A Mobile Manipulator System for Panel FOUP Handling: Work-in-Progress

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***Abstract*—Front-opening unified pods (FOUPs) are essential carriers in semiconductor manufacturing, traditionally transported via costly overhead AMHS. This work-in-progress presents a decoupled mobile manipulator combining a MiR100 robot with an elephant-inspired manipulator (elebot) for panel FOUP handling. The system integrates SMC linear actuators, DC grippers, and a Raspberry Pi controller via REST API and Ethernet/IP. A passive mechanical docking station eliminates mobile platform navigation uncertainty, while ultrasonic sensors extend obstacle avoidance. The decoupled architecture enables one AMR to serve multiple manipulator carts. Preliminary experiments validate 100% FOUP loading success. This paper presents the integration framework and initial validation.**

***Index Terms*—Mobile manipulator, AMHS, FOUP handling, mechanical docking, semiconductor manufacturing**

I. INTRODUCTION

The semiconductor industry demands ultra-reliable, contamination-free wafer handling. FOUPs are the dominant standardised containers for wafer transport [1]. Conventional fabs employ overhead AMHS, which requires substantial capital expenditure [2], [3]. Panel-level packaging (PLP) offers superior substrate utilisation [4], yet non-standardised P-FOUPs face compatibility challenges [5], [6]. Mobile manipulators offer flexible alternatives [7]. This work proposes a hybrid actuation–navigation system equipping a MiR100 robot with a custom elephant-inspired manipulator (elebot) for P-FOUP handling.

II. SYSTEM OVERVIEW

As presented in Fig. 1, the solution consists of four modules: manipulator, MiR100, controller, and safety modules.

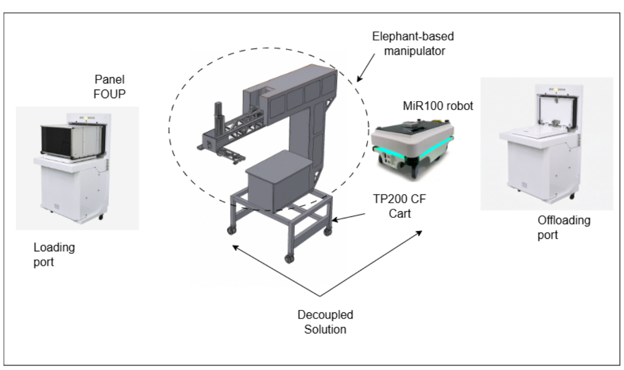

Fig. 1: Decoupled elephant-based mobile manipulator.

A. Manipulator Module

The mechanical structure is inspired by elephant trunk movements. It integrates a horizontal beam and vertically actuated carriage driven by SMC JXC918 controllers, allowing arm reach, lift, and FOUP retrieval. The assembly mounts on a TP200 cart with a docking interface for MiR100 alignment.

B. Autonomous Mobile Robot Module

Standard MiR100 navigation provides ± 10 [mm] precision [8], which is unsuitable for FOUP engagement. We implemented a mechanical docking station providing ± 1 [mm] repeatability through physical guidance [9], eliminating cumulative navigation errors.

C. Controller and Safety Modules

A Raspberry Pi 4 interfaces with SMC actuators via Modbus RTU, ultrasonic sensors, and a WISE4060LAN module. The REST API–Ethernet/IP bridge enables decoupled operation. SRF05 ultrasonic sensors extend obstacle avoidance, with WISE4060LAN relaying obstacle information via Ethernet/IP.

III. FORMAL DOCKING ERROR MODELLING

High-precision material handling requires separating mobile navigation uncertainty from final docking accuracy [10]. The MiR100 mobile platform pose is defined as:

$$\mathbf{p}_r(t) = [x_r(t), y_r(t), \theta_r(t)]^T \tag{1}$$

where $x_r(t)$ and $y_r(t)$ denote planar position in the global map frame [m], and $\theta_r(t)$ is the robot yaw angle [rad].

The coarse navigation trigger initiates manipulation when the Euclidean distance to the nominal load/offload pose $\mathbf{p}_{L/O}$ satisfies:

$$d_{L/O}(t) = \|\mathbf{p}_r(t) - \mathbf{p}_{L/O}\|_2 \leq \delta_{nav} \tag{2}$$

where $\delta_{nav} = 150$ [mm] is the coarse triggering threshold.

Fine docking via the passive mechanical station achieves deterministic pose accuracy:

$$\|\mathbf{p}_r(t) - \mathbf{p}_{dock}\|_2 \leq \delta_{dock} \tag{3}$$

where $\mathbf{p}_{dock}$ is the docking station reference pose and $\delta_{dock} = 2$ [mm] is the fine docking tolerance.

The end-effector position in the world frame is modelled as:

$$\mathbf{p}_e^W = \mathbf{p}_r + \mathbf{R}(\theta_r) \begin{bmatrix} l_0 + q_h \\ 0 \\ h_0 + q_v \end{bmatrix} \tag{4}$$

where $\mathbf{R}(\theta_r)$ is the planar rotation matrix, l_0 [mm] and h_0 [mm] are fixed mechanical offsets, and q_h [mm], q_v [mm] represent horizontal and vertical SMC actuator displacements.

FOUP engagement requires the end-effector to be within tolerance of the FOUP reference pose $\mathbf{p}_{foup}^W$:

$$\|\mathbf{p}_e^W - \mathbf{p}_{foup}^W\|_2 \leq \epsilon_{engage} \tag{5}$$

where $\epsilon_{engage} = 2$ [mm] is the engagement tolerance, consistent with semiconductor load port requirements [11], [12].

IV. PRELIMINARY RESULTS

Five complete FOUP transport trips validated the system. The setup comprises a prototype cleanroom with a 6 [m] $\times$ 8 [m] test area. Fig. 2 shows the trajectory during FOUP transportation. Fig. 3 shows actuator position during operation.

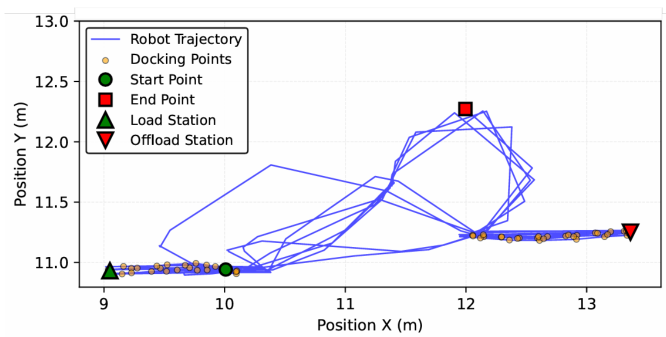

Fig. 2: Robot trajectory with docking positions.

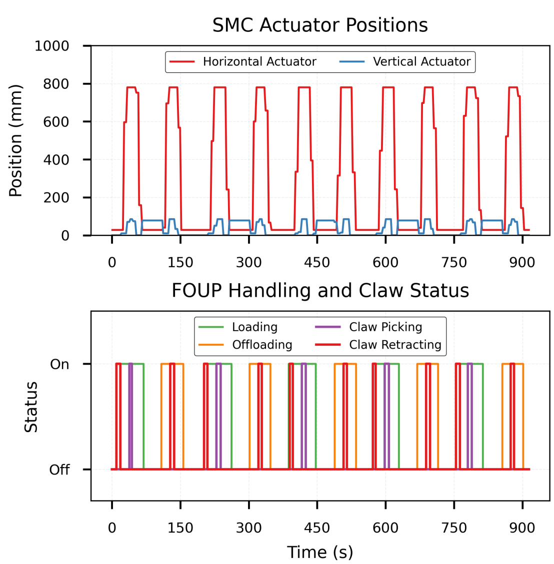

Fig. 3: Actuator position during operation.

A. Robot Trajectory

Fig. 2 shows smooth continuous path with straight-line convergence before docking, yielding steady-state positional error < 2.0 [mm] at both FOUP ports.

B. Actuator Position

As shown in Fig. 3, the horizontal actuator extends to 780 [mm] within 15 [s], followed by an 85 [mm] vertical extension. The system holds position steadily until claws engage, confirming no mechanical drift.

V. CONCLUSION

The elephant-based configuration decouples the mobile platform from the manipulator, offering flexibility and simpler integration. The system can be dynamically rerouted. MiR100 sensors enable real-time navigation and obstacle avoidance. This solution eliminates overhead rail capital expenditure.

Future work shall include fleet-level scheduling, active vision-assisted fine-docking, and SEMI-E82 compliance. Detailed characteristics following further experiments are reserved for journal publication.

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