Taking the First Step Toward Autonomous Quadruped Robots

The Quadruped Robot Challenge at ICRA 2023 in London

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Last year, the IEEE Robotics and Automation Society (RAS) CAB Competition Committee proposed the Quadruped Robot Challenge (QRC) as an exemplary robot challenge organized by RAS at RAS's major conferences. As a part of the project, the first version of the QRC was held in ICRA 2023 in London. In this column, we would like to introduce the challenges and the results.

Due to the late approval of funding to support the QRC, the announcement of the competition was made in late January 2023, only four months prior to the event in London. Between the approval of funding by the RAS AdCom and the call for participants for the QRC, the organizing committee invited local organizers (Figure 1) and prepared the competition rules. It also developed a simulation environment and provided a list of purchasing items for teams to set up their experimental setups and practice in their local areas. (The resources can be found at the QRC homepage: https://quadruped-robot-challenges.notion.site/ICRA-2023-Quadruped-Robot-Challenges.)

The original plan was to have two separate events: one for autonomous robots and another for remote control robots. Achieving autonomy requires integrating quadruped robot motion control, mapping, and localization technologies, which many research teams around the world have not successfully demonstrated in challenging environments like ours. On the other hand, remote control is technologically less complex but more practical for field operations. Therefore, the QRC organizing committee decided to host two separate challenges, one for autonomous robots and the other for remote control robots, at ICRA 2023 in London. To account for the advantages larger robots have in overcoming ground obstacles, each challenge was divided into two categories based on the size of the robots. In the month leading up to the event, nine teams registered for the remote control category, and six teams registered for the autonomous category.

All of the teams planned to use smaller robots, with most of them using commercial products, such as AlienGo or GoI from Unitree, and one team using a custom-made small-sized robot. This allowed the local organizers to simplify the design of the competition arena to accommodate only the smaller track.

In late April, the ICRA 2023 organizers finalized the location of the competition event, and the local organizers had an opportunity to discuss the issue of organizing the QRC at the London Excel venue. Since the competition arena was simplified for smaller robots, the organizers decided

FIGURE 1. The organizers and sponsor.

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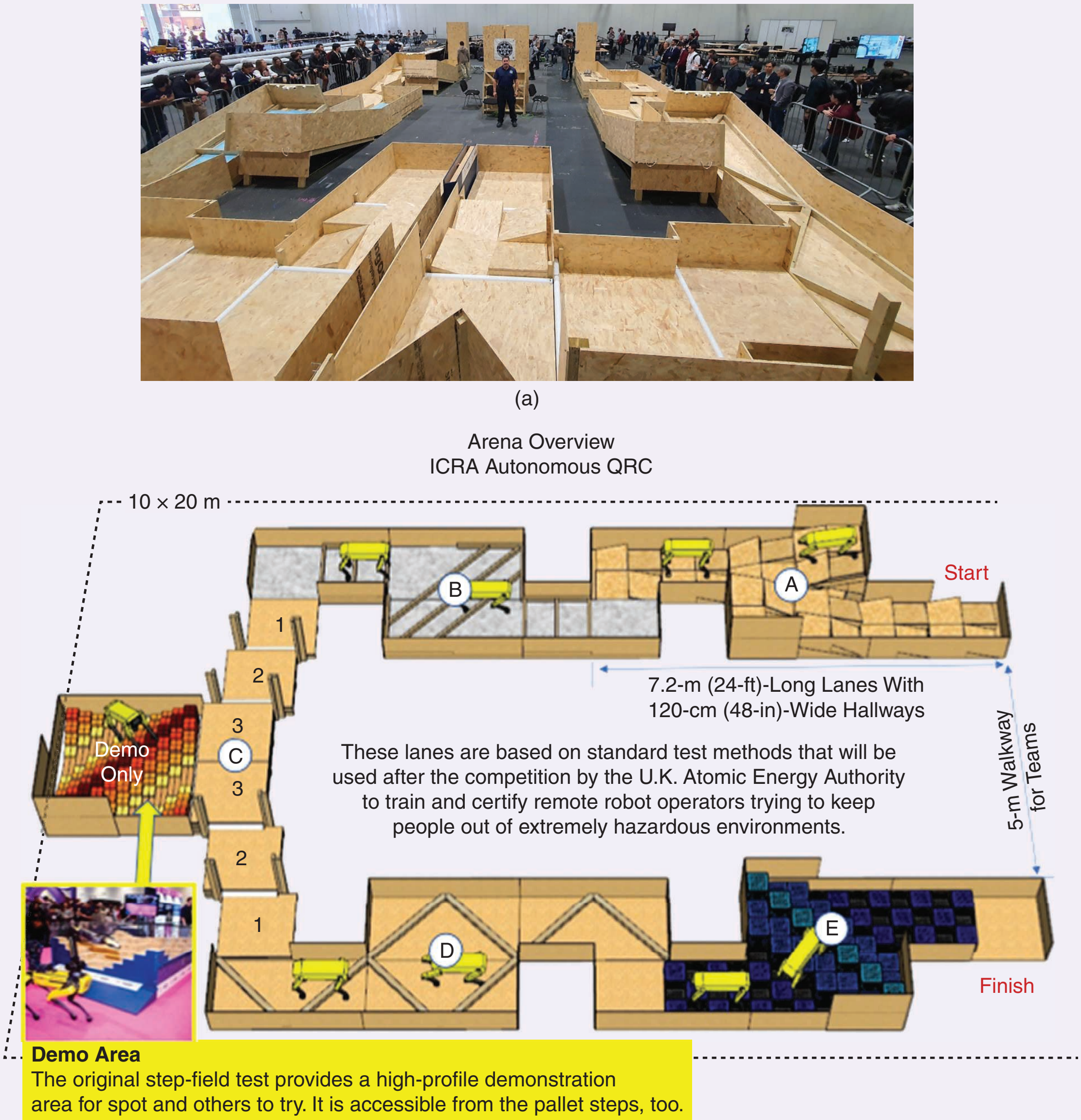


Ⓐ Ramp Terrains
Square 15° ramps can be rotated in place to form different terrains.
Initial: Continuous Ramps—Flat
Harder: Crossing Ramps—Slopes (Shown)

Ⓒ Pallet Steps With Pipes
The elevation changes using 15-cm (6-in)-thick covered crates with rolling pipes to step over.
Initial: Straight
Harder: Offset (Shown)

Ⓔ Crate Terrain
Several reconfigurable topographies are possible with negative obstacles (holes), too.
Initial: Diagonal Gap
Harder: Diagonal Hill (Shown)

Ⓑ Soft Floor With Step-overs
A 10-cm (4-in)-thick floor allows feet to sink like in sand, with step-overs of 5 × 10 cm (2 × 4 in).
Initial: Flat (Shown)
Harder: 15° Crossing Slopes

Ⓓ Slippery Floor With K-Rails
Smooth, oriented-strand plywood flooring has 10 × 10-cm (4 × 4-in) rails at 45° to step over.
Initial: Flat (Shown)
Harder: 15° Crossing Slopes

(b)

FIGURE 2. An overview of the arena for QRC 2023: (a) actual and (b) schematic.

to change the layout of the arena to better test the robots' and teams' capabilities in challenging environments and maximize visibility for the audience. Two weeks before the event, the local organizers finalized the arena layout and shared the setup, including changes to the grading policy, with the teams. Although this was a late change for the teams, the main idea of testing the quadruped robots' capabilities in handling challenging environments remained unchanged.

The new arena was divided into five sections: ramp terrains, soft floor, pallet steps with pipes, K-rails, and negative steps. Each section had a starting area and an ending area separated by a screen from other sections, allowing teams to run their robots in each section without interference from others during testing or the game. During the qualifying rounds, all five sections were populated with the teams' robots to make full use of the arena and provide more to show the audience. If teams ran the entire semicircular track one by one, only a part of the arena would be utilized, resulting in wasted time and space. Additionally, by having multiple rounds of qualifying events, teams had more opportunities to adapt their technologies to the environment and progressively improve their algorithms if necessary.

> "IN SUBSEQUENT STAGES IN A FEW YEARS, AS QUADRUPED ROBOTS WITH MANIPULATORS BECOME MORE PREVALENT AND ACCESSIBLE TO MORE TEAMS, PRACTICAL MOBILE MANIPULATION TASKS CAN BE INTRODUCED."

The arena was constructed by a team from the National Institute of Standards and Technology, led by Adam Jacoff, and Oliver Huke from the U.K. Atomic Energy Authority, Remote Applications in Challenging Environments (RACE) Test Facility. The difficulty of the terrain can be adjusted by changing the slope in sections A, B, and D as well as by adding more obstacles to create narrower and more complex passages (Figures 2 and 3). Section A features an inclined crossing ramp terrain, providing a reproducible level of complexity with slippery surfaces akin to dust-covered concrete. In section B, there is a foam floor with step-overs, which is designed to simulate walking on surfaces like sand and water that absorb the robot's feet below the perceived ground plane. Section C involves elevation changes using covered pallets with rolling pipe edges to step over, known to be challenging for tracked and wheeled robots. Section D replicates a slippery floor covered with collapsed objects, represented by diagonal rails. Finally, section E includes positive and negative obstacles (holes) that are difficult for the robot to perceive.

For the remote control category, the team's operator must control their robot remotely, relying solely on the scene transmitted from the robot's onboard sensors while being out of sight of the lane. All situational awareness must come through the operator interface. During the trial, no additional information is allowed for the operator except for resetting the robot, which concludes the current trial and places the robot back at the starting area of the section. Regarding autonomy, once the operator initiates the robot, no further interaction is permitted. Teams get a point for a successful run from the start to the end in the given section. To encourage teams to use autonomy, our scoring

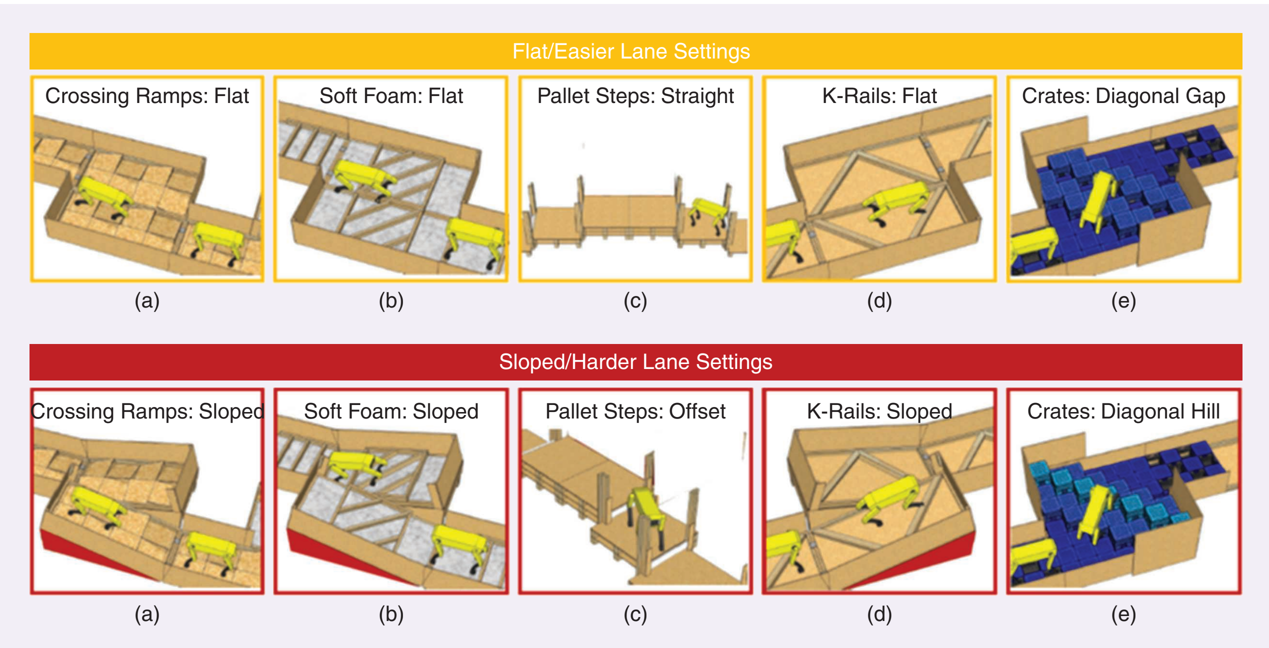


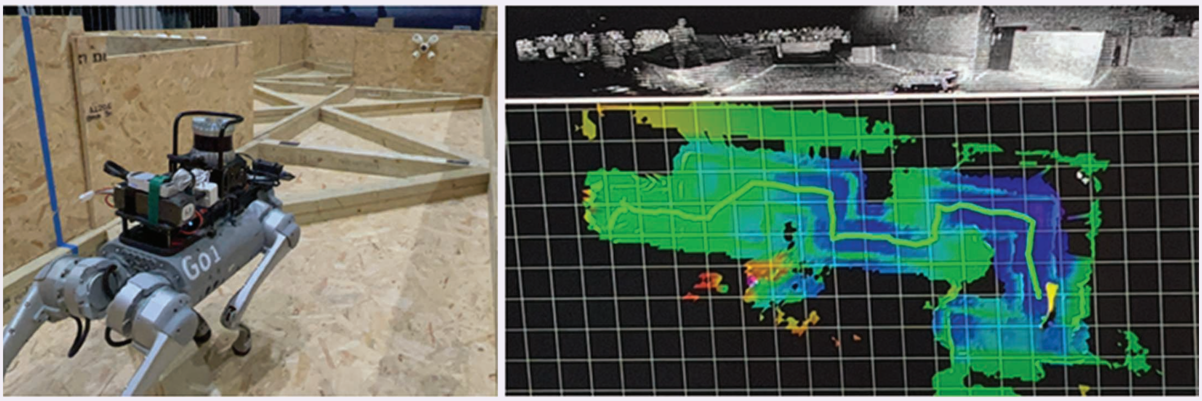
FIGURE 3. A reconfigurable setup was used to vary difficulties.

policy assigns a 4× multiplier to the autonomy operation. Each team is allocated 10 min and can undertake as many trials as possible within that timeframe, enabling them to rigorously evaluate their robots' performances across various terrains, obstacles, and tasks that align with their research objectives. Robot resets are permitted during the trials to ensure a measurable level of success. The operator or a team member with the best view of the robot should declare a reset. A 2-min penalty is imposed, during which the robot can be safely carried and reset to the starting point. The trial resumes after the penalty time has elapsed.

Teams dedicated one full day to practice, another day for qualifying, and a final day for the semifinals and finals. Since only six teams (Figure 4) were able to participate with their robots in the competition, all teams were given the opportunity to go through the qualifying, semifinal, and final procedures. Out of the participating teams, only two ran their robots autonomously. The initial qualifying round took place on a flat and straightforward setup but was later changed to a more challenging configuration with slopes. Teams encountered difficulties, particularly when crossing ramps on the slopes. Initially, the foam floor posed a challenge for the autonomous robots, but, as the competition progressed, they managed to overcome it. The rounded edges on the steps did not prove to be very challenging for legged robots. Smaller Go-1 robots encountered issues when crossing the K-rail section. Regarding autonomy, the rear leg often got stuck on the barrier during the crossing. For the smaller Go-1 robots, the negative obstacle appeared to be more challenging to overcome.

Due to the critical role of the first-person-view interface in remote control, one team added an extra camera during the event and utilized cellular communication to obtain a better view, resulting in improved remote control performance. However, the lack of proper recovery motion in instances of occasional clamping or falling on the slope made it difficult for the operator to restore the robot to a controllable position, necessitating a reset. One team implemented reactive autonomy, while another relied on map-based planning and tracking autonomy. Due to the late rule and setting changes, teams utilizing autonomy faced more challenges, but they managed the easier flat cases quite well. The champion team as well as the team with the best performance in autonomy, from KAIST, employed map-based approaches and inertial visual odometry with foot slip compensation (Figures 5 and 6). Their recovery motion enabled the robot to successfully navigate the terrain in most cases. Competition videos can be found at https://www.youtube.com/@rise-lab-skku/videos.

FIGURE 4. The QRC 2023 teams.


(a)

(b)

FIGURE 5. (a) The champion team KAIST's robot and (b) an autonomy example.

The remote control of quadruped robots from a first-person-view station is a relatively well-established practice (Figure 7). However, it continues to captivate audiences due to the dynamic actions of the robots. Furthermore, it holds practical value for the implementation of quadruped robots in various field applications. For instance, the current setup can be utilized to test operators' proficiency in handling quadruped robots deployed in real-world scenarios. To this end, the current layout will be transported to the U.K. RACE test facility for such purposes.

Initially, in the series of QRCs, stage 1 was designed to assess each team's ability to autonomously navigate diverse terrains individually. Team KAIST demonstrated that autonomous operation is feasible when the environment is premapped and guided by side walls. However, it remains unclear whether full autonomy would succeed without a preexisting map or when significant environmental changes are made to the original map. The presence of side walls also appeared to aid team KAIST in keeping the robot on track.

In stage 2, instead of increasing challenges for multiple robots, which would make game scoring more difficult (due to penalties for causing failures of opponents' robots through collisions), we are now considering real-world applicable tasks, such as inspecting an area of interest. Figure 8 illustrates an example facility for conducting such tests. The arrangement of pipe segments, with certain signs written inside, limits the robot's view angle and encourages active search for the signs. In subsequent stages in a few years, as quadruped robots with manipulators become more prevalent and accessible to more teams, practical mobile manipulation tasks can be introduced. The QRC has taken an important initial step toward real-world implementation and services by autonomous quadruped robots, showing great promise. We look forward to witnessing the participation of more talented and skilled teams in future editions of the QRC.

FIGURE 6. The champion and the best in autonomy: team KAIST.

FIGURE 7. The first place for remote control: team MIT.

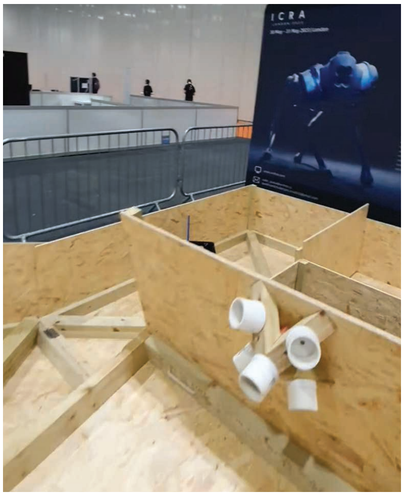


FIGURE 8. An example of the next task for the QRC.