SPACE ROBOTICS

CENTENNIAL CHALLENGE

CHALLENGE RULES

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1.0 Introduction

The Manned Space Flight Education Foundation, Inc. (hence forth referred to as Space Center Houston) has partnered with NASA to develop and execute the Space Robotics Challenge. This Challenge seeks to foster the creation of new or advance existing humanoid robotic dexterous capabilities. Humanoid robots, like NASA's R5, may one day venture ahead of or work side-by-side with our nation's astronauts. Expanding the abilities of these humanoid robots is critical in advancing deep-space missions, as well as improving life on Earth.

The Space Robotics Challenge is part of the NASA Centennial Challenges Program which was created to further NASA's journey to Mars while helping America maintain its' technology leadership. NASA Centennial Challenges were initiated in 2005 to directly engage the public in the process of advanced technology development. The program offers incentive prizes to generate revolutionary solutions to problems of interest to NASA and the nation. The program seeks innovations from diverse and non-traditional sources. Competitors are not supported by government funding and awards are only made to successful teams when the challenges are met.

In keeping with the spirit of the Wright Brothers and other American innovators, the Centennial Challenge prizes are offered to independent inventors including small businesses, student groups and individuals. These independent inventors are sought to generate innovative solutions for technical problems of interest to NASA and the nation and to provide them with the opportunity to stimulate or create new business ventures.

The Space Robotics Challenge focuses on developing software to increase the autonomy of dexterous mobile robots—particularly those of humanoid format—so they can complete specific tasks during space travel or after landing on other planets (such as Mars), as well as on Earth. Eventually, these robots will assist us with tasks such as:

- Deploying and preparing habitats, power systems and other infrastructure on Mars before humans arrive.
- Disaster relief and industrial plant maintenance on our own planet.

The following virtual challenge scenario serves as a backdrop for developing coding advancements that enable the autonomy of humanoid robotics:

In the not too distant future, R5 as arrived on Mars along with supplies ahead of a human mission. Overnight a dust storm damaged the habitat and solar array, and caused the primary communication antenna to become misaligned. R5 must now repair an air leak in the habitat, deploy a new solar panel, and align the communication antenna.

Teams will use software to control a simulated R5 in order to resolve the problems caused by the dust storm. Each team will be evaluated according to a scoring metric that considers the number of tasks completed and the time required to complete the tasks.

The competition arena will contain a rover, solar panels, communication dish, and a habitat on a Martian plain. Each component will be within eyesight and walking distance of each other. Practice environments, similar to those used in the final competition, will be provided to teams.

2.0 Prizes

A prize pool of up to $900,000 will be awarded across a Qualifying Round and the Virtual Competition.

Qualifying Round Awards:
Up to the top 20 teams will be invited to advance to the Virtual Competition and will each be awarded $15,000 (USD).

Virtual Challenge Award:
First place: $125,000
Second place: $100,000
Third place: $50,000
Fourth place: $25,000

The top 4 teams will also be awarded a code implementation partnership with an R5 Host Team for a time period of at least two weeks.

Virtual Challenge Bonus Awards: In addition to the above awards based on final scoring, up to 6 teams are also eligible for bonus awards of $50,000 each for successfully completing every task within one run (18 consecutive checkpoints within one run, see Section 10 for task details). Bonus awards are not limited to the top 4 teams.

3.0 Schedule

Date	Event	Remarks
August 16, 2016	SRC announcement	Registration open
**October 7, 2016	Registration closes	
**October 10, 2016	SRC software version 1	Software for qualification
**December 10, 2016	Qualification deadline	
**January 2017	Qualification results announced	Final participants selected
June 9, 2017	Virtual Competition dry-run	
June 13-16, 2017	SRC Virtual Competition	
June 30, 2017	Final results announced	

4.0 Eligibility

All individuals or entities that wish to participate in the Space Robotics Challenge (hereinafter referred to as "CHALLENGE" or "SRC") must register and sign a Team Agreement (separate form).

A Team is comprised of one or more individuals and/or entities, referred to as Team Member(s) and Entity Member(s) respectively. All Team and Entity Members, as applicable, shall be considered registered participants in the CHALLENGE. Each Entity shall assure that each of its Entity Members complies with all applicable terms of the Team Agreement and all rules of the CHALLENGE. The Team must designate a Team Leader who is a registered individual, or entity, within the Team.

Each individual, whether acting alone or as part of a team, must identify his/her nationality. No Team Member shall be a citizen of a country on the NASA Export Control Program list of designated countries. (The current list of designated countries can be found at http://oiir.hq.nasa.gov/nasaecp/).

If a Team Leader is unable to continue in the role due to death, debilitating illness, or other acts of God, then a new Team Leader may be named, as long as that person agrees in writing to fulfill the duties to be a Team Leader, and is otherwise eligible to be Team Leader as required by this section. Such a change must be documented and submitted to SCH along with an explanation of the circumstances as soon as possible, but no later than the 24 hours prior to competition. Proposed changes of Team Leader are subject to approval by SCH and sponsors (as required) in their sole discretion.

4.1 Eligibility for Prize

In order to be eligible to win the NASA Prize, a Team must be comprised of Team Members and/or Entity Members, as applicable, who are either (i) comprised of at least 51% citizens or permanent residents of the United States, or (ii) an entity that is incorporated in and maintains a primary place of business in the United States. Team Members must furnish proof of eligibility (including proof of citizenship or permanent resident status, for individuals, and proof of incorporation and primary place of business, for entities) which proof must be satisfactory to NASA in its sole discretion. A Team's failure to comply with any aspect of the foregoing requirements shall result in the Team being disqualified from winning a Prize from the NASA.

The Team Members must designate one Team Leader to act on behalf of the Team. The Team Leader will be a registered individual and will serve as the Team's sole representative in the Challenge, and the administrative contact for SCH. The Team Leader must be a citizen of the United States.

Notwithstanding the foregoing, a Team may include Entity Members who are foreign nationals and the Team shall still be eligible to win a prize from NASA as long as (i) the foreign national Entity Member is a bona fide, full-time student who is enrolled during and at the time of the Challenge in an accredited U.S. institution of higher education, (ii) the student is during the Challenge in the United States on a valid student visa and is otherwise in compliance with all local, state, and federal laws and regulations regarding the sale and export of technology, (iii) the student signs and delivers a disclosure (separate form) wherein the student discloses his/her citizenship and acknowledges that the student is not eligible to win a prize from NASA, and (iv) the percentage of such foreign national students on the Team is less than 50%. SCH shall determine, in its sole discretion, whether foreign national students are eligible to participate in the Challenge, but in no event shall such foreign national students be eligible to be awarded a prize from the NASA. No foreign student Entity Member may serve as a Team Leader for Prize eligibility purposes.

Current employees, consultants, and students of SCH may only participate as Team Members when the Team is not competing for the Prize from the NASA. Participation of such parties as Team Members on a Team will make a Team ineligible for any Prize award.

Teams will be ineligible to win the Prize if any Team Member is a Federal entity or Federal employee acting within the scope of their employment. This includes any U.S. Government organization or organization principally or substantially funded by the Federal Government, including Federally Funded Research and Development Centers, Government-owned, contractor operated (GOCO) facilities, and University Affiliated Research Centers.

Any such entity or individual shall obtain prior written approval from their cognizant ethics officer that such participation does not violate federal personnel laws or applicable agency policy. A copy of this approval to participate in the Challenge shall promptly be provided to SCH.

5.0 Registration

Registration for the SRC takes place at the website spaceroboticschallenge.com. Section 3.0 documents the registration schedule.

In exceptional circumstances, SCH may accept registration requests after the registration closure. Registration for or participation in the Challenge does not create or imply any contract with SCH or NASA.

6.0 Qualification

Registered entrants must qualify for the SRC by demonstrating a simple technological advancement prior to the Competition. Teams will be scored on their demonstration performance. Up to twenty (20) teams will advance to the next level of competition.

Each team will be required to complete two qualification tasks. The qualification tasks will be run independently at each team's site. Each team must submit two simulation log files, one for each qualification task. The log files will be evaluated by SRC officials. Instructions on how to complete the qualification tasks, and generate and submit log files will be provided to registrants upon release of the qualifying simulation software (details on challenge website). Teams may make any number of attempts at completing the qualification tasks, and submit only their best results – one file for each of two tasks.

6.1 Qualification Tasks

6.1.1 Task 1

The first task will require teams to find a series of lights on a panel. R5 will start standing in front of a textured panel that contains a number of colored lights. One at a time, the lights will turn on in a random pattern. Each light will remain on for fixed period of time, between 5 and 20 seconds. The light pattern starts once simulation is run, and will continue until simulation is complete.

Successful completion of Qualification Task 1 will entail:

1. Correctly identify ten lights in a row.
2. Light identification consists of an RGB value and position in R5's head frame.
    a. Both the RGB and position values are allowed an error tolerance that is TBD.

6.1.2 Task 2

The second task requires teams to press a button that opens a door, and then walk through the doorway. The button will be located on a wall and will be brightly colored and textured. R5 will start in front of the wall. The doorway will be located next to the button, and will open when the button is pushed.

Successful completion of the Qualification Task 2 will entail:

1. Pushing the button.
2. Walking through the doorway, where R5 must walk one (1) meter beyond the door without falling.

6.2 Qualification Scoring

Qualification score for Task 1 will be determined by comparing actual color/position and team's reported color/position and time to complete the Task 1. Qualification score for Task 2 will be determined by the time it takes to complete Task 2. In Task 1, teams with smaller error will receive a higher score than teams with larger error. In Task 2, teams completing the task using less time will receive a higher score than teams using more time.

Twenty (20) teams will be selected to advance to the Space Robotics Challenge final competition. If more than twenty teams successfully complete both qualifying tasks, the teams that completed qualifying Task 2 in the fastest time will be selected. In the event of a tie, the amount of error in qualifying Task 1 will be the deciding factor.

7.0 Practice

Variants of the SRC arenas will be released on which teams can practice. These arenas will be representative of the final SRC arenas in that they will reflect the same tasks and approximately the same configuration. However, parameters in the final SRC arenas will be altered from those of the practice arenas such that the exact configuration, fixture sizes and geometries, friction coefficients, the communications parameters, and a variety of other minor adjustments will not be known in advance.

8.0 Dry-Run

Teams must participate in a single dry-run of their systems using the software and services to be used in the SRC competition. The dry run will mimic conditions during the final competition, including access to the cloud service running the onboard robot code and SRC simulation code.

Section 3 identifies the overall schedule for the practice period. Detailed practice schedules and procedures will be announced at a later date.

9.0 Competition Tasks

The final SRC will consist of three tasks involving the life in a (fictional) day of R5 on Mars.

1. Alignment of a communication dish.
2. Repair a solar array.
3. Find and repair an air leak inside a habitat.

Each task is composed of multiple checkpoints, described in the following sections. Teams have the option of skipping checkpoints. Points are not awarded for skipped checkpoints. When a checkpoint is skipped, the environment is automatically altered to reflect completion of the checkpoint. Skipping a checkpoint allows a team to solve a subset of the checkpoints.

9.1 Task 1: Communication Dish

R5 will begin this task near a communication dish that is aligned incorrectly. R5 will be required to walk a short distance to the communication dish and locate two handles. One communication dish handle will adjust pitch and the other yaw.

R5 will be provided with the current dish orientation and the desired orientation. A tolerance of five degrees in pitch and yaw is allowed. A message will be sent to R5 when the dish is correctly aligned.

Task 1 checkpoints:
1. Move within 1 meter of the communication dish.
2. Move the communication dish to the correct pitch angle.
3. Move the communication dish to the correct yaw angle.
4. Walk into the finish box.

Note: The order of checkpoint 2 and 3 can be swapped.

Bandwidth limitation: TBD
Simulation time limit: 30 minutes

9.2 Task 2: Solar Array

R5 will begin this task in the finish box of the previous task. R5 will be required to walk to a rover in order to retrieve a new solar panel. After acquiring the new solar panel, R5 will walk to the solar array and deploy the new panel within reach of the power cable. Once deployed, R5 will connect the solar panel to the existing array.

The solar panel will have a handle for R5 to grasp and carry. Deployment of the solar panel consists of placing the solar panel on the ground and pressing a button on the top of the solar panel. An existing power cable, located on the ground near the solar array, must be picked up by R5 and plugged into the newly deployed solar panel.

Task 2 checkpoints:
1. Retrieve the new solar panel from a rover. The solar panel must be off the rover and held by R5 off the ground.
2. Place the solar panel on the ground within reach of the power cable.
3. Deploy the solar panel by pressing a button on the top of the solar panel.
4. Pick up the power cable.
5. Plug the power cable into the solar panel.
6. R5 walks into the finish box.

Bandwidth limitation: 1-2 Mbps
Simulation time limit: 1 hour

9.3 Task 3: Air Leak

R5 will begin this task in the finish box of the previous task. R5 will be required to walk to the habitat, climb the stairs to the habitat entrance, enter the habitat, find an air leak using a leak detector tool, and repair the air leak using a patch tool.

Stairs to the habitat entrance have railings on both sides. The habitat entrance consists of a door with a rotary valve that must be turned to unlock the door. The door is hinged to swing into the habitat, and must be pushed open by R5. Upon entering the habitat, R5 should pick up a leak detector device from a table, and walk to a designated wall that is known to have a leak. The leak detector tool will continuously emit a message that contains information about presence or absence of an air leak. By moving the leak detector tool in front of the wall, R5 should locate the source of the leak.

Once the leak is found, R5 should pick up a leak repair tool from a nearby table and press the tool on the leak location. The act of pressing the leak repair tool on the correct leak location will stop the leak.

Task 3 checkpoints:

1. Climb to the top of the habitat stairs
2. Open the habitat door
3. Pass through the habitat door
4. Pick up the leak detector
5. Find the leak
6. Pick up the leak repair tool
7. Repair the leak
8. Walk into the finish box.

Bandwidth limitation: 1-2 Mbps
Simulation time limit: 2 hours

9.4 Communication

The SRC will add latency to the communications link between the OCU and the Field Computer to create a round-trip latency up to 20 seconds.

The communications bandwidth between the Operator control unit (OCU) and the Field Computer shall be limited by the SRC. The available bandwidth will be task dependent, see Sections 9.1, 9.2 and 9.3.

Teams may use any communications protocol they desire for communications between the OCU and the Field Computer, including UDP and TCP. The SRC will not impose or require exclusive use of particular protocols.

10.0 Competition Runs

For each of the three (3) tasks described in Section 9, entrants will perform five (5) runs, for a total of fifteen (15) tasks. A team may optionally choose to complete multiple tasks without resetting simulation. This option is provided to teams when R5 enters the finish box for each task. If a team chooses to continue onto the next task, then expired time will reset to zero and new time will be allotted for the completion of the task. If a team chooses to end the task, simulation will end and teams will have to start the next task with a new simulation instance.

Each run will take place with a unique *configuration* specifying the location of all objects in the environment, the starting position of the robot, the communications parameters (latency), contact friction properties, obstacle placement, object geometry, and other relevant parameters.

The five configurations will be distinct from each other. However, each team will have the same five configurations.

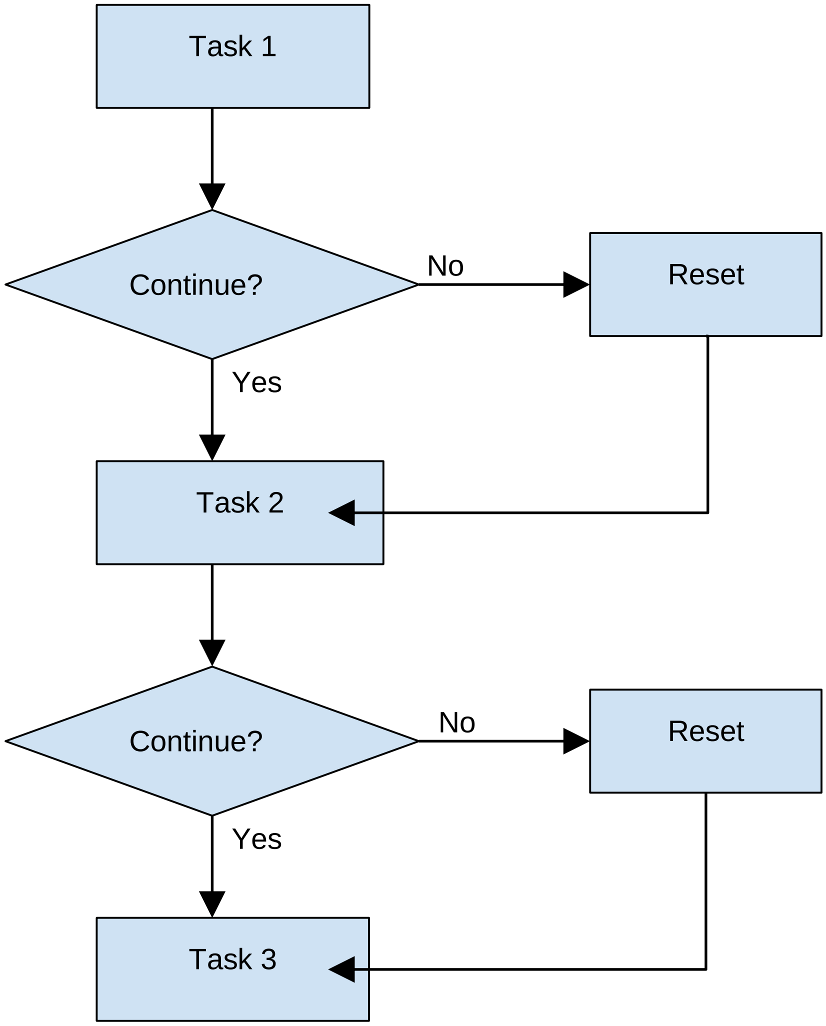
The following pseudo-code describes how the runs will take place:

```
Spawn instance in cloud of Field Computer running Field Code
Continuous_operation = false
For configuration(1: 5)
      For task(1: 3)
            If not continuous_operation
                  Spawn simulation in cloud of robot performing task with
                        Configuration settings
            Endif

            Start or continue scoring (configuration)
            Team simulates execution of task

            If end task or task == 3
                  Continuous_operation = false
                  Stop scoring (configuration)
                  Compute scores, log results
            Else
                  Continuous_operation = true
            endif
      Next
End Simulate
```

The following flowchart depicts how one configuration of the three tasks can be completed.



The expected completion time for a run varies according to the task. Refer to sections 9.1, 9.2, and 9.3 for allowed time for each task.

Time starts when the team initiates the run. As the system initializes, the robot will be able to view the terrain, and the team will be able to make the robot move so that the team is satisfied that all of their hardware and software processes are up and running. When the team initiates the run, the run time clock will start.

Time ends when the task is achieved or when the maximum allowed time is reached.

If the robot must be reset during a run, for example due to a software process crashing, time continues to accrue and is not reset with the robot. However, runs ended by software process crashes will not count if the crash occurred for reasons outside team control.

If the robot must be reset during a run, the robot location and state shall remain unchanged for the resumption of the run (no “teleportation”).

Teams will be allowed to successfully complete a run only once; teams may not perform a single run multiple times to obtain a better score.

11.0 Competition Scoring

11.1 Checkpoint Completion

Each task consists of a fixed number of checkpoints. The robot must complete or skip the checkpoints in the order given. Points are awarded only for checkpoints that are successfully completed.

The point value of a checkpoint equals the total number of consecutive checkpoints that were successfully completed (i.e. not skipped). For example, the first checkpoint completed is worth one point, the second two points, and the tenth checkpoint is worth ten points.

The consecutive count returns to zero when:

1. a checkpoint is skipped,
2. a reset is requested, or
3. a team chooses to end a task and restart simulation with the next task.

Examples:

If a team completes all checkpoints in Task 1, they will enter Task 2 with 10 points (1 + 2 + 3 + 4). If checkpoint 1 in Task 2 is completed, they will have a total of 15 points (1 + 2 + 3 + 4 + 5).

If a team completes checkpoint 1 in Task 1, chooses to skip checkpoint 2, then completes checkpoints 3 and 4, they will have a total of 4 points (1 + 1 + 2).

If a team completes the first three checkpoints of Task 1, then requests to reset for checkpoint 4, they will have a total of 6 points (1 + 2 + 3), but if checkpoint 4 is completed, they will only have a total of 7 points (1 + 2 + 3 + 1). Had a reset not occurred, and checkpoint 4 had been completed, they would have a total of 10 points (1 + 2 + 3 + 4).

If a team completes the first 2 checkpoints in Task 1, chooses to end Task 1 and begin Task 2, then completes only 2 checkpoints in Task 2, their total points will be 6 (1 + 2 + 1 + 2).

11.2 Allotments of Time and Communication

Shortly in advance of each run, teams will be told what bandwidth limitations will be in place for the run. Teams that choose to complete tasks in succession will be notified of bandwidth changes at the transition points in the task completion boxes.

The run shall end when one of the following is true:

1. A task is complete, and the team chooses to end simulation.
2. Expiration of the allotted time.
3. All three tasks were completed.

Teams that choose to complete tasks in succession will have their time reset at the beginning of each task.

Run time shall be calculated according to simulation time, not according to “wall clock” time. The rationale is to ensure fairness, since simulation time is the same for all teams, but the ratio of simulation time to wall clock time may not be the same for all teams.

Skipping a checkpoint will reset the sequential scoring to zero and subtract time from the allotted time for a task. The amount of time subtracted is equivalent to the allotted time divided by the number of checkpoints in the task.

Resetting the robot during a task will reset the sequential scoring to zero but will not incur a time penalty.

11.3 Ranking

Let *C* represent the total number of points a team received over all five runs. Larger values of *C* indicate greater proficiency in completing the challenge tasks, which is considered more favorable.

Let *T* represent the total number of seconds remaining from the initial allotment after all runs. T is computed by subtracting the total time to complete each checkpoint from the total allotted time. Time spent attempting to reach a checkpoint, and failing to reach the checkpoint is not counted. Larger values of *T* indicate that the system completed the challenge tasks more rapidly, which is considered more favorable.

Teams shall be ranked initially by their *C* values. A team with a higher *C* value shall be ranked higher (more favorably) than a team with a lower *C* value. If all teams have a unique *C* value, then the ranking process is complete.

Teams with the same *C* value shall be ranked according to their T value. Where a team with the largest T value ranks first.

If two or more teams have equal rank, then the Chief Judge will determine how to resolve the matter, possibly by conducting additional runs.

12.0 Modifications

The development of revolutionary technologies is a primary objective of the Space Robotics Challenge (SRC, the “CHALLENGE”). Entrants are invited to communicate directly with Space Center Houston using the Challenge email address (info@spaceroboticschallenge.com) regarding any rule that restricts their ability to demonstrate technical achievement and innovative solutions to space robotics.

SCH and Centennial Challenges reserve the right to alter the rules and/or schedule if deemed necessary. Teams will be notified of changes and given the opportunity to voice concerns or request modifications. Final authority for all changes will rest with the challenge administrator, SCH.

Requests for rules clarifications should be sent to info@spaceroboticschallenge.com. SCH will hold confidential any questions that are designated as team proprietary. SCH will ensure that answers do not give any team an unfair advantage.

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Appendix: Definitions

Checkpoint

A progress marker that defines accomplishment of a sub-task.

Chief Judge

The Chief Judge is the NASA SRC Program Manager or an official designated by the NASA SRC Program Manager. The Chief Judge is the final authority on all matters referred to in the rules and on all matters pertaining to the SRC that are not explicitly referred to in the rules.

Finish box

A well-marked rectangle on the ground. R5 should enter and stand in this box to mark completion of a task.

OCU

Operator control unit

Qualification

The qualification process performs an initial check in advance of SRC to guarantee that teams can demonstrate basic functionality in order to be allocated resources on the cloud.

SCH

Space Center Houston

SRC

Space Robotics Challenge

TCP

Transmission Control Protocol

UDP

User Datagram Protocol

Valkyrie

Valkyrie robot is also known as R5.