iRAP Robot: World RoboCup Rescue Championship 2016 and Best in Class Mobility Award

Amornphun Phunopas(✉), Aran Blattler, and Noppadol Pudchuen

King Mongkut's University of Technology North Bangkok, Bangkok, Thailand
amornphun.p@eng.kmutnb.ac.th
https://www.iraprobot.com

Abstract. This paper describes an approach to the rescue robot competition by iRAP Robot in World RoboCup 2016. Rescue Robot League is beneficial as competing robots can be used in real situations when a disaster occurs. The competition demonstrates the performances of the robots and the contribution of each team to robotics in mechanics and algorithms. The rules for this year's competition have greatly changed from the past years'. The rescue robot has been tested and evaluated in performing necessary tasks repetitively to indicate a strong capability to get a high score. This paper presents the history of the iRAP Robot team, the robot design, the results of the competition, and the lessons learned.

Keywords: Rescue robot · iRAP robot · Mobility

1 Introduction

The main purpose of the Rescue Robot League is to develop a rescue robot that can be used in a real disaster situation. The competition measures progress in rescue robotic systems to highlight breakthrough capabilities that responders can understand and appreciate. The rules of the competition are updated every year, especially this year; in 2016 the rules for endurance and repeatability testing changed greatly. Only a single robot is allowed, and it must do the tasks from the preliminary round to the final round with the same configuration. The preliminary round comprised four test suites: Maneuvering, Mobility, Dexterity, and Exploration. Each test suite had five sub-tests. Thus, there was a total of 20 ground robot trials. The RoboCup Rescue Complete Rule Book described the details of the competition (see [1]). The arena layout shows all test suites, which is similar to the real scene, as in Fig. 1. The preliminary test trials had no victims, but to reflect the expected performance in the finals, the robot had to travel in the arena to search for artificial victims.

In any trial, ten checkpoints before doing a ground test consisted of six inspections and four dexterity tasks, as shown in Fig. 2. The score from checkpoints was a multiplier for the number of rounds that the robot performed the repetitions

S. Behnke et al. (Eds.): RoboCup 2016, LNAI 9776, pp. 554–564, 2017.
https://doi.org/10.1007/978-3-319-68792-6_46

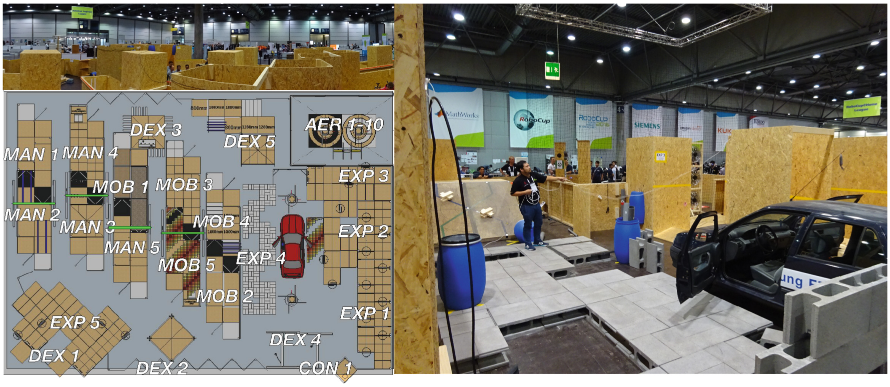

Fig. 1. Sample arena layout, showing the locations of all the test lanes set up for concurrent operation and a part of the real arena.

in the ground test. The new rules asked the robot to manipulate objects in the dexterity tasks; therefore, it forced our team to add a gripper to the robot, which formerly had only a robot arm for manipulating a visual system at the end effector. Our robot works in semi-auto mode. It can alert the operator in the six identification modes that are Video Image Resolution, Motion Detection, Thermal Image Resolution, Audio Acuity, Color/Pattern Recognition, and Gas. As well as the dexterity task, the robot had to inspect, touch, rotate and extract the pipes.

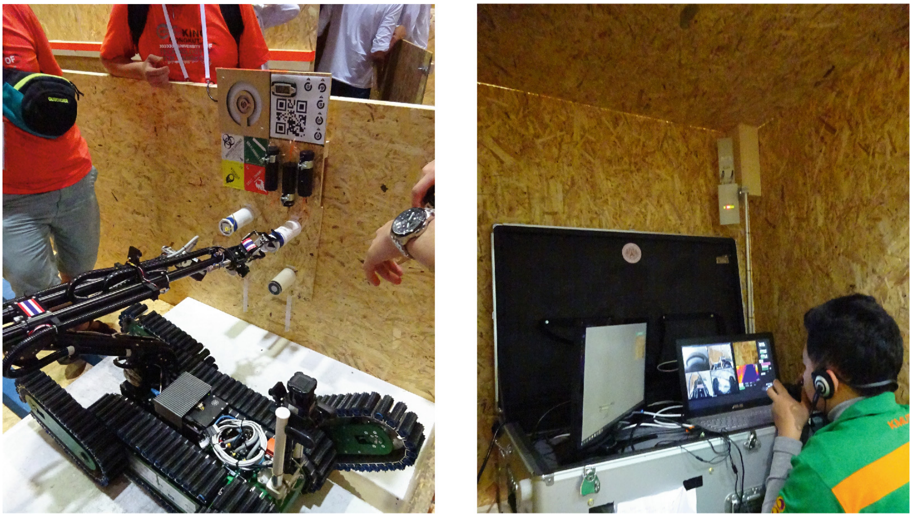

Fig. 2. The operator of the iRAP robot team operated the robot for ten checkpoints from the control station before doing a test suite in preliminaries.

2 Background

A group of students who were fascinated with making robots, formed a Student Robotics Club named iRAP, which stands for the Invigorating Robot Activity Project. Our iRAP robot team has a long history of about ten years and we have participated in the World RoboCup Rescue League since 2006. We have won an award at the competition every time that we have participated, which is seven times in total, and this is summarized in Table 1. From the year 2011, the Rescue Robot League introduced the Best in Class awards, namely: Best in Class Autonomy, Best in Class Manipulation, and Best in Class Mobility. It was a challenge to make the best robot in a class.

The rescue robot evolution, from 2006 to 2015, is shown in Fig. 3. The first era had a tele-operated robot with only a pair of flippers in the front. Many wheel materials were tested, for example, the different kinds of rubber and water tubes. The mechanism and driving system of the robot was improved, making it faster and stronger.

From 2009, besides the teleoperated robot, we had the autonomous robot shown in Fig. 4. The autonomous robot was not required to travel in harsh terrain like the teleoperated robot. Therefore, it had no flippers for climbing but had more sensors for full automation without human control. Knowing its position in the explored map was a big challenge. It had to do path planning and inspect signs and hazardous material labels [2].

From 2010, the teleoperated robot had two pairs of flippers in the front and the rear. As a result, the robot did not need to turn around to go backward and was able to move and climb backward using the rear flippers. This platform is still used in current robot design.

Table 1. The summary of iRAP robot team participating in the RoboCup rescue competition.

Year	Place	Team name	Award
2006	Bremen, Germany	Independent	1st place championship
2007	Atlanta, USA	Independent	1st place championship
2009	Graz, Austria	iRAP_Pro	1st place championship
2010	Singapore	iRAP_Pro	1st place championship
2011	Istanbul, Turkey	iRAP_Judy	- 1st place championship - Best in class mobility
2013	Eindhoven, Netherlands	iRAP_Furious	- 1st place championship - Best in class mobility
2015	Hefei, China	iRAP_Junoir	- 2nd place championship - Best in class mobility
2016	Leipzig, Germany	iRAP robot	- 1st place championship - Best in class mobility

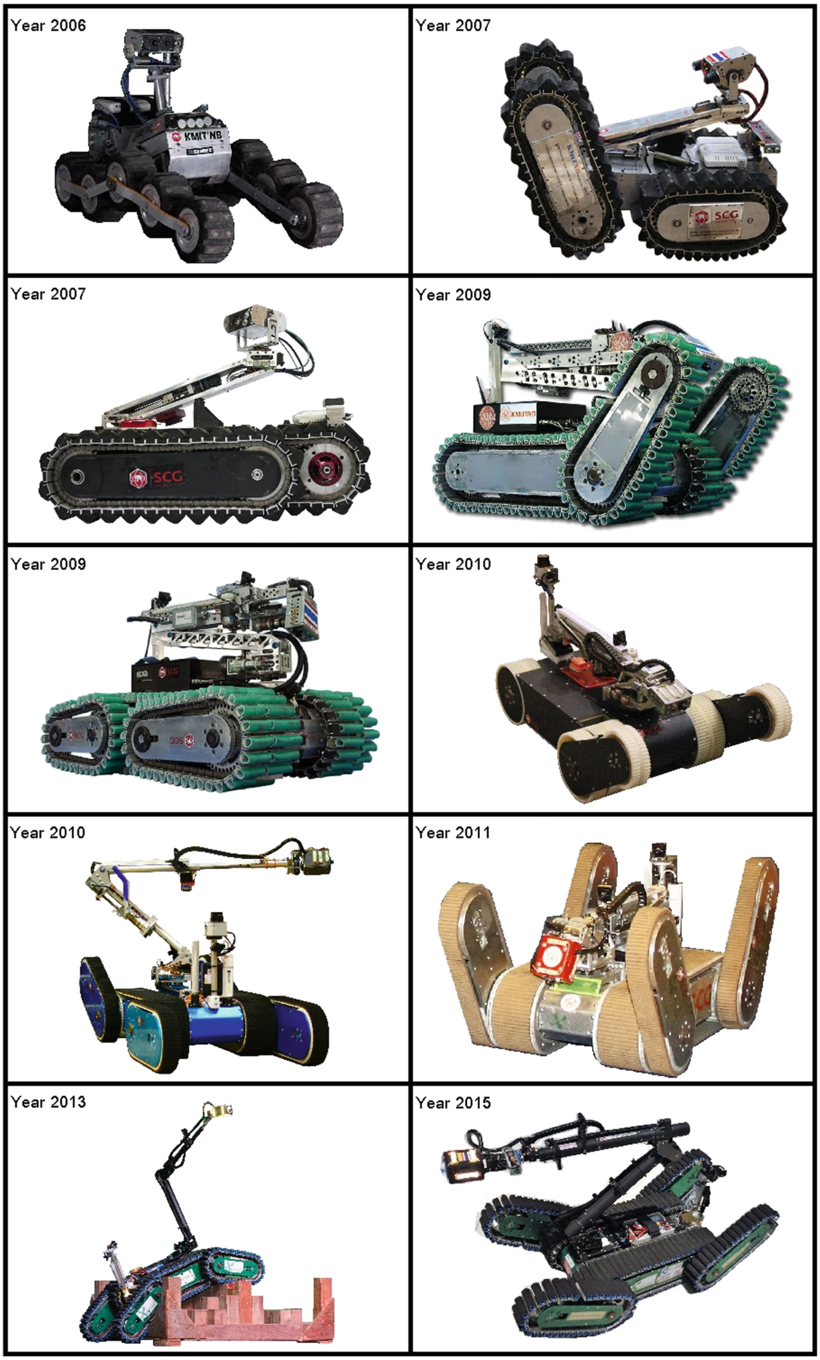

Fig. 3. Teleoperated robot configuration of iRAP robot team from 2006 to 2015

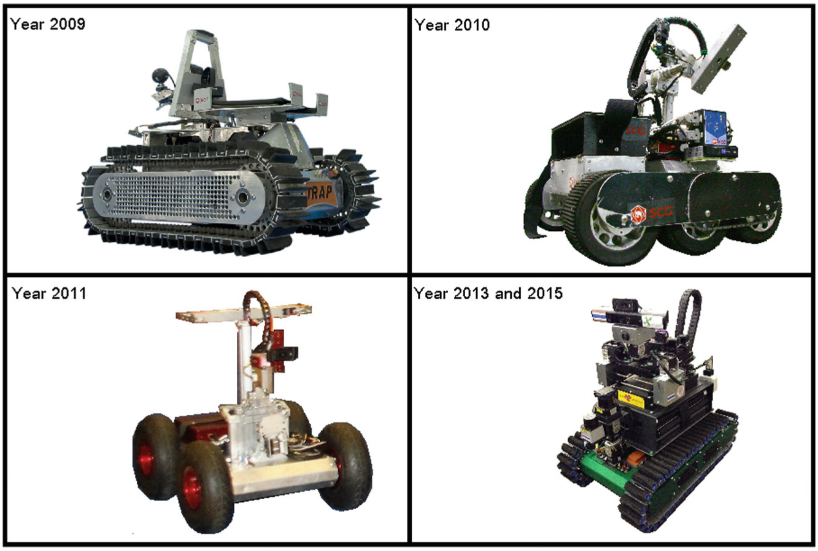

Fig. 4. Autonomous robot configurations of the iRAP robot team from 2009 to 2015

Although last year, 2015, we became the runner-up, we won back the championship in this year. The robot has been developed in many versions to improve its capability in the RoboCup Rescue competition from past failures. For example, we did not get a good score in map plotting last year. It was the main thing that defeated us. The robot could not map out the explored terrain because it lost map data to send them back to the operator station. We solved it by processing and backing up map information in the robot before sending it back to the station. However, the updated rules of the competition allow us to redesign and change one thing every year. For the status of this year, there are two main criteria that we have considered. First, the robot has to be robust enough to compete from the preliminaries to the finals. Second, the robot has to have a gripper for the dexterity task.

3 Robot Design

The four-flippered configuration has a high performance, and it obtained the Best in Class Mobility Award in every competition (see details in Team Description Paper [3]). The robot has four flippers in the front and the rear. It has proved its great capabilities regarding maneuvers and mobility. The configuration looks the same as the previous year. However, inside the robot, the mechanism, materials, and devices are partially different. The new gripper is designed, the new electrical wiring is for more devices, and the new thermal camera is installed onto the robot.

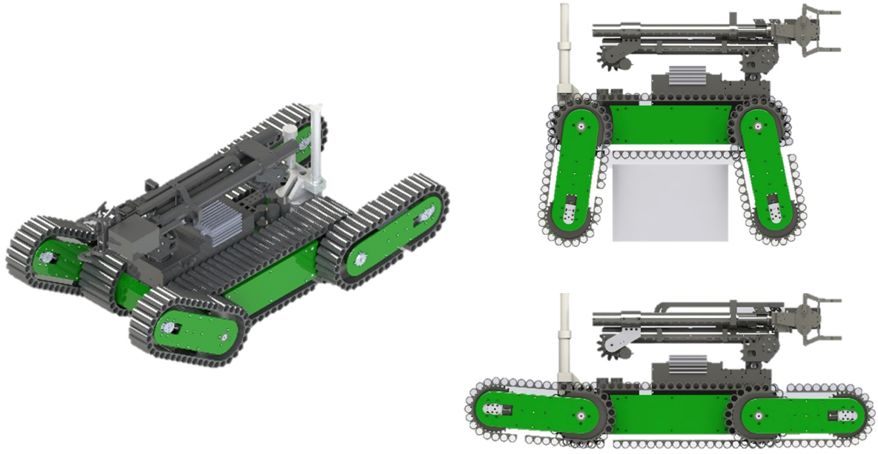

Fig. 5. The current robot design and configuration for participating in RoboCup rescue 2016.

Robot Body and Locomotive Driving Design. Our criteria for the rescue robot design base on the RoboCup Rescue Robot Competition 2016 rules. The competition rules and scoring metric focus both on the basic Urban Search and Rescue (USAR) tasks of identifying live victims and determining the victims' conditions. It provides accurate victim location, and enables victim recovery, all without causing damage to the environment. All teams compete in several missions and test performances with their robots, such as maneuvering, dexterity, and exploration, to define the standard of rescue robot.

The new design of our robot can be seen in Fig. 5. The solid aluminum is machined to be the base frame and the locomotive driving system, with all motors, is placed at the bottom of the base frame. Therefore, the center of gravity is low, which prevents the robot from turning over. The robot can move at an inclined 45° angle. When the robot stretches its front and rear flippers to a horizontal level, the overall length of the base frame must be more than the length of three levels of a standard staircase, so that the robot can climb across the stairway. Moreover, it can climb over an obstacle by using its front or rear flippers to lift itself. Two 24-V DC motors are used to drive the two caterpillar wheels separately. Each side of the caterpillar wheel works together with the flippers, linking the front and rear sprockets, to move forward, turn left, and turn right. The flippers are very useful for climbing over collapsed structures.

Robot Arm and Gripper design. Robot Arm and Gripper design Our robot arm aims to meet the requirements of the competition. First, the robot arm can reach the maximum height of a victim or an object from the ground floor. The second condition requires that the robot arm be able to manipulate an object such as a PVC pipe or door knob in the dexterity test suite. In particular, in the final round, the robot arm must be able to open a door using its gripper to pass through a victim zone. Our robot arm has a configuration resembling that of the PUMA robot arm except for a prismatic joint before the wrist joint of the end effector. Moreover, it has two end effectors: exploring head and gripper. The exploration head consists of a CCTV camera, a thermal camera, and a carbon dioxide sensor. The robot arm and gripper are designed in a module as shown in Fig. 6. They can be assembled at the base of our robot.

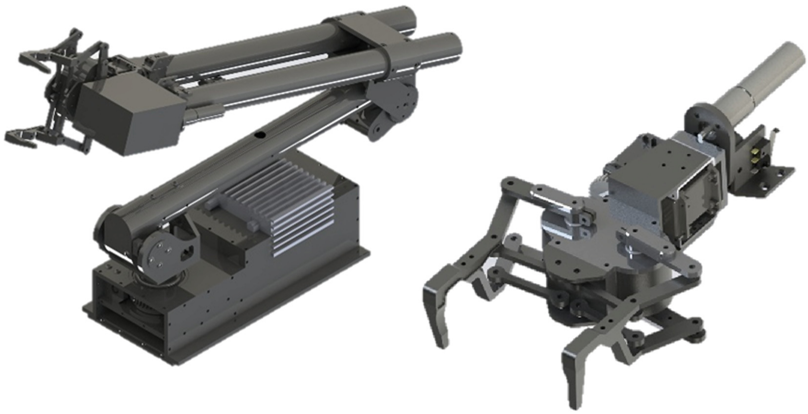

Fig. 6. The robot arm is designed as a module to fit together with the robot. It has a new gripper for dexterity tasks.

The reason that we separate the end effector into two parts is because the Exploring head and the gripper together are too large to pass through a small hole to search for hidden victims.

The Exploring head can inspect the temperature and the motion of the victim. Accordingly, a life signal of the victim can be examined by the carbon dioxide gas sensor because living creatures breathe out carbon dioxide gas. The gripper is designed based on the principle of a four-bar linkage using a worm gear to drive the mechanism because the worm gear is self-locking. The parallel gripper has a wide clamping range with slotted jaw faces that can grip objects tighter.

3.1 Simultaneous Localization and Mapping (SLAM)

In a mobile rescue robot, localization and mapping are very relevant abilities. The ability to sense the surrounding environment could help the operator to get a better grasp of the current situation. By using a 2D grid map representation, we can determine the current position and traveled trajectory of the robot. We can use data from the LIDAR sensor to get the surrounding distances, use odometry data from the robot's track encoder to refer the current position on the map, and use a Mems IMU to correct the robot frame and coordinates. However, in

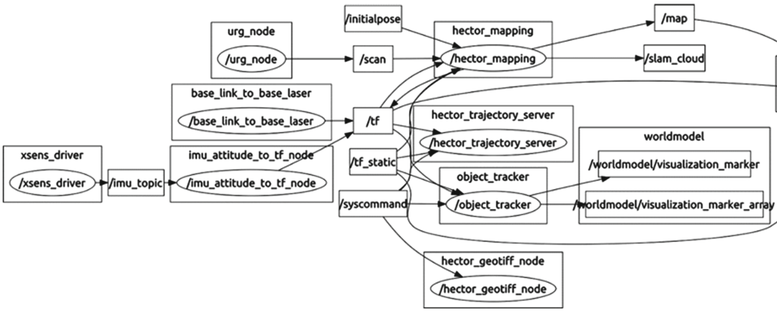

Fig. 7. ROS mapping system diagram of Simultaneous Localization and Mapping (SLAM).

a search and rescue operations scenario such as a collapsed building, there is a possible case that the ground is uneven or rocky. The debris can be scattered in the way, which makes the robot's track slip; the odometry data from the encoders would be useless in such a situation. Our approach is using the mapping system hector_slam [4] ROS packages, which are provided as an open source by Team Hector. Our ROS Mapping System Diagram is shown in Fig. 7. It uses only a LIDAR sensor to estimate the position from the surrounding environment by using a scan matching method. How this was possible is described elsewhere [5]. As the LIDAR platform alone might exhibit 6DOF motion, the scan has to be transformed into a stabilized coordinate frame using the estimated attitude

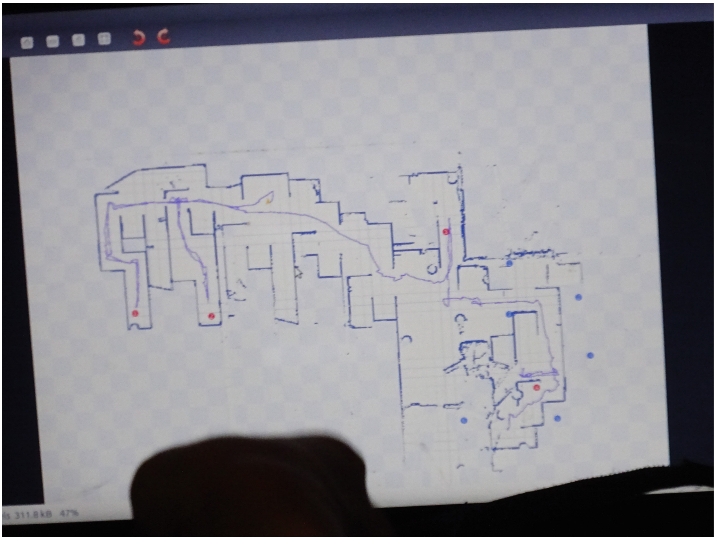

Fig. 8. The generated map and located victims in the finals.

of the LIDAR system; this is solved by using data from the IMU to correct the LIDAR's frame to the map's frame. During operation, the map is saved automatically every minute in a GeoTIFF file, which is the standard map format in the RoboCup Rescue League. The hector_worldmodel [6] ROS package plots the located objects or victims on the generated map (Fig. 8). This mapping system heavily depends on the LIDAR scan rate, so shaky movement might halt the map creation process. Scanning and matching cannot get to the data processing stage if the LIDAR scan rate drops or is not fast enough.

4 Competition Result

The results of the competition are shown in the official website of the World RoboCup 2016 [3]. In the preliminary test, there were 20 ground robot tests as stated in Sect. 1. A score was awarded in each test to qualify for the final round and get the best in class awards. There are four best in class awards in the main competition: Best in Class Dexterity, Best in Class Exploration, Best in Class Mobility, and Best in Class Autonomous Robot Exploration. However, it is expected that every robot can do the maneuvering tests. Each team has a different strategy to pass the different ground tests, focusing on maneuvering, mobility, dexterity, and exploration. It is hard to be the best and focus on every test. The robot can perform at least 12 missions because of the reserved time slots. More time slots may be available in case some teams cancel or cannot finish the mission. Therefore, the robot can probably perform more than 12 missions. There is no need to execute all the ground tests, and it is possible to repeat the same test to earn a higher score. The best team will get 100 points by normalizing the raw points per test method. We selected the test that let us accomplish two goals: first, to qualify in the final round and, second, to win the Best in Class Mobility award; therefore, we focus on the Mobility test suites in Fig. 9 from MOB 1 to MOB 5.

The result of the mobility test suites was what we had expected. The team had the highest score in every test. We earned the full score of 500 points in the five different tests for Best in Class Mobility as shown in Table 2.

The top six teams in the rank of the preliminary round qualified for the finals. Best in Class Awards showed a robot's performance and guaranteed it would pass to the next round as in Table 3, except Best in Class Autonomous Robot Exploration. Overall, the iRAP Robot team had the highest score in the preliminary round.

In the finals, the arena was divided into two areas. Two teams could compete at the same time and switch the areas. The robot had to travel, search for, locate, and identify simulated victims. As in the preliminaries, the robots could repeat to do the mission for the best score. In this round, we had a big problem with the wireless control of the robot. It was not only our team; every team had the same problem. It was probably because of signal interference. The robot worked well, but our score was not good and did not lead. To solve unexpected problems, we tried to fix the problem by changing the wireless router and antenna, but it did

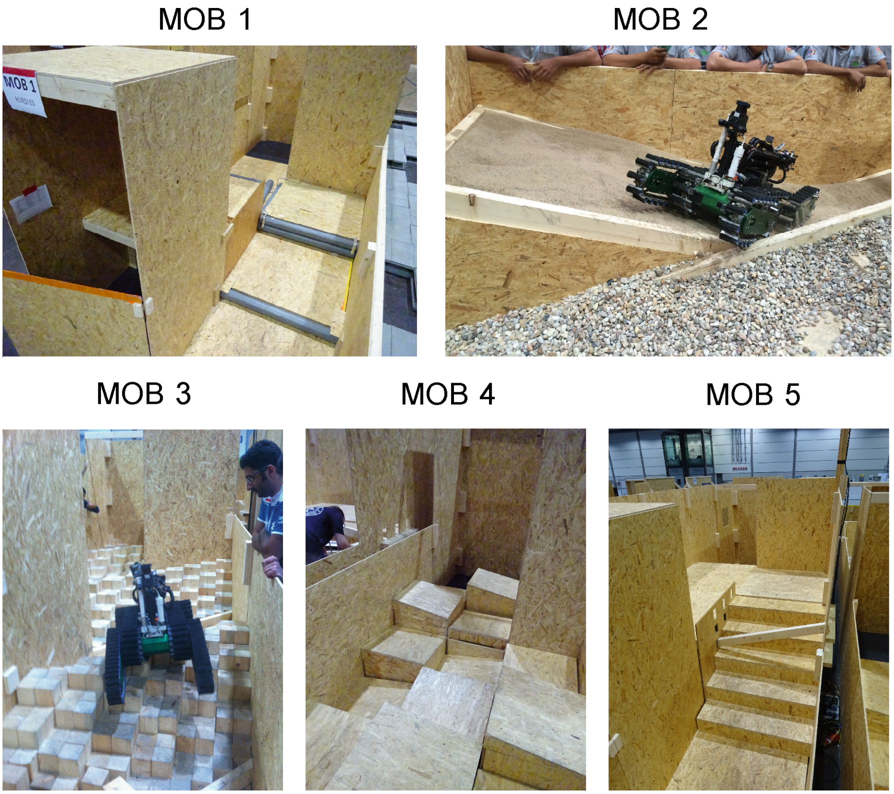

Fig. 9. The five mobility tests from MOB 1 to MOB 5: hurdles, sand/gravel hills, stepfields, elevated ramps, and stair debris.

Table 2. Best in class award in World RoboCup rescue competition 2016.

Award and team	Point
Best in Class Mobility: iRAP Robot King Mongkut's University of Technology North Bangkok	500
Best in Class Dexterity: UPROBOT-ICS University Panamericana Campus Bonaterra	390
Best in Class Exploration: MRL Islamic Azad University of Qazvin	293
Best in Class Autonomous Robot Exploration: TEDUSAR Graz University of Technology	300

not work. Many teams turned to Ethernet cable. In the last minute, we switched to using an Ethernet cable and everything went back to our way. We could get higher scores, and we won the competition as shown in Table 4.

Table 3. The advancing to finals team in World RoboCup rescue 2016.

Team	Country	Point
iRAP robot	Thailand	884.7
MRL	Iran	807.3
GETbot	Germany	577
UPROBOTICS	Mexico	496.1
Nubot	China	479.1
Autonohm	Germany	469.1

Table 4. RoboCup rescue championship 2016.

Award	Team
First place	iRAP robot
Second place	MRL
Third place	GETbot

5 Conclusion

The champion team does not have to have any Best in Class awards. However, our robot had an outstanding performance in mobility and won the first place award. The robot is fairly useful in other tests besides maneuvering and mobility. It is good enough to complete the tasks in the final round. Our team is very adaptive to new competition rules, which are getting more difficult every time. We have developed the new robot and innovated. Furthermore, we have tried to upgrade our robot's capabilities, including the dexterity task and the autonomous robot exploration.

References

1. RoboCup Rescue Complete Rule Book (2016). http://wiki.robocup.org/wiki/Robot_League
2. Hazardous Material Labels. http://wiki.robocup.org/images/2/27/Hazmatlabels.pdf
3. Official Website World RoboCup (2016). http://www.robocup2016.org/
4. Hector slam package. http://wiki.ros.org/hector_slam
5. Kohlbrecher, S., von Stryk, O., Meyer, J., Kingauf, U.: A flexible and scalable SLAM system with full 3D motion estimation. In: IEEE International Symposium of Safety, Security, and Rescue Robot (SSRR), pp. 155–160 (2011). doi:10.1109/SSRR.2011.6106777
6. Hector worldmodel package. http://wiki.ros.org/hector_worldmodel