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Digital Twin-based Optimization of Manufacturing Device Arrangement using Bayesian Optimization

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Background

- With 4th industrial revolution, Digital Twin (DT) has been applied to the manufacturing industry to build smart factories
- Most of the existing process optimization research has focused on single manufacturing processes not on equipment arrangement

[Limitations]

- The existing equipment arrangement methods are relying on the experience of experts
- Decrease of the productivity of smart factories that change manufacturing processes according to market demands

Need to new method to optimize the equipment arrangement

Research Objectives

- To implement DT to simulate equipment arrangement
- To reduce takt time and cost using DT and optimization
- To quantitively evaluate our new method

System Configuration

DT platform

- Nvidia Omniverse Isaac Sim is utilized as DT platform
- It offers high-fidelity rendering system and robotics tools

Bayesian Optimization (BO)

- BO is a global optimization method which models the black-box function as a probability distribution
- The equipment arrangement optimization problem is a black box problem requiring empirical solution
- Suitable with simulation in DT environment which allows for fast exploration of the objective function

1. Configuration of demo factory

- A robot arm, linear stage, two 3D printers, and a milling machine on the table where the tasks are taken

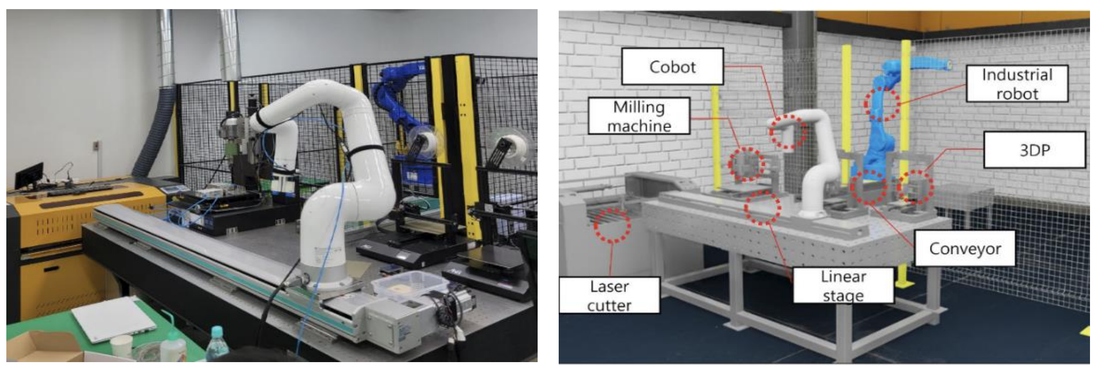


Fig. 1 Demo factory in real(left) and DT(right) environment

2. System workflow

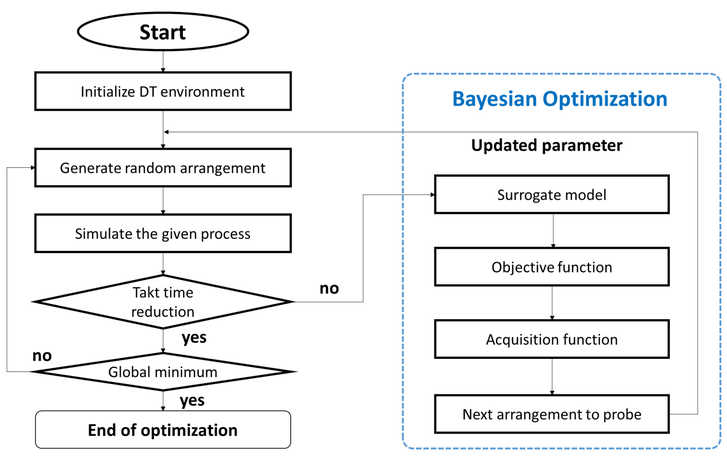
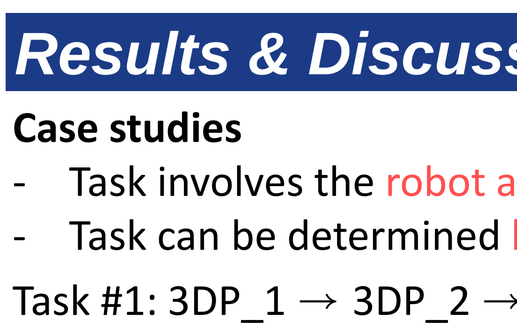


Fig 2. System workflow of DT-based arrangement using BO

3. Bayesian optimization for device arrangement

- Arrangement of a milling machine and two 3D printers



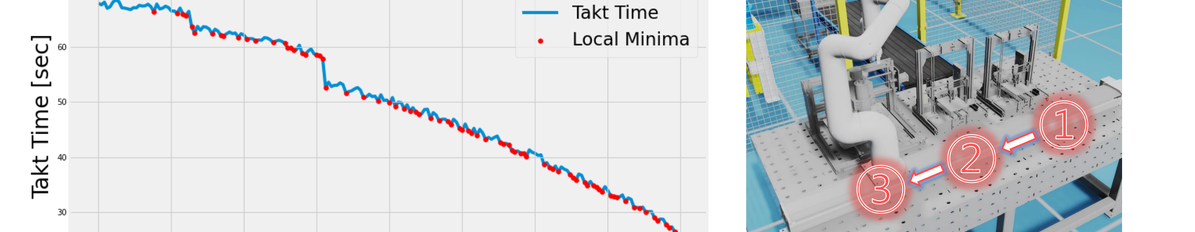
Algorithm Bayesian Optimization of the Equipment's Arrangement

```
S = processing order of equipments
A = Random equipment allocation
Iter = number of iterations

procedure Bayes-Opt(S, A, Iter)
    i = 0
    while i < Iter:
        T ← Simulation(A, S)
        f ← Surrogate Model(A, T)
        A ← Acquisition Function(f, A, T)
return A
```

Fig 3. Initial configuration of DT and pseudo code of BO

- BO re-arranges the equipment according to the tack time
- Robot arm on linear stage acts the pick-and-place task on each iteration



Iteration #1 Iteration # 30 Iteration # 100

Fig 4. Progress of equipment arrangement using BO

Results & Discussion

Case studies

- Task involves the robot arm moving on the linear stage
- Task can be determined based on the sequence as below

Task #1: 3DP_1 → 3DP_2 → Milling Machine
Task #2: 3DP_1 → Milling Machine → 3DP_2 → Milling Machine

Evaluation of arrangement results optimized by BO

Fig.5 Result of equipment arrangement by BO

- Reduction of takt time, 28.8% and 40.2% for task#1 and task#2 each, compared to the initial arrangement

Conclusion & Future Works

- We reduced the tack time of task by optimizing the arrangement of equipment with BO in DT
- This system can be adapted to the more complex tasks
- We plan to apply the optimized result to the actual system (Sim-to-Reality transfer)

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