decide to move to Phase 2, even if not all the changes have been detected. However, the task in Phase 2 can refer only to objects acquired during Phase 1.

Phase 2: knowledge use.

The robot has to show the use of the new acquired knowledge. This will be accomplished by executing a user command mentioning one of the items affected by the change.

Expected output.

The expected output of each task run is a set of files (that must be stored in a USB stick) containing the metric map of the environment and an explicit representation of the items selected for the change. More precisely: 1) doors and its status (position, rooms connected, status: open/closed); 2) pieces of furniture (position and rooms in which they are); 3) objects (position and piece of furniture in which they are placed)

The output must be provided in a standard format: 1) metric map: e.g., bitmap + ROS-like yaml file; 2) doors, furniture and object status in a standard format whose grammar will be provided; 3) images of door, furniture and objects.

The representation of changes is constrained as follows: 1) only one door must be reported as closed; 2) only two pieces of furniture must be reported as moved; 3) only three objects must be reported.

Moreover, the robot should demonstrate the use of the acquired knowledge, by executing a task regarding the objects/furniture acquired. The behavior must refer to furniture/object correctly identified in the first phase (inaccurate or wrong metric localization are still ok) and the target furniture/object must be in a different room with respect to the one in which the command is issued.

4.3.5 Procedures and Rules

Before the robot enters the apartment, any one of the doors in the environment will be closed, two randomly-selected pieces of furniture will be moved from their original position to a different position (can even be either in the same room or in a different room) and any three randomly-selected objects will be placed in random places (above some piece of furniture).

Phase 1 The robot can move around in the environment for up to the maximum time limit of this task, possibly accompanied by the user (a team member) and interacting with him/her: The robot has to detect the changes specified above, and then represent them in an explicit format as described in sub-subsection 4.3.4.

Phase 2 (Assuming that the robot has either finished the task requested in the previous steps, or has shown its incapability to do so and is physically idle) the robot will be asked (either by receiving a voice command or by following a person, i.e., a team member) to move one the objects recognised in Phase 1 to a piece of furniture, also recognised in Phase 1.

The robot can move around in the room for up to the maximum time limit of this task, possibly accompanied by the user (a team member) and interacting with him/her. The robot has to detect the changes specified above and then represent them in an explicit format as described in sub-subsection 4.3.4.

The knowledge acquired during Phase 1 must be reported in an explicit way by producing files in the given output format and by automatically saving them on a USB stick given to the team by the Technical Committee before the start of the run, as described in the Expected Output section. No manual intervention on the robot is allowed to save files on the USB stick.

The accomplishment of the behavior in Phase 2 will be rewarded only if it refers to an object/piece of furniture that has been correctly reported in the output of Phase 1.

Note also that the metric map can be generated offline (i.e., before the task run) and may not contain the changes. The metric map will not be evaluated specifically. However, a poor quality metric map or an out-of-date map can affect the evaluation of the position of the objects/piece of furniture selected for the task.

4.3.6 Acquisition of Benchmarking Data

During the execution of the benchmark, the following data will be collected[9]

- The output files produced by the robot, as described by section 4.3.4. [offline]
- The pose of the robot during the execution of the task.
- The pose of the robot while moving in the environment, as perceived by the robot. [offline]
- The result (success/failure) of the command issued to the robot.

Any additional information concerning formats and interfaces for the transmission of internal robot data (besides that provided by section 4.3.4) will be provided to the teams well in advance of the Competitions.

4.3.7 Scoring and Ranking

The set A of *achievements* for this task are:

- The robot detects the door with changed state.
- The robot detects each piece of moved furniture.
- The robot detects each changed object.
- The robot correctly executes the command given in Phase 2.

The set PB of *penalized behaviors* for this task are:

- The robot requires multiple repetitions of human gesture/speech.
- The robot bumps into the furniture.
- The robot stops working.

Additional penalized behaviors may be identified and added to this list if deemed necessary. The set DB of *disqualifying behaviors* for this task are:

- The robot hits Annie or another person in the environment.
- The robot damages the test bed.

Additional disqualifying behaviors may be identified and added to this list if deemed necessary. These sets will be completed in later rule revisions.

[9] In the following, 'offline' identifies data produced by the robot that will be collected by the referees when the execution of the benchmark ends (e.g., as files on a USB stick), while 'online' identifies data that the robot has to transmit to the testbed during the execution of the benchmark. Data marked neither with 'offline' nor with 'online' is generated outside the robot. NOTE: the online data should also be displayed by the robot on its computer screen, for redundancy purposes, in case problems with wireless communications arise.

5 Functionality Benchmarks

5.1 Object Perception Functionality

5.1.1 Functionality Description

This functionality benchmark has the objective of assessing the capabilities of a robot in processing sensor data in order to extract information about observed objects. All objects presented to the robot in this task benchmark are commonplace items that can be found in a domestic environment. Teams are provided with a list of individual objects (instances), subdivided into classes (see Section 5.1.3). The benchmark requires that the robot, when presented with objects from such list, detects their presence and estimates their class, identity, and location. For example, when presented with a bottle of milk the robot should detect it is in front of a bottle (class) of milk (instance) and that it is at a given position with respect to a known reference frame (i.e. the benchmark setup reference frame).

5.1.2 Feature Variation

The variation space for object features is represented by the (known) set of objects that the robot may be presented with. Variation space for object locations is the surface of the benchmarking setup area where objects are located (see subsection 5.1.3).

5.1.3 Input Provided

The set of individual objects that will actually be presented to the robot during the execution of the functionality benchmark is a subset of a larger set of available objects, here denoted as "object instances" (see Section 2 for complete list of possible objects). This can, in general, be a superset of the objects used in the actual RoCKIn@Home Task Benchmarks.

Object instances are subdivided into classes of objects that have one or more properties in common, here denoted as "object classes". Objects of the same class share one or more properties, not necessarily related to their geometry (for instance, a class may include objects that share their application domain). Each object instance and each object class is assigned a unique ID.

All object instances and classes are known to the team before the benchmark, but the team does not know which object instances will actually be presented to the robot during the benchmark. More precisely, the team will be provided with the following information:

- Descriptions/models of all the object instances in the form of 3D textured models;
- Subdivision of the object instances into object classes (for instance: boxes, mugs, cutlery);
- Reference systems associated to the table surface and to each object instance (to be used to express object poses).

Object descriptions will be expressed according to widely accepted representations, well in advance with respect to the competition dates.

5.1.4 Expected Robot Behavior or Output

The objects that the robot is required to perceive are positioned, one at the time, on a table (benchmark setup area) located directly in front of the robot. The robot does not move during the benchmark, and the team is allowed to choose its location, including height, with respect to the benchmark setup reference frame. However, no parts of the robot are allowed in the space above the table.

The actual pose of the objects presented to the robot is unknown before they are set on the table. For each presented object, the robot must perform all of the following:

- Object detection: perception of the presence of an object on the table and association between the perceived object and one of the object classes (see "Information provided to the team").
- Object recognition: association between the perceived object and one of the object instances belonging to the selected class (see sub-subsection 5.1.3).
- Object localization: estimation of the 3D pose of the perceived object with respect to the benchmark setup reference frame.

5.1.5 Procedures and Rules

Every run in all the stages of this functionality benchmark will be preceded by a safety-check similar to that described for the task benchmark procedures.

All teams are required to perform this functionality benchmark according to the steps mentioned below. During the first two days of the competition, all teams are required to repeat it (10 times on day 1 and 10 times on day 2). On the third day, only a selected number of top teams will be allowed to perform it. Maximum time allowed for one functionality run is 2 minutes.

Step 1 An object of unknown class and unknown instance will be placed in front of the robot.

Step 2 The robot must determine the object's class, its instance within that class as well as the 3D pose of the object and save it in the given format (see sub-subsection 5.1.6).

5.1.6 Acquisition of Benchmarking Data

During the execution of the benchmark, the following data will be collected[10]:

- Number of objects presented to the robot.
- Detection, recognition and localization data associated to the objects, provided by the robot. [online]
- Ground truth for object pose, object class, and object instance.
- Sensor data used by the robot to perform classification (e.g. images, point clouds). [offline]

Formats and interfaces for the transmission of internal robot data will be provided to the teams well in advance with respect to the competition dates.

5.1.7 Scoring and Ranking

Evaluation of the performance of a robot according to this functionality benchmark is based on:

1. The number and percentage of correctly classified objects.
2. The number and percentage of correctly identified objects.
3. Pose error for all correctly identified objects.
4. Execution time (if less than the maximum allowed for the benchmark).

[10] In the following, 'offline' identifies data produced by the robot that will be collected by the referees when the execution of the benchmark ends (e.g., as files on a USB stick), while 'online' identifies data that the robot has to transmit to the testbed during the execution of the benchmark. Data marked neither with 'offline' nor with 'online' is generated outside the robot. NOTE: the online data should also be displayed by the robot on its computer screen, for redundancy purposes, in case problems with wireless communications arise.

The previous criteria are in order of importance (since this functionality benchmark is primarily focused on object recognition): the first criterion is applied first and teams will be scored according to the common F-measure metrics; the ties are broken by using the second criterion, again applying F-measure metrics; finally the position error is evaluated as well. Since the position error is highly affected by the precision of the ground truth system we will use a set of classes in this as well and in case of ties we will resort to execution time.

5.2 Object Manipulation Functionality

5.2.1 Functionality Description

This functional benchmark is targeted at assessing the capabilities of a robot to correctly operate manual commands of the types that are commonly found on domestic appliances operated by humans. The objects to be manipulated include both digital (i.e., on/off) and analog controls.

The benchmark is based on the use of one or more *test panels* from a given set, each of which is fitted with a set of controls of different category, size and type. For each digital control in the set, the robot is required to change its state. For each analog control in the set, the robot is given the direction of motion of the control and a target setting: the robot must operate the control until notified that the required setting has been reached (see Section 5.2.6 for a description of the feedback mechanism).

5.2.2 Feature Variation

The test panel to be used is randomly selected before each functionality benchmark run. The desired target of the controls can be varied between different runs.

5.2.3 Input Provided

The robot must operate the following controls:

- Digital latching buttons (e.g. power button of a washing machine).
- Digital non-latching buttons (e.g. power button of a PC).
- Analog non-latching buttons (output changes with duration of push: e.g. light dimmer).
- Digital rocker switches (e.g. light switch).
- Digital sliders (e.g. lock switch of portable devices).
- Analog sliders (e.g. level controls of audio mixers).
- Analog rotary controls (e.g. volume knob).

The teams are provided with complete specifications for all panels (including the type, location, make and model of all the controls fitted to it) as part of the specifications for the RoCKIn-@Home test bed. Panel specifications include ID and location of the markers on each panel. On each test panel, controls are assigned unique IDs/markers. The markers are compliant with publicly available localization software (e.g., QR codes). Robots are allowed to use the markers to localize the controls to be operated.

For the functionality benchmark runs, one of the panels is affixed to a wall of the test bed, at a height chosen by the team. The team is required to set the robot on the floor in front of the panel; then, the robot receives from the test bed an ordered list of the IDs of the controls to operate. Robot positioning by the team is arbitrary, provided that the end effector is not closer to the panel than a specified distance limit.

5.2.4 Expected Robot Behavior or Output

The robot has to correctly operate the controls specified in the list, in the correct order. Correct operation of a control includes the following phases:

- The robot uses its end effector(s) to bring the switch in the required final state, without damaging it.
- The robot notifies the test bed (through the wireless network, using an application provided by the OC) that such state has been reached.
- The robot releases the control.

The functional benchmark ends as soon as one of the following situations occurs: (i) all the controls in the list have been operated, or (ii) the time available for the functional benchmark expires.

5.2.5 Procedures and Rules

Every run in all the stages of this functionality benchmark will be preceded by a safety-check similar to that described for the task benchmark procedures.

All teams are required to perform this functionality benchmark according to the steps mentioned below. During the first two days of the competition, all teams are required to repeat it once on each of the first 2 days. On the third day, only a selected number of top teams will be allowed to perform it. Maximum time allowed for one functionality run is 10 minutes.

Step 1 The team is required to setup their robot on the floor in front of the *test panel*.

Step 2 The robot receives an ordered list of 10 digital and analog controls which should be operated in the right order.

5.2.6 Acquisition of Benchmarking Data

The test panels are fitted with hardware dedicated to reading the setting of all controls. This is especially important for analog ones, which the robot is required to bring to a precise setting.

During the execution of a benchmarking experiment, the control readings will be made available to the robot through the wireless network of the test bed although for functionality benchmarks wired connection will be allowed as well.

During the benchmark the following benchmarking data is collected[11]:

- Notifications issued by the robot. [online]
- Initial and final setting of all controls on the test panel.
- Internal robot data referring to end effector position and target object position. [offline]
- External ground truth about panel position and end effector position.

Formats and interfaces for the transmission of internal robot data will be provided to the teams well in advance with respect to the competition dates.

[11] In the following, 'offline' identifies data produced by the robot that will be collected by the referees when the execution of the benchmark ends (e.g., as files on a USB stick), while 'online' identifies data that the robot has to transmit to the testbed during the execution of the benchmark. Data marked neither with 'offline' nor with 'online' is generated outside the robot. NOTE: the online data should also be displayed by the robot on its computer screen, for redundancy purposes, in case problems with wireless communications arise.

5.2.7 Scoring and Ranking

Evaluation of the performance of a robot according to this functionality benchmark is based on:

- Number and percentage of controls correctly operated by the robot, among those in the ordered list provided to the robot.
- Final state of these controls.
- Number of controls accidentally operated by the robot (these include both controls not in the list and controls operated out of order).
- Damages inflicted to the controls by the robot.
- Time (if less than the maximum allowed for the benchmark).

The teams will be scored on the number of devices correctly operated according to the sorted set (this functionality benchmark is focused on the robot manipulation capability). The scoring will follow the Levenshtein distance between the list of required devices to operate (e.g., $[a\ c\ e\ d\ \ldots\ q]$) and the list of operated devices (e.g., $[q\ c\ e\ d\ \ldots\ a]$). This distance takes into account also out of order execution and missing items. For analog devices a threshold for considering the device correctly operated will be defined well in advance with respect to the competition dates.

5.3 Speech Understanding Functionality

5.3.1 Functionality Description

This functional benchmark aims at evaluating the ability of a robot to understand speech commands that a user gives in a home environment. A list of commands will be selected among the set of predefined recognizable commands (i.e., commands that the robot should be able to recognize within the tasks of the competition or in similar situations).

Each implemented system should be able to capture audio from an on-board microphone, to record the capture audio in a file and to interpret audio files. A standard format for audio files will be chosen (e.g., WAV) and communicated to the teams in advance before the competition. The system should produce an output according to a final representation defined in the following sections. Such a representation will have to respect a command/arguments structure, where each argument is instantiated according to the arguments of the command evoking verb. It is referred to as *Command Frame Representation* (CFR) (e.g., "go to the living room" will correspond to `GO(goal:"living room")`).

Summarizing, for each interpreted command the following relevant information will be collected: an audio file, its correct transcription and the corresponding correct CFR.

5.3.2 Feature Variation

For this benchmark, the variation can affect mainly four aspects: different complexity in the syntactic structures of the spoken commands; use of complex grammatical features, as pronouns; use of synonyms for referring to objects; use of sentences where more than one action is expressed, resulting in a composed command (e.g. "take the bottle and bring it to me"). Furthermore, variation in the quality of the audio corresponding to the user utterances can be considered, as for representing more or less noisy conditions.

5.3.3 Input Provided

Some information about the lexicon (verbs and nouns of objects) used in the benchmark will be made available to the teams at least eight weeks before the competition. Moreover, a set of samples (audio files) will also be distributed.

For the generation of the output, teams will be provided with a knowledge base (Frame Knowledge Base, FKB) containing a set of *semantic frames*. Each frame corresponds to an action, or robot command. The FKB contains a description of each frame, in terms of allowed arguments (e.g. `destination` for a *motion* command), their names and additional information on how to model the activated frame into the CFR. The list of frames and related arguments is the following:

- *Motion*: The action performed by the robot itself of moving from one position to another, occasionally specifying a specific path followed during the motion. The starting point is always taken as the current position of the robot.
  - Goal: The final position in the space to be occupied at the end of the motion action.
  - Path: The trajectory followed while performing the motion towards the Goal.
- *Searching*: The action of inspecting an environment or a general location, with the aim of finding a specific entity.
  - Theme: The entity (most of the time an object) to be searched during the searching action.
  - Ground: The environment or the general location in the space where to search for the Theme.
- *Taking*: The action of removing an entity from one place, so that the entity is in robot possession.
  - Theme: The entity (typically an object) taken through the action.
  - Source: The location occupied by the Theme before the action is performed and from which the Theme is removed.
- *Bringing*: The action of changing the position of an entity in the space from a location to another.
  - Theme: The entity (typically an object), being carried during the bringing action.
  - Goal: The endpoint of the path along which the carrier (e.g. the robot - and thus the Theme) travels
  - Source: The beginning of the path along which the carrier (e.g. the robot - and thus the Theme) travels

Composition of actions is also possible in the CFR, corresponding to more complex action as the *Pick_and_place* action, represented by a sequence of *Taking* frame followed by a *Bringing* frame (e.g. for the command "*take the box and bring it to the kitchen*").

The grammar specifying the correct syntax for a CFR will be also provided, and is reported in the following.

```
Command → Single_command | Composed_command

Composed_command → Single_command#Command

Single_command → Action(Arguments)

Action → GO | TAKE | BRING | SEARCH
```

```
Arguments → Argument | Argument, Arguments

Argument → Argument_name:“Role_filler”

Argument_name → theme | goal | source | path | ground

Role_filler → Defined_lexicon
```

where `Defined_lexicon` is the lexicon provided, and defined in the following. This grammar, together with the FKB will allow the teams to correctly yield the CRF for the final evaluation. The `Defined_lexicon` for the home domain will be released before the competition, including names of rooms (e.g. *hallway*, *living room*, etc.) and objects (e.g. *cereal box*, *jar*, etc.).

5.3.4 Expected Robot Behavior or Output

The robot should be able to understand a command starting from the speech input. The robot should correctly transcribe the user utterance and recognize the action to perform, resulting in the correct command frame (e.g. `GO` for a *motion* command) and the arguments involved (e.g. the `goal` of a *motion* command). The output of the robot should provide the CFR format for each command, as reported in Section 5.3.1 and defined in Section 5.1.3.

5.3.5 Procedures and Rules

All the teams will be evaluated on the same set of spoken sentences. These spoken sentences are divided in two groups: a first group is formed by pre-recorded audio files, a second group by voice commands uttered by a user during the benchmark. The robots will be disposed in circle, and the audio will be broadcast using a 360° speaker (or an equivalent structure of speakers) with high fidelity performance placed in the center. In this way, all the robots will receive the same audio at the same time.

All teams are required to perform this functionality benchmark according to the steps mentioned below. During the first two days of the competition, all teams are required to repeat it (2 runs on day 1 and 2 runs on day 2). On the third day, only a selected number of top teams will be allowed to perform it. Maximum time allowed for one functionality run is 2 minutes.

The benchmarking procedure is performed for all the teams in parallel.

1. Each team receives a USB stick containing the audio files randomly selected among the predefined set. This subset will be the same for each team in order to reproduce fair conditions in the evaluation. After inserting the USB stick in the computer of the robot, only one button can be pressed (either a button in a GUI or a key in the keyboard). This will be done by a member of the OC instructed by a team member. This operation will be done in parallel for all the teams. So the starting time of processing the files will be (approximately) the same for all the teams.

2. For each audio file in the USB stick, the system should generate the corresponding interpretation in the CFR format. This information must be saved in an output file called `results.txt`. A line in the format

   $\texttt{audio\_file\_name}_i\texttt{|CFR}_i$

   has to be added to the output file for each audio file. The `audio_file_name` field represents the name of the currently analyzed audio file, while `CFR` is the related CFR produced after the Speech Understanding process ends. An example is reported in the following:

   ```
   fb_speech_audio1.wav|GO(goal:“living room”)
   fb_speech_audio3.wav|TAKE(theme:“the jar”, source:“the table”)
   ```


...

3. Two minutes after all the teams have received and inserted the USB stick, a user speaks some sentences to all the robots. This will be done by using loud-speakers so that all the robots will be able to hear the command. Notice that loud-speakers will be available during the set-up days and audio tests will be performed before the benchmark, so teams can properly calibrate their audio systems. For these additional sentences, the interpretation process explained above will be repeated and the results will be added to the `results.txt`. Moreover, the corresponding audio files must be recorded in the USB stick.

4. After the test is completed, one button can be pressed. Again this will be done by a member of the OC instructed by a team member.

5. The USB stick is removed from the robot and it should contain: new audio files, `results.txt` file with the recognition of both the already present audio files and the new ones recorded during the benchmark.

5.3.6 Acquisition of Benchmarking Data

During the execution of the benchmark, the following data will be collected:

- Sensor data (in the form of audio files) used by the robot to perform speech recognition[12];
- The set of all possible transcription for each user utterance;
- The final command produced during the natural language analysis process;
- Intermediate information produced or used by the natural language understanding system during the analysis as, for example, syntactic information.

Formats and interfaces for the transmission of internal robot data will be provided to the teams well before the Competitions. Please note that, according to the procedure described by Section 5.3.5 and to the definitions of 'offline' and 'online' used for the other benchmarks[13], all data acquisition occurs offline.

5.3.7 Scoring and Ranking

During the functional benchmark, different aspects of the speech understanding process will be assessed:

1. The Word Error Rate on the transcription of the user utterances, in order to evaluate the performance of the speech recognition process.

2. For the generated CFR, the performance of the system will be evaluated against the provided *gold standard* version of the CFR, that is conveniently paired with the analyzed audio file and transcription. Two different performances will be evaluated at this step. One measuring the ability of the system in recognizing the main action, called *Action Classification* (*AcC*), and one related to the classification of the action arguments, called

[12] Speech files from all teams and all benchmarks (both Task benchmarks and Functional benchmarks) will be collected and used to build a public dataset. The audio files in the dataset will therefore include all the defects of real-world audio capture using robot hardware (e.g., electrical and mechanical noise, limited bandwidth, harmonic distortion). Such files will be usable to test speech recognition software, or (possibly) to act as input during the execution of speech recognition benchmarks.

[13] 'Offline' identifies data produced by the robot that are collected by the referees when the execution of the benchmark ends; 'online' identifies data that the robot has to transmit to the testbed during the execution of the benchmark. NOTE: the online data should also be displayed by the robot on its computer screen, for redundancy purposes, in case problems with wireless communications arise.

Argument Classification (*AgC*). In both cases the evaluations will be carried out in term of Precision, Recall and F-Measure. This process is inspired to the *Semantic Role Labeling* evaluation scheme proposed in [3]. For the *AcC* this measures will be defined as follow:

- Precision: the percentage of correctly tagged frames among all the frames tagged by the system;
- Recall: the percentage of correctly tagged frames with respect to all the *gold standard* frames;
- F-Measure: the harmonic mean between Precision and Recall.

Similarly, for the *AgC*, Precision, Recall and F-Measure will be evaluated, given an action f, as:

- Precision: the percentage of correctly tagged arguments of f with respect to all the arguments tagged by the system for f.
- Recall: the percentage of correctly tagged arguments of f with respect to all the *gold standard* arguments for f.
- F-Measure: the harmonic mean between Precision and Recall.

3. Time utilized (if less than the maximum allowed for the benchmark).

The final score will be evaluated considering both the *AcC* and the *AcG*. Only the F-Measure will be considered for both maeasures, each one contributing for 50% of the score. The *AcG* F-Measure will be evaluated for each argument, and the final F-Measure for the *AcG* will be the sum of the single F-Measure of the single arguments divided by the number of arguments. This final score has to be considered as an equivalence class. If this score will be the same for two or more teams, the *WER* will be used as penalty to evaluate the final ranking. This means that a team belonging to an equivalence class can not be ranked lower than one belonging to a lower one, even though the final score, considering the *WER* of the first is lower than the score of the second.

6 Competition Structure

6.1 Competition Elements

RoCKIn competitions are scientific competitions where the rules are designed in such a way that the rankings also take the role of measurements of the performance of participants, according to objective criteria. This is called in RoCKIn jargon, a *benchmarking competition*.

The elements composing a *benchmarking competition* were defined in [4]. We recover the most relevant here for the rulebook document to be self-contained.

Definition 6.1 (*Functionality*)

One of the basic abilities that a robot system *is required to possess in order to be subjected to a given* experiment*.*

The list of *functionalities* for RoCKIn@Home is defined in Section 5.

Definition 6.2 (*Functional Module*)

The (hardware and/or software) components of a robot system *that are involved in providing it with a specific* functionality*.*

Definition 6.3 (*Task*)

An operation or set of operations that a robot system *is required to perform, with a given (set of) goal(s), in order to participate in* a benchmarking competition*.*

The list of *tasks* for RoCKIn@Home is defined in Section 4.

Definition 6.4 (*Benchmarking*)

The process of evaluating the performance of a given robot system *or one of its* functional modules*, according to a specified* metric*.*

Definition 6.5 (*Benchmark*)

The union of one or more benchmarking experiments *anda set of* metrics *according to which the course and the outcome of the experiments – described by suitable data acquired during the experiments – will be evaluated.*

Definition 6.6 (*Functional Benchmark*)

A benchmark *which aims at evaluating the quality and effectiveness of a specific* functional module *of a* robot system *in the context of one or more* scenarios*.*

Definition 6.7 (*Task Benchmark*)

A benchmark *which aims at evaluating the quality of the overall execution of a* task *by a* robot system *in the context of a single* scenario*.*

Definition 6.8 (*Score*)

The result obtained when a robot system *is subjected to* a benchmark *(*task benchmark *or* functionality benchmark*).*

The *scores* will be used in the RoCKIn@Home competitions to order the teams according to their performance in *tasks* and *functionalities*.

Benchmarking data will be logged by the Organizing Committee and posteriorly used to analyse off-line teams performance in the RoCKIn@Home *tasks* and *functionalities*, so as to provide relevant scientific information, such as the impact of *functional modules* performance in the *robot system task* performance, or to improve the scoring system of future RoCKIn@Home competitions.

6.2 Structure of the Competition

Each *task benchmark* and *functional benchmark* will be performed by each of the competing teams several times, to ensure some level of repeatability of the results.

Task benchmarks and *functional benchmarks* will be executed as much as possible in parallel, i.e., while one team executes a *task benchmark*, another team executes a *functional benchmark* simultaneously in another area of the arena.

7 RoCKIn@Home Award Categories

RoCKIn Competition 2014 awards will be given in the form of cups for the best teams, as specified below. Every team will also receive a plaquette with the RoCKIn logo and a certificate. Awards will be given to the best teams in RoCKIn@Home *task benchmarks*, *functional benchmarks* and overall.

7.1 Awards for Task Benchmarks

The team with the highest score in each of the three *task benchmarks* will be awarded a cup ("RoCKIn@Home Best-in-class Task Benchmark <*task benchmark* title>"). When a single team participates in a given *task benchmark*, the corresponding *task benchmark* award will only be given to that team if the Executive and Technical Committees consider the team performance of exceptional level.

7.2 Awards for Functionality Benchmarks

The two top teams in the score ranking for each of the three *functionality benchmarks* will be awarded a cup ("RoCKIn@Home Best-in-Class Functionality Benchmark <*functionality benchmark* title>" and 'RoCKIn@Home Second-Best-in-Class Functionality Benchmark <*functionality benchmark* title>"). When less than three teams participate in a given *functionality benchmark*, only the "RoCKIn@Home Best-in-class Functionality Benchmark <*functionality benchmark* title>" award will be given to a team, and only if the Executive and Technical Committees consider that team's performance as excellent.

7.3 Competition Winners

Teams participating in RoCKIn@Home Competition 2014 will be ranked taking into account their rank in all the *task benchmarks*. The overall ranking will be obtained by combining task benchmark rankings using the Social Welfare principle (see `http://en.wikipedia.org/wiki/Social_welfare_function`); the overall winning team of RoCKIn@Home Competition 2014 will be the top team in this combined ranking, and will receive the corresponding award cup ("Best Team RoCKIn@Home Competition 2014"). The second and third placed teams in the ranking will also receive award cups (respectively "2nd place RoCKIn@Home Competition 2014" and "3rd place RoCKIn@Home Competition 2014")).

The three awards will be given only if more than 5 teams participate in the competition. Otherwise, only the best team will be awarded, except if it is the single team participating, in which case the Executive and Technical Committees must consider that team performance of exceptional level so as for the team to be awarded. Only teams performing the total of the three tasks will be considered for the "Best Team RoCKIn@Home Competition 2014" award.

8 RoCKIn@Home Organization

8.1 RoCKIn@Home Management

The management structure of RoCKIn@Home has been divided into three committees, namely *Executive Committee*, *Technical Committee* and the *Organization Committee*. The roles and responsibilities of those committees are described in the following paragraphs.

8.1.1 RoCKIn@Home Executive Committee

The Executive Committee (EC) is represented by the coordinators of each RoCKIn partner related to the respective activity area. The committee is mainly responsible for the overall coordination of RoCKIn@Home activities and especially for dissemination in the scientific community.

- Pedro Lima (Instituto Superior Técnico, Portugal)
- Daniele Nardi (Sapienza Università di Roma, Italy)
- Gerhard Kraetzschmar (Bonn-Rhein-Sieg University, Germany)
- Rainer Bischoff (KUKA Laboratories GmbH, Germany)
- Matteo Matteucci (Politecnico di Milano, Italy)

8.1.2 RoCKIn@Home Technical Committee

The Technical Committee (TC) is responsible for the rules of the league. Each member of the committee is involved in maintaining and improving the current rule set and also in the adherence of these rules. Other responsibilities include the qualification of teams, handling general technical issues within the league, deciding about giving awards in case the number of participants is lower than the thresholds specified in Section 7, as well as resolving any conflicts inside the league during an ongoing competition. The members of the committee are further responsible for maintaining the RoCKIn@Home Infrastructure.

The Technical Committee currently consists of the following members:

- Pedro Miraldo (Instituto Superior Técnico, Portugal)
- Luca Iocchi (Sapienza Università di Roma, Italy)
- Sven Schneider (Bonn-Rhein-Sieg University, Germany)
- Andrea Bonarini (Politecnico di Milano, Italy)

This committee can also include members of the Executive Committee.

8.1.3 RoCKIn@Home Organizing Committee

The Organizing Committee (OC) is responsible for the actual implementation of the competition, i.e. providing everything what is required to perform the various tests. Specifically, this means providing setting up the test arena(s), providing any kind of objects (e.g. manipulation objects), scheduling the tests, assigning and instructing referees, recording and publishing (intermediate) competition results and any other kind of management and advertisement duties before, during and after the competition.

The Organizing Committee currently consists of the following members:

- **Chair:** Pedro Lima (Instituto Superior Técnico, Portugal)
- João Mendes (Instituto Superior Técnico, Portugal)
- Emanuele Bastianelli (Sapienza Università di Roma, Italy)
- Frederik Hegger (Bonn-Rhein-Sieg University, Germany)
- Graham Buchanan (InnoCentive EMEA, UK)

8.2 RoCKIn@Home Infrastructure

8.2.1 RoCKIn@Home Web Page

The official RoCKIn@Home website can be reached at

`http://rockinrobotchallenge.eu/home.php`

On those web pages, teams can find introductory information about the league itself as well as relevant information about upcoming events, the most recent version of the rulebook, videos and pictures of past competitions and links to further resources like the official mailing list or wiki.

8.2.2 RoCKIn@Home Mailing List

The official RoCKIn@Home mailing list maintained by the league is as follows

`rockin-at-home@rockinrobotchallenge.eu`

Anyone can subscribe by using the following subscription page.

`http://rockinrobotchallenge.eu/mailman/listinfo/rockin-at-home`

Every subscriber is requested to register either with an email address which already encodes the real name or alternatively specify it in the provided field at the subscription page. In order to prevent the mailing list from spammers, this mailing list is moderated.

The mailing list will be used for any kind of official announcement, e.g. upcoming RoCKIn-@Home competitions, rule changes, registration deadlines or infrastructure changes. Teams are also welcome to raise any kind of question regarding the league on this list.

8.3 RoCKIn@Home Competition Organization

8.3.1 Qualification and Registration

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

All teams that intend to participate at the competition have to perform the following steps (using the forms at the web site http://rockincompetition.eu):

1. Preregistration (deadline: 15 April 2014) – optional
2. Submission of qualification material (e.g. team description paper and video; deadline: 9 May 2014) – mandatory
3. Final registration (between 1 June and 1 July 2014) – mandatory, and for qualified teams only

Preregistration A team must provide the following information during the preregistration process:

- Team name + Affiliation
- Team leader name
- Team leader email address
- Expected number of team members
- Whether the team plan to bring their own robot or not
- Middleware used for software development

This step can be considered as an *Intention of Participation* declaration and serves as planning basis for the Organizing Committee.

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

The evaluation criteria will include, but will not be limited to, the following items:

- Team description paper
- Team web site
- Relevant scientific contribution/publications
- Professional quality of robot and software
- Novelty of approach
- Relevance to domestic service robotics
- Performance in other competitions
- Contribution to RoCKIn@Home league (e.g. by organization of events or provision and sharing of knowledge)

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

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

The body of the TDP should contain information on the following: focus of research/research interests:

- Description of the hardware, including an image of the robot(s)
- Description of the software, esp. the functional and software architectures
- Main involved research areas in the team work
- Innovative technology (if any)
- Reusability of the system or parts thereof
- Applicability and relevance to domestic service robotics

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

The length of the team description paper is limited to 6 pages and has to be to submitted in the IEEE Conference Proceedings format[14].

Registration Only if a team has passed the qualification procedure successfully it is allowed to register officially for the competition and has to provide additional information, e.g., the exact number of team members. Further information about the registration procedure will be communicated through the mailing list of qualified teams. The number of people to register per team may be unlimited, but during the competition the organizers will provide space only for 6 persons to work at tables in the team area. During the final registration, each team has to designate one member as team leader. A change of the team leader must be communicated to the Organizing Committee.

[14] http://www.ieee.org/conferences_events/conferences/publishing/templates.html

8.3.2 Setup and Schedule

RoCKIn Competition 2014 will take place in La Cité de L'Espace in Toulouse, France, from 26-30 November 2014.

24–25 November will be the assembly days, during which the arenas, team areas, power, audiovisual equipment and other infrastructure will be put in place.

26–27 November will be setup days, that the teams can use to unpack their robots, calibrate the robot systems, and get information about the test bed, important objects and other relevant details. The site will be closed to the public.

There will be three competition days: 28, 29 and 30 November. During those days, the competitions will occur following the procedures and rules described in the subsections of this document with the same title. The site will be accessible to the public during the actual competitions.

The award and closing ceremony will take place in the evening of the last day, 30 November 2014.

Several satellite events, with the participation of industry and academia stakeholders, will take place during the five days of the main event. These include talks by members of RoCKIn's Advisory Board, and the assessment of the Competition by the members of RoCKIn's Experts Board.

Schedule: For the scheduling of particular stages, tests, and technical challenges of the competition the following applies:

- The exact schedule of task-functionality tests will be announced one week before the actual competition by the OC on both the website and the mailing list of qualified teams.
- In order to avoid to much "traffic" inside the testbed, an additional schedule only for test slots will be established on site by the OC.
- A set of test slots will be assigned to each team between the official test slots, where a team has exclusive access to the testbed without any other team/robot inside the arena.

Setup: For the arrival, setup, and preparation of teams participating in the competition, the following procedures apply:

- A first draft of the rulebook will be made public on 1 April 2014.
- Revisions will be possible and updated in the online versions of the document, based on suggestions of all relevant stakeholders (including pre-registered and registered teams) until 31 May 2014.
- The final version of the rulebook will be made public, no later than eight weeks before the actual event, by the the TC, including all the items referred as open in this document (e.g., some benchmarking and scoring items) and revisions resulting from the discussion referred in the previous item.
- The competition side will be divided into a competition arena and a team area.
- The competition arena consists of one or more testbeds (the arena) and is open for public.
- The arena must be kept clean and in a representable condition all the time.
- The team area is a dedicated area only for team members, no public access here.
- Each team will be assigned to a designated area with tables and chairs (based on the number of team members), with power sockets, a shelf internet connection and a reasonable area to park their robot and other equipment.

8.3.3 Competition Execution

- Referees will be determined by the OC out of the group of team leaders and TC members.
- The referees ensure the correct execution of a benchmark run, are in charge of keeping the time and counting the scores, being always helped by a TC or OC member.
- In case of any dangerous situation the referees are allowed to immediately stop a run and trigger the emergency stop functionality of the respective robot.
- The official language for all kind of communication within the league is English (e.g., team leader meetings, announcements, schedule)
- The order in which the teams have to perform a particular benchmark run will be determined by a draw through the OC.
- The order will be announced on the day before the actual run.
- No team members or other persons are allowed to be in the arena during an official benchmark run (only if the rulebook explicitly allows/requires this).
- Regular team leader meetings (every day) will be organized and announced by the TC/OC during the competition in order to discuss open issues for upcoming benchmark runs.

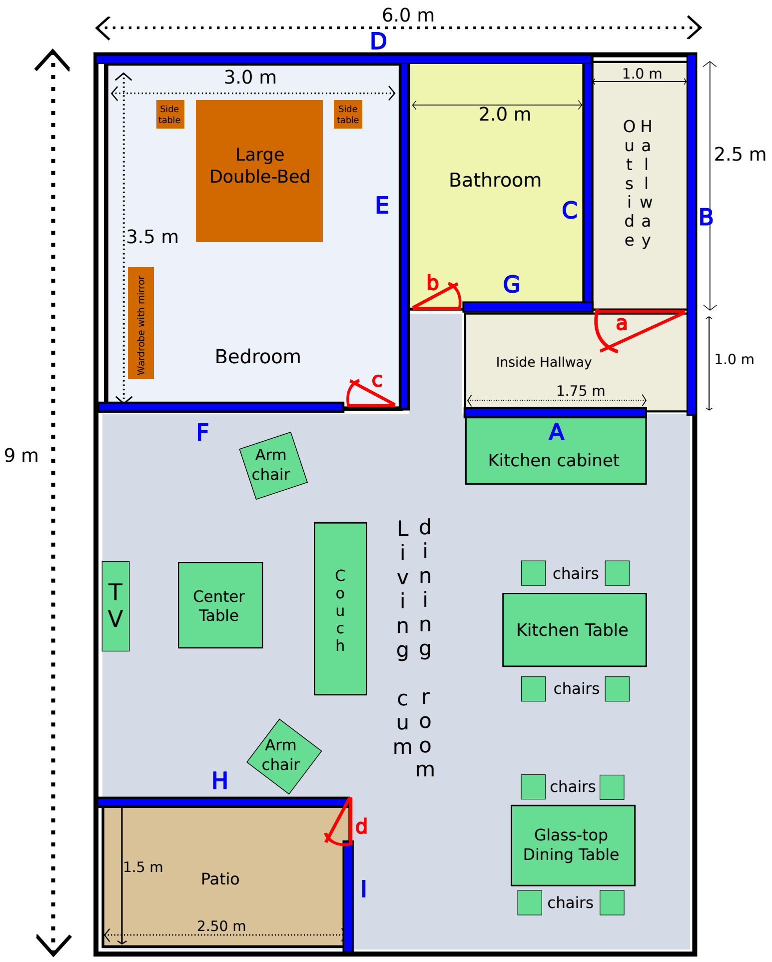
8.3.4 Measurements Recording

Several variables of interest will be recorded by the EC, TC and OC during the actual runs of the teams during the competition, while performing their *task* and *functionality benchmarks*. Some of these will be performed by RoCKIn equipment, though requiring the installation of markers on the team robots. Other logging will require the teams to accommodate, in their software, modules that respond to solicitations from test bed-installed software.

Details on these procedures will be provided closer to the competition dates, but the teams must be ready to commit to such requirements as one of the key requirements to be selected for the RoCKIn competitions.

The logging and benchmarking activities will be under the responsibility of Giulio Fontana (Politecnico di Milano, Italy).

A The @Home Test Bed at IST - Implementation Details



	Width	Height
A	1.75 m	1.50 m
B	3.50 m	
C	2.50 m	
D	5.00 m	
E	3.50 m	1.00 m
F + c	3.00 m	
G + b	2.00 m	
H	2.50 m	
I + d	1.50 m	
a	1.00 m	

* Only wall A is the high wall
* A - I in blue are wall segments
* a - d in red are doors
* doors c,b and d should have a minimum width of 80 cm

Figure 6: Layout and dimensions of the @Home testbed at ISR/IST, Lisbon.

Based on the general design and specifications of the RoCKIn@Home test bed detailed previously in this text, in this sub-section we present the exact design specifications of the @Home test bed installed at the premises of the Institute for Systems and Robotics (ISR) of IST, Lisbon. Note that this @Home test bed is not an exact replica of the actual RoCKIn@Home competition test bed but fits its general specifications and, as such, can be seen as a concrete example of using them for an actual implementation. Pictures of this test bed are presented in Figures 8–10.

A.1 Environment Structure and Properties

- Ensemble of five spatial areas accessible to the robots and three others inaccessible. Rooms and spatial areas (accessible to the robot): Living room, dining room, kitchen, inside hallway, bedroom. Spatial areas (inaccessible to the robot): outside hallway, bathroom, patio.
- Flat with no stairs
- Open-plan architecture followed for the living room, dining room and kitchen. The bedroom is separated by walls.
- Sizes of spatial areas: Please refer to Figure 6.
- Connectivity of spatial areas: Same as depicted in Figure 4.

- Floor: Parquet, well-leveled and uniform all over the test bed.
- Walls: Final version not yet in place – will be reported in version 3 of this document.
- Ceilings: Uniform false roof made of coated and perforated aluminum segments without slopes.
- Bedroom specifications (and furnitures): one open-able and tilt-able window, a double bed, two side tables, two table lamps and one large wardrobe with mirror.
- Living room specification (and furnitures): contains windows that cannot be opened, couch, two armchairs, one coffee table, one TV table and one large floor lamp.
- Dining room specification (and furnitures): One glass-top dining table and 2 dining chairs.
- Kitchen specification (and furnitures): One kitchen table and 2 chairs, kitchen cabinet with multiple drawers and wash sink, two wall-mounted kitchen shelves.
- Hallway: consists of one coat rack.

A.2 Objects in the Environment

A list of all objects present in the environment of this test bed is given below through Tables 1 to 3. As most of the objects were purchased from the IKEA furniture store, the IKEA-reference code of the objects are provided to facilitate the readers of this documents. Note that this reference code is from the Portuguese version of IKEA's homepage[15].

A.3 Network Devices

The @Home Testbed at IST is equipped with network devices capable of opening/closing the blind and turning on/off the lamps. The network is organized as shown in Figure 7 followed by a description of each block.

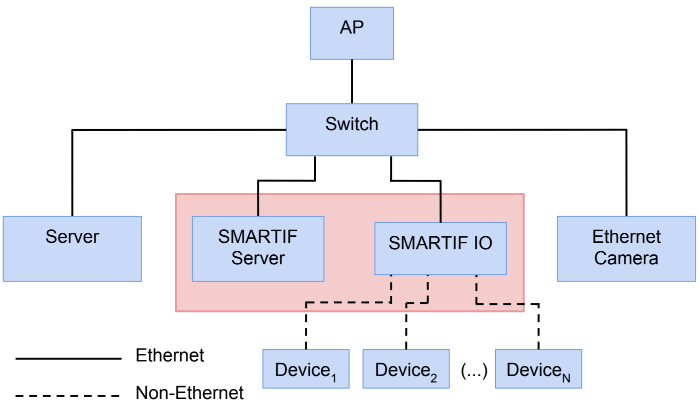


Figure 7: Diagram of the network connections in the @Home testbed at ISR/IST, Lisbon.

- Server: A computer used to manage the network.
- Switch: An ethernet switch used to connect all the devices.

[15] www.ikea.pt

Task-relevant Objects					
Navigation-related					
Object	**Quantity**	**IKEA Code**	**Size (cm)**	**Ref-code**	**Observations**
Double bed	1	BRUSALI	140x200	702.499.07	bed-frame
	1	BRUSALI	140x200	901.245.34	bars
Matress	1	HAFSLO	140x200x18	602.443.64	
Slatted bed base	1	SULTAN LÖDINGEN	140x200	401.602.37	
Bedside tables	2	BRUSALI	44x36	502.501.57	
Wardrobe + mirror	1	BRUSALI	131x190	402.501.67	
Rug	1	HAMPEN	80x80	502.037.88	green
	1	HAMPEN	80x80	102.037.90	red
Coffee table	1	LACK	90x55	401.042.94	black
Couch	1	KLIPPAN		100.722.56	couch
	1			202.788.55	cover
Armchairs	2	PELLO		500.784.64	
Bookshelf	1	BORGSJÖ	75x181 cm	002.209.50	shelf
				202.209.54	doors in glass
Dining table	1	INGATORP	59/88/117x78	802.214.27	without glass
Dining Chairs	3	SIGURD		002.522.48	black
	1	KAUSTBY		400.441.96	brown
Kitchen cupboard		FYNDIG			white
	1		80x60x86	702.266.80	closet with doors
	1		126x60.6	502.375.33	top cover
	1		40x60x86	702.266.75	closet with 1 door and 1 drawer
	1		70x50	502.021.33	sink
	1	SUNDSVIK		800.318.61	tap
	2	SATTA		602.700.70	(1 red and 1 transparent)
Coat Rack	1	KROGKIG	128 (height)	201.745.08	multi-color
	1	HEMNES	185 (height)	002.468.70	black
TV table	1	BYAS	160x42x45	802.277.97	with drawers
Kitchen Shelf	2	EKBY JARPEN / VALTER	119x28	699.265.93	
Dinning table - With Glass	1	GLIVARP	75/110x70	802.423.02	with glass

Table 1: List of task-relevant navigation-related objects in the environment

Task-relevant Objects				
Manipulation-related				
Object	**Quantity**	**IKEA Code**	**Ref-code**	**Observations**
Coffee Mugs	8	FÄRGRIK (2) + OMBYTLIG (1) + TECKEN (1) + UNGDOM (1 pack of 4)	401.439.93 + 202.099.80 + 702.160.49 + 702.348.97	
Coffee cups	6	DINERA	001.525.50	
Dessert plates	1	ÖVERENS	202.097.20	(1 pack of 6)
Cake plate	1	ARV BRÖLLOP	401.255.50	
Small glasses	6	GODIS	800.921.09	
Large glasses	6	POKAL + KROKETT	102.704.78 + 201.952.52	
Water jug	1	LÖNSAM + VÄNLIG	202.135.43 + 101.316.99	

Table 2: List of task-relevant manipulation-related objects in the environment

- AP: An Access Point where the robot is supposed to connect. This is the only connection between the robot and the network. Acts as a bridge between WLAN and LAN. The Access Points used work in Dual-band Standalone 802.11a/g/n. The models used are Cisco AIR - AP1042N-E-K9 [16].

- Ethernet Camera: Perspective camera facing the Outside Hallway. The camera can have its parameters (frame rate, resolution, color gains) changed over ethernet and it is not motor controlled (no pan-tilt). The model of the camera can be found here [17].

- Devices: Different devices may exist in the house. In our test bed the devices are: a motor to control the window blinds, 3 controlled power plugs, 1 light dimmer, and 1 door bell button.

- SMARTIF IO: This module controls the different devices/sensors existing in the house. It is prepared to add more devices in case of need.

- SMARTIF Server: Device responsible for the communication between the SMARTIF IO mentioned above and the network. It is also where the system configurations (through the "SMARTIF Config Tool") are stored and changed. Technical details regarding SMARTIF products can be found at the official site [18].

In our network, robots are supposed to communicate with the devices by sending a message to a specific IP and port. A SDK existent on the server will receive that message and transmit it to the SMARTIF IO witch will then control the device. Images from the ethernet camera are also available through the AP. The quick set-up in the SMARTIF Configuration Tool, along with the possibility of adding/removing more devices, allows us to change the network if needed and with ease.

[16] `http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-1140-series/data_sheet_c78-609338.html`
[17] `http://www.axis.com/products/cam_p1344`
[18] `http://www.smartif.com/smarthome/techspecs.html`

Non-task-relevant Objects				
Object	**Quantity**	**IKEA Code**	**Ref-code**	**Observations**
Curtains	1	RITVA	145x300	24 - number in the curtains' section. 1 pack of 2
Table mats	8		102.361.11	
Napkins	1		101.012.73	pack of 50
Couch Pillows	3	FJADRAR	400.667.39	inside of the pillow
	1	STOCKHOLM	302.366.76	cover of the pillow (multi-color, squares)
	1	GURLI	202.496.03	cover (plain blue)
	1	SVARTTALL	002.897.13	cover (spots)
Linien for bed	1	DVALA	401.499.52	
	1	SVARTTALL	602.911.38	
Pillow for bed	2	GOSA VADD	501.291.66	
Lamp (small, bed side)	2	KVART	601.524.58	
Lamp (floor, living room)	1	SAMTID	202.865.63	white
Plants in pots (small)	3	FEJKA	702.514.72	
Plants in pots (large)	1	FEJKA	302.340.07	
Small picture frames with pics	6	NYTTJA	601.674.93	
Medium pic frames	5	NYTTJA	601.170.35	
Large paintings	1		102.340.46	each pack contains 3 pics without frame
Decoration bowl	2		901.244.02	bowl
	2		902.508.86	stuffing for the bowl (dry flowers)
Triples of candles	3	FLORERA	302.514.69	
Flower Jar	2	BLOMSTER	301.136.18	jar
	12	SNARTIG	101.391.91	flowers

Table 3: List of Non-task-relevant objects in the environment

Figure 8: View of the living room in the @Home test bed (without walls) at IST.

Figure 9: View of the dining space and kitchen in the @Home test bed (without walls) at IST.

Figure 10: View of the living room and bedroom in the @Home test bed (without walls) at IST.

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[1] S. Schneider, G. K. (editors), A. Ahmad, F. Amigoni, I. Awaad, J. Berghofer, R. Bischoff, A. Bonarini, R. Dwiputra, F. Hegger, N. Hochgeschwender, L. Iocchi, G. Kraetzschmar, P. Lima, M. Matteucci, D. Nardi, and S. Schneider, "RoCKIn@Home – A Competition for Domestic Service Robots – RoCKIn@Home in a Nutshell," Bonn-Rhein-Sieg University of Applied Sciences, Sankt Augustin, Germany, Deliverable D-2.1.1 nutshell (public), The RoCKIn Project (FP7-ICT-601012 grant agreement number 601012), March 2014.

[2] DHL. Packing material. [Online]. Available: https://www.dhl.de/en/paket/pakete-versenden/deutschlandweit-versenden/verpacken.html

[3] D. Croce, G. Castellucci, and E. Bastianelli, "Structured learning for semantic role labeling." *Intelligenza Artificiale*, vol. 6, no. 2, pp. 163–176, 2012.

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