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BB SEGMENT GRASPING PIPELINE WITH VARIABLE ADMITTANCE CONTROL FOR EU DEMO REMOTE MAINTENANCE

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ABSTRACT

- Secure grasping of the EU DEMO breeding blanket (BB) segments is essential to achieve reliable remote maintenance.
- The grasping pipeline is broken into four tasks: interface detection and localization, approach, insertion and locking, with multisensory measurements for state awareness and dynamic re-planning.
- AI-based object detector is deployed for interface localization.
- Variable admittance control is implemented to robustly solve the challenging insertion step, where collision is practically inevitable.

BACKGROUND

- A key challenge for safe and economical EU-DEMO operation is developing robust remote maintenance tools and strategies for the breeding blanket, which weigh 125–180 tonnes.
- The BB Vertical Transporter (BBVT), shown in Fig. 1, is being developed for this remote handling task. It must withstand large moments during operation while positioning the breeding blanket with sub-centimeter accuracy to prevent costly collisions.
- The projected gamma dose rate to silicon near the blankets during RH operations is about 100 Gy/h, which could cause faults in onboard sensors and microcontrollers and degrade joint servo trajectory tracking accuracy.
- A robust pipeline for safe and efficient BB segment grasping with supervision is necessary.

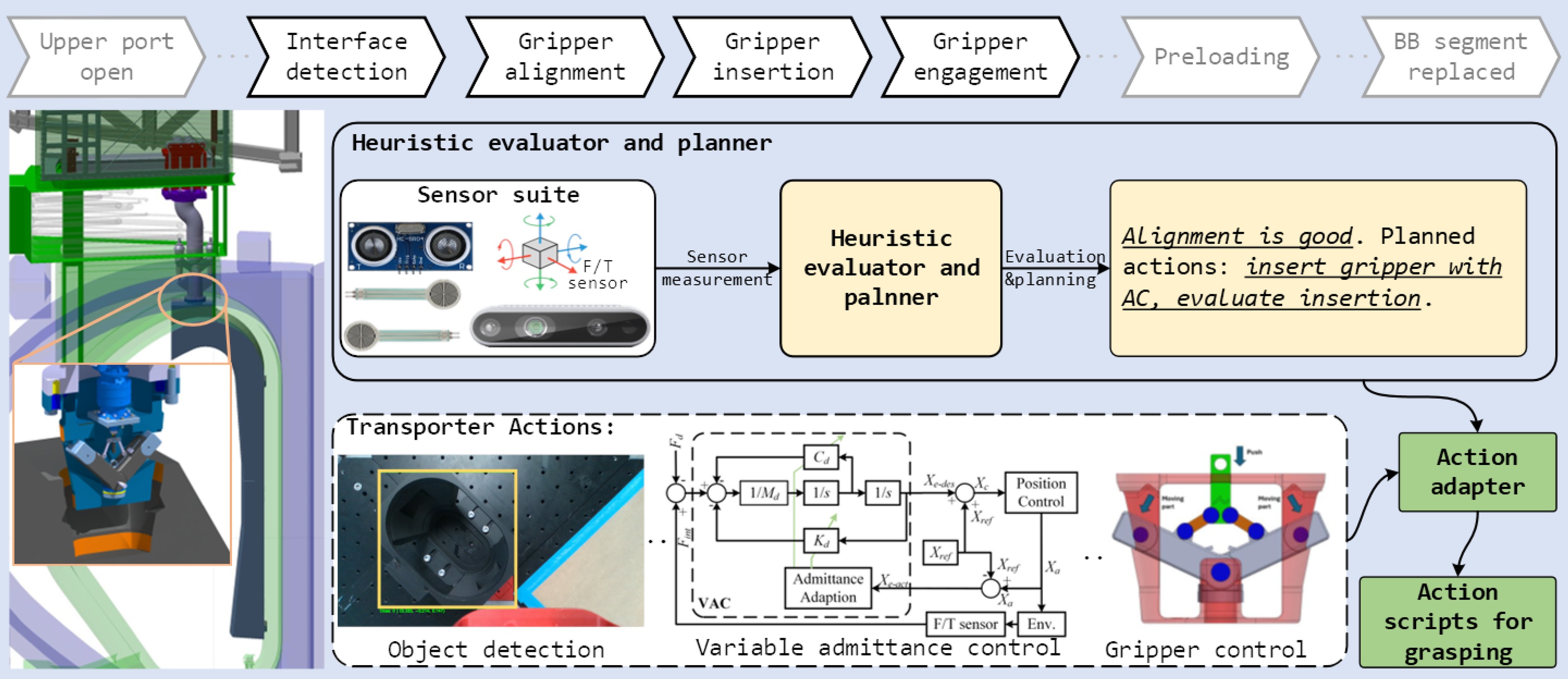

FIG. 1. Overview of the proposed pipeline and associated methods.

METHODS

Robust Grasping Pipeline with State Evaluation and Re-Planning

As shown in Fig. 1, at the task-planning level, the pipeline consists of four actions: detection and localization, alignment, insertion, and engagement. After each step, the robot's state is evaluated using heuristic criteria from multiple sensor readings to decide whether replanning is required. The complete workflow is shown in Fig. 2(a).

Learning-based Object Detector and Eye-in-hand Calibration

As shown in Fig. 2(b), the YOLOv8 object detector is trained on a customized dataset of 210 images with varied viewpoints and lighting for robust performance. Eye-in-hand calibration is then conducted to determine the camera-to-robot transform, enabling precise object localization and manipulation.

Variable Admittance Control for Contact-rich Manipulation

Fig. 2(c) illustrates the variable admittance control scheme, which adapts stiffness and damping based on insertion depth: low gains at shallow depths allow compliant guidance, while higher gains deeper in the interface hole improve stability and ensure accurate alignment.

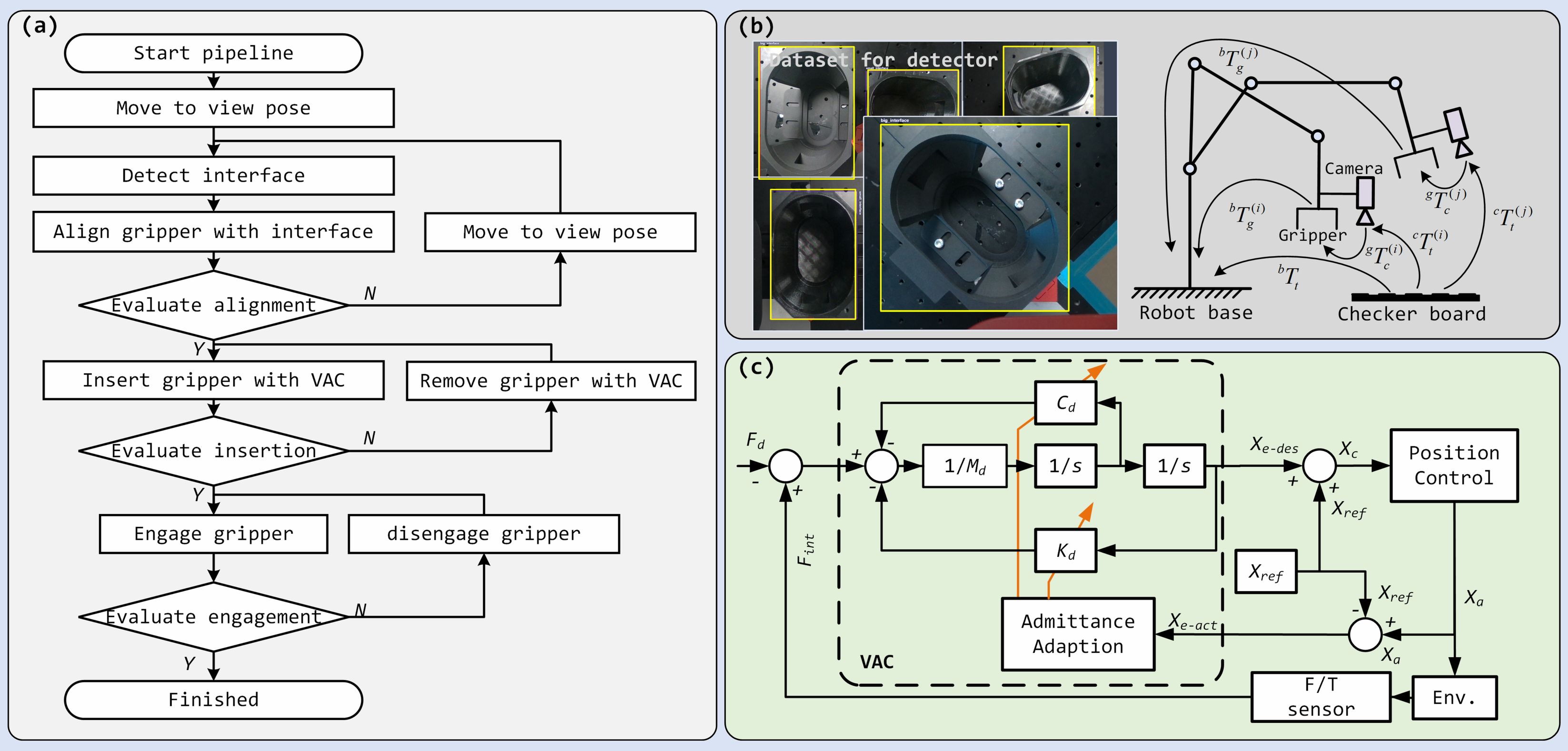

FIG. 2. Technical details: (a) the complete process , (b) dataset and eye-in-hand calibration, and (c) variable admittance control

OUTCOME

- **A hierarchical control architecture for BB segment grasping at EU-DEMO,** in which high-level fault-tolerant action planning based on multisensory state evaluation is combined with a low-level variable-admittance control (VAC) policy. The VAC enhances the safety and reliability of contact-rich insertion (Fig. 3).
- **A detailed pipeline** for BBVT-based grasping of EU-DEMO's BB segments using object detection and allowing resilient re-planning.
- **Experimental results with down-scaled (3:10 scale) interface**, shown in Fig. 4, demonstrate 57% success rate of the proposed pipeline even when the detection and alignment poses are subject to large, uniformly random disturbances causing collision in 60% of trials.

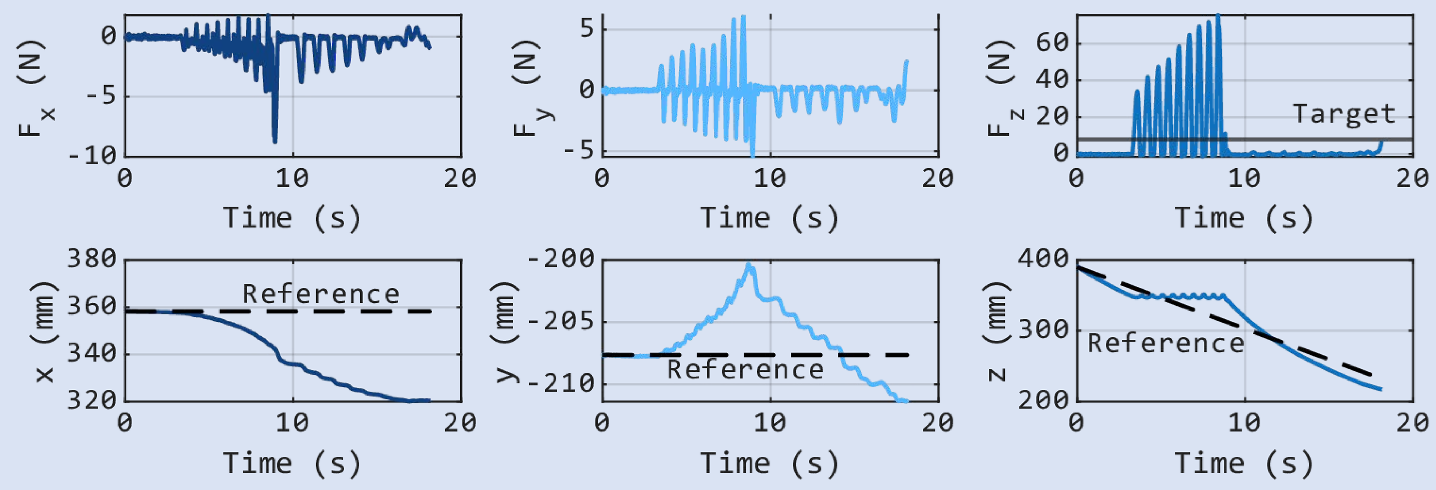

FIG. 3. Trajectory data from a gripper insertion using VAC.

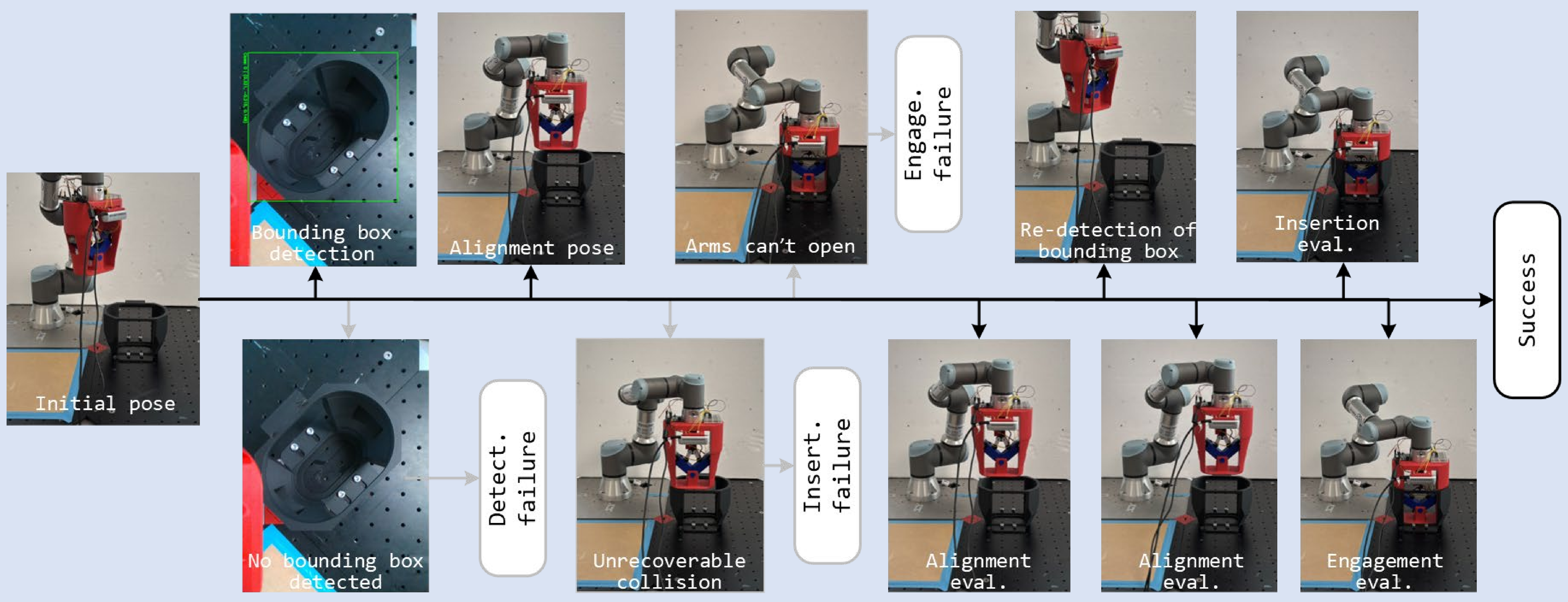

FIG. 4. Demonstration of the pipeline as implemented.

CONCLUSION

- The framework combines fault-tolerant action planning with multisensory evaluation to reduce single-sensor dependency and improve reliability for EU-DEMO remote maintenance.
- The use of YOLO-based detection with variable admittance control enables fast, robust, and compliant gripper insertion.
- Future work will improve evaluator robustness through additional sensor data and advanced fusion algorithms.

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