Approach for Automatic Planning for Line Heating Using Reinforcement Learning and Non-linear FEM Simulation

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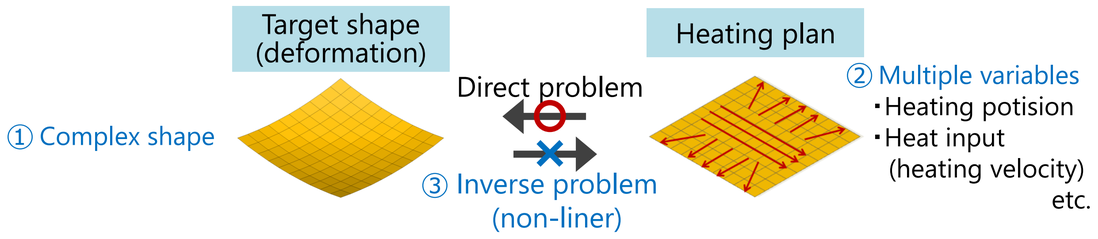
Introduction

Line heating

- Bending by using plastic deformation due to heating to form skin plate of ship hull.
- Arbitrary complex shapes can be formed by combining multiple heating lines.

Problem

It is difficult to make heating plan due to following factors:



- Skilled workers are necessary
- The work time and dimensional accuracy depends on their skills
- Transfer of this technique to the next generations is necessary
  → over 10 years to master

Automation of line heating is agent issue

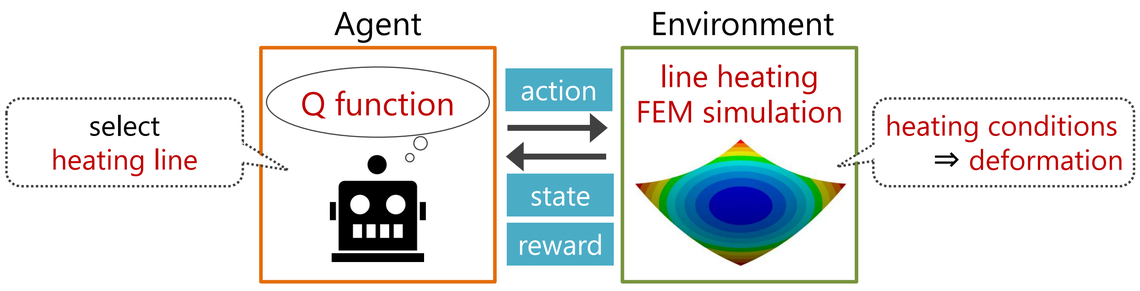
this study: To develop **AI line heating system** by **reinforcement learning** and **non-liner FEM simulation**.

➡ Auto generation of heating plan from deformation

Proposal system

Reinforcement learning

- AI learns autonomously through a trial and error process.
- "Agent" in an "Environment" learns relationship among "state", "action" and "reward" as value function Q.



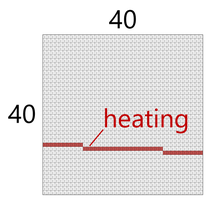
In line heating problem, numerous combination of state, action and reward

➡ Q function is approximated by Convolutional Neural Network (CNN).

Definition of "action", "state" and "reward"

action shape: [40, 40, **2**]

1 : heating line (front) **2** : heating line (back)

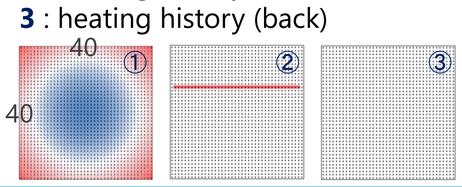


express tensor component as follows:

heating element : 1
non-heating element : 0

state shape: [40, 40, **3**]

1 : difference from the target shape
2 : heating history (front)
3 : heating history (back)



reward how much approaches to target shape current shape is

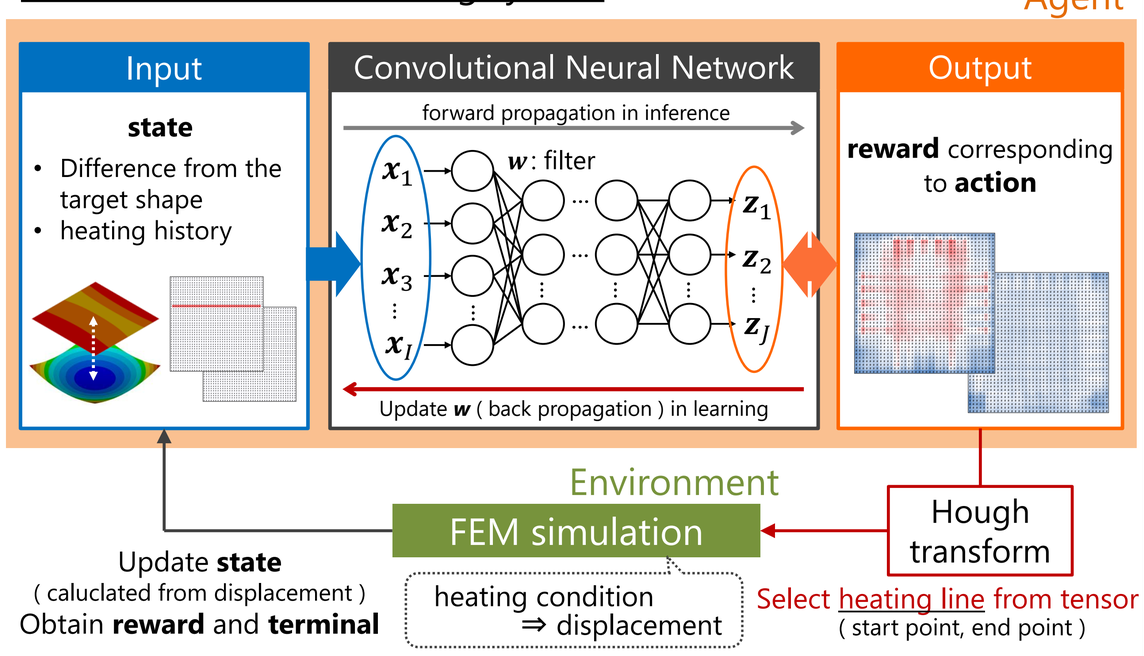
Employed method

Optimization method :
Adam optimization algorithm
Exploration method :
ε-greedy algorithm

Configuration of CNN

Layer	Dimension	Layer	Dimension
Input	[40, 40, 3]	Deconv. ①	[10, 10, 128]
Conv. ①	[40, 40, 32]	Deconv. ②	[20, 20, 64]
Conv. ②	[20, 20, 64]	Deconv. ③	[40, 40, 32]
Conv. ③	[10, 10, 128]	Output	[40, 40, 2]

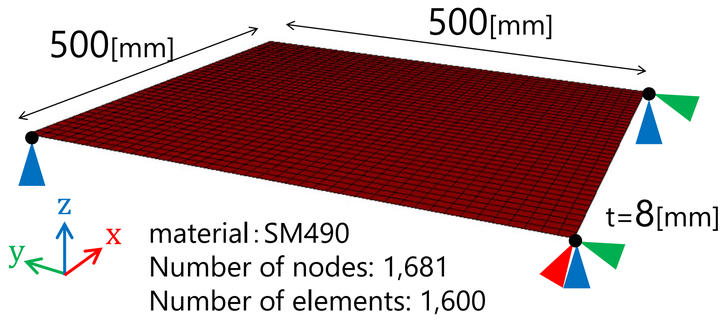
Over view of AI line heating system



By using proposed system, it's expected to select heating line that can obtain a closest shape to the target shape

Analysis conditions

Analysis model



material : SM490
Number of nodes: 1,681
Number of elements: 1,600

*) Define reference plane by constraint points in the z direction and change them according to target shape

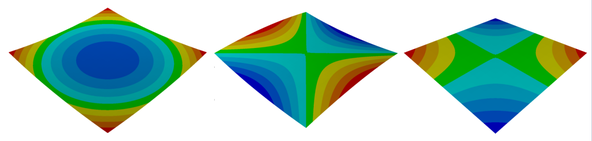
Analysis conditon (inherent strain)

shrinkage		bending	
δ_x^* [mm]	δ_y^* [mm]	θ_x^* [rad]	θ_y^* [rad]
-7.58E-04	-2.32E-02	-5.18E-06	8.64E-04

Apply inherent strain to the element along heating line

Target shape

Bowl shape / Saddle shape / Twist shape



*) offset so that the displacement is 0 at constraint points and define plane z=0 as reference plane

Terminal (termination conditions of analysis)

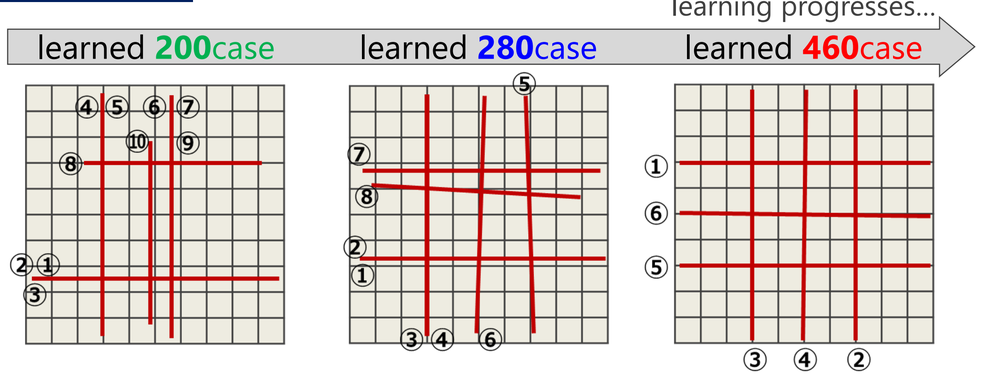
Finish current analysis if it meets any condtions as follows:

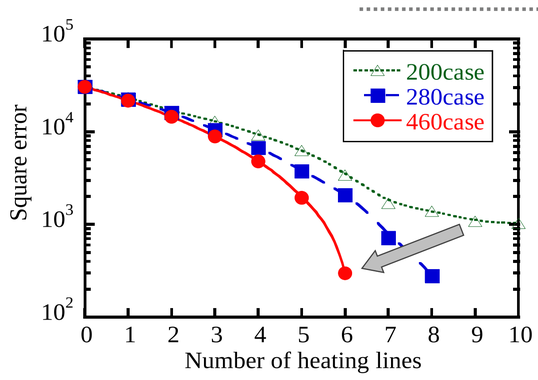
- Number of heating line exceeds specified number
- Difference from target shape is too large
- Obtained shape is close to target shape enough

Forming target shapes

Learning process

Ex) Bowl shape



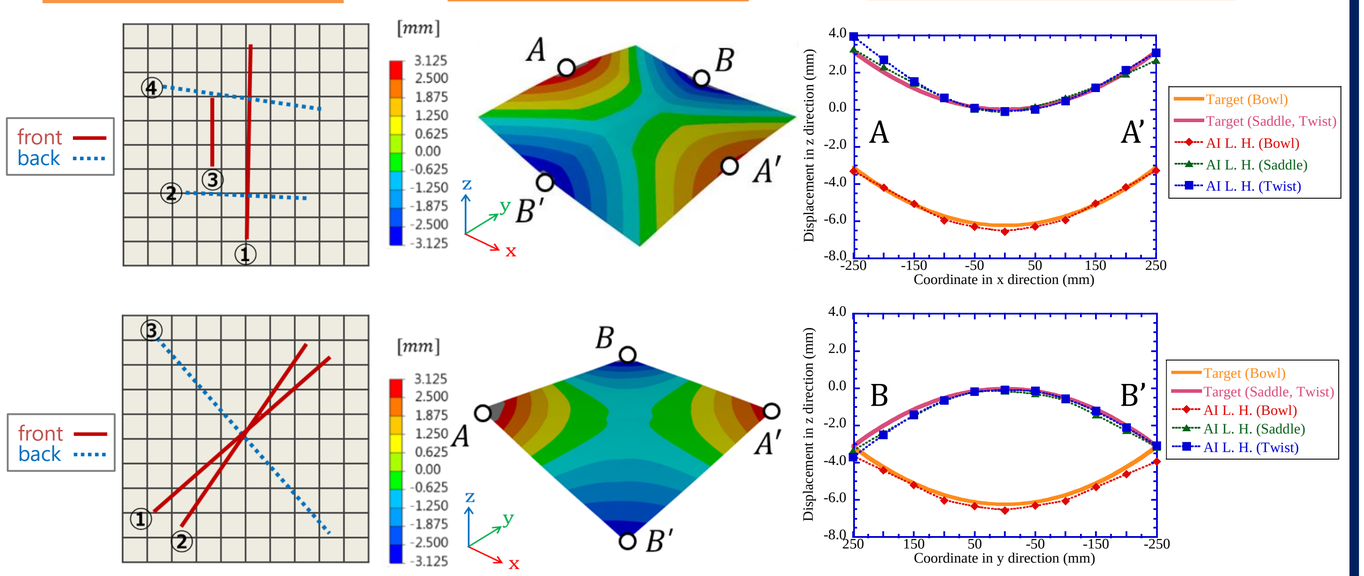


As learning progresses,

- number of lines needed decreases
- arrangement of heating lines become organized
- obtained shape become close to target shape

➡ AI learns deformation and combination of heating lines

Automatic planning by enough learned AI



Calculation time

for learning (bowl, saddle, twist): 16, 2, 6 hours
for obtaining next heating line: 10 seconds

It can be said that heating plan is obtained in practical calculation time by well-learned AI

It is possible to make heating plan which can obtain close shape to the target shape in a short time by proposed system automatically

Conclusions

We proposed AI line heating system which can learn the relationship between heating position and deformation without human intervention during learning by using reinforcement learning and non-linear FEM simulation. In addition, it was confirmed that a heating plan approaching the target shape can be predicted in a short time using proposed system.