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Review:

Tsukuba Challenge 2019: Task Settings and Experimental Results

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This paper overviews Tsukuba Challenge 2019. The Tsukuba Challenge is an experiment for autonomous navigation of mobile robots on public walkways. Navigation tasks through pedestrian paths in the city are given. Participating teams develop their own robot hardware and software. We describe the aim of the task settings and the analysis of the experimental results for all the teams. We studied the records of real-world experiments of Tsukuba Challenge 2019.

Keywords: Tsukuba Challenge, autonomous navigation, real world, practices and perspectives

1. Introduction

The authors are members of the steering committee that runs the Tsukuba Challenge [a]. Held every year since 2007, the Tsukuba Challenge is an open experiment of mobile robots in urban areas such as pedestrian walkways. Its objective is to achieve autonomous navigation in the real world as it is, where ordinary people live on an everyday basis. Each participating team is expected to conduct research and development of a mobile robot, conduct experiments, and share its experience and results among the participants.

The period from 2007 to 2011 was the first stage of the Tsukuba Challenge. In 2012, in response to a request, the challenge was held on a small scale for only two days. The period from 2013 to 2017 was the second stage. The period from 2018 to the present is its third stage.

This paper overviews Tsukuba Challenge 2019, including the aim of the task settings and the analysis of the experimental results for all the teams. The past sessions of the Tsukuba Challenge were reported in references [1–7]. Furthermore, details of the first and second stages were summarized in reference [8].

2. Overview of Past Tsukuba Challenges

Tables 1–3 present the records of the first to third stages, respectively. **Fig. 1** presents a plot of historical records of the Tsukuba Challenge.

The first stage did not have optional tasks, and the "goal" of autonomous navigation meant "mission achieved." The second stage included an optional task of "target object search," and "goal" + "success in the optional task" meant "mission achieved." For the current third stage, the following optional tasks are set: "area without prior data acquisition," "crossing with traffic light recognition," "passing checkpoints," and "target object search"; "goal" + "success in two or more of the optional tasks" means "mission achieved."

Approximately 10% of the participant robots are successful in autonomous navigation every year. A few of them successfully achieve the mission. Notably, although the use of ROS is increasing year by year, only a few of the robots are able to finish. The difficulty level of the tasks is increasing yearly, and the navigation length of the course is also increasing. The real world is highly uncertain and diverse. It is not easy to achieve autonomous navigation in such circumstances, and many open problems remain.

3. Task Settings for 2019 Experiments

The course map of Tsukuba Challenge 2019 is presented in **Fig. 2**. An enlarged view of the park is presented in **Fig. 3**.

The mandatory task was autonomous navigation. The participant robots were required to carry out autonomous navigation on the course of approximately 2.5 km from start to end. As optional tasks, "area without prior data acquisition," "crossing with traffic light recognition," "pass-

Table 1. Records of the first stage of the Tsukuba Challenge.

	2007	2008	2009	2010	2011	2012 (two days)
participant robots	33	50	72	70	69	36
finished (goal)	3	1	5	7	6	5
finished teams	Kanazawa Tech, U. of Tsukuba × 2	Yamaha Motor	Hitachi, FujiSoft, Tohoku U., Chiba Tech fuRo, Utsunomiya U.	National Defense Academy, Chiba Tech fuRo, U. of Tsukuba, Hitachi, UEC, AIST, FujiSoft	Chiba Tech fuRo, AIST, Utsunomiya U., Mitsuba, U. of Tsukuba, National Defense Academy	(the final was conducted several times) Utsunomiya U.×2, Waseda U., U. of Tsukuba, National Defense Academy
mission achieved	ditto	ditto	ditto	ditto	ditto	ditto
using ROS	0	0	0	1 Meiji U.	4	3
finished using ROS	0	0	0	0	0	0

Table 2. Records of the second stage of the Tsukuba Challenge.

	2013	2014	2015	2016	2017
participant robots	47	54	56	62	65
finished (goal)	3	8	3	4	11
finished teams	Utsunomiya U., National Defense Academy, U. of Tsukuba	Utsunomiya U., U. of Tsukuba × 2, Tohoku U., National Defense Academy × 2, Mitsuba, Utsunomiya PJ	(the final was rainy) Utsunomiya PJ, Tsuchiura PJ, Revast	(except for finishing in the short course) Revast, U. of Tsukuba, Tsuchiura PJ, Utsunomiya U.	Chiba Tech fuRo, National Defense Academy, Chiba Tech × 2, Shibaura Tech, Tsuchiura PJ, Utsunomiya U., U. of Tsukuba, Nippon Tech, Chiba U., Hosei U.
mission achieved	3 Utsunomiya U., NDA, U. of Tsukuba	4 Utsunomiya U., U. of Tsukuba, NDA, Mitsuba	0	1 U. of Tsukuba	3 Tsuchiura PJ, Utsunomiya U., U. of Tsukuba
using ROS	6	13	21	33	48
finished using ROS	0	1 U. of Tsukuba	1 Revast	2	6

Table 3. Records of the third stage of the Tsukuba Challenge.

	2018	2019	2020	2021	2022
participant robots	75	66	--	--	--
finished (goal)	6	3	--	--	--
finished teams	Chiba Tech fuRo, Ouchi Mirai PJ, Chiba U., Tier IV, Revast × 2	Meitantei Kohitsuji, Revast, Tsuchiura PJ	--	--	--
mission achieved	2 Chiba U., Revast	1 Revast	--	--	--
using ROS	51	49	--	--	--
finished using ROS	5	3	--	--	--

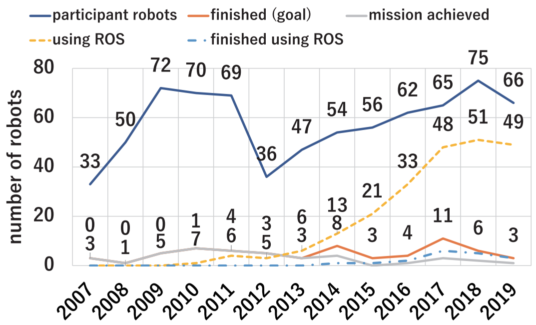


Fig. 1. Historical records of the Tsukuba Challenge.

Fig. 2. Map of the entire course.

Fig. 3. Enlarged view of the park (checkpoint candidates, search areas).

ing checkpoints + detour of closed roads," and "target object search" were set.

"Area without prior data acquisition" is a task aimed at achieving autonomous navigation even in places the robot visits for the first time. "Crossing with traffic light recognition" is a task aimed at enabling the robot to travel on a pedestrian crossing to recognize a traffic signal and vehicles on the roadway. "Passing checkpoints + detour of closed roads" is a task aimed at planning the route online such that the robot travels not a single fixed route but a variety of routes, and detours closed roads. "Target object search" is a task aimed at improving the level of object recognition in the outdoor real world and planning the path online on the basis of recognition results.

Fig. 4. Scene of two robots starting simultaneously.

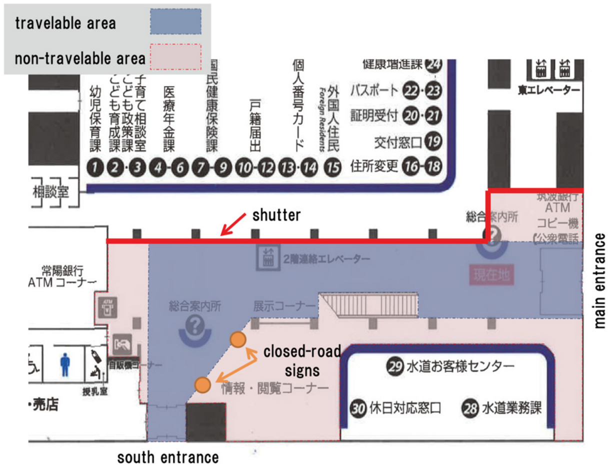
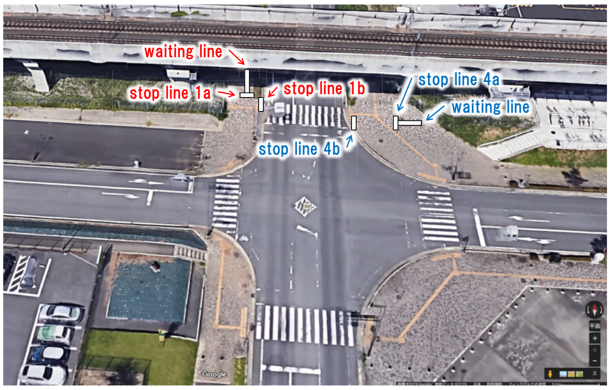


Fig. 5. Floor map of the city hall building.

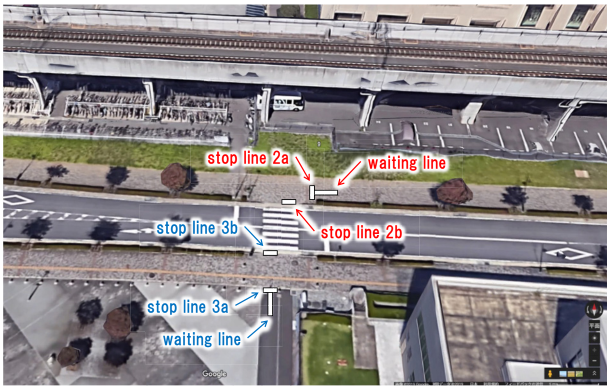
Two robots start autonomous navigation simultaneously. As presented in **Fig. 4**, two starting positions are provided separately on the right and left sides. The side of the starting position depends on the order of departure; thus, the robots need to be able to start from either position.

The optional task "area without prior data acquisition" requires the robot to travel inside the city hall building on the course without acquiring prior data. The floor map presented in **Fig. 5** is given as prior information. The robot can only enter this area at the final experiment. Prior data acquisition using a sensor mounted on the robot is prohibited. However, team members are allowed to check the site in advance.

The optional task "crossing with traffic light recognition" requires the robot to start traveling and traverse a pedestrian crossing with traffic signals on the basis of recognition of the pedestrian traffic signal and the conditions of vehicles on the roadway. If "crossing with traffic light recognition" is not executed, the operator judges and



(a) Pedestrian crossing with traffic signals



(b) Pedestrian crossing without traffic signals

Fig. 6. Pedestrian crossing in the course (Google Maps).

Fig. 7. Example of installation of stationary obstacles.

operates the robot to start the crossing. **Fig. 6** presents aerial photographs of pedestrian crossing with and without traffic signals. The robot needs to line up in a queue on the waiting line and stop at stop lines autonomously.

In the park, stationary obstacles, as presented in **Fig. 7**, are installed at random locations. In addition, the optional task "passing checkpoints + detour of closed roads" requires the robot to pass all the multiple checkpoints (the checkpoint numbers are notified the day before the experiment) and recognize and detour the closed-road sign (no prior notification on this). **Fig. 8** presents an example of the installation of closed-road signs. The route needs to be planned online for the robot to detour the closed road.

Fig. 8. Example of installation of closed-road signs.

(a) Adult male (b) Adult female (c) Child

Fig. 9. Search target mannequins.

The optional task "target object search" requires the robot to find a plurality of mannequins as search targets (clothing are notified the day before the experiment) in the search area in the park. **Fig. 9** presents the mannequins as search targets. The path needs to be planned online for the robot to get closer to the search target it finds.

With the above task settings, Tsukuba Challenge 2019 was held. For details about steering, please refer to website [a]. By performing such tasks, the objective is to achieve autonomous navigation at a higher level in the real world, and to integrate various functions into the robot system. Thus, it is expected to improve a wide range of technologies, such as selection and development of devices, e.g., sensors on hardware, and recognition, planning, and control implementation on software.

4. Results of 2019 Experiments

Sixty-six teams amounting to 419 members registered for Tsukuba Challenge 2019. A total of 59 robots appeared in the final experiment.

In the final experiment, three robots finished the goal, and one of them achieved the mission. The breakdown of the robots successes in the optional tasks was as follows: one robot was successful in "area without prior data acquisition"; two robots were successful in "crossing with traffic light recognition"; one robot was successful in "passing checkpoints + detour of closed roads"; and zero

Fig. 10. Group photograph taken after the closing ceremony of the final experiment.

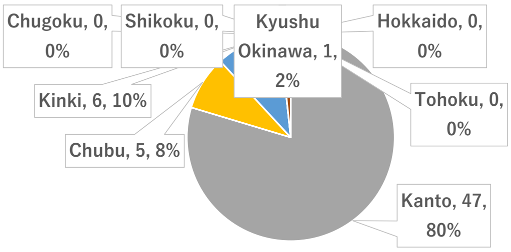


Fig. 11. Base regions of the teams.

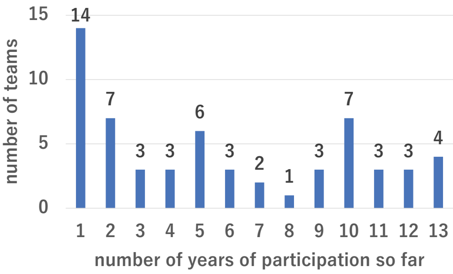


Fig. 12. Number of years of participation so far for each team.

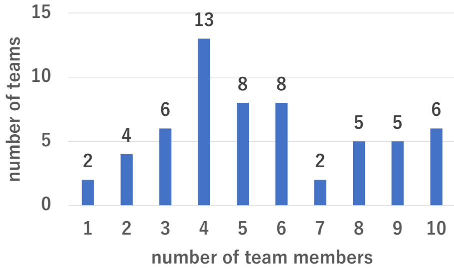


Fig. 13. Number of members per team.

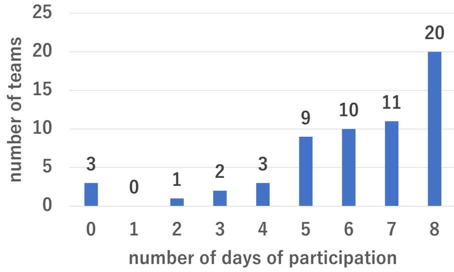


Fig. 14. Number of days of participation per team in the experiments.

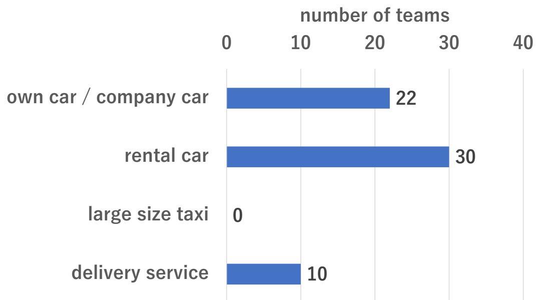


Fig. 15. Robot transportation method for each team.

robots were successful in "target object search."

For details on the results of the final experiment, please refer to the website [a]. **Fig. 10** presents a group photograph taken after the closing ceremony of the final experiment.

Next, a summary of the results of the survey data for all the teams is provided. We analyzed the experimental results for each team. The survey data are published in website [b]

Figure 11 presents the regions in which these teams are based. Since recent years, the majority of participants come from the Kanto region, and there are also many from the Chubu and Kinki regions. There used to be participants from the Hokkaido, Tohoku, and Chugoku regions, but there are no participants from these regions at present. Participation from Kyushu is also declining. In the past, there were also participants from overseas.

Figure 12 presents the number of years of participation per team. Contrary to the authors' expectations, the number of teams participating for the first time was the largest. By contrast, some teams have been participating every year since the first Tsukuba Challenge held in 2007. Team members, particularly university teams, tend to be frequently replaced by other members. Some people have been participating in the challenge every year since the first time even if their affiliation is changed.

Figure 13 presents the number of members per team. In 2019, four-member teams were the most common case, and the maximum number of team members was ten. In case the number of team members were larger than ten, they tended to form a different team even if they belong to the same organization.

Figure 14 presents the number of days of participation per team in the experiments. The majority of the teams participated in all the trial and final experiments. By contrast, for example, teams from distant regions seem to participate only for a few days immediately before the final experiment.

Figure 15 presents the method for each team to transport its robot. The majority of teams use rental cars. In some cases, participants employ their own cars or company cars. It seems that most of them carry their robots by themselves.

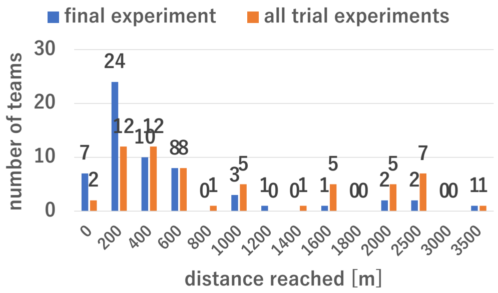


Fig. 16. Distance reached in the trial and final experiments.

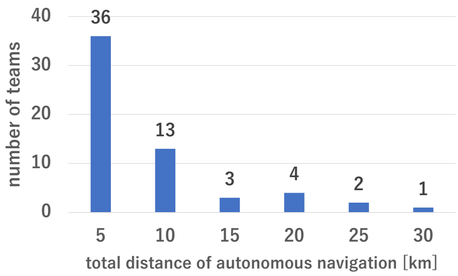


Fig. 17. Total distance of autonomous navigation in all the trial and final experiments.

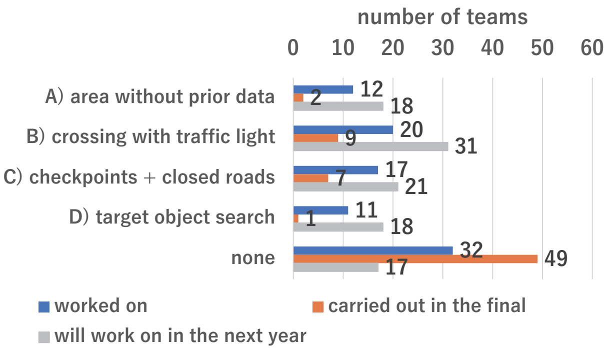


Fig. 18. Challenges to the optional tasks.

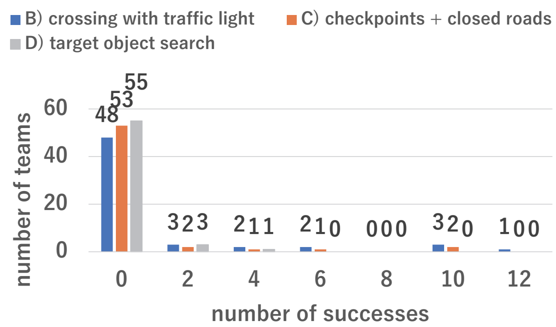


Fig. 19. Number of successes for the optional tasks in all the trial and final experiments.

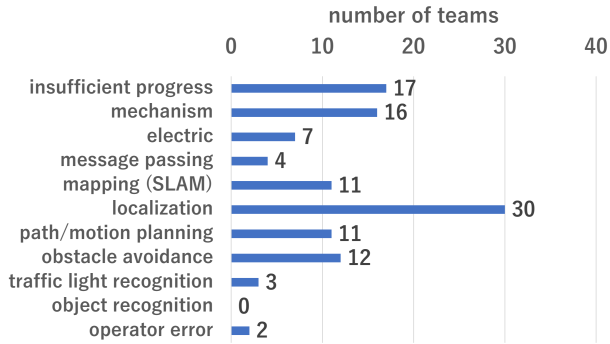


Fig. 20. Causes of failure in autonomous navigation in the trial and final experiments.

Figure 16 presents the distance reached in the trial and final experiments. The routes vary depending on the teams, and thus the distances are different even in case of the goal. Many teams failed to travel before approximately 600 m. There were many cases in which the robot failed at approximately 200 m in the final experiment, even if it successfully traveled long in the trial experiments.

Figure 17 presents the total distance of autonomous navigation in all the trial and final experiments. Those teams that succeeded in autonomous navigation conducted actual tests of several tens of kilometers in trial experiments for a total of eight days. However, there were cases in the final experiment in which it was not possible to finish the course at approximately 2.5 km. This fact evidences the difficulties emerging in the real world.

Figure 18 presents the challenges to the optional tasks. The majority of them were for "crossing with traffic light recognition"; "passing checkpoints + detour of closed roads" was also very popular; "area without prior data acquisition" and "target object search" were approximately the same. In addition, each optional task was not often carried out in the final experiment, although efforts were made for it. Less than half of the teams carried out the optional tasks. However, it seems that they have a strong will to perform them the next year.

Figure 19 presents the number of successes for the optional tasks in all the trial and final experiments. Only a few robots successfully performed the optional tasks more than once. Besides, in the final experiment, only an even smaller number of robots were successful as described above.

Figure 20 presents causes of failure in autonomous navigation in the trial and final experiments. Localization failure is the most common case. Hence, on the one hand, localization can be considered important because the environmental recognition ability is still low. On the other hand, it can be said that robots are too dependent on localization. In addition, it is necessary to pay attention to a case in which the cause of localization failure lies in map inconsistency. Besides, the real world (field) is difficult and gives rise to many hardware problems.

5. Conclusion

This paper overviews Tsukuba Challenge 2019, including the aim of the task settings and the analysis of the experimental results for all the teams. The Tsukuba Challenge has been held 13 times so far. There is no doubt that the technical level of the participant teams is improving every year, but the number of robots that finish the goal and the number of robots that successfully achieve the missions are still small.

The real world is highly uncertain and diverse, and many open problems remain. We will continue to contribute to the acceleration and deepening of robotics research and development for the entire community by setting appropriate tasks in line with technological progress and by sharing the experiences and results of each team among participants.

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