Advancing AI Education by Participating in the RoboCup@Home Competition

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This study explores the integration of AI and robotics technologies in domestic service robots through participation in the RoboCup Japan Open 2024 @Home League DSPL. The team "Re@dy" engaged in three competition tasks: TidyUp, GPSR, and Restaurant. Notable achievements include second place in the TidyUp task and a tie for second place in the GPSR task. Technical solutions involved the use of YOLACT Edge for object recognition, Point3D for 3D position estimation, and GPT-3 for contextual understanding. Despite these successes, several challenges were identified, including limitations in object recognition accuracy, insufficient flexibility of task execution, and failures in map generation for unknown environments.

From an educational perspective, this project provided valuable opportunities for students to apply advanced AI technologies and robotics concepts in real-world scenarios. Through iterative development and team collaboration, students enhanced their problem-solving skills and gained experience connecting theoretical knowledge with practical implementation. Future work will focus on improving object recognition accuracy, developing dynamic task control methods, and introducing more advanced SLAM technologies to further advance the capabilities of domestic service robots.

Keywords: *Domestic Service Robots, AI, Educational Effectiveness, RoboCup@Home, SLAM and Navigation*

1. Introduction

In recent years, the rapid advancement of artificial intelligence (AI) technologies has opened up opportunities for application across various fields. In Japan, the development of human resources specializing in mathematics, data science, and AI has become an urgent priority. According to the "AI Strategy 2022" formulated by the Japanese Cabinet Office, numerous initiatives have been launched in higher education institutions to promote the development of such talent[1]. While Japan maintains a strong industrial foundation in sectors such as automobiles and robotics, it lags behind major global technology corporations—such as GAFA and BATH—in core AI technologies. Therefore, combining Japan's strengths in robotics with advanced AI technologies is essential for pioneering new application areas.

Against this backdrop, domestic service robots have attracted significant attention as a promising application of AI technology. According to a market survey by the Fuji Keizai Group, the service robot market exceeded 2 trillion yen in 2023 and is expected to continue growing[2]. Particularly, domestic service robots equipped with manipulators and mobile platforms are anticipated to perform practical tasks such as waiter services in restaurants and household chores in home environments [3][4]. To accomplish these tasks, highly integrated AI technologies—including object recognition, speech recognition, speech synthesis, and contextual understanding—are required.

This study focuses on RoboCup@Home as a practical platform for addressing these technological challenges. RoboCup@Home is an international competition aimed at evaluating the performance of domestic service robots in real-world environments, providing an ideal setting to test the integration of AI technologies and robotics. The objective of this research is to explore practical integration methods of AI and robotics through participation in RoboCup@Home and to assess the associated educational outcomes. In particular, this study aims to foster students' ability to bridge theoretical knowledge and practical skills through hands-on development and collaborative team projects.

2. Related Research

2.1 Initiatives for AI Education at National Institute of Technology, Kitakyushu College

At the National Institute of Technology, Kitakyushu College (Kitakyushu KOSEN), courses related to AI and data science are embedded from the third academic year onward in order to foster AI- and data-science-literate engineers. The discussion below highlights two core subjects.

2.1.1 "Experiment (3rd year, PBL)"

We focus on a data-centric AI course in which students fine-tune a pre-prepared object-detection model for a small mobile robot and compete in an in-house challenge. Although students iterate on data collection and hyper-parameter tuning, they still work on teacher-prepared infrastructure and rarely select or integrate AI models entirely on their own.

2.1.2 "Artificial Intelligence" (5th year, lecture and work)

It is a survey-style course that traces AI from the first boom to the present, introducing individual algorithms and models through guided coding assignments. While comprehensive, it concentrates on model-centric knowledge acquisition; opportunities to deploy AI in realistic contexts are limited.

Across both courses, students have insufficient opportunities to identify suitable AI techniques through their own literature survey and to apply those techniques appropriately to the diverse situations encountered in real-world practice.

2.2 Domestic Service Robots

Domestic service robots are designed to assist or substitute human activities in everyday living spaces. As illustrated in Figure 1, these robots take various forms; however, in the Domestic Standard Platform League (DSPL) of RoboCup@Home, all teams utilize the Human Support Robot (HSR) developed by TOYOTA. The HSR stands approximately 100 cm tall, making it well-suited for operating in human environments. It is equipped with a wide range of sensors and actuators, including an RGB-D camera and laser range finder for vision (analogous to human eyes), microphones for auditory input, speakers for communication (analogous to a human mouth), robotic arms for manipulation, and a mobile vehicle base for locomotion.

Since the HSR does not come with a high-performance computing unit by default, each team equips the robot with an external computer according to its computational needs. In this study, we mounted a laptop equipped with a GPU on the back of the HSR to enable advanced cognitive processing tasks such as object recognition and speech processing. Furthermore, the system connects to cloud computing services as needed, utilizing various cloud APIs, including OpenAI's ChatGPT. This hybrid architecture allows the robot to achieve both real-time responsiveness through local processing and advanced AI inference via cloud-based services.

When performing tasks, domestic service robots operate based on a three-step process: **Perception**, **Decision**, and **Control**. Figure 2 illustrates this process. In the Perception step, the robot uses sensor data to recognize its environment; for example, in a tidying-up task, it identifies nearby objects using object recognition algorithms. In the Decision step, the robot determines the next action based on the recognized information, such as prioritizing the closest yellow ball for collection. Finally, in the Control step, the robot executes the chosen action by controlling its actuators, such as using its robotic arm to grasp the target object.

Through the integration of various sensors and actuators, domestic service robots are required to perform sophisticated cognitive processes and demonstrate flexible decision-making in complex and dynamic human environments.

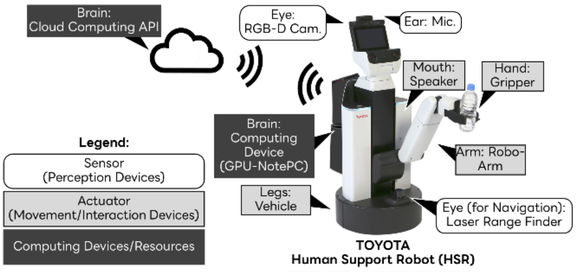

Figure 1 Overview and Key Components of a Domestic Service Robot

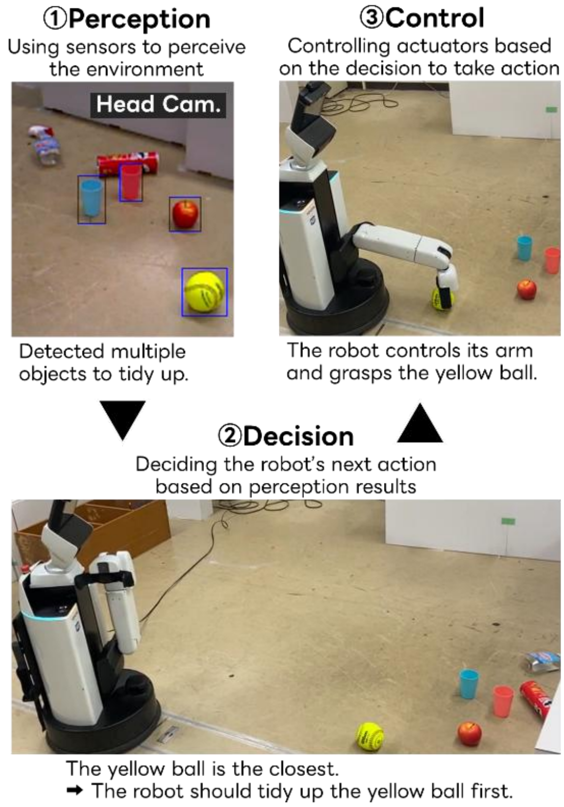

Figure 2 Processing Flow of Perception, Decision, and Control in a Domestic Service Robot

2.3 RoboCup@Home

2.3.1 Competition Overview

RoboCup is an international robotics competition established with the ambitious goal of "developing a team of fully autonomous humanoid robots capable of winning against the human world soccer champion team by the year 2050." While RoboCup initially focused on robotic soccer, it has since expanded into various leagues, including RoboCup@Home, which aims to advance the capabilities of domestic service robots and promote the development of solutions to real-world challenges.

The RoboCup@Home league focuses on practical tasks in diverse home environments, requiring a wide range of AI and robotics technologies such as object recognition, speech recognition and synthesis, contextual understanding, navigation, and manipulator control. In particular, the Domestic Standard Platform League (DSPL), a sub-league of RoboCup@Home, mandates that all participating teams use the same hardware platform—the Human Support Robot (HSR) developed by TOYOTA. This standardization eliminates hardware disparities and emphasizes competition based solely on software capabilities, making it an ideal platform for evaluating algorithm design and system integration skills.

Moreover, RoboCup@Home encourages not only technical competition but also the development of practical robotic solutions that directly address social issues and improve the quality of human life. Accordingly, adaptability and flexibility in complex real-world environments are key evaluation criteria. In this study, by participating in RoboCup@Home DSPL, we aim to practically validate advanced integration methods of AI and robotics and assess their educational effectiveness.

2.3.2 League Tasks

In the RoboCup@Home DSPL, multiple tasks are designed to comprehensively evaluate the diverse capabilities required for domestic service robots. As of the 2024 competition, the three main tasks included **TidyUp**, **General Purpose Service Robots (GPSR)**, and **Restaurant**. Each task poses distinct technical challenges, requiring advanced cognitive processing and flexible decision capabilities from the robots.

The **TidyUp Task** evaluates the robot's ability to tidy up a cluttered room. The robot must accurately recognize objects scattered throughout the environment and correctly place them in their designated locations. High-precision object recognition and accurate pick-and-place operations are critical factors for success in this task (Figure 3).

The **GPSR Task** assesses the robot's ability to understand and execute voice commands issued by humans. This includes not only simple instructions but also more complex directives such as "Count the number of people in the room" or "Answer the person standing near the trash can." As such, this task requires the integration of advanced AI technologies, including speech recognition and synthesis, contextual understanding, and flexible action planning (Figure 4).

The **Restaurant Task** challenges the robot to perform waiter duties in an unknown environment without prior map information. In this task, the robot must navigate a new space, locate customers, take orders, retrieve and deliver items, and interact with humans. Success in this task depends on the robot's ability to combine environmental perception, navigation, gesture recognition, and human interaction capabilities (Figure 5).

Through these tasks, the RoboCup@Home DSPL provides a comprehensive evaluation of the technical capabilities required for domestic service robots to address real-world challenges.

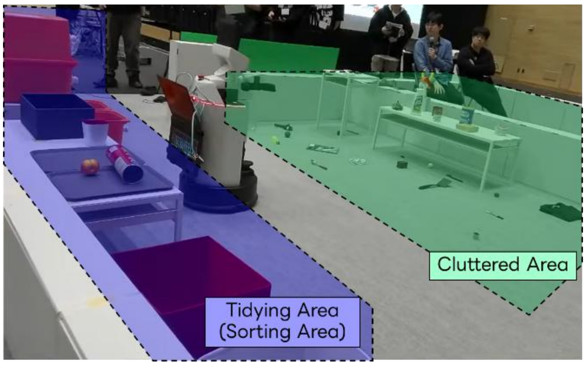

Figure 3 Robot Operation in the TidyUp Task

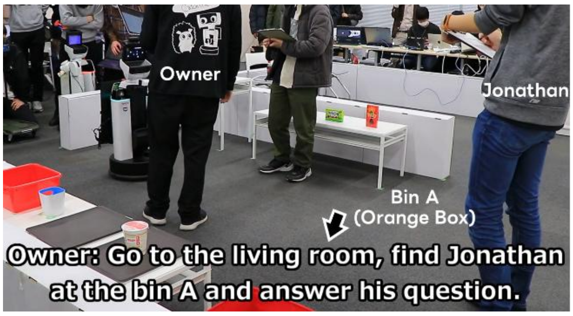

Figure 4 Robot Interaction in the GPSR Task

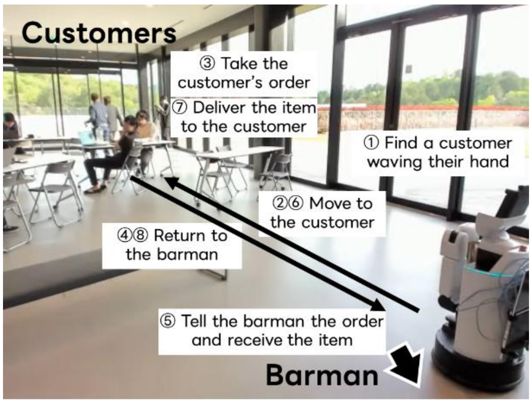

Figure 5 Robot Task Sequence in the Restaurant Task

3. Materials and Methods

In this study, we participated in the Domestic Standard Platform League (DSPL) of the RoboCup Japan Open 2024 @Home League to evaluate the integration methods of AI and robotics technologies for domestic service robots in real-world environments. The team "Re@dy" organized its members according to their assigned tasks, as shown in Table 1, to ensure an efficient development process. An agile development methodology was adopted, and a competition field was set up within the laboratory to conduct iterative cycles of planning, design, development, and testing. By working in a shared physical space, the team facilitated real-time communication and rapid problem-solving.

The Human Support Robot (HSR) developed by TOYOTA was used as the robotic platform. Since the HSR does not come equipped with high-performance computing resources by default, a laptop with a GPU was mounted on the robot's back to enable advanced processing tasks such as object recognition and speech processing. ROS 1 (Noetic) was used for software development, and each AI module was implemented as a ROS 1 node. When necessary, cloud-based APIs such as OpenAI GPT-3 and Azure Speech Services were utilized, allowing for a hybrid processing system that combines local and cloud-based computation.

During the development of key technologies, the team analyzed the competition rulebook to extract the required functionalities, as summarized in Table 2. These technologies were integrated using the ROS 1 state machine library Smach to construct task execution flows compliant with competition rules.

In particular, for the TidyUp task, a task flow was implemented using Smach as follows:

1. Navigate to the area where objects are scattered.
2. Recognize nearby objects using the object recognition algorithm.
3. Calculate the 3D positions of objects using Point3D.
4. Grasp the objects using arm control.
5. Navigate to the designated storage area.
6. Place the objects and return to step 1.

In the GPSR task, Whisper was used for speech recognition, and GPT-3 handled contextual understanding, enabling the system to flexibly respond to complex instructions. For the Restaurant task, Cartographer was used for navigation in unknown environments, enabling autonomous map generation and navigation.

Table 1 Assignment of Students to Tasks

Student	Grade	Task
A	4	TidyUp
B	5	TidyUp
C	5	GPSR
D	5	Restaurant
E	5	Restaurant

Table 2 Utilization of Key Technologies in Each Task

Task	Technology	Software	AI or Not
TidyUp	Object Recognition	YOLACT Edge	Yes
	3D Position Estimation	Point3D	No
	State Machine	Smach	No
GPSR	Speech Recognition	Whisper	Yes
	Context Understanding	GPT-3 (API)	Yes
	State Machine	Smach	No
Restaurant	Navigation /SLAM	Cartographer	No
	State Machine	Smach	No

4. Results

In this study, we participated in three tasks of the RoboCup Japan Open 2024 @Home League DSPL: TidyUp, GPSR, and Restaurant. The results of the team "Re@dy" in each task are summarized in Tables 3 to 5. Notably, the team achieved 2nd place in the TidyUp task and tied for 2nd place in the GPSR task. However, no points were scored in the Restaurant task.

In the **TidyUp Task**, high-precision estimation of object positions was achieved using Point3D-based 3D point cloud processing, and appropriate pick-and-place operations contributed to the high score. Although YOLACT Edge was employed for object recognition, some misrecognition of small objects occurred. The task was executed stably by following the pre-designed Smach state machine flow.

In the **GPSR Task**, Whisper was used for speech recognition, and GPT-3 was employed for contextual understanding, enabling the robot to handle relatively complex commands. By dynamically switching among pre-defined state machines based on GPT-3 outputs, the robot was able to respond to a variety of instructions. However, due to the limited number of prepared states, the system was unable to handle all possible commands.

In the **Restaurant Task**, Cartographer was utilized for navigation in unknown environments, but an appropriate environmental map could not be generated on-site, and the task could not be completed.

Table 3 Competition Results of the TidyUp Task[9]

Rank	Score	Team	Affiliation
1st	780	TRAIL	The University of Tokyo
2nd	422.5	**Re@dy (Ours)**	National Institute of Technology, Kitakyushu College
3rd	410	HMA Tamunosuke	Kyushu Institute of Technology
4th	220	eR@sers	Tamagawa University
5th	145	OIT-RITS	Osaka Institute of Technology, Ritsumeikan University
6th	30	SOBITS	Soka University
7th	5	iPutok	Osaka International Professional University of Technology
8th ~ 11th	0	N/A	N/A

Table 4 Competition Results of the GPSR Task[9]

Rank	Score	Team	Affiliation
1st	50	HMA Tamunosuke	Kyushu Institute of Technology
2nd (tie)	25	**Re@dy (Ours)**	National Institute of Technology, Kitakyushu College
2nd (tie)	25	TRAIL	The University of Tokyo
4th	22.5	OIT-RITS	Osaka Institute of Technology, Ritsumeikan University
5th	12.5	SOBITS	Soka University
6th	1.25	eR@sers	Tamagawa University
7th ~ 11th	0	N/A	N/A

Table 5 Competition Results of the Restaurant Task[9]

Rank	Score	Team	Affiliation
1st	1300	eR@sers	Tamagawa University
2nd	1100	TRAIL	The University of Tokyo
3rd	650	HMA Tamunosuke	Kyushu Institute of Technology
4th	650	SOBITS	Soka University
5th	100	OIT-RITS	Osaka Institute of Technology, Ritsumeikan University
6th ~ 11th	0	**N/A (include ours)**	N/A

5. Discussion

5.1 Technical Insights

In the **TidyUp task**, stable pick-and-place operations were achieved through the integration of Point3D-based object position estimation and arm control. However, YOLACT Edge occasionally misrecognized objects, which led to decreased task efficiency. Future improvements should include adopting a more accurate object recognition model, and enhancing recognition accuracy through data augmentation techniques.

In the **GPSR task**, the limited number of pre-defined state machines constrained the system's flexibility in handling various tasks. To overcome this limitation, future work should focus on developing methods for dynamically generating and expanding state machines based on situational requirements.

In the **Restaurant task**, the failure to autonomously generate a reliable map of an unknown environment was the primary cause of task failure. This prevented the robot from performing autonomous navigation. Incorporating more advanced SLAM algorithms is a key challenge to be addressed in future research.

Beyond these technical lessons, the project also yielded important educational insights, discussed next.

5.2 Educational Insights

Robotics competitions such as RoboCup address these gaps. Unlike traditional lecture/exercise/homework formats, they (i) require students to survey, choose, and integrate appropriate AI models with minimal staff guidance, (ii) expose them to diverse, unstructured scenarios that are impossible to reproduce in class, and (iii) provide an external, high-stakes evaluation that motivates sustained, team-based iteration under time pressure. Such authentic engineering constraints sharpen problem-solving skills and deepen the link between theory and practice.

To gauge learning gains, we administered an Artificial Intelligence Learning Questionnaire (AILQ) after the competition (Table 6). Students first recalled and reported their pre-competition state (Before) and then completed the After section. Despite this retrospective design, mean scores rose uniformly across affective, behavioural, cognitive, and ethical domains, suggesting broadly positive effects.

In the present study, five students benefited. Scaling the model wide could follow two paths: (i) organising an internal RoboCup-style event, which is logistically simple but lacks external interaction; or (ii) encouraging participation in external competitions of comparable calibre, which delivers similar benefits but requires careful alignment of schedules and technical prerequisites. A full AI curriculum cannot yet rely solely on competition-based learning, but hybrid programmes—combining lectures, data-centric projects, and progressively larger competitions involving university labs or AI companies—are under consideration. Future research will adopt a prospective pre-/post-design with larger cohorts to validate these trends under more rigorous conditions.

Table 6 Mean AILQ Learning-Domain Scores Before and After RoboCup Participation ("Before" scores were collected after RoboCup; participants were instructed to recall and answer how they had felt prior to the competition.)

Subscale	Before	After
Affective Learning	3.06	3.19
Behavioural Learning	3.51	3.72
Cognitive Learning	3.19	3.42
Ethical Learning	2.99	3.04

6. Conclusion

In this study, we conducted a practical evaluation of AI and robotics integration methods for domestic service robots by participating in the RoboCup Japan Open 2024 @Home League DSPL. As a result, the team achieved second place in the TidyUp task and tied for second place in the GPSR task, demonstrating the effectiveness of applied technologies such as object recognition, speech recognition, and navigation. However, several technical challenges were also identified, including limitations in object recognition accuracy, insufficient task flexibility, and difficulties in map generation for unknown environments.

For the participating students, this project provided a valuable learning opportunity to apply advanced AI and robotics technologies in practical scenarios. Their abilities to connect theoretical knowledge with practical applications, collaborate effectively in teams, and proactively identify and address issues were significantly enhanced. These experiences are expected to become valuable assets for their future careers and improve their problem-solving capabilities in real-world environments.

Furthermore, the agile development approach and problem-based learning (PBL) methods implemented in this project are applicable not only to AI and robotics education but also to other fields of engineering and general education. Specifically, these methods can be incorporated into classroom-based PBL activities by introducing structured team development, task division, and sprint reviews to foster practical problem-solving skills alongside theoretical learning. In addition, applying the agile development framework to extracurricular activities such as the NHK College of Technology Robocon (Robot Contest) can improve project planning, task management, and effective team communication within limited timeframes.

In future work, we plan to further explore the versatility of these educational methods and investigate their applicability across various disciplines to contribute to the qualitative improvement of engineering education.

Future work will also focus on introducing more accurate object recognition models, developing dynamic task control methods, and applying advanced SLAM technologies to further promote the practical development of domestic service robots.

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