Episode 2
Through the Door

Technical Committee

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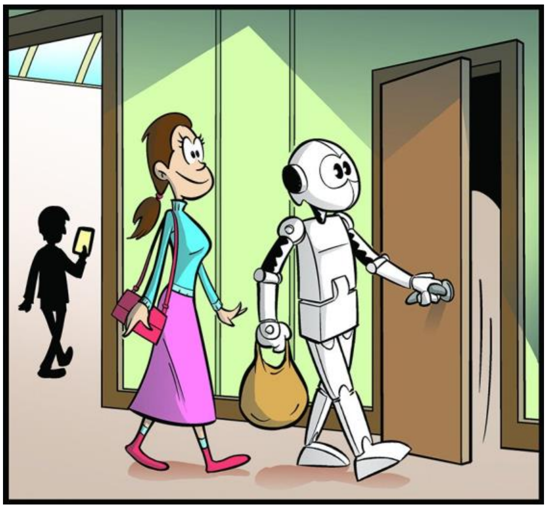
1. General Description



Episode 2 aims at evaluating the capability of a robot to interact with one of the most ubiquitous devices found in environments designed for humans: the **hinged door**.

A hinged door (often simply called "door" in the following) is an especially challenging device for robots. This is because it has a very long history[1] of development over which the only design constraints were cost and fitness for human usage. Consequently, a door is one of the pieces of human engineering that are most closely matched to human capabilities and limitations. Due to this perfect match, a door is as easy and natural to use for standard humans as it is awkward or impossible for "non-standard" actors. These include -for instance- small children, people on wheelchairs, animals and mobile machines. In the context of this document, we are going to focus on one specific kind of mobile machine: the **autonomous robot**.

In environments that can be subject to modifications to make them more machine-friendly (such as factories), hinged doors are usually banned and substituted with more suitable devices, e.g. automated sliding doors. However, approach taken by research on autonomous robots is usually the opposite, i.e. it is the robot which must adapt -thanks to its physical and/or cognitive capabilities- to unmodified human environments. Given the previous considerations, this puts "operating a hinged door" very high on a hypothetical shortlist of capabilities that any robot must possess to successfully operate in common human environments.

[1] The history of the hinged door is indeed extraordinarily long. Devices similar to those used today date back to the Roman Empire, while stone-hinged doors were in use in ancient Egypt more than 3500 years ago. A consequence of this is that doors are extraordinarily present -with different roles- in human folklore and culture, as exemplified by the (slightly edited) image above.

1.1 Definition of “door”

We humans are so used to doors, and their features are so standardised, that it seems strange to write them down in a systematic way. However, for the sake of a clear and unambiguous definition of the type of problem represented by Episode 2, it is useful to define a (hinged) door as a device with the following features:

- the door has the shape of a vertical and flat *panel* surrounded by a *frame*;
- the panel can be transparent to light, opaque or light-diffusive, or be a combination of areas with different light-transmitting properties;
- panel dimensions are suitable for easy traversal by a standard human (for indoor applications, typical dimensions are 70-90 cm of width by 210 cm of height);
- there may be *subpanels* enclosed in the door panel, i.e. areas of the door panel having different visual properties (colour, light transmission, texture, ...) from the rest of the panel;
- the door’s only possibility of movement is rotation around a vertical axis located in proximity (i.e., within a few centimetres) from one of the vertical edges of the panel: the physical mechanism supporting the rotation is usually composed of two or more *hinges*;
- the hinges are the only points of contact between the door panel and the rest of the environment, and connect the panel to the frame;
- the door is intended to be incorporated into a wall or other partition separating two environments: the door is *closed* when coplanar with such partition, and *open* when in any other position;
- usually angular movement (around the rotation axis) is only allowed in one of the two possible directions: i.e., the door panel can move into one of the two environments separated by the partitioning wall, but not into the other;
- the range of angular positions that the door can take spans from 0° (corresponding to the *closed* position) to at 90° or more;
- the hinges support the weight of the door panel so that -whatever its angular position- its lower edge is in close proximity to the floor but does not touch it;
- the frame surrounds the door panel along its vertical edges and usually also along its upper edge, but not along the lower edge (i.e., the one in proximity to the floor);
- the door has a locking mechanism that, when the door is closed, must be disengaged before the door can be moved;
- the door is manipulated by through the handling of a *handle*, which can take a wide variety of shapes but is always designed to be easily gripped by humans;
- handles are usually fitted on both sides of the door panel, to let users operate it from both environments separated by the door;
- the handle is located on the door panel in the vicinity of the vertical edge of the door that is farther from the rotation axis: this has the consequence of transforming modest forces perpendicular to the door panel applied to the handle into a significant torque around the rotation axis;
- the height of the handles from the ground is such that a standing adult human of standard height can easily manipulate them;
- the locking mechanism is usually linked to the handle, in the sense that the handle must be moved (rotated, depressed, ...) to unlock the door;
- the locking mechanism is usually designed in such a way that to lock the door it is usually sufficient to push it to its *closed* position;

- unlocking the door can require the application of significant forces to the handle, while moving the door once unlocked requires, in optimal conditions, the application of very small forces.

Section 4 of this document provides information about the setup used to implement a hinged door in the context of Episode 2.

It must be noted that the features above describe doors that do not have any mechanisms influencing the dynamic behaviour of the door panel. Such mechanisms are indeed common and include both intentional and unintentional ones.

Among intentional alterations to door behaviour, we can cite:

- elastic forces opposing panel rotation;
- automatic (elastic or motorised) return to the closed position;
- viscous damping of panel rotation.

Unintentional alterations to door behaviour are usually due to faults and/or obstructions, and include:

- friction, either constant or dependent on angular position;
- limitations of the angular range;
- torque opposing door motion, either constant or dependent on the angular position of the panel (e.g., effect of wind);
- effect of other users operating the door from the other side;
- ...

In many real-world situations more than one among the above cited alterations can affect the same door, thus leading to a wide range of altered door behaviours with respect to the baseline.

Episode 2 (in its 2022-12 version) focuses on baseline door behaviour.

2. Main scientific challenge

Dexterous motions and gestures are of key interest to address countless applications where the robot must act on the environment. This is especially relevant for humanoid robots that are designed to surrogate -- and eventually substitute -- human motions, and to properly behave in a human-friendly world. In fact, human environments, and its components, are designed to accommodate our body strengths and limitations. For example, let us consider the shape of keyboards, chairs, windows, doors and handles. Operating in such environments without the capability to interact with those components is extremely difficult and prevents agents to be effective and independent.

Robots are no exception, and to allow them to freely operate in our world, we need to provide them with the ability to smoothly interact with all the environmental components, and to replicate human motions. This is an extremely challenging task that has become to be regarded as fundamental to truly enable autonomy on robots.

In this episode, we focus on one of these robot-environment interactions to improve local robot behaviour in addressing doors [Meeussen et al., 2010; Rühr et al., 2012; Gu et al., 2017]. This episode is designed to provide a common testbed and a baseline for generating effective behaviours for robots acting in typical human-populated environments.

Since doors are a constant and dynamic component of our scenarios, being capable of mastering doors is key to develop autonomy in robots. Moreover, not being able to cope with them can be harmful as it might prevent the robot to complete its jobs (e.g. delivery).

The community has already shown a great interest in tackling such a problem. Given the existing literature, the task of opening a door can be divided in four distinct phases: detection, approach, manipulation and traversal. Hence, related works can be classified in accordance with their contribution to these phases. For example, several approaches have been proposed to door detection. Image-based methods have been proven to be capable to detect different doors in various scenarios [Borgsen et al., 2014; Goron et al., 2012], though this class of solution is often affected by false positives [Sekkal et al., 2013].
Conversely, [Quintana et al., 2016] proposes a model-based method for detecting doors in cluttered environments using rgb-d sensor information. [Chen et al, 2014] describe their solution based on a deep model learned through a convolutional network. It is important to say that, as highlighted by these contributions, the challenge of this phase of the task is to develop a system able to recognize doors (1) in different states (closed, open and semi-open) [Quintana et al., 2016] and (2) with different environmental conditions (cluttering, occlusions, lightning) [Chen et al, 2014], as well as (3) to estimate the orientation of the door [Klingbeil et al., 2010].

The approach phase is key to have an exploitable positioning of the robot with respect to the door. Such a task is usually considered as a navigation and positioning task, which is not strictly depending on the object to approach [Kriegel et al., 2011; Koyuncu et al., 2010]. However, we can summarize the key aspects that might affect a successful robot positioning in the object-target appearance, and the robot embodiment [Gomez et al., 2013].

The manipulation phase is key to this episode and usually requires the robot to detect the type of handle, trigger the related behaviour, and perform the desired movement [Li et al., 2015]. This is a crucial phase of the task that requires visual monitoring and manipulation, simultaneously. For example, [Rusu et al., 2009; Klingbeil et al., 2010] exploit 3D laser scan to detect the type of handle and determine robot motions. [Meeussen et al., 2010] improve handle detection by considering both geometry and appearance. Then, upon detection, the authors use a compliant and force-controlled task formalism (TFF - Task Frame Formalism) to plan for robot motions. Similarly, [Rühr et al., 2012] propose a general framework to open doors and drawers. They also rely on geometry and appearance of the handle, but they improve robot manipulation skill by exploiting impedance control and learning the kinematic model of the objects. It is worth highlighting that the authors store learned handle models to improve future interactions and motions executions. Differently, [Gu et al., 2017] exploit deep learning to develop an end-to-end system that collects images and generate desired motions by relying upon off-policy training of deep Q-functions. The author reduced training time by running several parallel simulations of the robot. Numerous approaches address the problem of locating and manipulating doors handles; however, a key challenge remains that of generating a flexible approach able to generalize to different types of handles and doors (e.g. sliding doors).

The last phase of the task is to traverse the door, which can be considered as a navigation task once the door is open. Few works start the manoeuvre while opening the door [Jain et al., 2008]. For example, [Chitta et al., 2010] generate a cost map depending on the current position of the door and then run an Anytime Repairing A* (ARA*) to determine the best motion for the robot base. [Srinivasa et al., 2010] introduce HERB, a complete system able to manipulate and traverse a door simultaneously. The authors developed the Constrained Bidirectional Rapidly-exploring Random Tree (CBiRRT) to generate effective robot motions.

The key challenge of this phase is to provide the robot with the ability to plan several steps ahead of both base motions and handle manipulation actions.

The contributions highlight how door negotiation is widely perceived as a fundamental skill for achieving autonomy through the robotics community, a fact confirmed by the role given to it in robotic competitions as the DARPA challenge[2]. In this competition, the robots had to approach a closed (hinged) door, open it and walk through it. The task was considered complete when all points of robot ground contact were past the door threshold[3]. In this context, the IHMC team [Johnson et al., 2015] exploited a combination of two methods to locate handles (and doors). The first a colouring technique to adapt the colour in a point cloud and the second a texturing method to adapt the colour of the real object to the point cloud. The robot then manipulates the handle by exploiting the concept of interactable object as introduced by the authors. In [Banerjee et al., 2015] the WPI-CMU team exploited a mix of 2D and 3D geometric segmentation techniques to detect the door and approach it. Then, the robot uses a modified TrajOpt algorithm to generate effective trajectories while maintaining a reduced computation time. [Zucker et al., 2015] describe the DARPA challenge of the DRC-HUBO robot. They also detect the door handle through geometrical features and plan for robot motions by exploiting key poses to interpolate the task.
Despite the remarkable contributions and effort done to address and complete this challenge, proposed solutions still do not satisfy the expected level of dexterity nor achieve the desired natural and robust behaviour. This suggests the difficulty of mastering such a task for an autonomous robot, and the need to tackle such a challenge. In the SciRoc project we propose the Door episode to contribute in this direction.

We come finally to Episode 2, whose goal is to define a standardised way to test the capabilities of autonomous robots to solve the door-related problems described in this section. In doing so, Episode 2 leverages the methodological framework developed by former research projects RoCKIn and RockEU2 [Amigoni et al., 2015]. In fact, the ambitions of Episode 2 go beyond a simple “door test” and aim, instead, at a scientifically grounded “door benchmark”.

3. Platforms allowed

This episode is open to any robot capable of executing the actions described in Section 6, (possibly with human help when allowed). Being able to manipulate the door handle is not necessary to complete Episode 2, though it is necessary to get a full score (see Section 8 for details).
The robot should be easily moved in and out the competition scenario, even if completely unresponsive, by maximum two team members with minimum effort.
The robot must be provided with a clearly visible and easily accessible **emergency button** that can be pressed at any time by anyone involved in the episode (referees, team members, etc.). Upon pressing the emergency button, the robot should immediately stop executing any motion with any moving parts.
Teams must provide a document describing safety procedures and risk analysis for the use of their robot and any other equipment used during the challenge (see Section 12).

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[2] A quick recapitulation of the tasks that the robots participating to the last DARPA challenge were required to perform is available in video form here: https://www.youtube.com/watch?v=YQvEy3qTm8c
[3] Defining a criterium to decide if a robot has gone through a door is indeed a key problem. The approach of Episode 2 is described in Section 6 of this document.

IMPORTANT General rule: Robot inspection will be performed to test safety devices and procedures before the runs of the competition. No robot is allowed to participate in any test if safety procedures are not completed. Teams must guarantee that safety devices and procedures are always working and enabled. Referees can check safety procedures at any time during the competition.

4. Scenario Setup

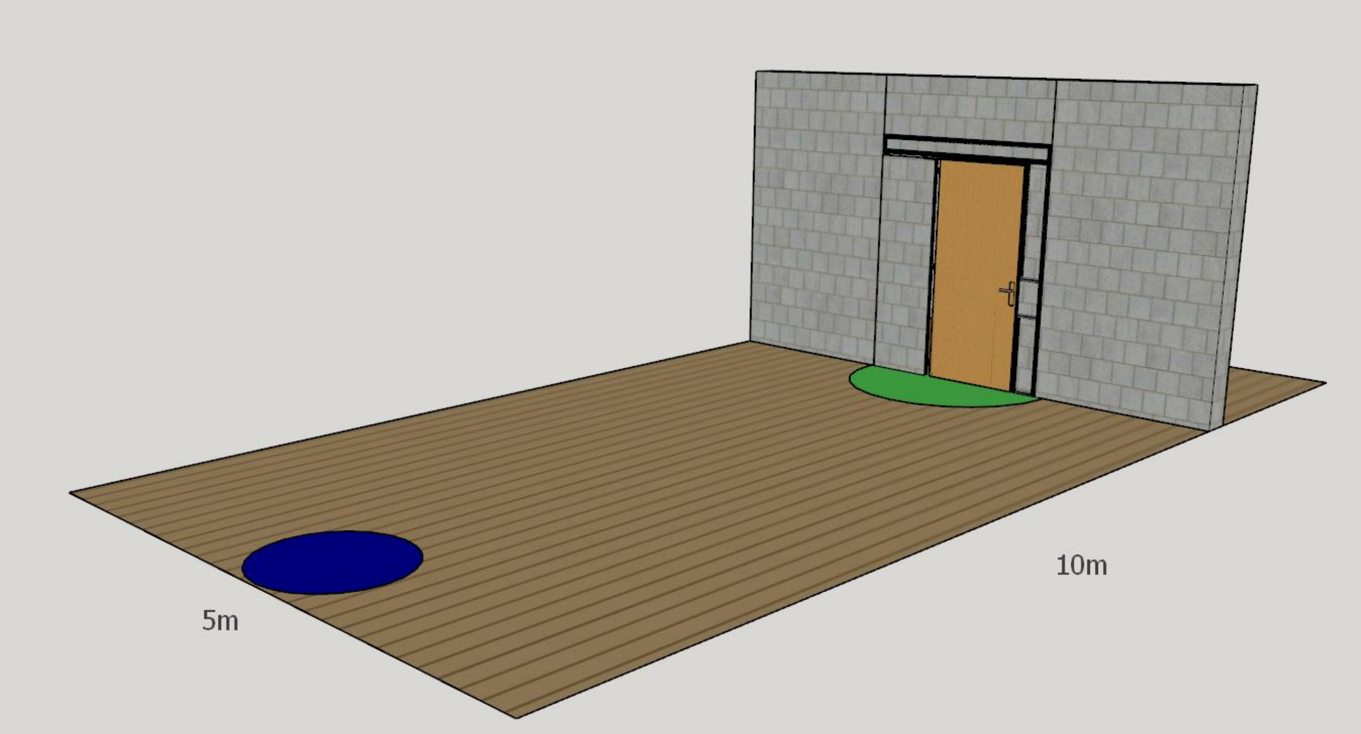
The scenario setup is composed of a **door assembly** comprising the door that the robot has to operate, and a surrounding **test area** where the robot can move. Additional information about the setup concerns the materials used to build the door assembly and the methods to affix the door assembly to the floor of the test area, so that it will not be moved if the robot hits its elements or applies anomalous forces to the door. All these elements are defined in the following parts of this section.

4.1 Door assembly

Being Episode 2 focused on door operation by robots, the key element of the scenario setup is -quite naturally- a door. While all locations where Episode 2 takes place can be reasonably be expected to include doors, it is not possible to expect that such doors are both suitable for Episode 2 and sufficiently similar from one location to the other. For this reason, a suitable door setup must be prepared locally at every venue where the Episode takes place. We call this setup *door assembly*.
The door assembly must fulfil requirements that are partly conflicting. Among these:

- it is necessary that the door is fully realistic, but also sufficiently robust not to be damaged by the robots;
- it is preferable that the door cover can be easily exchanged -in order to test how robots behave with different types;
- it must be sufficiently stable to withstand being hit by a robot without collapsing, and at the same time it must be as small and light as possible for easy transportation and storage;
- it should be built in such a way that additional devices can be easily added to the assembly (e.g., laboratory equipment) while maintaining a standard-door look;
- it should be compatible with both a stand-alone, self-supported installation and with being mounted as part (or at one extremity of) existing walls and partitions;
- if installed in a stand-alone way it should include wall-like surfaces on the sides of the door in order to simulate a realistic setting, while such surfaces should be absent for in-wall installations.

The test area for Episode 2 is the area where the door assembly is located, comprising also the operating areas for the robot on both sides of the door. Its preferred shape and dimensions are those of a rectangle of 6m x 6m, where the projection on the floor of the door panel (door closed) lies on the major axis of the test area and is perpendicular to it. In the preferred setup, the plane of the door is at a distance of 3m from one of the short sides of the test area, and the start pose of the robot (as exemplified blue circle in the picture, see Section 6) lies within the larger of the two areas that the plane of the door divides the test area into, i.e. in the 3m x 5m portion that is on the left in the figure.



As already specified above, these features of the test area are *preferred* but not mandatory. Shape, dimensions and positioning of the test area, as well as location of the door assembly within it, can be subjected to change to adapt the testbed to the available space where it is installed.
The only mandatory constraints on the test area are those needed for the feasibility of the benchmark procedure described in Section 6 of this document, i.e.:

1. every robot executing the benchmark must be given sufficient space to comfortably manoeuvre on both sides of the door;
2. the door panel must be visible from the starting position of the robot (possibly requiring only a rotation of the robot on the spot to reach visibility, but no translation).

A note on door panels

Door dimensions are standardised. **90 cm of width is the dimension chosen for Episode 2.** It is also the largest of the most common standard widths.
It must be noted that a 90 cm *door* does not have a 90 cm *door panel*: standards specify the dimension of the passage, not of the panel. Door panels are slightly wider than the passage, as they are designed to rest against the borders of the door frame when closed: this makes the door not bi-directional (differently from panel of the door assembly of Episode 2), as it lets the door only open in one direction.
The arrangement where the door goes against the frame when closed is useful to limit the passage of air around the door. To further limit such passage, standard doors also have “lips” protruding from both long sides (i.e. the one with the hinges and the opposite one) that partially overlap elements of the frame. Such “lips” also contribute to increase the overall width of the door panel with respect to the width of the door passage.
In the end, dimensions for a standard 90 cm door are:

- width of passage: 90 cm
- height of passage: 210 cm
- width of door panel, including lips: 93 cm
- width of door panel, without lips: 91.5 cm

4.3 Materials

For what concerns the door assembly, if it is specially built at the location where the Episode takes place, for easy construction and adaptation it is suggested to use modular aluminium profiles as structural elements[4]. This way, not only assembling and modifying the assembly is easier, but also -and most importantly- additional elements can be fitted to the frame as required in a secure and quick way to suit the requirements of each instalment of Episode 2, without any need to modify the structure in any way. Such modular systems, in fact, include mechanisms (such as slots and special nuts to be inserted into the slots) to easily mount and dismount additional objects.

5. Smart City Data Hub Interaction

The Smart City data hub will provide the links to the competition. The interface will receive activity from the robot required for the benchmarking and scoring. This data hub is part of data acquisition and management infrastructure live sensors and robotic teleoperation for different functions of the city (transport, environment, energy, water, etc.). The data gathered by the robots in this episode, such as the status in the scenario, the start and end of activities within the task are communicated to the infrastructure to contribute to the smart city data platform.

Teams are notified before the competition by the competition organizers about the data and communication protocols, and which messages are required to track progress in the competition.

6. Procedure

The procedure that a robot must follow to execute the benchmark of Episode 2 is described below. In the description we will refer to the elements of the door as defined in Section 1.1.
Please note that in this section action descriptions are focused on their execution; the criteria used to determine -for scoring purposes- if an action has been successfully executed are described in Section 8.

The door used for Episode 2 is always in the *closed* position at the start of the benchmark. The closed door is also locked by its standard locking mechanism. The robot system subjected to the benchmark of Episode 2 is required to perform, in order, the following actions:

1. **Reach or be brought to the start pose.**
   [This is a preparatory step that does not contribute to the scoring. For this reason, it is acceptable if the robot is positioned in the start pose by human team members.] The position of the start pose is chosen by the referees, in the previous pictures it is represented by the blue circle on the ground. Its maximum distance from the door is 8m (calculated on a horizontal plane, from the door handle). The orientation of the start pose does not necessarily put the door in view of the robot; however, the door panel will be fully visible to the robot from the start pose.
   Episode 2's door will be incorporated into a wall or other partition. More than one door can be present in the environment where the Episode takes place: in such a case the robot should select the door that is closest to the start pose.

[4] Many suppliers exist of such elements: an example is https://www.item24.com/

2. **Approach the door.**
At least one point of the robot must arrive within 1 m from the handle located on the *starting side* of the door assembly. The starting side of the door assembly is the side visible from the start pose[5].
3. **Touch the door handle.**
There are no limitations concerning what part of the robot touches the handle, provided that a physical contact occurs.
4. **Unlock the door.**
Unlocking the door means “prepare it so that it can be subsequently opened by applying only a pushing or pulling force”. For most types of locking mechanism, the process of opening the door must be initiated during the unlocking to be successful. In these cases, action “unlock the door” comprises also action “initiate opening”, as the robot will need to execute both actions in a coordinated way. The two types of handles are the lever handle and the knob handle (see section 6.2).
It is faculty of the robot’s team to request that a referee executes action “Unlock the door” instead of having it executed by the robot. The team can take this decision before the execution of the Episode or during its execution: in both cases, the referee waits for the robot to have completed the “Touch the handle” action before proceeding to unlock the door.
When referee intervention has been requested, as soon as the referee touches the door or the handle the unlocking action is considered irreversibly as executed by the referee, independently from the actions of the robot and their effects.
If the door lock requires initiation of door opening concurrently with the unlocking, the referee will also perform such initiation, leaving the door in a state that: (i) is stationary and (ii) is as close to the closed state as allowed by the physical characteristics of the locking mechanism and the need to leave the door unlocked. If the robot accidentally locks the door again after it has been unlocked by a referee, the referee will repeat the unlocking action. This can occur any number of times but leads to penalisation (see Section 8).
IMPORTANT: the referee will proceed to unlock the door only if they feel that the procedure is completely safe. No actions requiring proximity between robot and referee will be executed if the robot is behaving in a way that is deemed as “possibly dangerous” by the referee. To promote safety, whenever possible the referee will try to unlock the door from the other side.
5. **Pass through the door.**
The robot needs to open the (now unlocked) door sufficiently for the robot to go through it, and to navigate through the opening to reach the other side. The opening of the door can be executed with any technique (excluding those that can damage the door), e.g. by manipulating the handle or the door panel with a hand effector, by pushing the panel using the robot base, by using a special-purpose tool, etc.
6. **Close the door.**
The door must be moved towards its closed position until its locking mechanism touches the corresponding plate on the door frame.
7. **Lock the door.**
The locking mechanism must be brought back to the “locked” state that it had at the

[5] The starting side defines a half-space, whose only boundary is a plane. Such plane is the one parallel to the door panel (when closed) that has equal distances to the two faces of the standard door panel incorporated into the door assembly. The point where such distances are measured is at handle height vertically, and horizontally on the median vertical axis of the standard door panel.

start of the benchmark. This action can be executed with any technique (excluding those that can damage the door), e.g. by manipulating the handle or the door panel, or by pushing the panel using the robot base. Most standard door locks engage automatically if the door panel is pushed or pulled to its closed position; other types require manipulation of the handle.

During the execution of the benchmark, nobody except referees is allowed to be closer to the robot than 2m.
Note: special exceptions to this rule can be made by referees in case the robot executing the benchmark is a biped needing a supporting crane pushed by a human. In these cases, special instructions are given by referees to the team members (usually one) operating the crane: a typical example is the prohibition to touch the robot or the door assembly. Failure to comply with the special instructions counts as a *disqualifying behaviour* (see Section 8).

6.1 Falls and manual get-up

Some types of robots -notably, bipeds- are dynamically stable, and thus subject to the risk of falling to the floor.
If a robot falls to the floor during a run of Episode 2, the benchmark is considered as ended at the moment of the fall. The only exceptions are the following:

1. the robot gets up on its own **within 2 minutes**;
2. the robot's team requests a **manual get-up**, if this is the first such request during the run.

A manual get-up is the possibility for the team to intervene and bring back the robot to its operational position manually. During a manual get-up, the only action allowed to team members is physically hauling the robot from the ground and setting it down again on the floor in the same pose it was in before falling.
A team can make a maximum of one request for manual get-up per benchmark run. The request must be addressed to the referees. Team members cannot enter the test area until the request has been explicitly accepted and must leave the area as soon as the robot is again in its operational position.
After the execution of the manual get-up, the referees check that the pose of the robot is the same it had immediately before the fall. Referees can request that the team changes the robot's pose as many times as needed to meet this requirement. Once the referee declares that the requirement is met, the robot can proceed with the execution of the benchmark.

Requesting a manual get-up counts as a penalising behaviour for the robot and thus influences its score: see Section 8 for details.
The manual get-up does not reset the timer, and the benchmark must be completed within the original timeslot.

6.2 Variable elements of the door assembly

The procedure described above is fixed, but the physical setup of the door assembly used for its execution is subject to variations: not only among different instalments of Episode 2, but also *during a single instalment*. These have the objective of making the features of the benchmark not completely known to teams (or at least not known well in advance of the execution of the benchmark). Variations are used to differentiate the features of different executions of the benchmark, while leaving both the procedure of the benchmark and its broad level of difficulty unmodified. The organisers of the Episode can execute variations at any time and with any frequency, the only constraint being their compatibility with the schedule of the Episode and of the whole SciRoc Challenge, and the need to avoid disruptions to the work of teams.

Variations in the door assembly correspond to exchanging one or more of its **variable elements** (see below) for alternative ones. Such variations can occur at any time during the competition, and especially from one day to the next[6].

Variable elements that can be exchanged are:

1. the door panel;
2. the handle;
3. the unlocking mechanism;
4. the opening direction.

Differences among door panels might include but are not limited to type of surface (flat or shaped), colour, presence and type of subpanels. In general, any commonly available type of commercial door panel can be used for Episode 2.

For the handle, similar considerations apply. Thus, the set of handles that the robot may find installed on the door panel during the execution of Episode 2 includes any commonly available type of commercial door handle: there are two types of handles that a robot might find while approaching the door and trying to unlock it. The first one is the most common one found in most doors: the *lever handle*. In this case it is required to apply some force on the lever, towards the ground, to unlock the door. Next is the *knob handle*: this is a more complex operation for a robot since it is required to rotate the knob to unlock the door.

Possible unlocking mechanisms are of two types:

- those requiring that the handle is turned *and* (at the same time) pushed or pulled[7];
- those only requiring that the door is pushed or pulled, with or without need to overcome a small initial mechanical resistance.

The robot needs to inspect the door and/or try it in order to ascertain what kind of unlocking mechanism is installed.

During the team preparation days of the competition and during the competition itself, samples of all the cover panels, all the door handles and all locking mechanisms that may be used for the current instalment of Episode 2 are available to teams for inspection at the competition venue. In this context, "inspection" means "*any activity (including measurement or scanning) that does not require to manipulate the inspected item or move it from its location*".

IMPORTANT Teams are required to allow other teams the same access to the samples that they are getting. Referees have the faculty of inflicting score penalisations or -in the worst cases- disqualification from the Episode to teams "hogging" the samples.

Finally, for the opening direction of the door there are three possibilities:

- inwards (i.e., the robot should pull the door panel to open the door);
- outwards (i.e., the robot should push the door panel to open it);

[6] The door assembly should be designed in such a way that it is easy to perform these exchanges.

[7] The fact that pushing or pulling is required depends on the opening direction of the door.

- both (i.e. the robot can choose among pulling and pushing since both allow to open the door).

It is suggested to realize the door assembly in such a way that it allows both opening directions, leaving the definition of the opening direction to quickly operate mechanical detents. The detents should be built in such a way that it is impossible for the robot to detect their state, so the robot needs to try and move the door to find out its direction of movement. Knowing beforehand the direction of movement of the door is a big help for the robot. For this reason, such direction should be changed often and without letting team members know it.

7. Timing

For each team the start of the benchmark is determined in accordance with the schedule of of Episode 2. Each scheduled execution of Episode 2 by a robot is called a **run** of the benchmark. The final score achieved by the robot X depends on its performance over multiple runs of the benchmark, according to the scoring mechanism described in Section 8.

Scheduled times for the runs of a given team are published by the referees well in advance of the runs. **Such times are not flexible**. In particular, the *scheduled end time* for each run is rigidly enforced[8] and is not influenced by the fact that the robot is or is not ready at the scheduled start time. These times are defined as follows:

- **Scheduled start time** is defined as the time chosen by the referees for the beginning of the run;
- **Scheduled end time** is defined as *scheduled start time* + *timeout* (timeout is defined in Section 7.1).

In case of delays due to the organisation, the scheduled start time is moved forward accordingly in order not to penalise the team.

The start of a run occurs at the scheduled start time if the robot is ready to execute the benchmark. If it is not ready:

- if the robot gets ready *before the scheduled end time for the run*, the run starts as soon as the robot is ready;
- if the robot gets ready *after the scheduled end time for the run*, the run does not take place at all.

The end of a run occurs when the scheduled end time is reached. The run ends earlier if any of the following events occur:

1. The door is back in the “locked” state while the robot is not on the *starting side*[9] of the door assembly.
2. the robot enacts a *disqualifying behaviour* (see Section 8);
3. a team member requests the end of the benchmark.

The execution time used for the scoring (see Section 8) is always the actual duration of the run, i.e. from actual start time to actual end time. Values of the execution time are always

[8] This rigidity is necessary to preserve the timing of the SciRoc Challenge, in order to make it more attractive to the public. Unexpected pauses and delays have, in fact, a heavily disruptive effect on an event such as the Challenge and must be avoided. Also, rigidity in timing ensures that the scoring takes into consideration the capability of a team to get the robot ready for a benchmark in a reliable and repeatable way.

[9] See Section 4 for the definition of *starting side*.

between zero and the maximum timeout for Episode 2 (see Section 7.1). *The maximum value of the execution time is only available to robots that are ready at the scheduled start time.*

The following table recapitulates when the start and end of a run of Episode 2 occur:

The run starts...	**The run ends...**
between scheduled start time and scheduled end time, as soon as robot is ready	as soon as any of the following occurs: ● scheduled end time reached ● door is back in the “locked” state with robot not on starting side ● a disqualifying behaviour occurs ● team requests the end of the benchmark

For organisational reasons, scheduled times for the runs can be changed by the referees and republished after their first publication. When this occurs, the referees make sure that the teams involved by the changes are aware of them and, if possible, get feedback from the teams before finalising the changes.

7.1 Timeout

For Episode 2, timeout has a predefined maximum value, called **maximum timeout**. Maximum timeout for Episode 2 is **10 minutes**. The timeout value used while managing benchmark runs is a percentage of the maximum timeout, increasing monotonically during the benchmark according to the following mechanism:

- timeout is **50% of maximum timeout** until the robot reaches the **achievement threshold** defined in Section 8;
- timeout increases to **100% of the maximum timeout** as soon as the robot reaches the achievement threshold.

This variable timeout mechanism aims at preserving the interest of the public by ending early the benchmark runs where the robot is stuck, inactive or ineffective.

8. Score

The scoring mechanism used for Episode 2 is the same one used for the Task Benchmarks of the European Robotics League. As such, it is based on three sets: *Achievements*, *Penalising behaviours* and *Disqualifying behaviours*. Such sets are defined below.

Achievements

- **A1 - The robot approached the door.**
  The achievement is awarded when two conditions are both true at the same time: (1) the robot is on the *starting side*[10] of the door assembly and (2) there are at least one point of the robot and one point of the handle that are less than 1 m apart. This distance is assessed by the referees. As shown in the previous pictures, a circle can be drawn on the floor to determine when the robot is 1m away from the door, though it should not be too visible so robots can’t use it to navigate the environment.

[10] See Section 4 for the definition of *starting side*.

- **A2 - The robot touched the door handle.** In order to get this achievement, the touched handle must be the one on the starting side of the door assembly. The handle is considered as “touched” if any part of the robot comes in physical contact with it.
- **A3 - The robot unlocked the door without human intervention.** The robot gets this achievement when the door panel moves from the “closed” position of an amount incompatible with the locked state, according to the judgement of the referees. This achievement can be awarded only if no request to referees to intervene in the unlocking procedure has been issued by the robot’s team, or if a request was issued but the robot unlocks the door by itself before a referee touches the handle or the door.
- **A4 - The robot passed through the door.** The robot gets this achievement when it has moved through the door enough that there are no physical elements of the robot on the starting side of the door assembly. Reaching this state requires to open the door and pass through the aperture. The position of the door panel is not significant for this achievement.
- **A5 - The robot closed the door.** This achievement is awarded if two conditions apply: (1) the robot is not on the starting side of the door assembly, and (2) the door is brought back against its own frame by the robot so that its locking mechanism touches the corresponding plate on the door frame.
- **A6 - The robot locked the door.** The robot gets this achievement when the locking mechanism of the door is back to the same “locked” state that it had at the start of the benchmark. This achievement is assigned only if, when this occurs, the robot is not on the *starting side* of the door assembly.

Penalising behaviours

- **PB1** - The robot hits any piece of the benchmark setup (e.g., a part of the door assembly) without inflicting damage[11]. An exception is made for the door cover panel and the door handle, which can be hit without penalty (provided that they do not get damaged).
- **PB2** - The robot exits the test area defined in Section 4 (even if it comes back in later).
- **PB3** - The unlocking action executed by a referee needs to be repeated (e.g., because the robot accidentally locks the door again).

An additional penalising behaviour is inflicted to the team every time the corresponding event occurs, even if the team has already been penalised for the very same behaviour.
In addition to the behaviours listed above, a request by the robot’s team to perform a *manual get-up* (see Section 6.1) counts as an additional penalising behaviour (**PB4**) for the robot.

Disqualifying behaviours

1. **DB1** - The robot hits a human (e.g., a referee)[12].
2. **DB2** - The robot damages any piece of the benchmark setup.

[11] For the purpose of this rule, a “hit” is defined as a physical contact event where the robot applies forces sufficient to cause damage (even if no damage occurs).
[12] For the purpose of this rule, a “hit” is defined as any touch that has the capability of inflicting damage to the human or their accessories (e.g., clothes), independently from the fact that a damage actually occurs.

Achievement threshold

Achievement A2 (The robot touched the door handle) is the **achievement threshold** for Episode 2. The achievement threshold is used to establish the timeout of the benchmark according to the mechanism described in Section 7.2.

8.1 Admission to the ranking

To be admitted to the ranking for Episode 2, a robot must have performed **at least 3 successful runs** of the benchmark, where a *successful run* is one during which the robot collected at least one achievement.
Only teams whose robots are admitted to the ranking for Episode 2 receive a score, are included into the final ranking of teams, and can receive prizes or awards related to Episode 2.

8.2 Overall score

The competition is arranged in two stages: 1) Competition Days, 2) Final. The top 3 teams in the ranking of the Competition Days qualify for the final to be held in the last day of the competition. The final ranking for assigning the first, second and third place will be determined by the performance in the Final. During the competition days, several runs will be available to each team (let this number be M). Notice that M is the number of slots available for each team, it may differ from the actual number of performances of each team, if teams are not ready to attend some runs. During the Final, only one run will be performed.

Aggregate score of the Competition days. The aggregate score for each team for the M episodes performed during the Competition days will be determined according to the score system of the European Robotics League as follows:

- select the best N trials of the team
- determine the median of the scores of the N trials selected.

Let n be the position of the median in the ordered list of team scores, i.e., n = (N + 1) / 2 (when N is odd), then N (and consequently n) are determined according to the number of episodes scheduled M, according to the following table

M	N	n
6-9	5	3
10-12	7	4
13-15	9	5

In case of tie score for the access to the Final, the policy for tie breaking is described below. If such policy does not break the tie, all teams with the same score will enter the Final.

Tie breaker: In the case in which two teams have the same score the {maximum, minimum, last, average, cumulative} execution time over all the runs of the teams will break ties.
In case of tie score again, the rank will be the same. If teams with the same score are in the border limit to access the Final, all such teams will enter the Final.

9. Detailed instructions for referees

The information included in Section 6 (Procedure) and Section 8 (Score) should be sufficient to inform referees about -respectively- the events expected during the execution of the benchmark of Episode 2, and the aspects of such events that are significant with respect to the robot's score.
The only special indications that need to be provided are the following.

Check that the door assembly is in order.

Before each execution of the benchmark, the referees should make sure that the assembly works correctly. Special attention should be given to check the following aspects.

- Horizontality. As explained in Section 4, perfect horizontality of the door assembly is necessary to ensure perfect verticality of the rotation axis of the door panel. This, in turn, is needed to avoid gravity influencing the motion of the panel. A quick and precise way for the referee to check the verticality of the rotation axis is to perform motion checks with the door panel, by observing its motion when pushed. The key point is uniformity in panel motion over different parts of its angular range and while inverting the direction of motion.
- Friction. As explained in Section 4, the door hinges should have low friction, but not too low. The referee can check friction by ensuring that the door motion caused by a moderate push of the door panel is halted by friction within 30°-45°.

Referees should be aware that the physical interaction between robot and door assembly can compromise both horizontality and friction, so checks should be frequent.

Be alert against cheating.

If undetected, cheating is vastly superior to working in its reward-to-effort ratio. For this reason, a lack of checks against cheating means that it will likely occur, maybe in the next instalment of Episode 2. To avoid this, referees should be alert, while avoiding being overly suspicious and therefore annoying to teams.
Given the way Episode 2 is structured, there are basically two types of cheating mechanisms, described below.

1. Before the execution of the benchmark. The robot is provided with *a priori* knowledge about the door (e.g., its location, its opening direction). This cheating mechanism can be prevented by trying to limit the amount of information about the benchmark setup that a robot's team has access to, and by changing often that setup. For instance, the starting pose should be changed randomly at every execution of the benchmark.
2. During the execution of the benchmark. This cheating mechanism is based on the transmission of information from a team member to the robot. Especially dangerous is the case when a manual get-up occurs (see Section 6.1). This type of cheating can be prevented through vigilance and -if necessary- exemplary punishment inflicted to infringing teams.

The minimum requirement of Episode 2 on the number of referees is one. However, this is a suboptimal situation (especially when human intervention occurs) that is only acceptable when the setup of the benchmark allows the referee to move freely and quickly from one side to the other of the assembly.

A more effective configuration, and one that does not impose any constraint on the setup, is to have two referees, one on each side of the door assembly.

10. Detailed instructions for teams

The information included in Section 6 (Procedure) and Section 8 (Score) should be sufficient to inform teams about -respectively- what their robot and themselves are expected to do during the execution of the benchmark of Episode 2, what elements of such execution have an impact on their robot's score, and what is such impact.

11. Ethical issues

There are no ethical issues involved in Episode 2.

12. Safety procedures

The only safety procedures concerning the setup of Episode 2 concern the physical construction of the door assembly (see Section 4). As such, the only interested parties are the organizers of the competition, not the teams or visitors participating to it. Once installed, the door assembly does not require special safety procedures for usage (e.g., by team members during tests), since the procedure is completely equivalent to using a standard hinged door for indoor environments.
The only significant risk that the door assembly can pose to people (without considering those posed by standard doors, such as closing one's fingers in it) is its collapse, possibly due to being hit by a robot. The weight of the assembly can, in fact, be sufficient to cause harm. However, provided that the assembly is installed correctly (i.e., as part of an existing and stable partition such as a wall) this risk is negligible[13].

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Appendix A. Score sheet

Team: ____________________ **Execution Time:** ____________________

Trial number: ______________

Achievements:

- [ ] The robot approached the door.
- [ ] The robot touched the door handle.
- [ ] The robot unlocked the door without human intervention.
- [ ] The robot passed through the door.
- [ ] The robot closed the door.
- [ ] The robot locked the door.

Penalizing behaviours:

- [ ] The robot hit a piece of the setup without damaging it. Number of hits: ______
  [*Note: non-damaging hits to door panel or handle should be ignored*]
- [ ] The robot exited the test area. Number of exits: ______
- [ ] Door unlocking by a referee needed to be repeated. Number of repetitions: ______
- [ ] The robot required a manual get-up

Disqualifying behaviours:

- [ ] The robot hit a human.
- [ ] The robot damages any piece of the benchmark setup.

Notes:

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Appendix B. Referee/audience Visual Interface

This section describes some of the recommended features for the judge's application and the display for the audience.

Judge's interface:

- Checklist showing the preparation steps needed before starting the trial (Section 9)
- Menu to select the team's name and the trial number
- Timer showing the execution time
- Button to start the trial/timer
- Select the goal and robot's current objective
- List of achievements and penalties to tick.

Public interface:

- Team name and trial number
- Current phase and objective of the robot
- Results for estimation of the table's status and the number of customers per table
- List of achievements with the next aimed achievement highlighted
- Current score and time

Questions and Answers

This section contains a list of questions asked by competition teams with their corresponding answer, available to all competitors.