中国科学院材料力学行为和设计重点实验室

CAS Key Laboratory of Mechanical Behavior and Design of Materials

Deep Visual-guided and Deep Reinforcement Learning Based for Multip-Peg-in-Hole Assembly Task of Power Distribution Live-line Operation Robot

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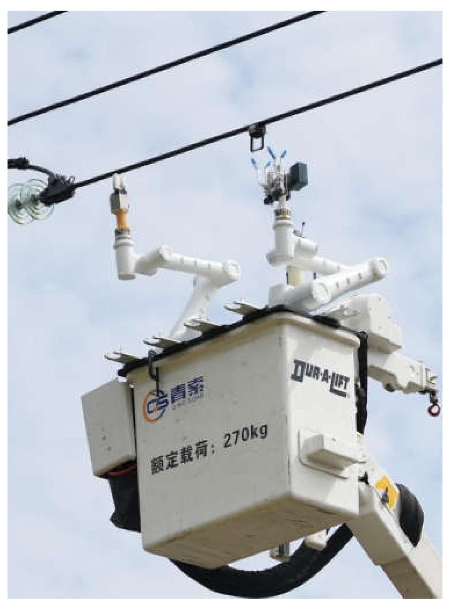
INTRODUCTION

This study researches a Power Distribution Network Live-line Operation Robot with autonomous tool assembly capabilities to replace humans in various high-risk electrical maintenance tasks. To address the challenges of tool assembly in dynamic and unstructured work environments for PDLOR, an assemble framework was proposed consisting of deep visual-guided coarse localization and prior knowledge and fuzzy logic driven deep deterministic policy gradient high-precision assembly algorithm. First, we propose a multiscale identification and localization network based on YOLOv5, which enables the peg-hole close quickly and reduces ineffective exploration. Second, we design a main-auxiliary combined reward system, where the main-line reward uses the hindsight experience replay mechanism, and the auxiliary reward is based on fuzzy logic inference mechanism, addressing ineffective exploration and sparse reward in the learning process.

MODELING AND DESIGN

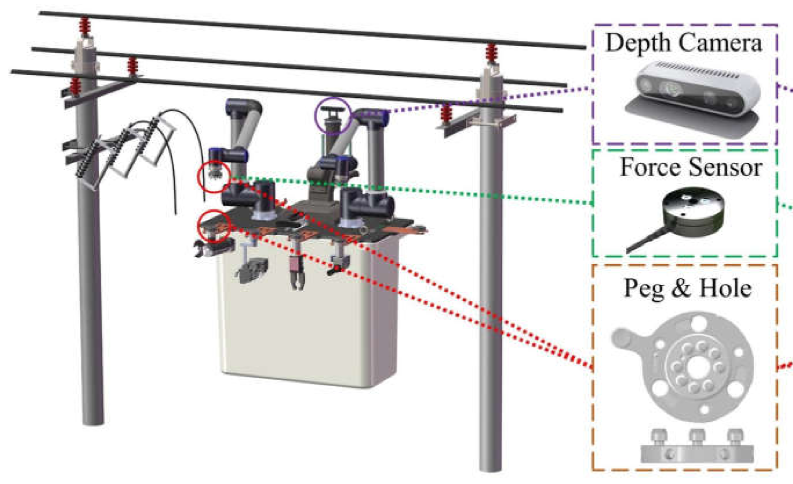
1. In live-line operations in distribution networks, many types of tasks *(a-c)* such as live-line earthing operation, install arrester operation, and replacement operation tools can be abstracted as peg-in-hole assembly tasks.


(a)


(b)


(c)

2. A physical and digital twin model of the PDLOR platform *(d-e)* was established, including individual objects such as robot manipulators, two force sensors, a visual perception system, and various multip-peg-in-hole operating tools. The manipulators are UR10, and the 6-axis force sensors ATI are installed between the end joint and flange, which can provide x, y, and z directional contact forces and torques. The visual perception system consists of a 3D gimbal and a Real Sense Depth Camera D435i. The end-effector flange is used to simulate pegs, while the tool end flange is used to simulate holes.

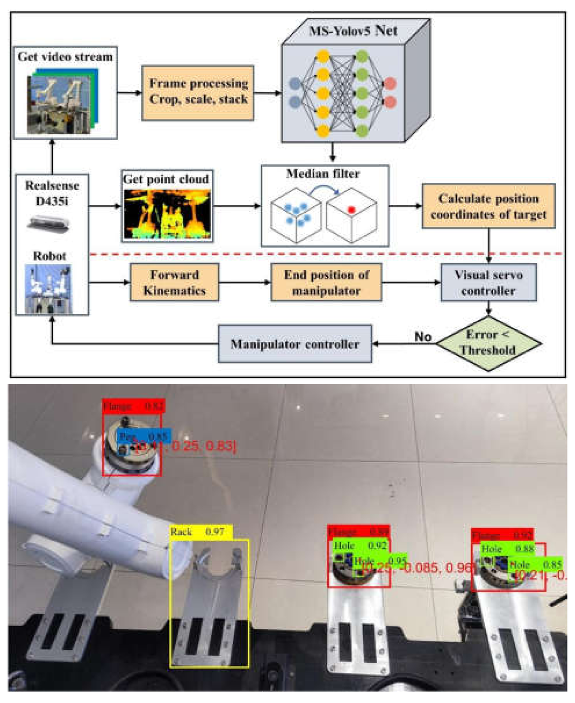


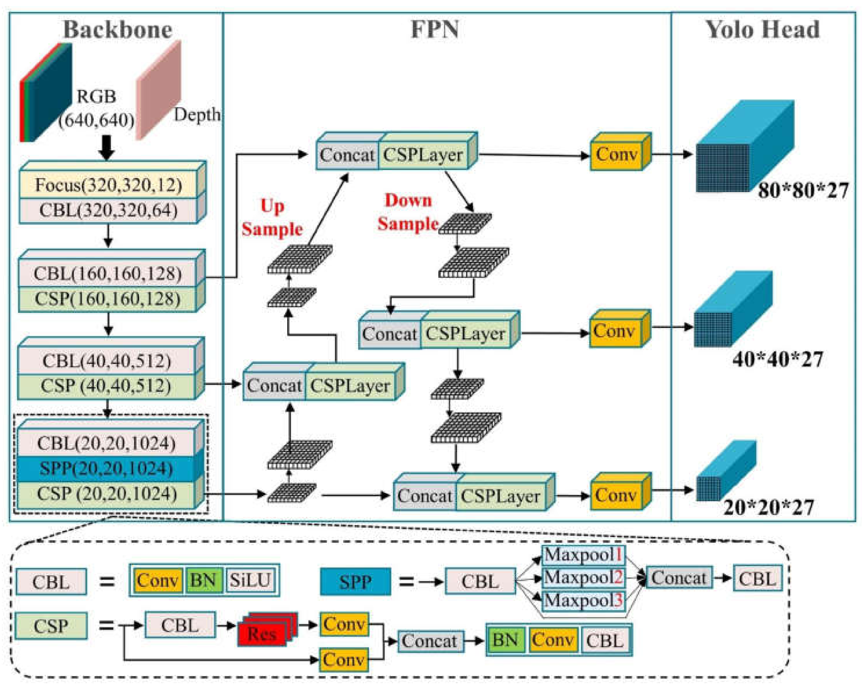
(d)


(e)

METHOD

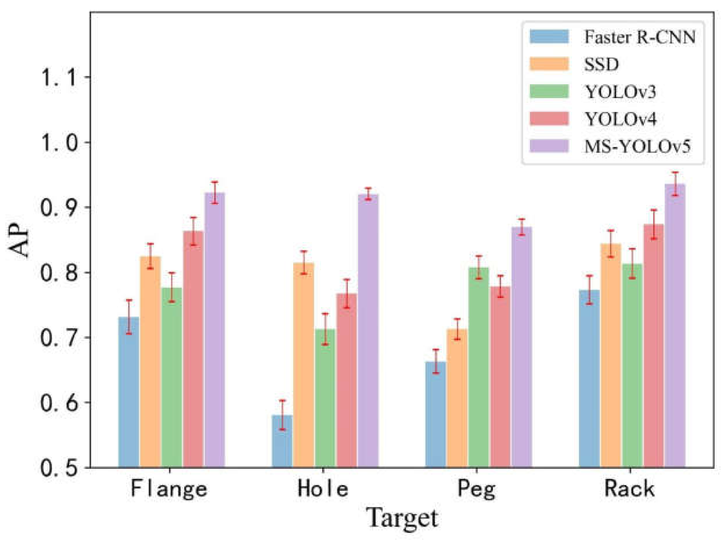
1. The study proposed a multiscale identification and localization network *(f)* based on YOLOv5 *(g)*, which can quickly and accurately obtain the spatial position of pegs and holes centers.


(f)

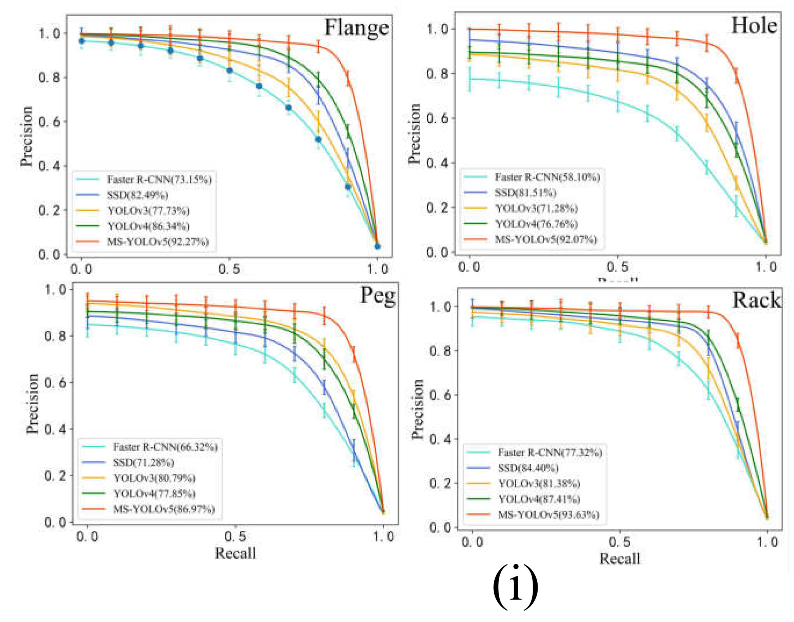


(g)

We employed a 5-fold cross-validation method to conduct target detection experiments on four types of targets by using MS-YOLOv5, Faster R-CNN, SSD, YOLOv3 and YOLOv4, respectively *(h-i),* on the constructed dataset.

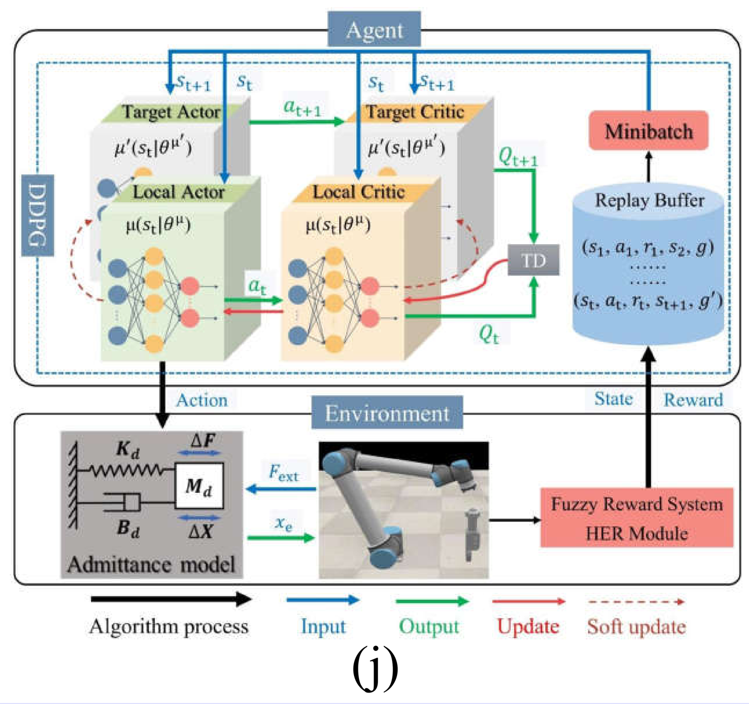


(h)

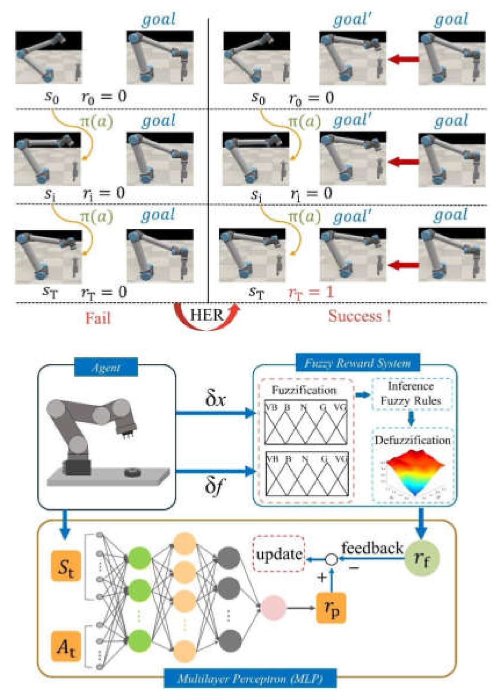


(i)

2. The study designed a combined main-auxiliary reward system *(i-k)*, where the main-line reward uses the HER mechanism, and the auxiliary reward is based on fuzzy inference.

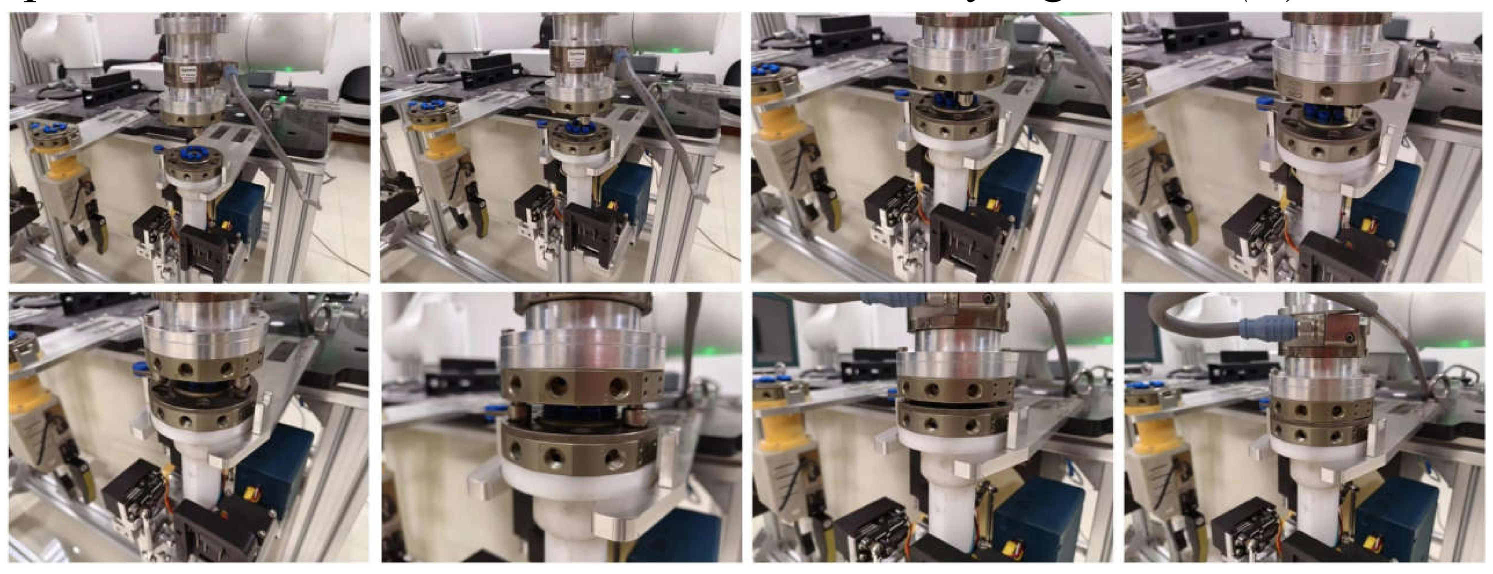


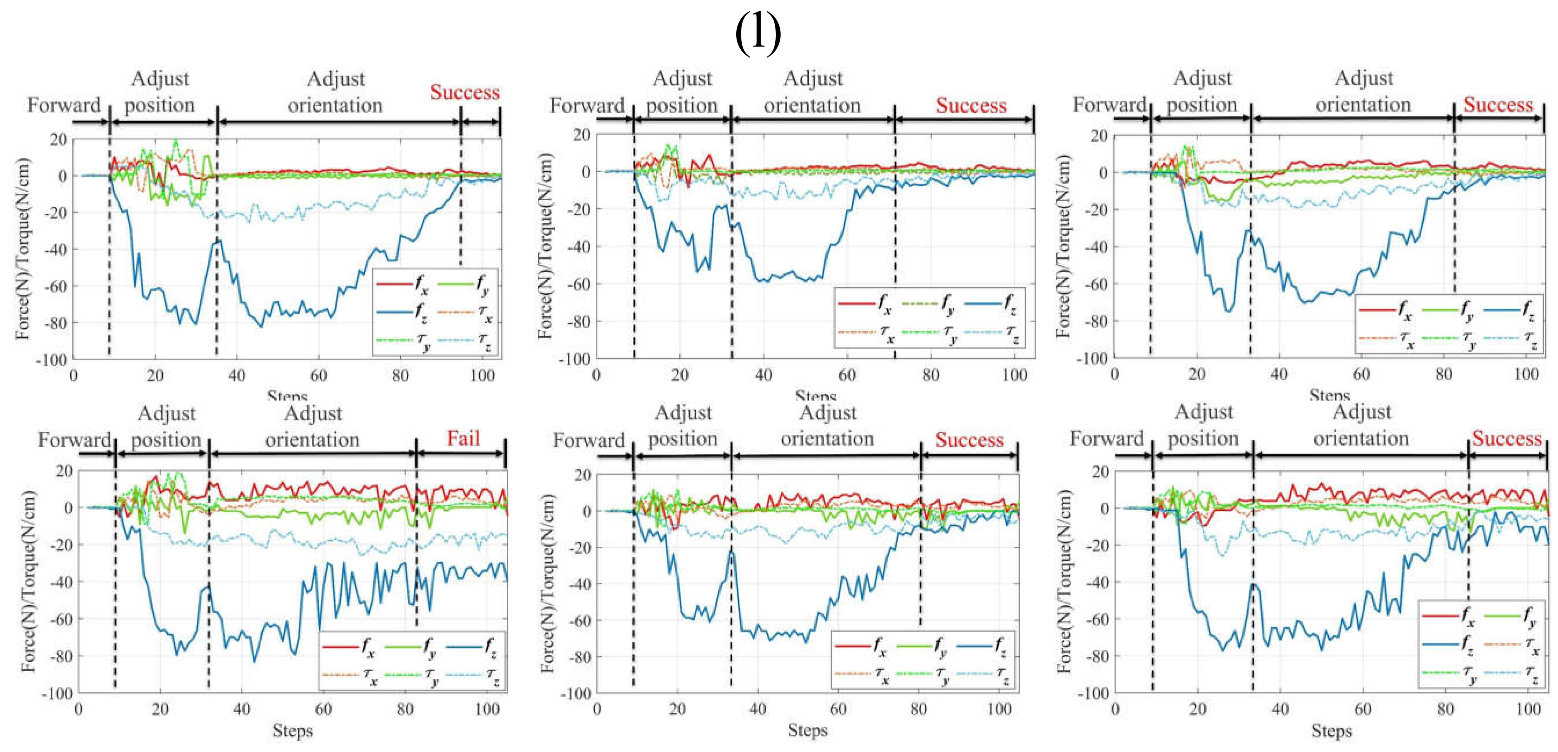
(j)


(k)

EXPERIMENTS AND RESULTS

We simulated the tool assembly in the CoppeliaSim software to verify the feasibility and effectiveness of the proposed PKFD-DPG algorithm. And we used the simulation results to guide real-world assembly tasks *(l)* and compared them with some other classical assembly algorithms *(m)*.


(l)



(m)

CONCLUSIONS

In response to the demand for autonomous tool assembly by PDLOR, this study proposed a deep visual-guided coarse localization and prior knowledge and fuzzy logic driven deep deterministic policy gradient high-precision assembly algorithm framework. The effectiveness and superiority of the proposed algorithm are verified by simulation and physical experiments, and its performance is compared with other assembly algorithms. The experimental results show that the success rate of PKFD-DPG method is 17% and 53.4% higher than other methods, respectively.

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