Standard Rescue Tasks Based on the Japan Virtual Robotics Challenge

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Abstract. Robotic technology can be effectively used in the inspection and maintenance of aging social infrastructure. The capabilities of these robots are similar to those required for disaster response robots. This paper presents the concepts and outlines of the Japan Virtual Robotics Challenge (JVRC). The tasks in this challenge were designed based on the Sasago tunnel disaster, in which ceiling panels fell over 130 m as a result of the release of the anchor bolts from the walls over time. Lessons from JVRC indicate that service robots can function as first responders, and that disaster rescue tasks have much in common with every day maintenance tasks. Standard tasks for robots are proposed and one scenario is demonstrated to show its validity. We hope that the application of robots used for everyday maintenance can improve the availability of robots at disaster scenes.

Keywords: rescue robot, standard task, service robot, maintenance

1 Introduction

Disasters can occur at anytime and anywhere around the world. When a disaster strikes, the long period of time taken for emergency inspection of social infrastructure and its hindrance to quick recovery is always highlighted. Since the damage and malfunction of social infrastructure has an adverse effect on human life and civil society, both preventive maintenance and quick recovery are important for disaster prevention.

Any social infrastructure that is over 50 years old experiences serious problems because of the limited lifespan of concrete structures. Although periodic inspection of major infrastructure is conducted, it is still insufficient to ensure the detection of abnormalities or signs of rapid deterioration. Additionally, there

Table 1. History of Rescue Robot Competition and Test Field

Year	Title of competition	Target		Field	Background case
		Operation	Robot		
1997	Disaster City	rescue	land/air	Standardization	Oklahoma City bombing (1995)
1998	RoboSub		sea		
2000	RoboCup Rescue	rescue	land/air	Real	Hanshin-Awaji Earthquake(1995)
2005	Robotics Test	Facility	Field/Facility	Land	Real Filed
2006	ELROB		land/air		
2008	Roboboat		sea		
2011	Guardian Centers	rescue	land/sea/air	Real Field	
2012	ICARUS	rescue	land/sea/air		Earthquakes in l'Aquila, Haiti
2013	DARPA	rescue	land	Real/Simulation	Fukushima nuclear disaster
2013	euRathlon	rescue	land/sea/air		Fukushima nuclear disaster
2014	ARGO challenge	survey	land	Real Field	
2015	JVRC	maintenance /rescue	land	Simulation	Sasago Tunnel Ceiling Accident

are some areas where it is difficult to perform human inspection. The Sasago tunnel accident in Japan was such a case [15]. The anchor bolts were being forced out from the walls over time and ceiling panels had fallen by over 130 m.

Robotics is being applied for different purposes in social infrastructure of various fields. The ICARUS project in EU and NEDO Robot White Paper 2014 are examples of the application of robotics in the fields of infrastructure, construction and civil engineering, factory plant maintenance, agriculture, disaster response, and nuclear energy[5][9]. If robots that perform maintenance tasks of social infrastructure can also be adapted to act as first responders at disaster sites, it would increase their range of applications.

The Japan Virtual Robotics Challenge (JVRC) was held at October 7-10, 2015[6]. Eight teams participated and their robots (six humanoids, one with crawler, and a hybrid of a humanoid and crawler) performed seven tasks. The concept of the tasks was based on the idea of search and rescue operations conducted by robots, and robots conducting inspection tasks share many of their characteristics. In this paper, a list of standard tasks from the lessons of JVRC is proposed tasks that robots can perform as first responders during emergencies. The following section describes the background of social infrastructure inspection and a history of rescue robots. The outline of the JVRC with tunnel disasters and the idea of an “equivalent task” are introduced in Section 3. Sections 4 and 5 contain lessons learnt from the JVRC and describe standard rescue tasks in case of future emergencies.

2 Rescue robots and their history of competitions

Many projects on rescue tasks and robots have been promoted in the form of robotics competition (Table 1). Their purposes range from search-and-rescue operations at disaster sites to inspections of social infrastructure and oil platforms. The RoboCup Rescue [11], DARPA Robotics Challenge (DRC)[3] in US, and ARGOS Challenge in France[1] are a few such examples. They have concrete targets that open up to the areas or fields wherein robots were used in real life, such as the Hanshin-Awaji earthquake, the September 11 attacks at the World Trade Center, and the Fukushima Daiichi Nuclear Plant in 2011. The validity of these projects has been recognized internationally [7].

In 1980s, the possibility of accidents caused by aging social infrastructure was pointed out in US[10] and disasters related with social infrastructures have been reported around the world recently. In order to prevent the accident from the aging accidents, periodical inspection and constant maintenance are considered to be important. Perform inspection and maintenance tasks urge to work at narrow and closed areas, e.g., pipe lines, bridges, and inside of hazardous facilities. Robot technology have been applied to tasks where human are difficulu to access the places and hard do perform. Those task are in the same ones in disaster response application, e.g., inspection of damaged places and flammable/hazardous areas [4].

3 Overview of Japan Virtual Robotics Challenge

3.1 Background and scenario

The JVRC is a robotics competition involving the use of computer simulations. It is part of a collaborative project between the US and Japan, organized by the New Energy and Industrial Technology Development Organization (NEDO). The participants in JVRC developed control software for robots that were provided by the organizer or were designed by the participants themselves. The participants remotely operate their robots by using the Choreonoid robot simulator and compete in various tasks[2][8].

The Sasago tunnel disaster was chosen as the scenario for the tasks in the JRVC. The reason for the collapse of ceilings was that they were suspended by bolts that eventually became loose. It is believed that regular checks for signs of deterioration would have prevented the ceiling from falling. The tasks involve the design of periodic safety checks via visual inspection and hammering test and rescue operations during disasters.

The scenario is as follows: an earthquake caused the tunnel wall to collapse onto moving vehicles, causing a crash, which in turn led to a massive pileup of following vehicles. The affected vehicles included a tanker and a large truck. The tanker overturned and the truck scattered its cargo across the roadway. A few of the victims remained trapped inside their vehicles. The maintenance of the tunnel facilities is required to be performed by robots.

3.2 Outline of tasks

Table 2 shows a list of tasks included in the JVRC. There are two categories: ordinary tasks and rescue tasks. Ordinary tasks are typical inspection tasks that involve visual inspection and a hammering test (Fig. 1). Both tasks, and especially the hammering test, are difficult to recreate in a simulation as they are; therefore, their equivalent tasks were created. These equivalent tasks are explained in the following section.

Fig. 1. Two inspection tasks: vision inspection and hammering test.

O1: Visual Inspection

This task represents the visual inspection of cracks, swelling, and leakage in the walls and roads of the tunnel. It is given by the figures in O1 in Table 2. A tunnel is approximately 3.6 m wide and inspection targets are placed on the tunnel wall at heights up to 2.4 m.

After inspection, the condition of the cracks must be reported in the form of an Inspection Report [14].

O2: Hammering Test

This test is used to inspect the condition of the parts of the fastener and the damaged wall by hammering the parts or close to the damaged area. The sound produced by hammering reects the difference between normal areas and the areas that need to be repaired. The figures in Table 2 show that a fan is installed on the tunnel roof with the help of fasteners. Target areas for inspection are located near the fastener components.

The report of the condition of the components must be prepared in the same format as O1.

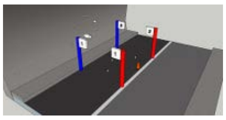
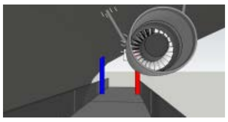
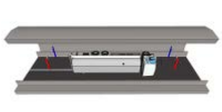
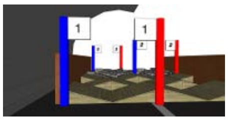
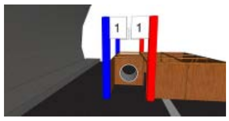
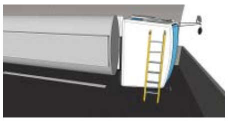
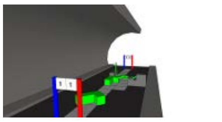
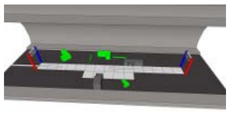
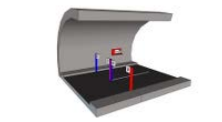
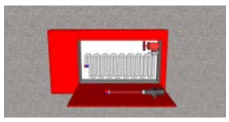
R1: Vehicle Inspection

Sometimes vehicles are overturned in tunnel accidents. This makes it necessary to check for someone in the vehicle or investigate the possibility of oil being spilled outside. The situations vary depending on whether the vehicle is a standard or large car, the tires are in contact with the road, etc.

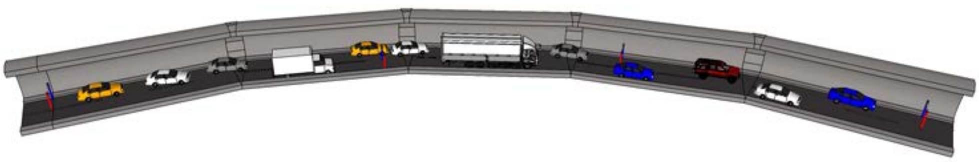
R2: Traversing Obstacles

After an accident, the roads are filled with fallen objects. Exploring the tunnel requires one to go through the area filled with debris or to squeeze

Table 2. Task of JVRC

Id	Purpose	Images
O1	Visual Inspection Check for cracks on the tunnel wall and road	 
O2	Hammering test Check the conditions of fastener components and damaged wall	 
R1	Vehicle Inspection Check the vehicles and surrounding conditions for vehicle damage, leaking fuel and survivors outside vehicles	 
R2	Traverse Obstacles Traverse obstacles, or in the confined space formed by obstacles	 
R3	Vehicle Inspection using Tools Investigate condition inside the vehicle by using tools	 
R4	Secure the Route Remove the obstacles from the specified route to secure the route	 
R5	Support Fire Extinguishing Use equipments in "Road tunnel emergency facility installation standards".	 

overhead view of tunnel before accident:



into conned spaces formed by obstacles. Obstacles in the left diagram of Table 2 consist of 40 cm^2 blocks with a $15°$ ramp[1]. The diagram on the right is the confined space through which some robots are required to crouch down to pass.

R3: Vehicle Inspection using Tools

Tools must be used to check the inside of the vehicle for people who may be trapped inside. These tools include spreaders and ladders, which are used in everyday situations.

In case the overturned vehicle is a large car, there are two kinds of tasks to undertake. One scenario involves climbing the ladder and identifying the target through the upper window. The other is to investigate through the upper window without using a ladder.

R4: Secure the Route

It is necessary to remove obstacles from the road to secure the route for smooth evacuation and rescue operations. In Table 2, the obstacles are represented by L-shaped bars and blocks whose size and weight are variable. The obstacles over the route are targets to be removed, and the routes are the obstacles are designated by color.

R5: Support Fire Extinguishing

Facilities for extinguishing fires are installed in a tunnel. This task involves utilizing the facilities to extinguish fires instead of relying on human effort. It begins with opening the box, pulling out the hose, removing the nozzle, connecting the nozzle to the hose, and finally opening the valve.

3.3 Equivalent tasks for inspection

When a robot performs the hammering test, it moves its end effector to the specified position, manipulates the effector along a specified direction relative to the test object, and collects sound when the end effector hits the target. The series of moves can be simulated. However, it does not seem to represent the function of the hammering test in actual inspection tasks. Instead, the test is replicated to a more feasible level that evaluates the equivalent of this basic inspection function. The basic task is to maintain control over the robot.

The equivalent tasks in the JVRC include the visual inspection of targets consisting of QR codes and a pipe [2]. Figure 2 shows the target and snapshots of robots executing O1 and O2. The QR code is attached at the bottom of the pipe, and the robot is required to move its end effector along the pipe without making contact. The size of the QR codes and the pipe length can be changed to modify the difficulty of the task.

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[1] This field is composed of the specified used in DRC

[2] The same structure of pipe star or visual target used in RoboCup Rescue Robot League.

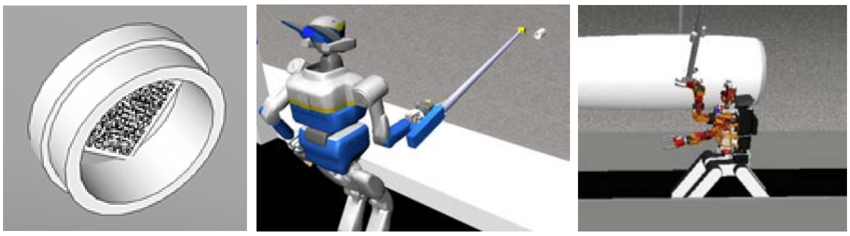


Fig. 2. Image of inspection target as equivalent task in O1 and O2: QR code in the pipe(left), a robot inspecting a target on the wall of tunnel(center), and performing a hammering test(right).

3.4 Comparisons to DRC tasks and result

The DRC was inspired by the Fukushima-Daiichi nuclear accident in Japan in 2011. In this challenge, humanoid robots were supposed to follow the following eight instructions in a simulation and in the real world instead of humans.
Vehicle: Drive and exit utility vehicle
Terrain: Walk across rough terrain
Ladder: Climb industrial ladder with 60-70 degree inclination
Debris: Remove debris from doorway
Door: Open series of doors with lever door handle
Wall: Cut through wall by using tools
Valve: Locate and close leaking valves
Hose: Carry and connect fire Hose.

The design of the JVRC tasks is based on the concept that ordinary tasks and rescue tasks have a lot in common with elementary robotic tasks, even though robots for ordinary tasks are designed with suitability in mind. Table 3 shows the common points between the tasks of the DRC and the JVRC. Ordinary tasks O1 and O2 and inspection task R1 are not in the DRC. The ordinary tasks are thought to be one category of service robots such as RoboCup@Home. The tasks of service robots include manipulation and object recognition at the conditions of everyday environment. Further, the vehicle task in the DRC has no corresponding task in JVRC.

Table 4 shows the scores of the top four teams in the competition. All robots, except one ranked below the top four teams, got no points in R5. The winning team was a centaur-type robot, in which the upper body was a humanoid and the lower body was a crawler-type robot. Figure 3 shows the centaur-type robot and a humanoid robot pull the hose from the box in the R5 task. The second and third places went to humanoid robots who participated in the DRC. In the fourth place was a crawler-type robot with one manipulator. Whereas the robots of the other three teams were simulated models, the robot of the top team was a combination of parts of a real humanoid robot and a real crawler. This was the only robot that was not a simulation.

Table 3. Comparision between the tasks of JVRC and DRC

	R1	R2	R3	R4	R5
Vehicle					
Terrain		√			
Ladder			√		
Debris				√	
Door					
Wall			√		
Valve					√
Hose					√

Table 4. Scores of the top four robots in JVRC

Robot type	O1	O2	R1	R2	R3	R4	R5	Total
1 Centaur	57	6	59	85	10	54	-	271
2 Humanoid	20	6	64	54	10	29	-	182
3 Humanoid	29	12	62	15	10	30	-	158
4 Crawler	18	0	17	61	0	30	-	126

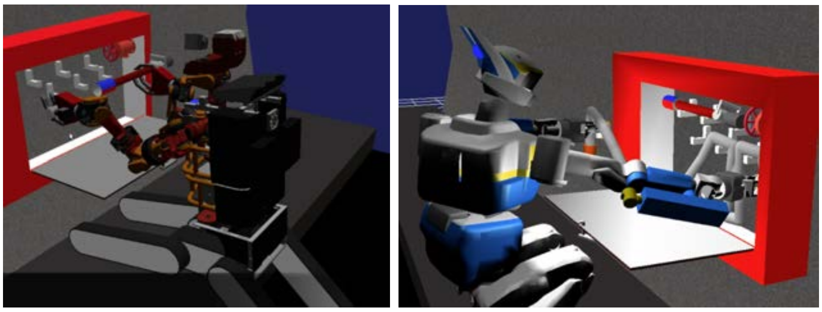


Fig. 3. A centaur-type and humanoid robots pulling the hose from the box in R5.

4 Proposal of standard rescue tasks

4.1 Types of robot

The tasks of JVRC are redesigned from typical rescue tasks; service robots involved in maintaining and inspecting social structures would be first responders to emergencies. At Fukushima, exploration inside buildings was an urgent issue in the aftermath of the disaster. At present, various kinds of robots are in operation, and plans are being made to use them in the decommissioning of nuclear plants [13]. Various kinds of services and tasks have been developed with the use of drones, including delivery services and bridge inspection. Decommission and service tasks have a lot in common with maintenance and inspection tasks.

4.2 Standard rescue task as first resonder function

Disaster scenes include a variety of cases, and different scenes require different functions and operations of rescue robots. The following four tasks are proposed as elemental tasks highly similar to inspection tasks.

1. Quick exploration of a changed area after disaster: Exploration and the associated map generation of the scene following the disaster are important

tasks for rescue robots. These two tasks are the main topics of rescue leagues. For service robots used in maintaining social structures, maps of structures are used every day. At disaster sites, the information required concerns the changes in the scene that have occurred due to the accident. Robots are assessed on how efficiently and completely they can explore and report on the damaged area, given a map of the scene from prior to the disaster.

2. Sensor monitoring task:
   In addition to map generation, sensor data are used to detect victims, gas leakages, res, and other important features of the scene. Robots are required to report the data to the operators either on line or offline. The data consist of time, place and sensing information. The sensing data are either raw or recognition data. Fig. 4 shows three pictures of a QR code. A program will commonly read Fig. 4 (a) correctly, and not read Fig. 4 (b) and (c). The three pictures are an example of a sensing task requirement, and QR code mark sensing is proposed as the second task.

(a) readable QR image. (b) an distorted image. (c) blobby or blocked image.

Fig. 4. QRcode marks:

3. Manipulation task:
   Fig. 4 (c) shows an example of how something like a cable or dirt on a mark can prevent code recognition. If this were encountered by a human worker, he/she would get rid of the cable, or wipe off the dirt in order to read the code. Simple manipulation functions that are used in maintenance tasks widen the rescue task, as the task R4 from JVRC indicates.
4. Action in dark and confined spaces:
   Inspection of anchor bolts in tunnels is an example of dark places where flashlights are typically used to light the space. Falling furniture, ceilings or other obstructions are caused by accidents and these result in confined spaces for robots to operate. The traverse of these confined space in R2 of JVRC is thought to be an energy consuming task for robots.

4.3 New scenario containing the standard task

In 2014, a new challenge was proposed to demonstrate the potential of the RoboCup rescue league (RSL) in minimizing losses during disasters [12]. They uploaded the CAD data of Portmesse Nagoya; the venue of RoboCup 2017. Fig. 5 (a) and (b) shows the overview of Portmesse Nagoya and a 3D model of Hall No. 1 with the exhibition hall.

Using the CAD data, more concrete rescue scenarios can be created than the scenarios used presently at RSL competitions. The following scenario is such a case; during an emergency, a robot travels through a hall toward an exit. This situation is motivated from R4 task of JVRC. The task of the robot is to check on damage in the center of the hall. Two blocks that have fallen in the corridor are observed from the exit. After dealing with these obstructions, the robot is required to continue past and explore the area further.

(a) An overvie of Portmesse Nagoya. (b) 3D CAD model of Hall 1 with display.

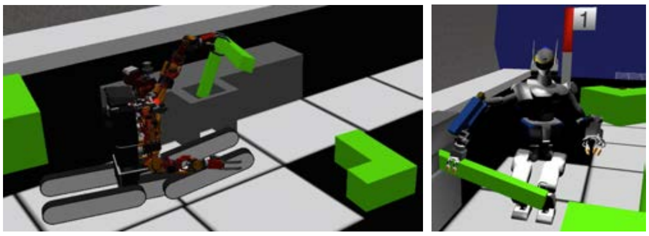
Fig. 5. RoboCup 2017 venue: Portmesse Nagoya

The activity consists of two standard tasks; quick exploration and manipulation tasks. Figs. 6 (a) shows screenshots of JVRC that robots pulls a rod to go their goals. Figs. 6 (b), (d) and (d) show areas near an entrance in Portmesse Nagoya Hall 1. The rescue robot pushing a block to the side, and proceeding to the center of the hall of the hall for further exploration. This demonstration shows a combination of standard, realistic tasks in inspection, maintenance, and rescue scenarios.

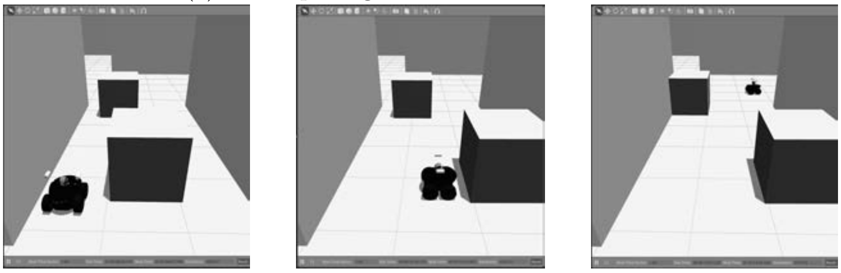
5 CONCLUSIONS

In this paper, tasks of robots at rescue and maintenance sites are compared and discussed. In 2015, the JVRC competition was held and the competition tasks were designed based on the maintenance tasks of social infrastructures. As with the maintenance of social infrastructure, in which robots are already being used, plans are being made to use robots to inspect areas not easily accessible by humans. These tasks have many similarities with rescue tasks, which DRC employed as target tasks. The concept of equivalent tasks is introduced in simulations and the tasks were used in the JVRC. From the lessons of the JVRC, new standards for tasks are proposed, and one simulation task is demonstrated to show the possibility of creating more realistic scenarios for RSL.

We hope these tasks can be used to broaden the functional standards for robots.



(a) robots pulling a rod to secure the route.



(b) corridor with two blocks. (c) one block is removed. (d) cleared corridor.

Fig. 6. Clearing spaces task to perform next tasks.

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