JST ASPIRE "AI-Physical Systems"
Kick-Off Meeting

Introduction to Autonomous Ship Navigation Research at OMU

Marine Technology & Systems Lab.

Dept. of Marine System Engineering
Graduate School of Engineering

Hirotada Hashimoto

Osaka Metropolitan University

Today's Presentation

Hirotada Hashimoto
Professor, Dr. Eng.
"Introduction to Autonomous Ship Navigation Research at OMU"

Takefumi Higaki
Assistant Professor, Dr. Eng.
"Data-Driven Route Planning for Maritime Autonomous Surface Ships"

Hitoshi Yoshioka
PhD course student, (Dr. Eng.)
"Graph-Based Reinforcement Learning Method with Control Barrier Functions for Safe Marine Traffic Control"

Background

- The shortage of seafarers engaged in domestic shipping has become a serious concern in Japan.
- Autonomous ships are expected to provide a solution to this issue.

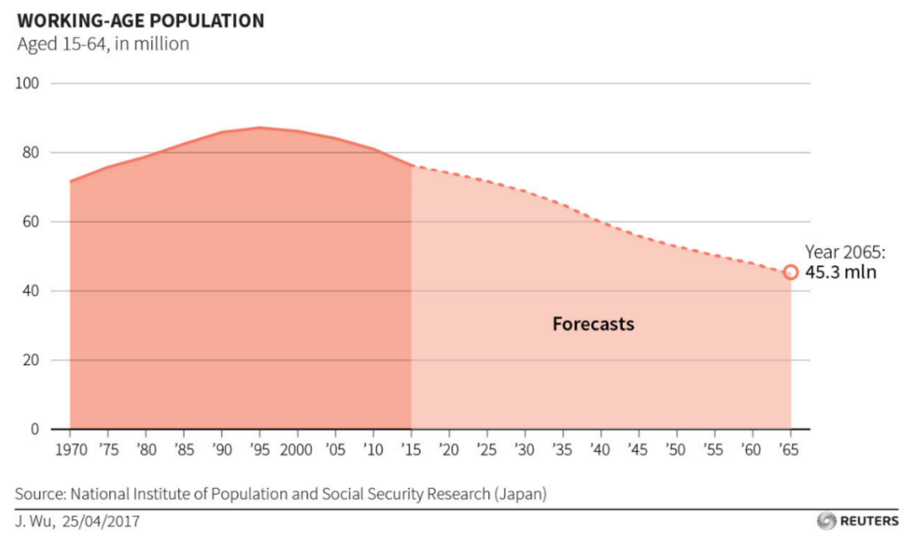


Image: Reuters

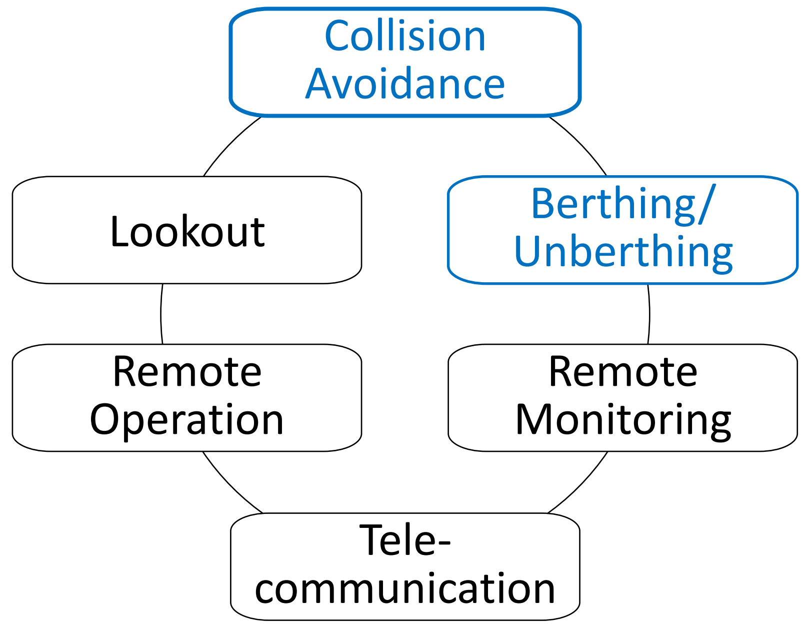
- The Nippon Foundation predicts that half of Japan's domestic shipping vessels will be unmanned by 2040.
- Recent advances in technologies such as IoT, big data, and AI are making autonomous ships a reality.

Introduction

- The International Maritime Organization (IMO) is developing non-mandatory goal-based code for Maritime Autonomous Surface Ships (MASS), which is scheduled to be adopted in 2026 to ensure the safety of life at sea as well as the safety of the vessels themselves.
- Automatic collision avoidance and automatic berthing/unberthing are key technologies enabling autonomous ship navigation.

Source: Kongsberg

Elementary technologies for MASS



https://www.mlit.go.jp/common/001215815.pdf

Challenges in Collision Avoidance

- Incorrect decision-making can result in serious collision accidents.
- Given the countless encounter patterns between vessels and the requirement to comply with the International Regulations for Preventing Collisions at Sea (COLREGs), determining an appropriate maneuver is highly complex.
- Ships do not have braking capability.
- There is no uniquely correct maneuvering solution. It depends on the expert's judgment and experience.

A flexible and regulation-compliant collision avoidance algorithm is required to ensure navigational safety while minimizing risks to surrounding vessels across diverse operational scenarios.

Challenges in Berthing/Unberthing

- Incorrect decisions may lead to collisions with a quay.
- Ships exhibit low responsiveness to maneuvering inputs and are strongly affected by external disturbances such as wind and currents.
- Maneuvering performance varies significantly depending on the vessel type.
- Ships have no braking capability, which increases the difficulty of safe maneuvering.

Accurate prediction of ship motion in the presence of natural environmental disturbances, proper route planning that ensures adequate safety margins, and precise maneuvering are required.

Approach & Problems

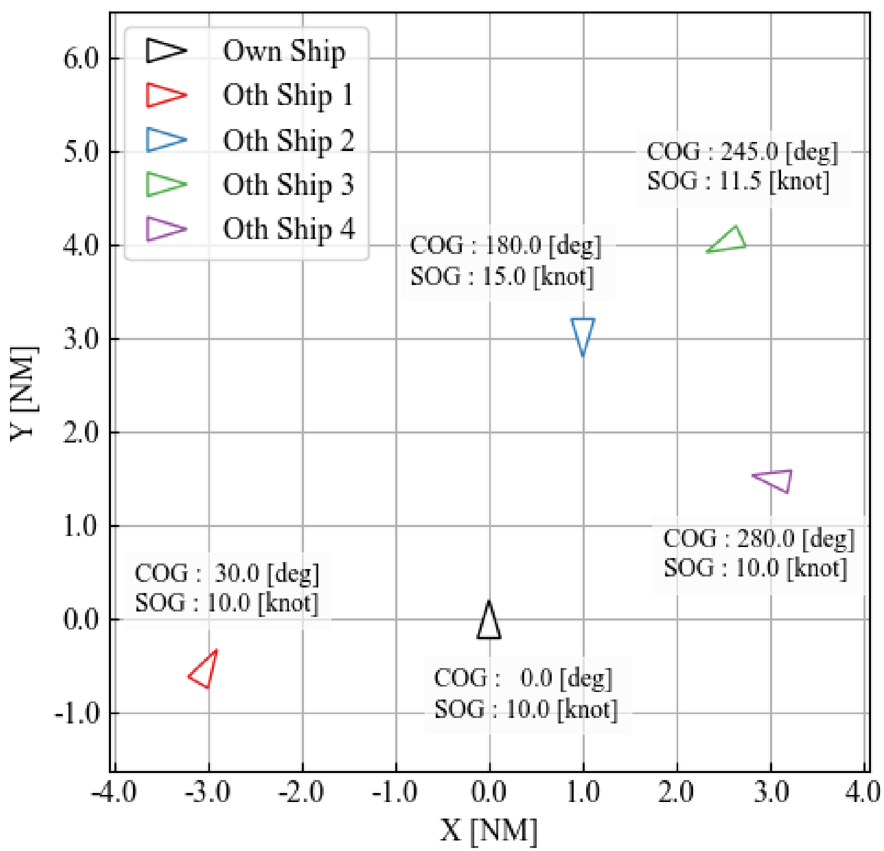
Approach

- ☐ Knowledge-based Optimal Routing (OR)
- ☐ Deep Reinforcement Learning (DRL)
- ☐ Inverse Reinforcement Learning (IRL)
- ☐ Imitation Learning (IL)
- ☐ Diffusion Policy (DP)

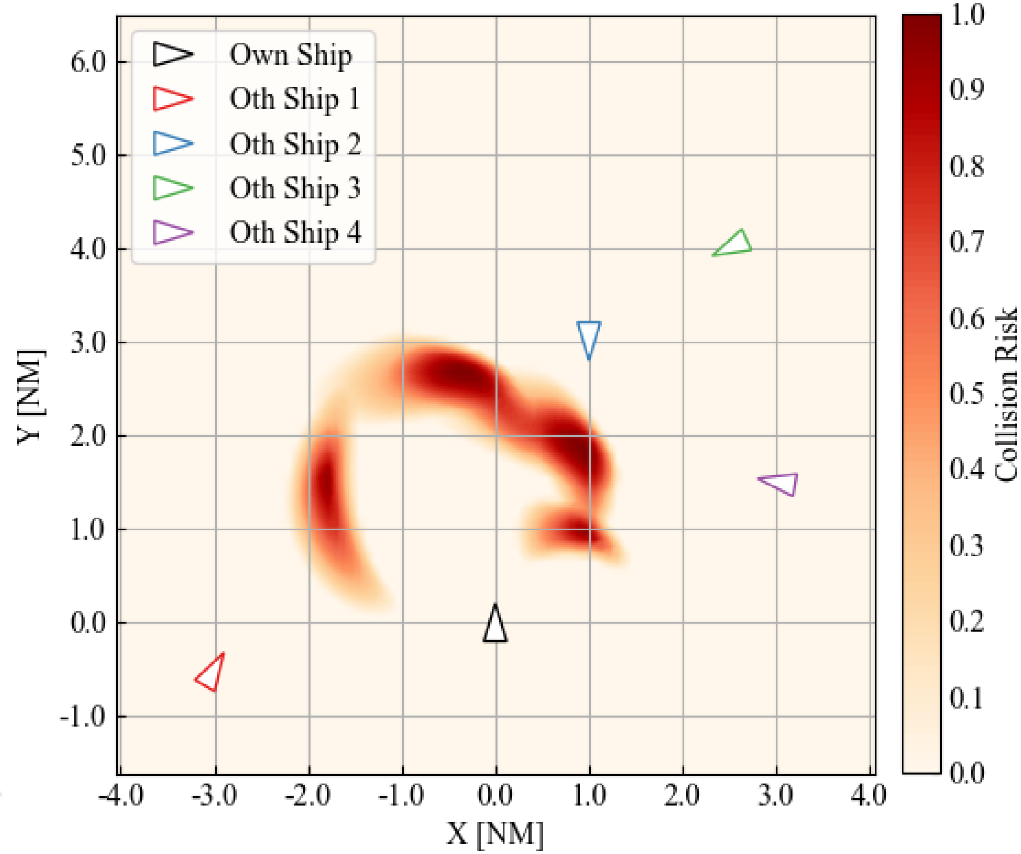
Problems for social implementation

- ➢ Cost settings/flexibility
- ➢ Evaluation/Reliability
- ➢ Black box nature/Explainability
- ➢ Safety guarantee
- ➢ Modelling error/Uncertainty
- ➢ Multi-vessel control

Knowledge-based (Collision Avoidance)

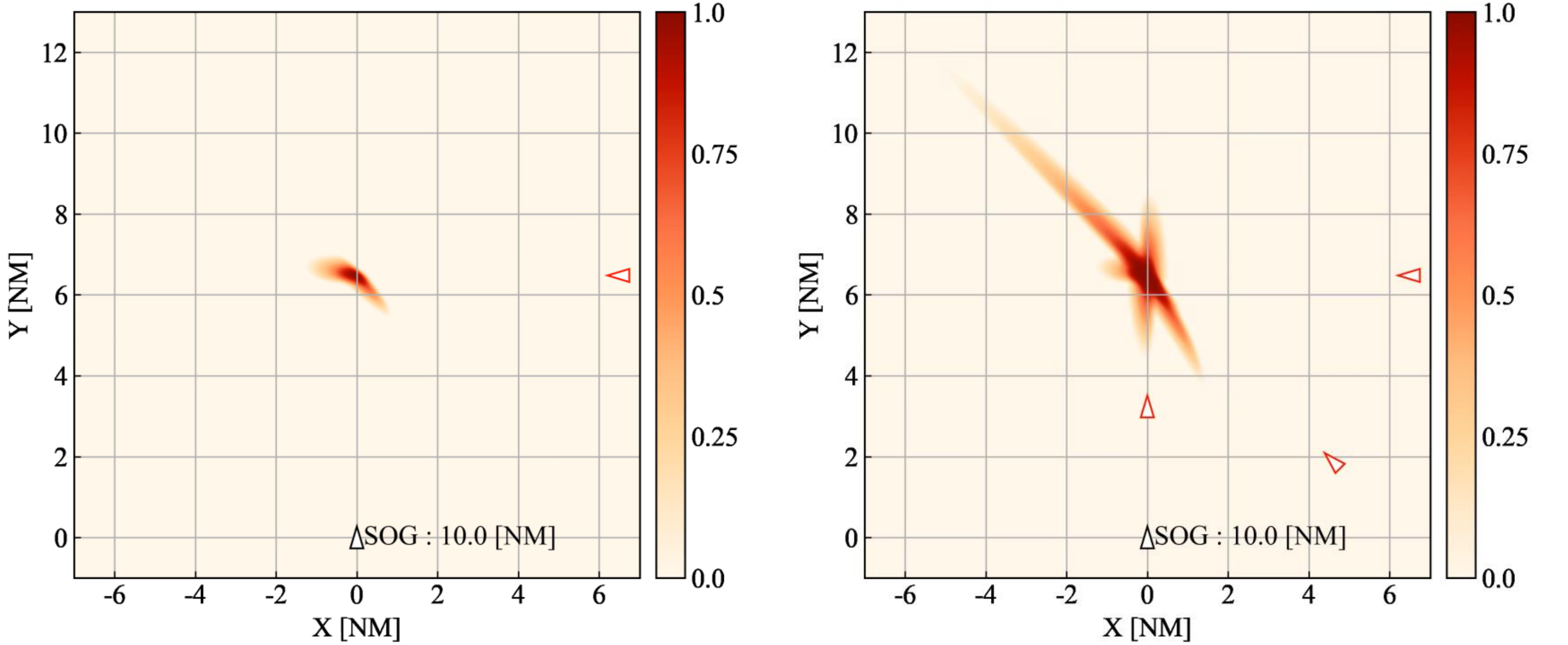


Collision Risk Map (CRM)



Yoshioka, H., Hashimoto, H. et al. (2023) Ocean Engineering https://doi.org/10.1016/j.oceaneng.2023.115705

Knowledge-based (Collision Avoidance)



The combination of course changes and speed control enabled safe and efficient collision avoidance; however, the results strongly depend on the cost settings. ***It is difficult to design cost functions with human-like flexibility.***

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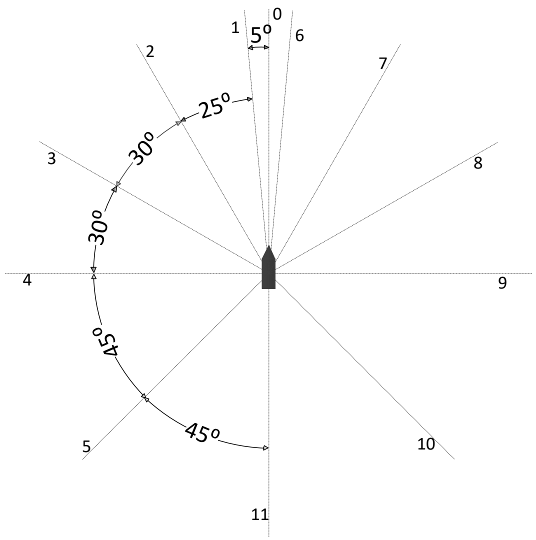
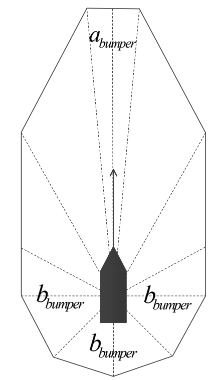
DRL (Collision Avoidance)



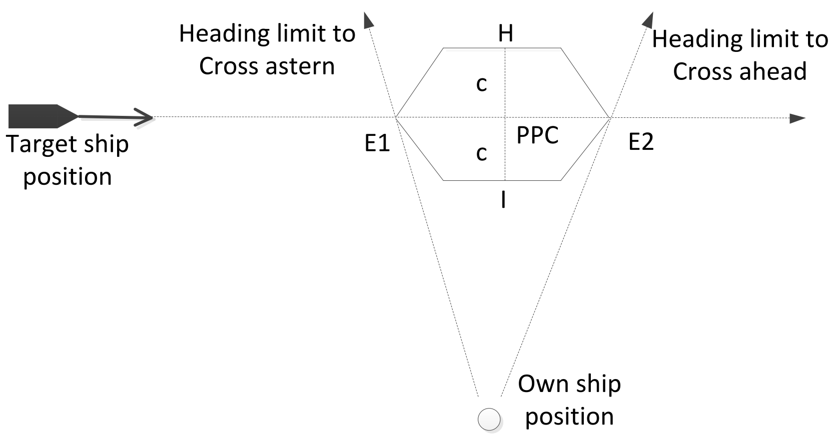
Method: DQN

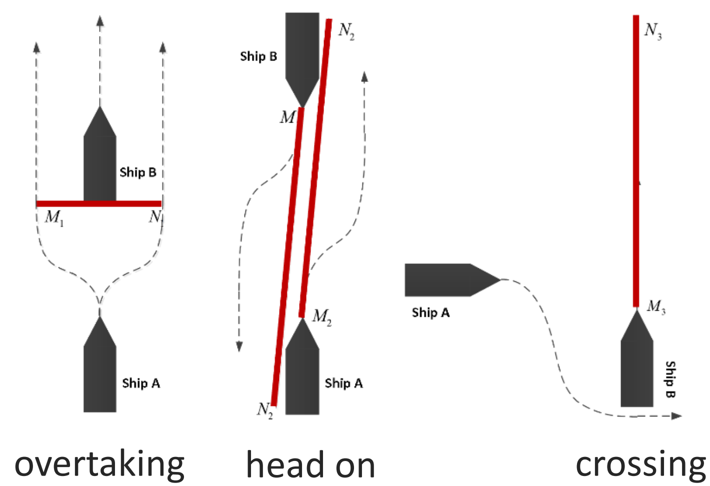
$$a_t \in \{-\Delta\psi, 0, \Delta\psi\}$$

$$r_e(t) = \begin{cases} negative\ \ value,\ if\ \ collided \\ \sum_{i=0}^{11} w_i d_i\ ,\ otherwise \end{cases}$$



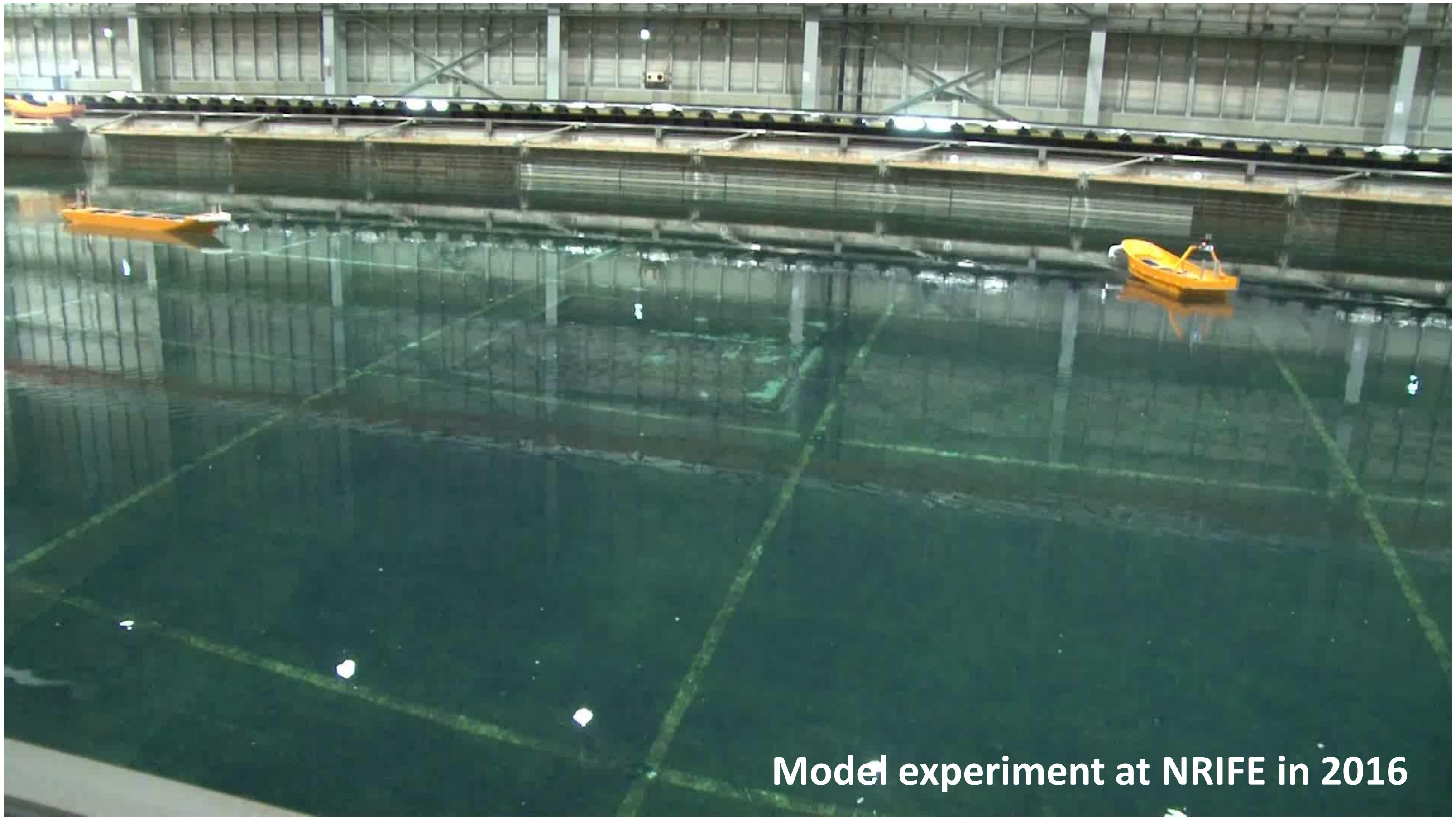
$$a_{bumper} = 6.4L,\ b_{bumper} = 1.6L$$





Shen, H., Hashimoto, H. et al. (2019) Applied Ocean Research https://doi.org/10.1016/j.apor.2019.02.020

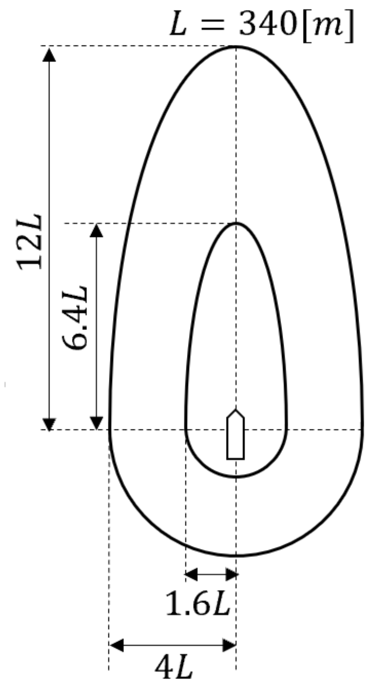
DRL (Collision Avoidance)



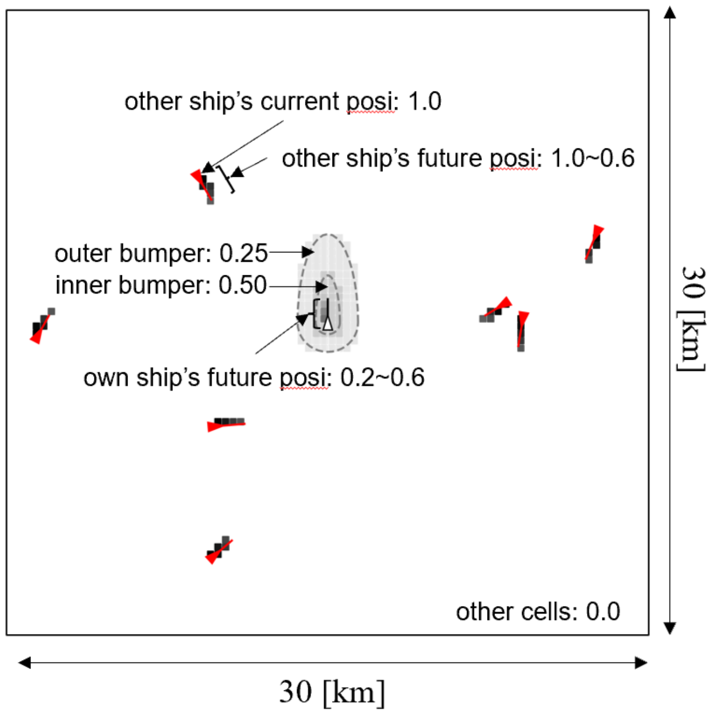
The ship models successfully navigated autonomously while avoiding collisions.

Shen, H., Hashimoto, H. et al. (2019) Applied Ocean Research https://doi.org/10.1016/j.apor.2019.02.020

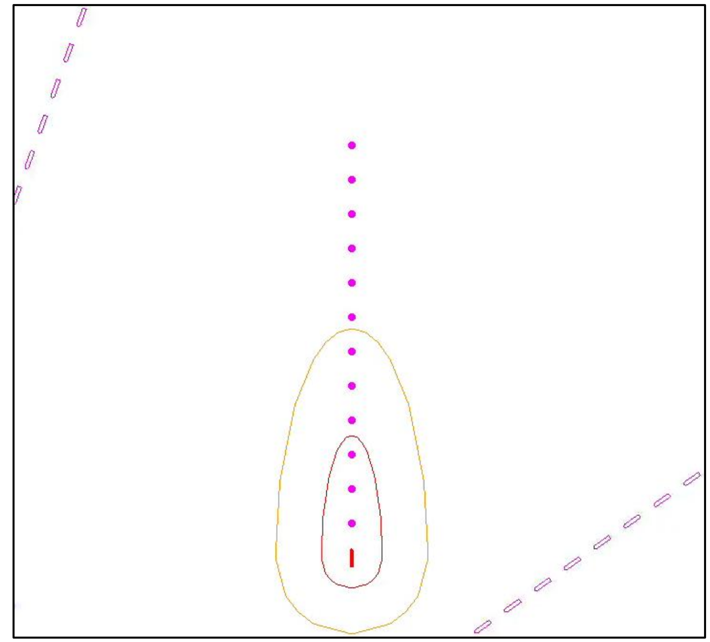
DRL (Collision Avoidance)



double bumper model
for reward setting



82 × 82 meshes for
state observation

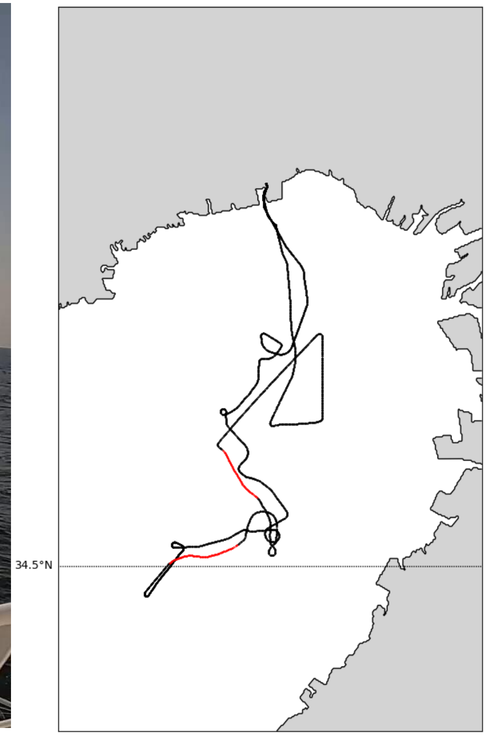


Numerical experiment using
a well-trained model

Yoshioka, H. and Hashimoto, H. (2023a) Proc. of Advanced Maritime Engineering Conference (AMEC 2023)

Experimental Validation

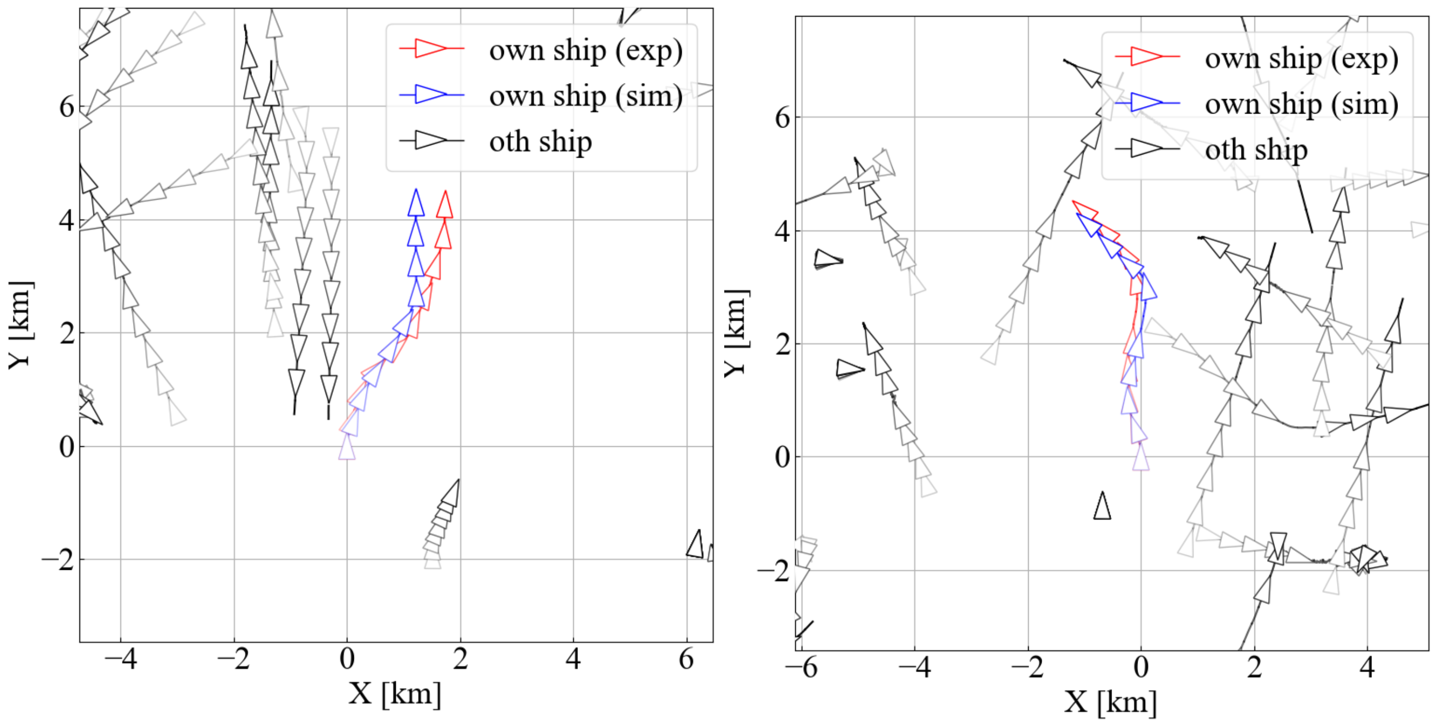
Full-scale ship experiment using the training vessel “Fukae-Maru” in Osaka Bay (2020)



The ship successfully navigated by following the AI-generated desired course.

Yoshioka, H. and Hashimoto, H. (2023a) Proc. of Advanced Maritime Engineering Conference (AMEC 2023)

Experimental Validation

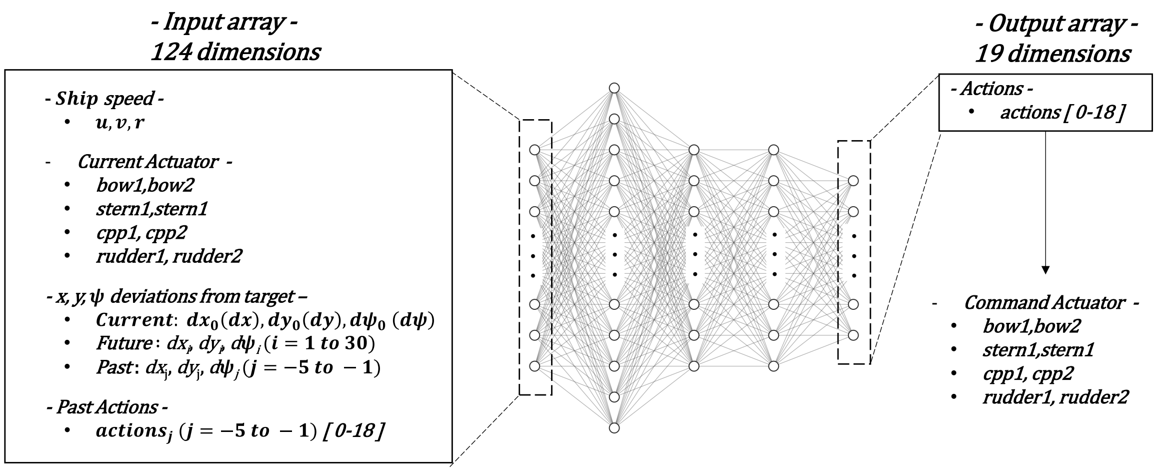


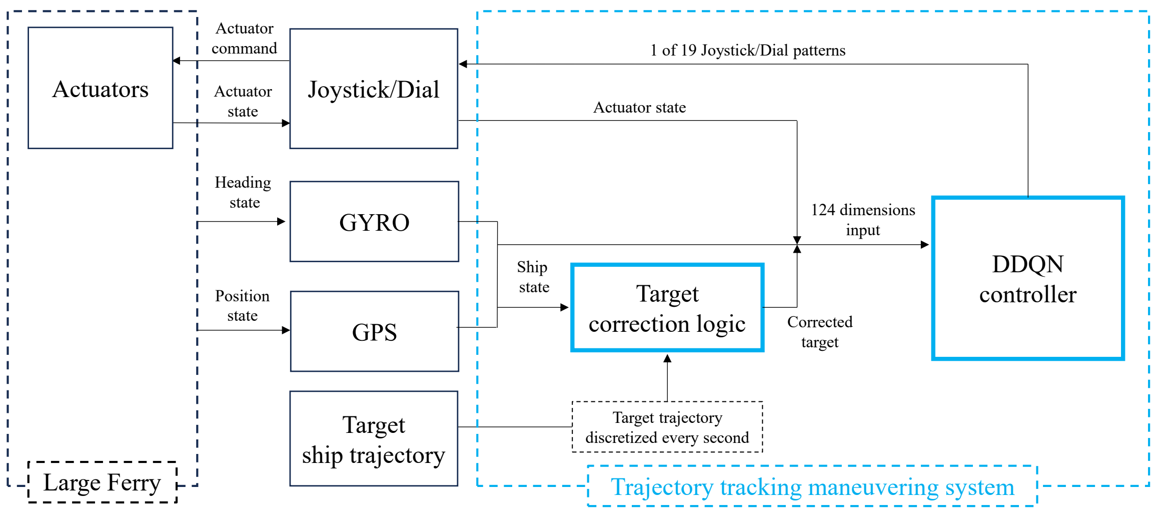
The simulated trajectory obtained using the observed data from the experiment does not match the actual experimental results. ***This discrepancy may become problematic in congested waters.***

Yoshioka, H. and Hashimoto, H. (2023a) Proc. of Advanced Maritime Engineering Conference (AMEC 2023)

DRL (Berthing/Unberthing)

Method: double DQN





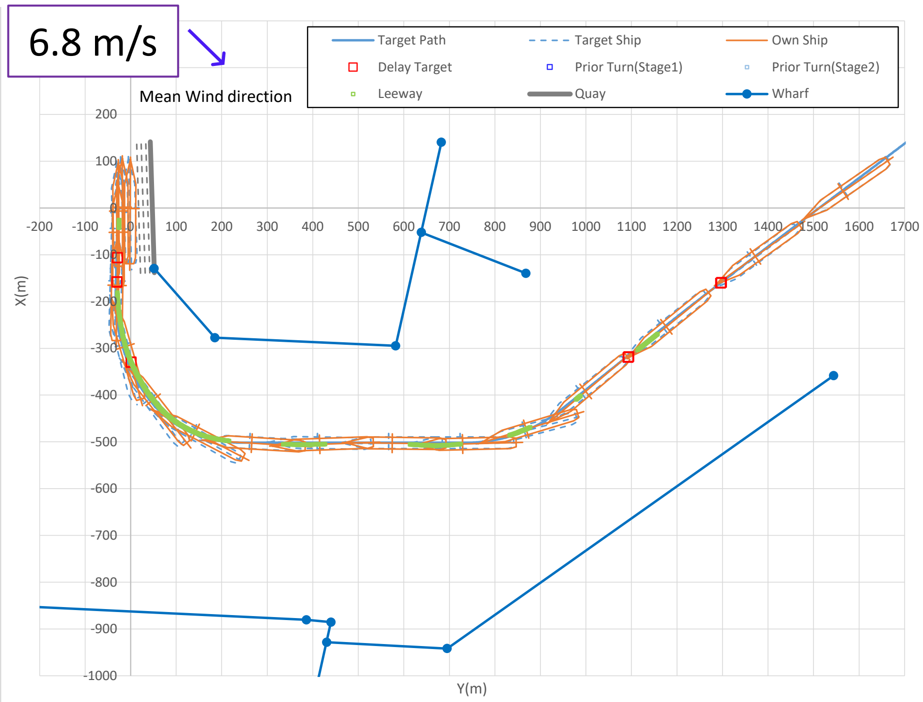
Higo, Y. et al. (2023) Ocean Engineering https://doi.org/10.1016/j.oceaneng.2023.115750

Experimental Validation

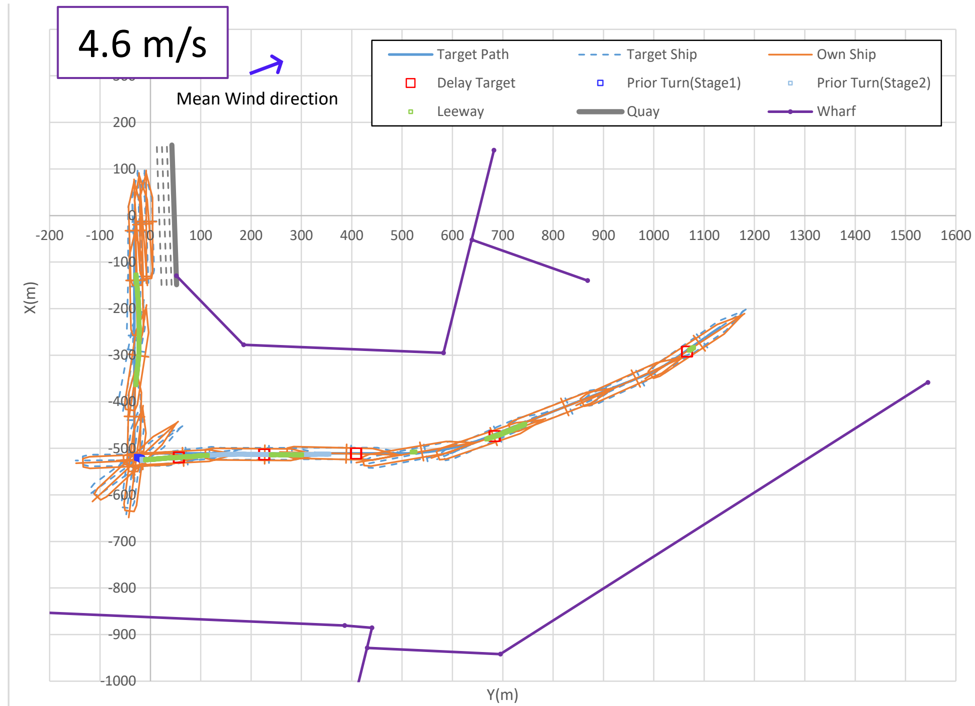
Full-scale ship experiment using a large ferry at Shin-Moji Port (2021)

Experimental Validation

Berthing



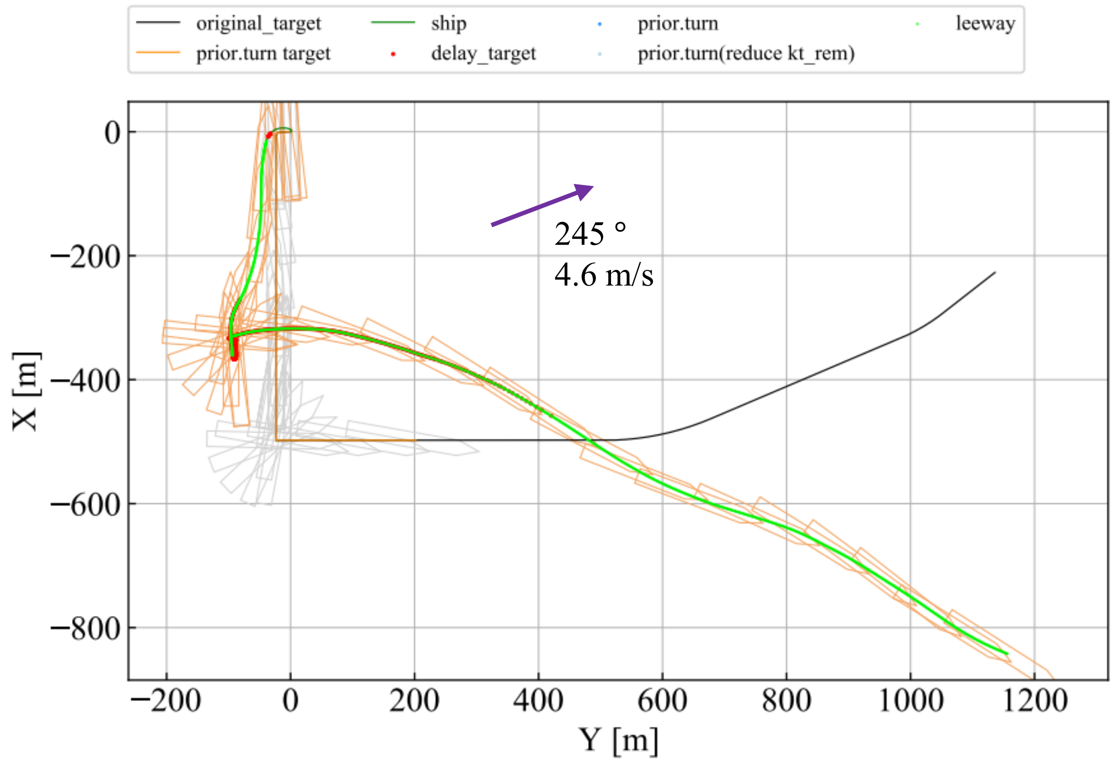
Unberthing



Berthing was successfully achieved through AI-based maneuvering that tracked the planned trajectory.

Higo, Y. et al. (2023) Ocean Engineering https://doi.org/10.1016/j.oceaneng.2023.115750

Experimental Validation



The simulated trajectory obtained using the observed actuator movement from the experiment does not match the actual experimental results. ***Thus, online local trajectory correction was essential.***

Higo, Y. et al. (2023) Ocean Engineering https://doi.org/10.1016/j.oceaneng.2023.115750

Summary

- Key technologies and challenges related to autonomous ship navigation were introduced.
- It is not easy to model the judgment and decision-making processes of skilled captains.
- Consequently, the design of cost functions or reward formulations becomes difficult, which limits the ability to realize flexible, human-like decision-making.
- Validation results from past full-scale ship experiments demonstrated that, in real-world operations, mitigating the effects of modeling errors and environmental disturbances is a key issue for DRL-based control.