

Comparative Study of Adaptive Robotic Arm Grasping with Human-Like Capabilities

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 **Agenda**

01	Research Question
02	Research background
03	Current State of the Art
04	Research Design/Method
05	Research Conclusions
06	References

// Research Question

Service robots in bubble tea shops often cause spills or damage when grasping cups of different materials, as they lack human-like material perception and tactile feedback



Research Areas

**Multi-modal
Material
Perception**

01

**Commonsense-
Driven Adaptive
Control**

02

**Computer Vision
& Multi-modal
Perception**

03

**Autonomous
Decision Making**

04

// Research Significance

01

Non-Standard Objects:

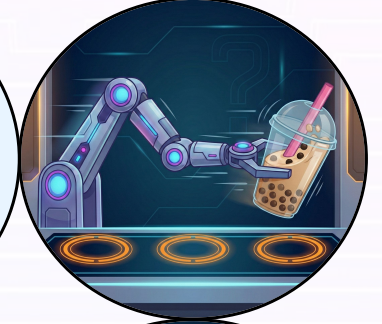
Robots must handle liquid-filled cups with **diverse materials**, **conical shapes**, and **friction changes** caused by condensation.



02

Dynamic Challenges:

The task requires more than grasping; it involves **slosh control**, managing **inertial disturbances** (from stops/turns), and ensuring **high precision**.



03

Failure Sensitivity:

Even without dropping the cup, **micro-slippage** in the gripper can alter the cup's pose, increase sloshing, and cause **placement errors or spills**.



// Current State of the Art

01

Fixed Grasping (Industrial Standard): Uses preset angles and fixed force to handle standard objects repeatedly.

02

Vision-based Grasping: Uses cameras and AI to identify shapes and predict the best grasping point.

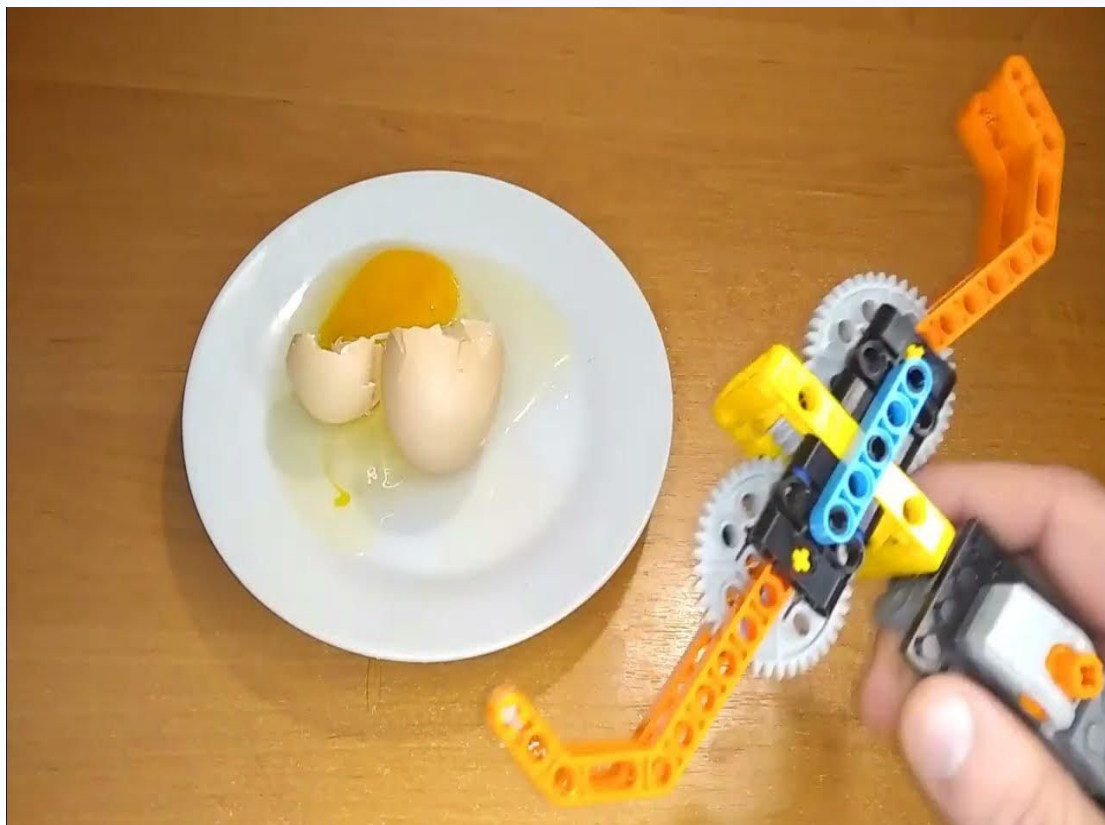
03

Tactile & Force Feedback Uses sensors to detect contact and adjust grip strength in real-time.

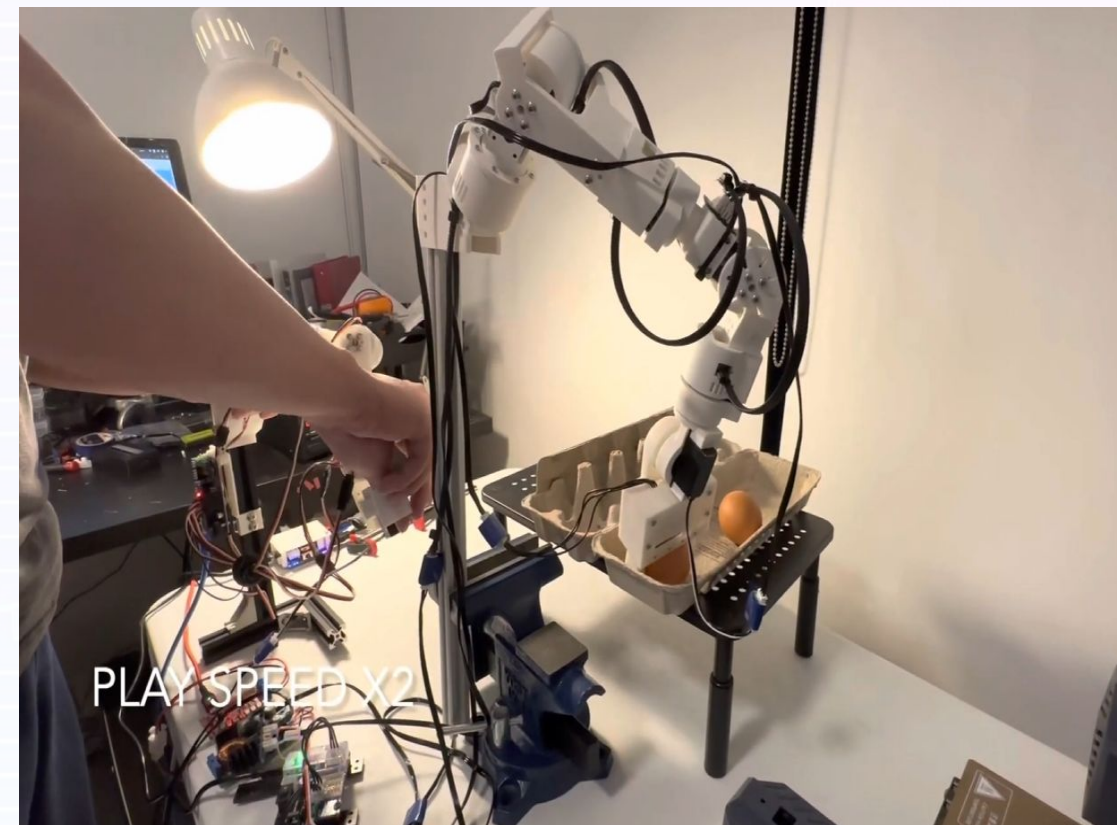
04

Soft Grippers Uses flexible materials to gently wrap around fragile items like food.

// Current Issues



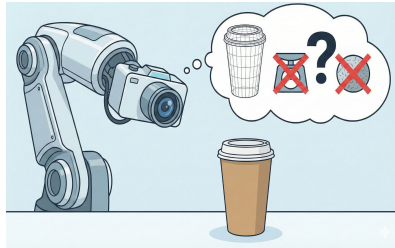
Not realizing eggs are fragile items, they ended up crushing them directly.



People know eggs are fragile, so they can handle them gently.

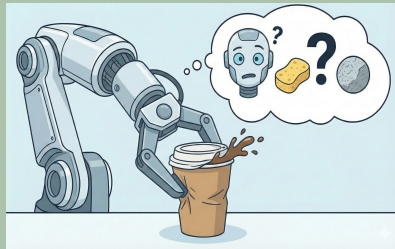
// Current Issues

1



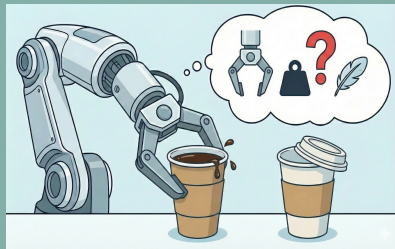
Visual Perception Limits Cameras can identify shape but cannot detect "invisible" physical properties like weight, friction, or stiffness.

2



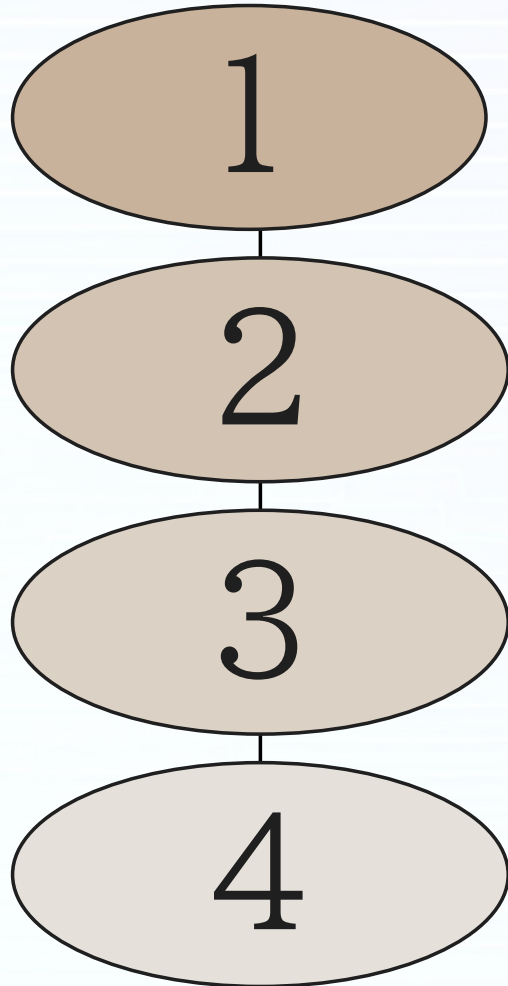
Lack of Material Intuition Robots lack human-like common sense and do not understand how different materials (e.g., paper vs. glass) react to force.

3



Poor Real-World Generalization Fixed algorithms struggle to adapt to changing internal states. For example, the robot applies the same strategy regardless of whether a cup is **full of liquid or empty**, leading to potential spills or crushing.

// Specific Research Problem



Baseline System Flaws: Under a "fixed parameter" approach, the robot systematically fails by crushing fragile paper cups, dropping heavy glass ones due to slippage, and spilling liquids caused by rigid, unadaptive motion.

Impact of Vision & Cognitive Intelligence: Combining visual correction with cognitive reasoning enables the robot to **pre-plan** actions: it identifies materials to set safe force limits and switches to smooth S-curve trajectories for liquids, significantly reducing deformation and spill risks.

Impact of Tactile Closed-Loop: Tactile feedback adds a layer of **stability**, allowing the robot to detect slippage and adjust grip force in real-time while preventing excessive pressure on fragile items.

Failure Modes & Trade-offs: Visual-cognitive methods excel at **strategic planning** but fail if classification is wrong, whereas tactile methods ensure **execution stability** but are purely reactive to errors.



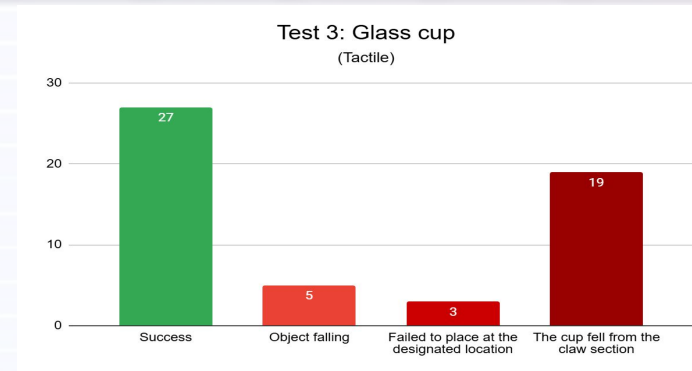
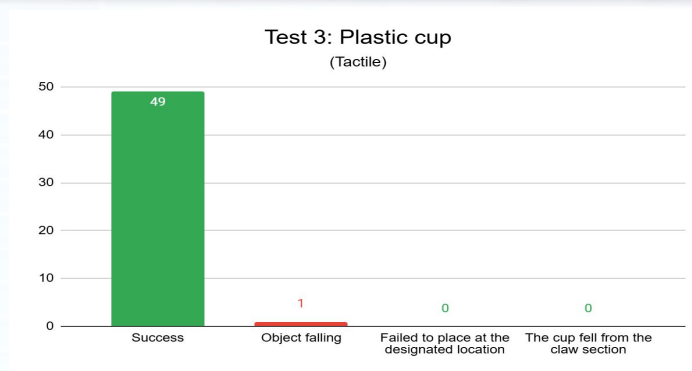
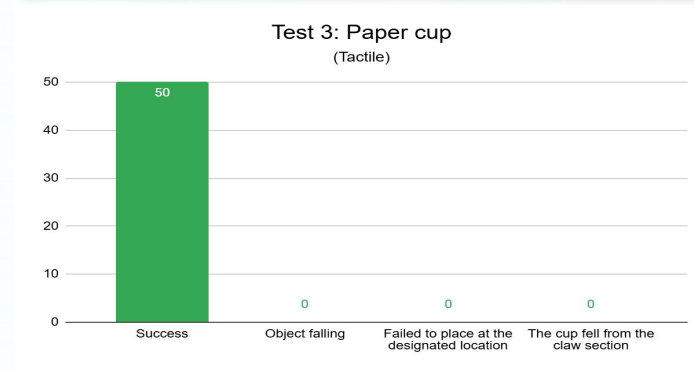
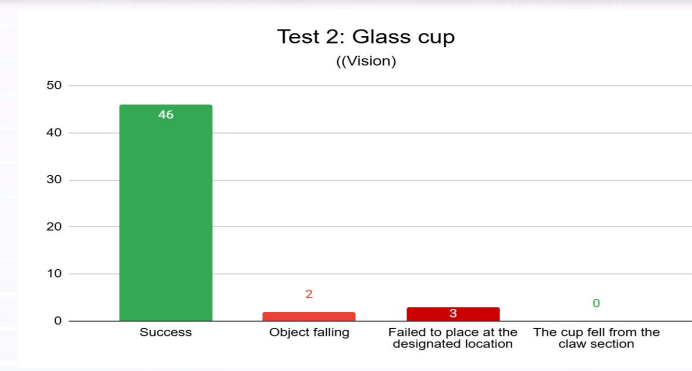
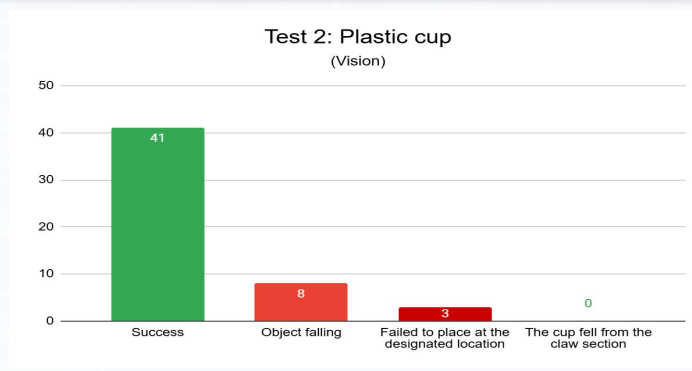
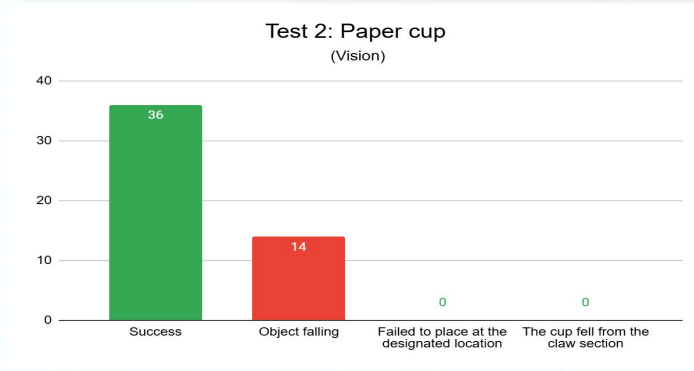
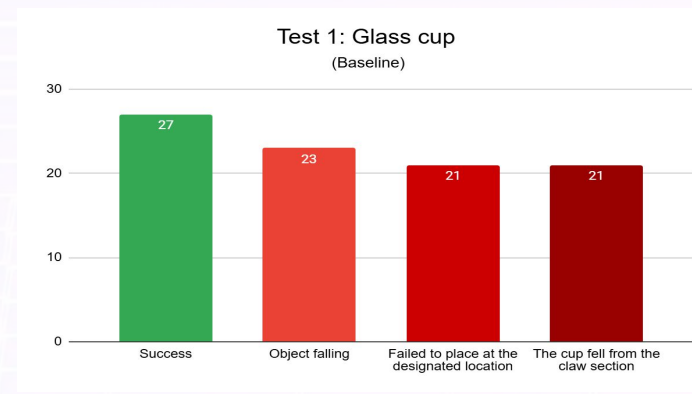
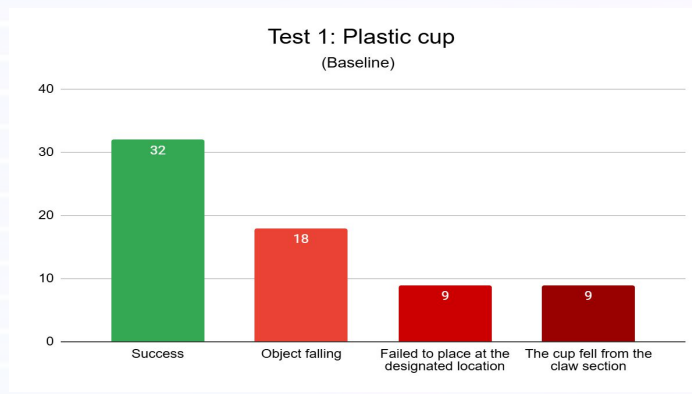
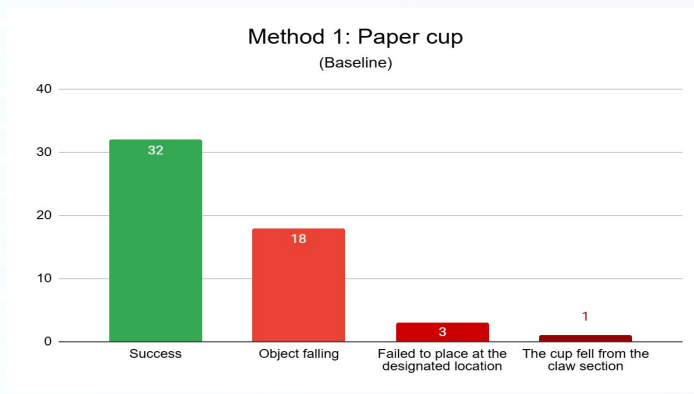
Experimental Plan

Item	Method 1 (Baseline)	Method 2 (Vision)	Method 3 (Tactile)
Object	Plastic, Glass, Paper Cups	Plastic, Glass, Paper Cups	Plastic, Glass, Paper Cups
Method	No Sensors / Blind Execution	Camera + Cognitive Commonsense	Pressure Sensor
Parameter	Fixed Force & Trajectory (Repeats same values regardless of material)	Retrieve Parameters via Material ID (Identifies cup type and loads specific force/motion values for that object)	Adjust Degrees based on Pressure (Detects pressure during the grasp and decides whether to modify gripper angle to optimize force)
Results	Success: Task Complete Fail: 1. Liquid Spilled 2. Misplaced 3. Cup Dropped	Success: Task Complete Fail: 1. Liquid Spilled 2. Misplaced 3. Cup Dropped	Success: Task Complete Fail: 1. Liquid Spilled 2. Misplaced 3. Cup Dropped

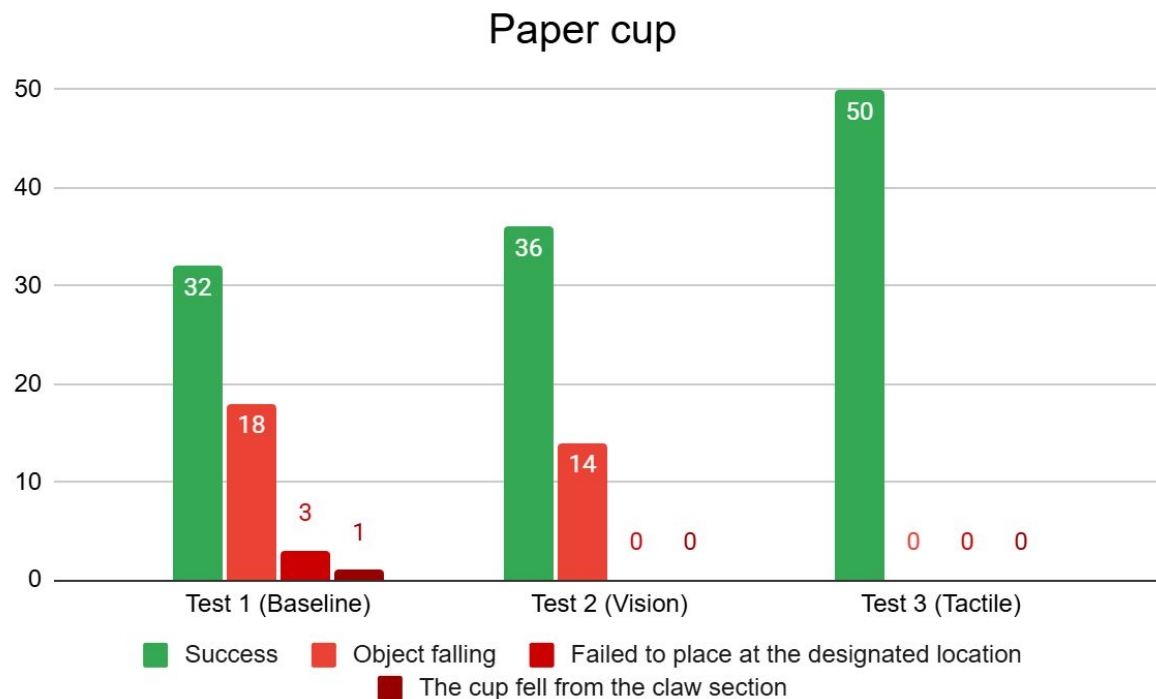
// Experimental results (Video)

Experimental results

If a single failed trial involves multiple failure types, the counts by failure type may overlap.



// Experimental results (Paper cup)



1

Test 3 (Tactile) achieved 100% success (50/50) with no failures recorded.



2

Test 2 (Vision) shows clear improvement over the baseline: success increases from 32 → 36.



3

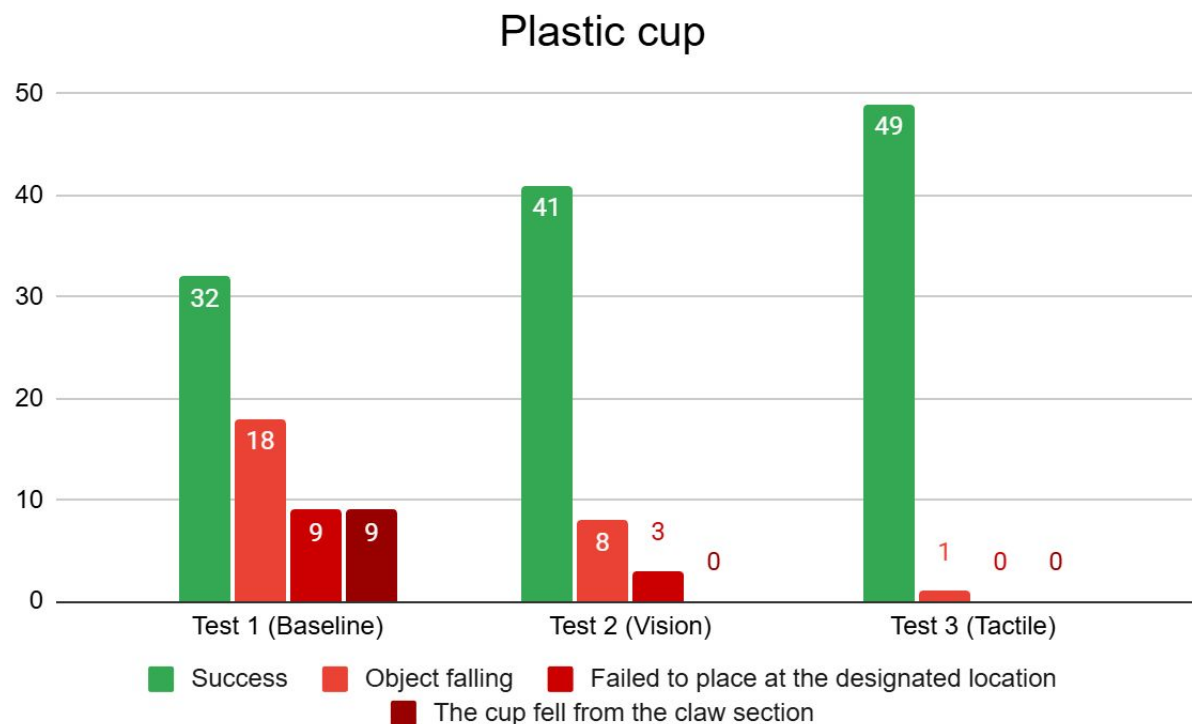
The main failure mode in the baseline is “object falling,” and it decreases when using vision, then disappears with tactile control.



4

Overall: performance improves monotonically from Baseline → Vision → Tactile, with tactile feedback providing the biggest gain for paper cups.

Experimental results (Plastic cup)



Test 3 (Tactile) is near-perfect: 49/50 success (98%), with failures almost eliminated.



Test 2 (Vision) shows a clear improvement over the baseline: success increases from 32 → 41.

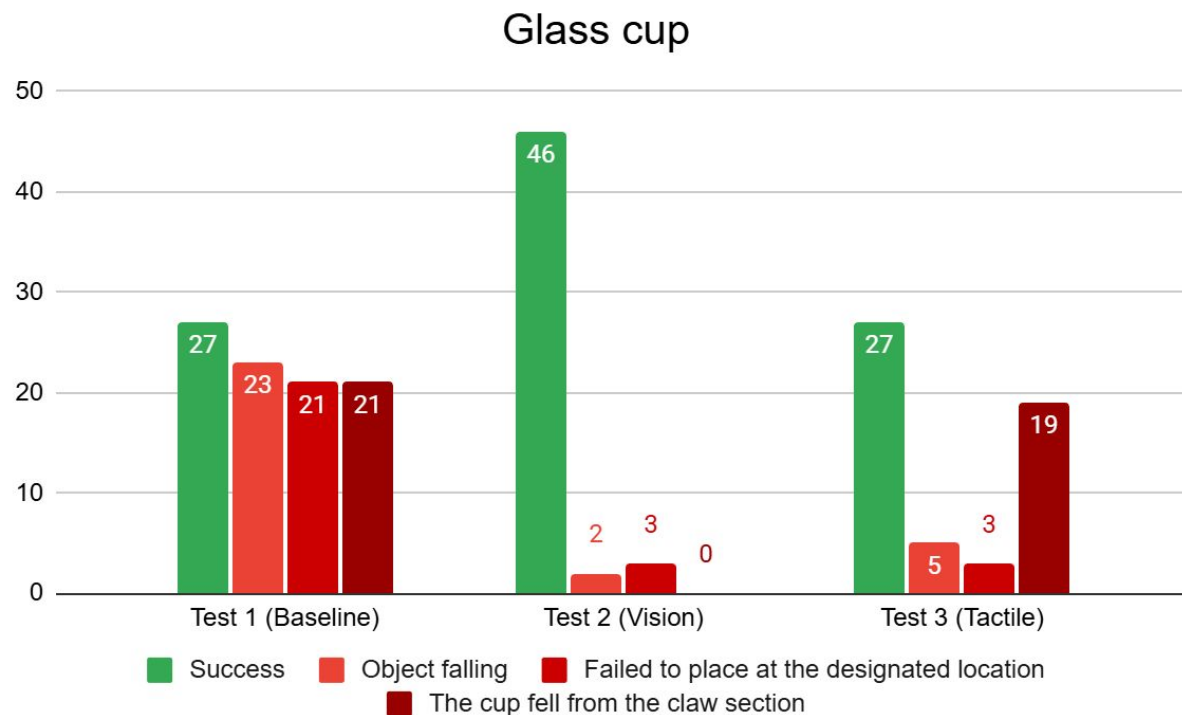


Baseline failures are spread across multiple modes (falling, misplacement, and slipping), which drop sharply with vision and nearly disappear with tactile control.



Overall trend: performance increases from Baseline → Vision → Tactile, and tactile feedback delivers the most stable results for plastic cups.

// Experimental results (Plastic cup)



➤ 1

Test 2 (Vision) delivers the largest gain: success increases from 27 → 46 (+19), indicating vision support greatly improves glass-cup handling stability.

➤ 2

Test 3 (Tactile) shows no improvement: success remains 27/50 (54%), the same as the baseline.

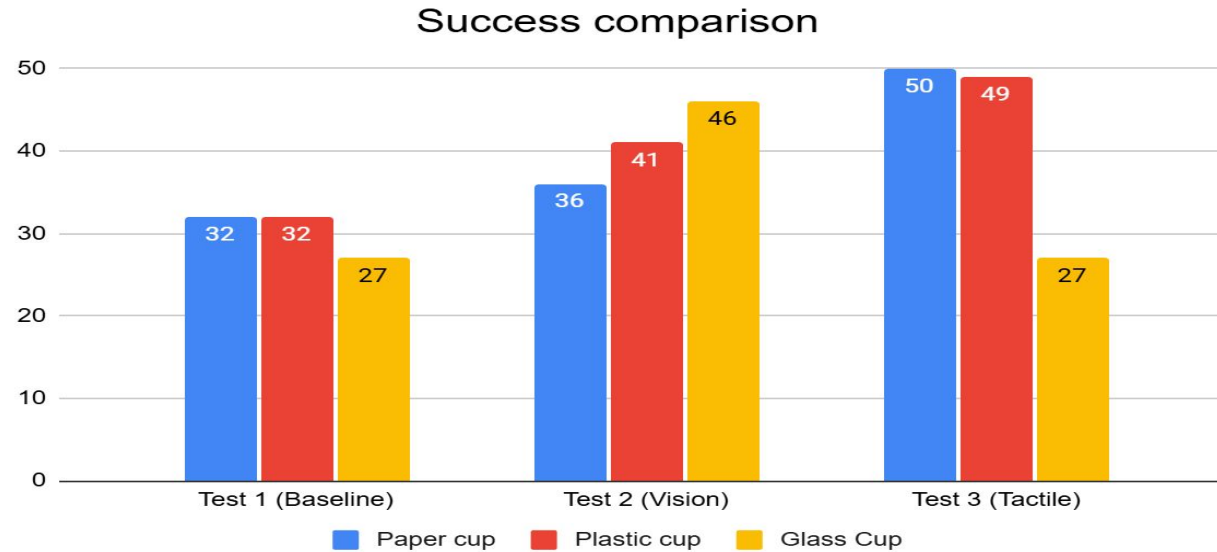
➤ 3

The dominant issue in Test 3 is “cup slipped from the claw” (19 occurrences), suggesting tactile/threshold control alone is insufficient to prevent slipping on glass.

➤ 4

Overall conclusion: glass cups benefit most from vision (better positioning/parameter selection); further improvement requires addressing slip at the gripper as the key failure mode.

Experimental results



The experiments show that adding human-like capabilities (vision-based material understanding + tactile/force control) significantly improves a service robot's success in handling cups of different materials in bubble-tea shops and reduces the risk of cup damage and drink spillage.

// References

- Zhu, Y., Xie, D., Lu, J., Feng, X., Yang, H., Tang, Q., & Yu, H. (2025). *Deformable and fragile object manipulation: A review and prospects*. *Sensors*, 25(17), 5430. <https://doi.org/10.3390/s25175430>.
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- *Sim-to-real gentle manipulation of deformable and fragile objects with stress-guided reinforcement learning*. (2025). arXiv (arXiv:2508.00697). <https://arxiv.org/abs/2508.00697>.

**Thank you for your
constructive feedback!**

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