RIVER FLOW PATH CONTROL WITH REINFORCEMENT LEARNING

Dongqi LIU[1], Yutaka NAITO[1], Chen ZHANG[1], Shogo MURAMATSU[2]
Hiroyasu YASUDA[3], Kiyoshi HAYASAKA[4], and Yu OTAKE[5]

[1]Graduate School of Sci. & Tech., Niigata Univ., Japan,
[2]Faculty of Eng., Niigata Univ., Japan,
[3]Research Inst. for Natural Hazard & Disaster Recovery, Niigata Univ., Japan,
[4]Faculty of Sci., Niigata Univ., Japan, [5]School of Eng., Tohoku Univ., Japan

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Outline

① Introduction

- Background
- Artificial Variable-Width Channel
- Problem & Purpose

② System concept

- River flow path control system

③ Proposed method

- Control with reinforcement learning
- Overview of reinforcement learning

④ Performance evaluation

- Simulation specifications
- Simulation results

⑤ Conclusion

- Summary and future task

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Background

■ A frequent occurrence of river disasters cause economic loss and human victims

In Japan,

- The torrential rain in July, 2020
- Typhoon No.10 in Sept., 2020
- Typhoon Hagibis in Oct.,2019
- etc.

◆ One of the causes is the meandering due to changes in the flow path of the river channel

Fig.1 Bank corruption of Otofuke River (Hokkaido, Japan) due to meandering in 2011 [1]

It is necessary to

- ➢ elucidate the mechanism of the flow path change
- ➢ control the path changes in the river channel

[1] T. Kuwamura et al., *Advances in River Engineering (in Japan)* , Jun.2016

Artificial Variable-Width Channel (AVWC)

- ■ Change the flow path channel by placing river groynes periodically
- ■ AVWC maintains healthy riverbed

- ●Without groynes :
  - ➢Meandering
- ●With groynes:
  - ➢Straight

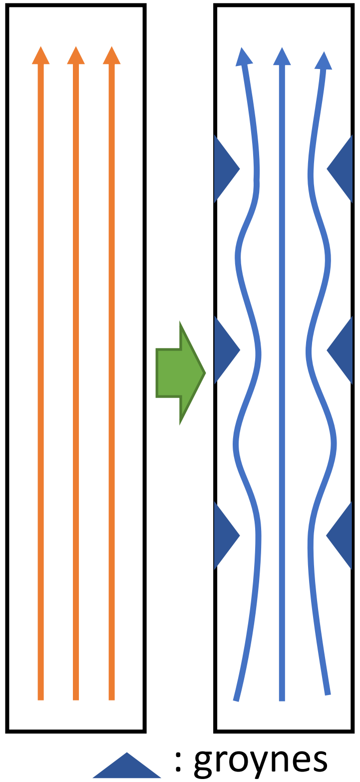

Fig.2 AVWC

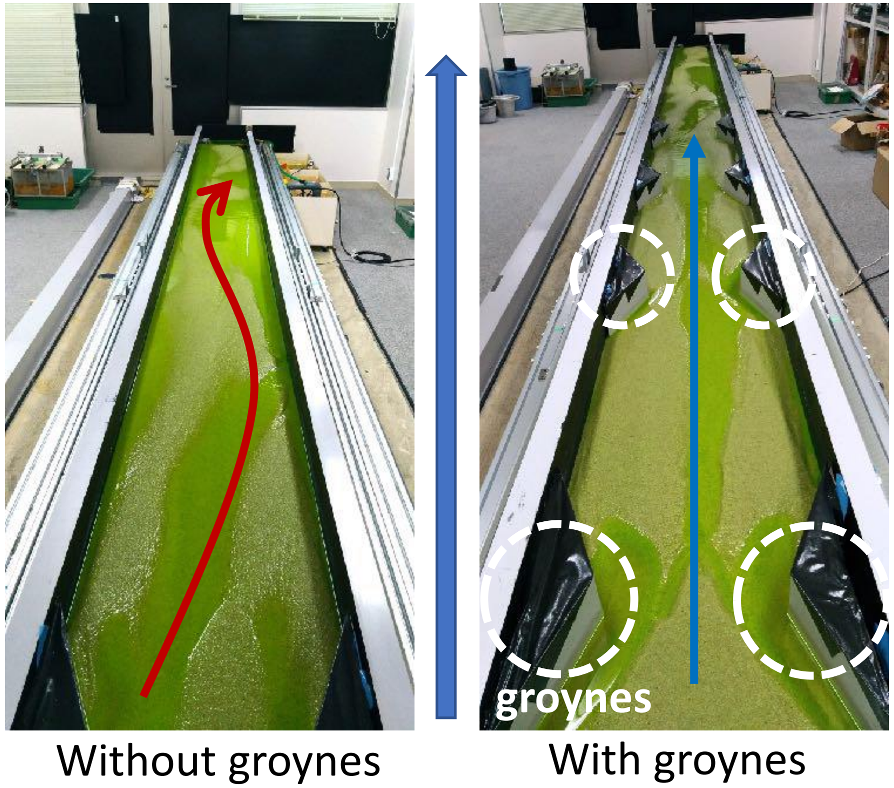

Fig.3 Experiments of AVWC using the indoor experiment setup [2]

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[2] T. Hoshino et al., *Journal of Japan Society of Civil Engineers Ser.A2 (Applied Mechanics (AM))* , 2018

Artificial Variable-Width Channel (AVWC)

- Both function of flood control and environmental protection of AVWC have been verified in real rivers [3]

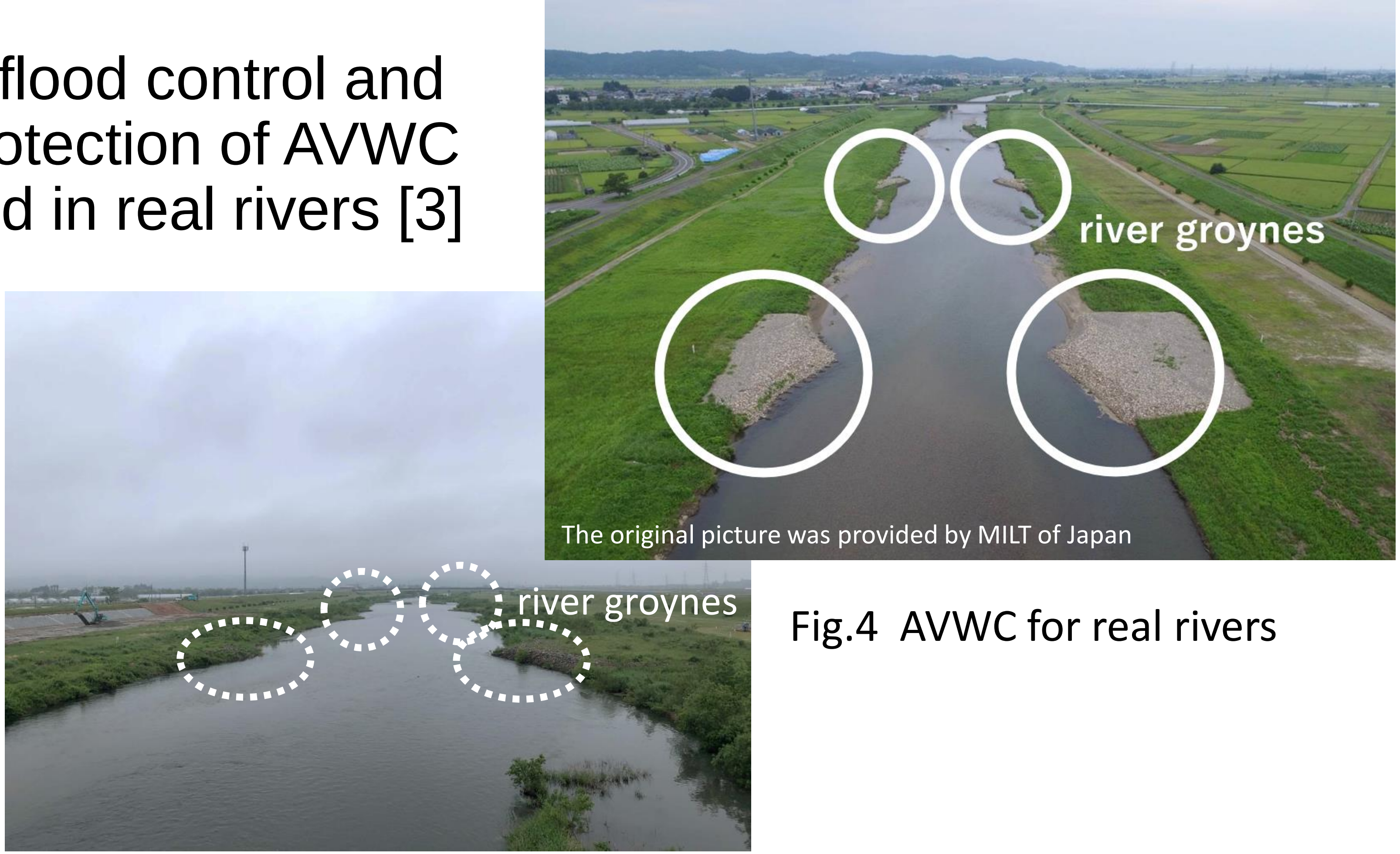

Fig.4 AVWC for real rivers

[3] K. Umeki et al., *Advances in River Engineering (in Japan)* , Jun.2021

Problem & Purpose

Problem :

- River groynes of conventional AVWC are **static**
- Difficult to find an optimized placement and shape due to **unclear mechanisms** of riverbed and flow path change
- Immediate measures are demanded

Purpose :

- Control river flow path channel **dynamically**
- Maintain healthy rivers on a daily basis

River Flow Path Control System

- ■ Build an autonomous system to control river groynes according to changes as needed in real rivers
- ■ Build the system as a CPS for using less human resources

- □ The control method has not existed due to the unclear mechanisms

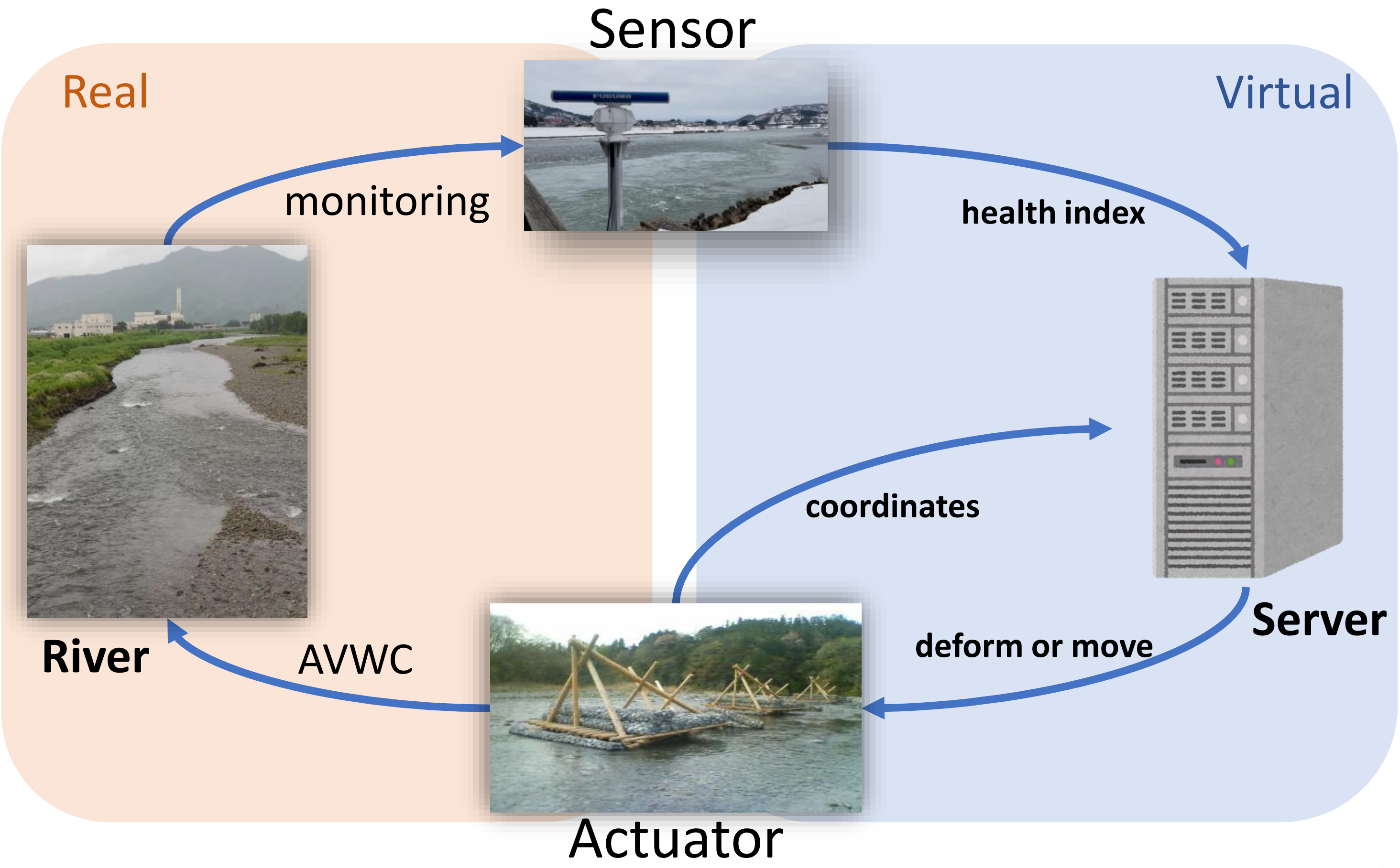

Fig.5 Concept river flow path control system

Control with Reinforcement Learning

- Propose to apply reinforcement learning as a control method
- Determine actions by reinforcement learning according to current coordinates and health index

- Conduct experiments with simulation and prototype system

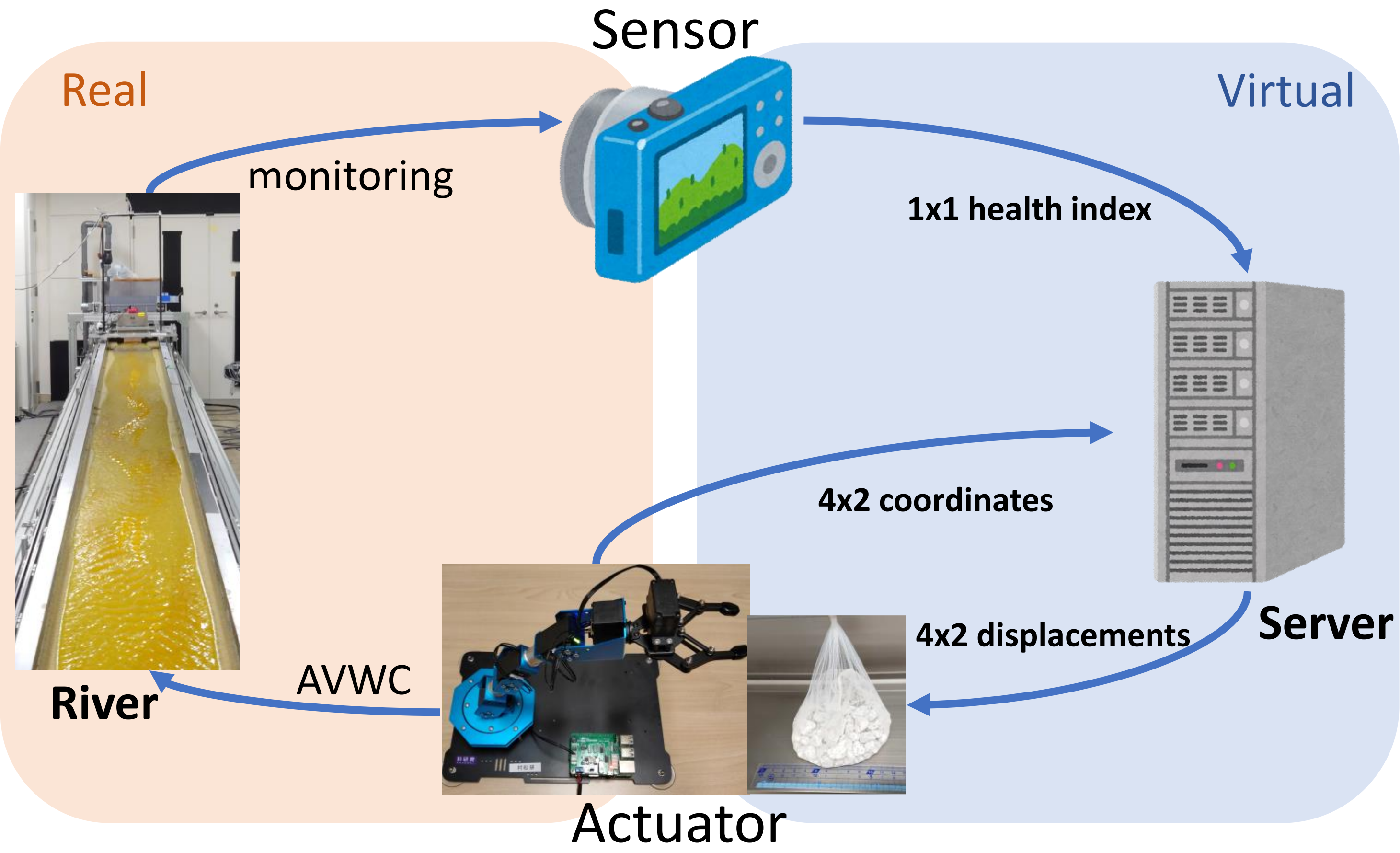

Fig.6 Configuration of river flow path control system

Reinforcement Learning (RL) [4]

- One of machine learning methods
- "State", "Reward", "Action"
  - Decide the optimal action based on the perceived state
  - e.g. AlphaGo, Autonomous car, etc.

- Double Deep Q-learning Network (DDQN) [5]
  - An algorithm of RL based on the value of actions
  - Use 2 networks of action-selecting network and value-calculating network to learn more quickly and accurately

➢ To verify the effectiveness, modeled parts of the system and simulated

Fig.7 AlphaGo

[4] K. Arulkumaran et al., *IEEE Signal Processing Magazine*, Nov.2017
[5] H. van Hasselt et al., *30th AAAI Conference on Artificial Intelligence, 2016*

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Simulation Specifications

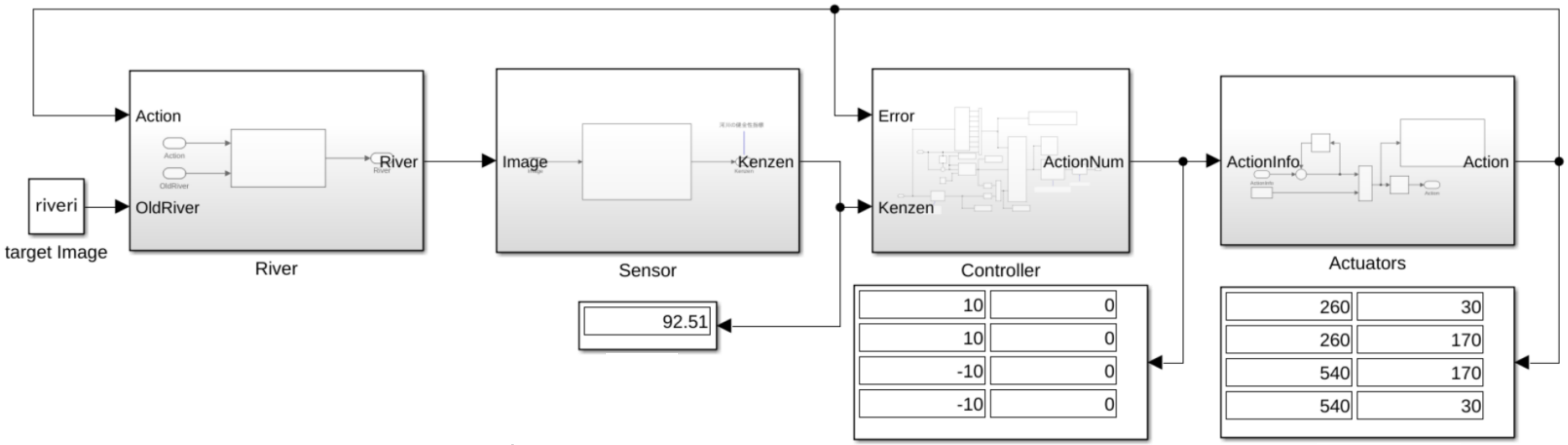

Fig.8 MATLAB/Simulink model of river flow path control system

Table1 Experiment specifications

OS	Ubuntu 18.04 LTS
Env.	MATLAB/Simulink R2020b
Toolbox 1	Reinforcement Learning Toolbox
Toolbox 2	Deep Learning Toolbox

Table2 Parameters of the DDQN model

Discount Factor γ	0.9
Learning Rate	0.001
Maximum Number of Episode	2500
Maximum Steps per Episode	20

Definition of Health Index

- The health of a river flow path is defined by a variety of factors
  - e.g. water level, meandering, flow rate, etc.
- A health index of real river flow path is being studied through experiments

◆ In this study, defined the health index by the ratio of the river soil area in the entire image in terms of preventing erosion to the embankment

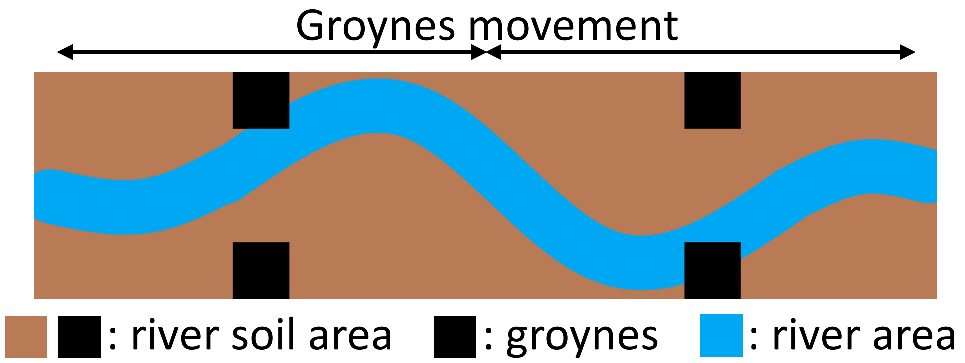

Fig.9 Definition of the health index for simulation

Reinforcement Learning Model

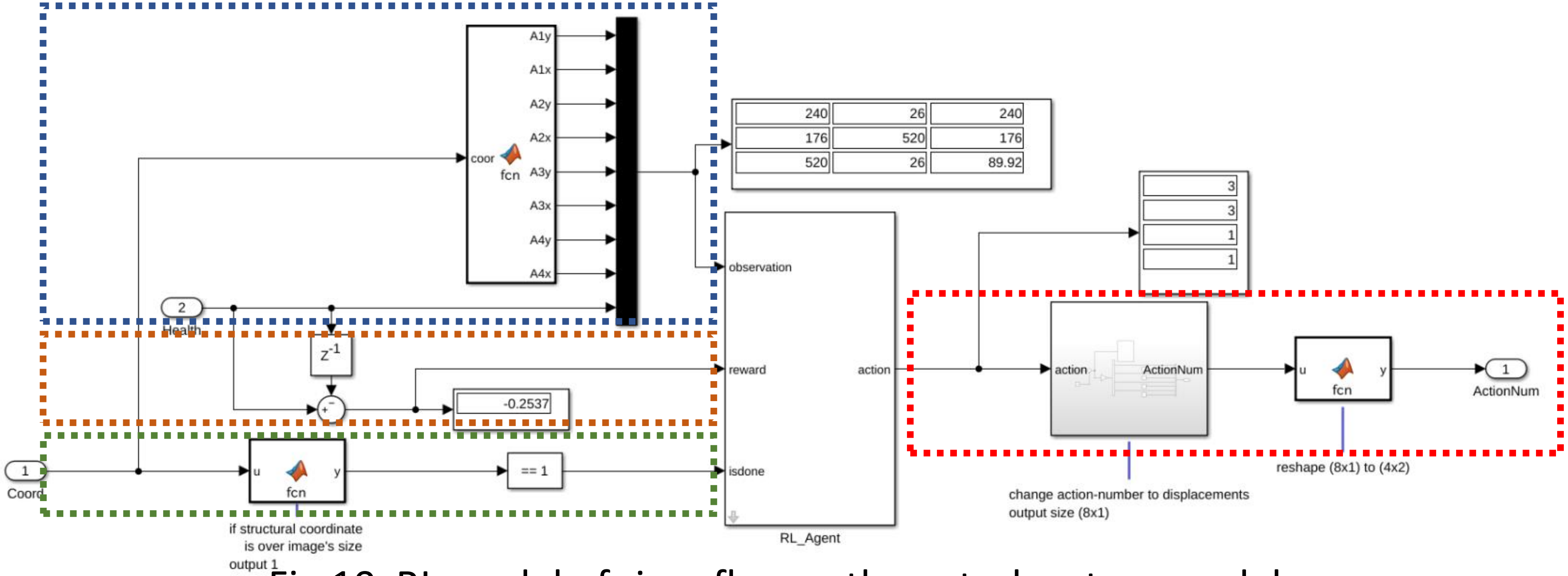

Fig.10 RL model of river flow path control system model

- Combine the coordinates and the health index as a signal of observation
- Input the change of the health index as a reward of actions
- Send a logical decision of the operating range to “isdone”
- Determine actions and send a signal to “Actuator” block

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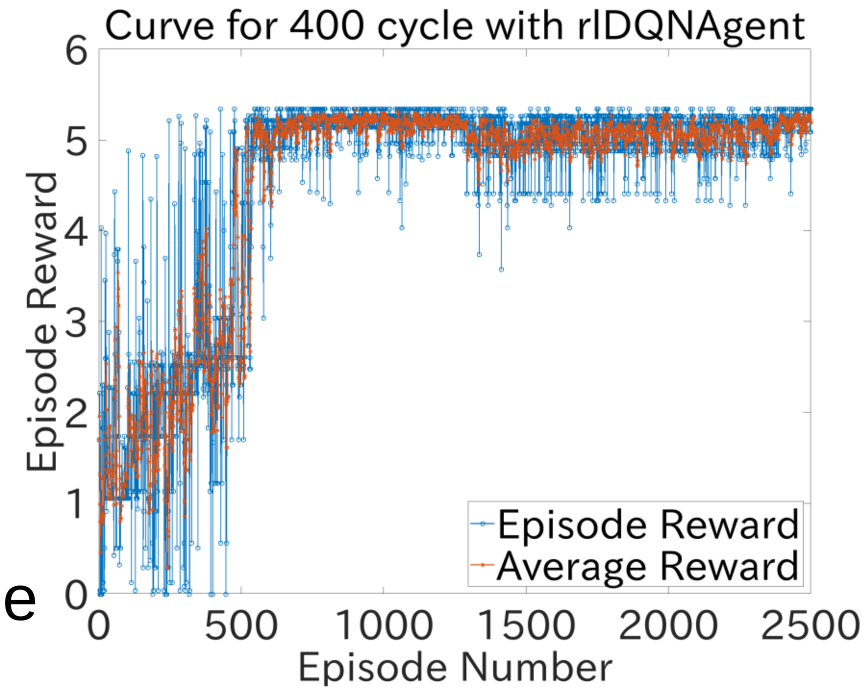
Simulation Result with River Images

Image size : 800x200 pixels
(Similar to the indoor experiment setup)
Meander cycle : 400, 600 and 800 pixels

For meander image of cycle 400 pixels :

- ■ Learning curve converged to almost highest value
- ■ The health index changed from 0.848 to 0.899
- ■ Groynes moved to configured optimal placement
- □ Learning curve oscillated on the last part



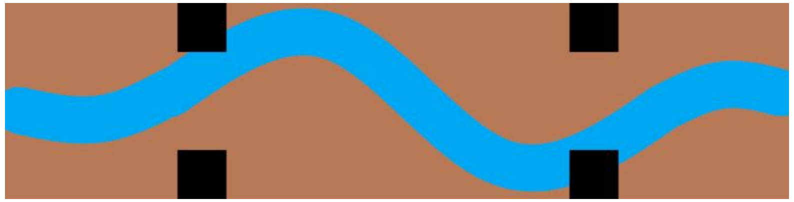


Fig.11 Result of river image with meander cycle 400 pixels

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Simulation Result with River Images

Common features :

- Learning curve converged to a high value
- The health index increased by the movements

Differences :

- The longer the meandering period changed, the more difficultly the RL model learned

➢ River CPS with reinforcement learning is **effective**

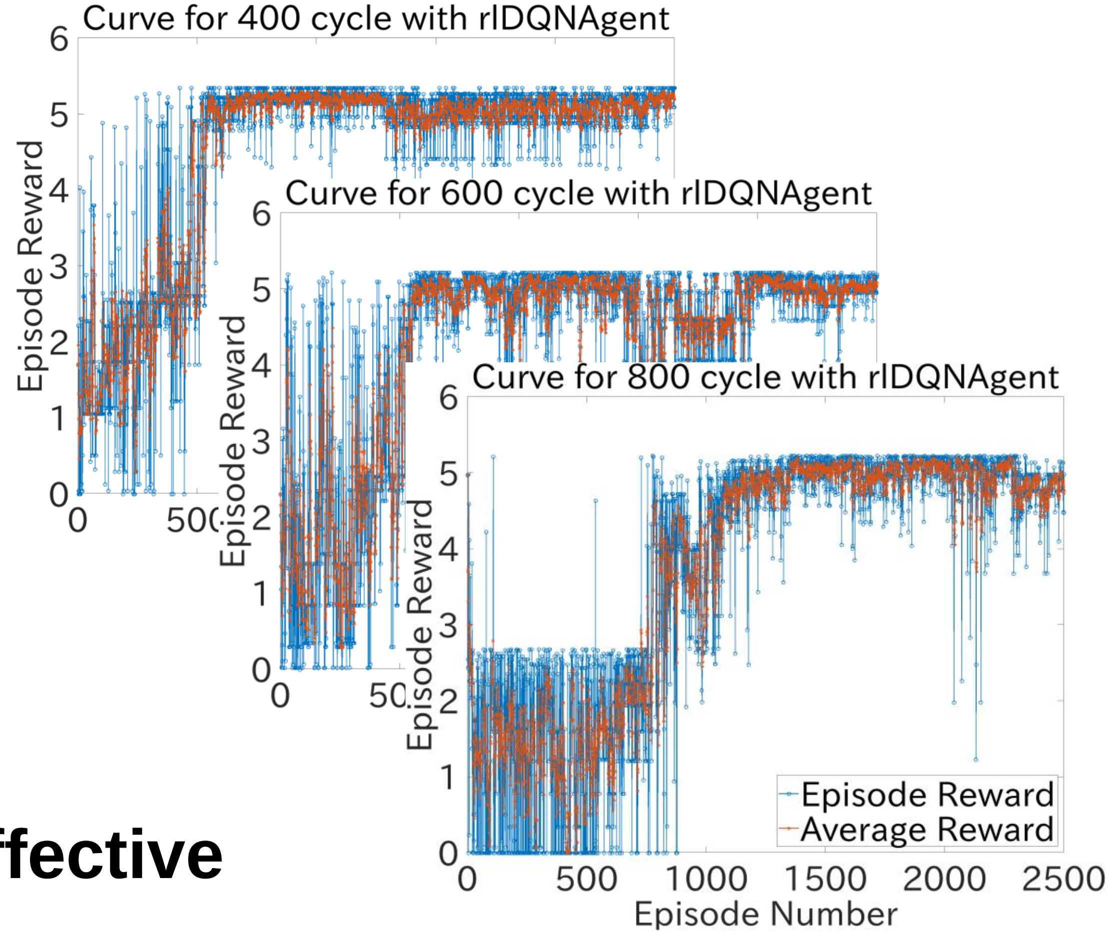

Fig.12 Comparison of learning curves

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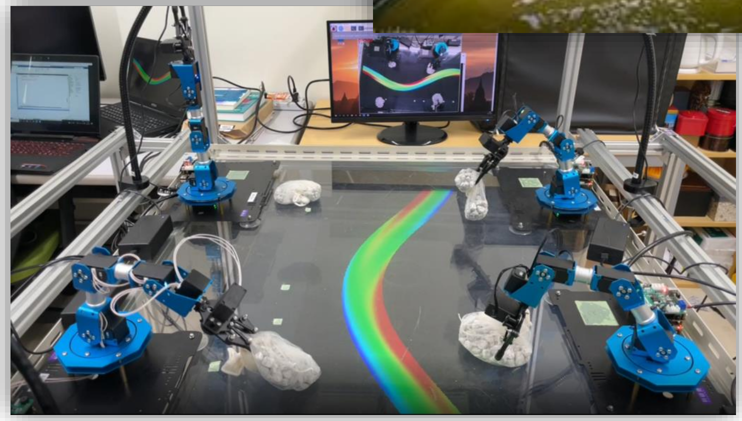
Summary and Future Task

- ■ Created a simulation model of River CPS
- ■ Verified the effectiveness of the river flow control system with reinforcement learning

In future,

- ➢ Conduct experiment on prototype system
- ➢ Update simulation model to learn on dynamic river flow simulation
- ➢ Control and maintain rivers dynamically



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