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SEMI-AUTONOMOUS FRAMEWORK FOR COMPLETING CONTACT TASKS IN THE PRESENCE OF LATENCY

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1. Abstract

We present a novel semi-autonomous framework integrating an Enhanced Path Stepping with Statics (ePSS) planner and a task-based situational awareness (SA) module. The ePSS framework combines kinematic and static considerations to generate continuous configuration space paths within the robot's reachable workspace while incorporating task wrenches to produce the joint torques necessary for handling long motions beyond the dexterous workspace. The SA module improves operator performance during teleoperation by offering a streamlined GUI that overlays real-time, task-relevant data onto 2D or 3D views. This approach leverages psychophysics principles to align with human perception, enhancing depth information, force feedback, and system status. It addresses challenges such as latency, limited depth perception, and constrained fields of view. This combined approach demonstrates substantial improvements in the execution of complex contact tasks under latency conditions.

2. Contributions

- Developed an ePSS planner that generates long motion plans exceeding the manipulator's dexterous workspace.
- Integrated kinematic and static considerations for task wrenches in motion planning.
- Leveraged Screw Theory to model Affordance Templates and Sequential Force Exploration (SFE) to explore task wrenches.
- Implemented a Situational Awareness module for improved teleoperation.
- Achieved high success in teleoperation as a fallback for failures or when finer control was needed for complex contact tasks under latency conditions.

3. Enhanced Path Stepping with Statics (ePSS) Module

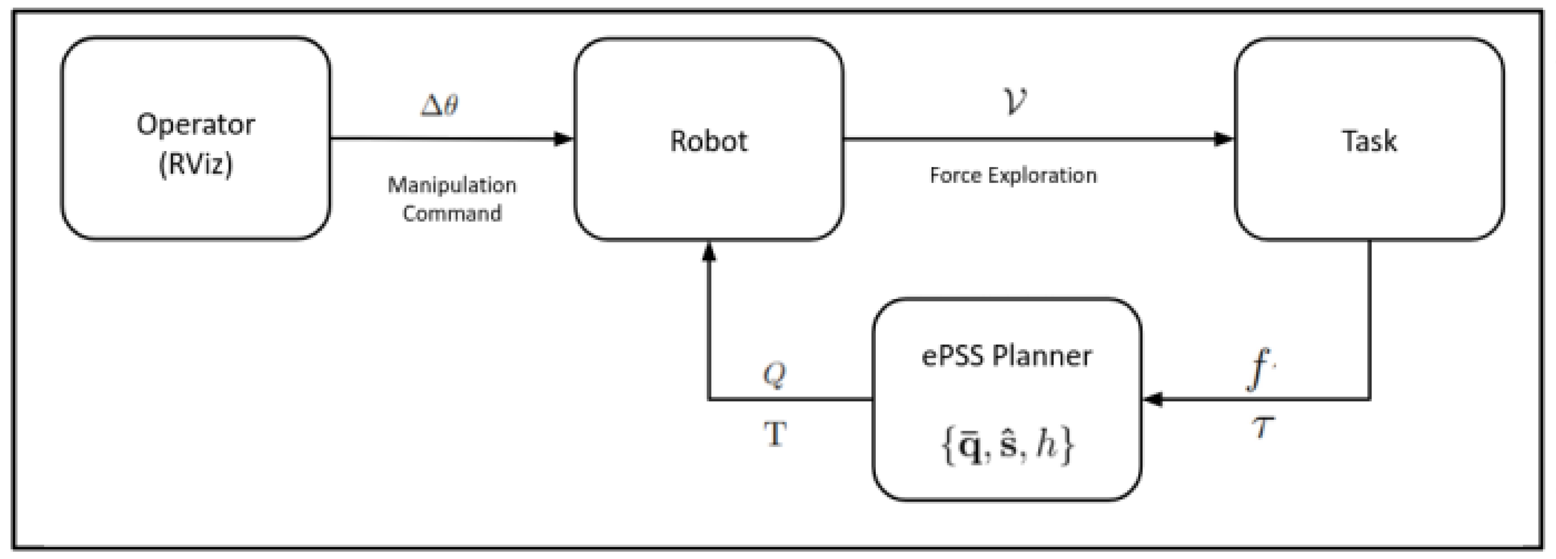


Figure 1: A high-level manipulation framework showing command & planning components interaction. Upon receiving a request to turn Δθ degrees, an initial force exploration is performed by commanding the EE with a twist, *V*. The recorded task wrench, [f ,τ]^T and the screw parameters in the ePSS planner are used to generate the motion plan, where *f* is the force vector and *τ* is the torque vector. The output is a trajectory with a vector of joint state vectors, (*Q*), and joint torque vectors (*T*)

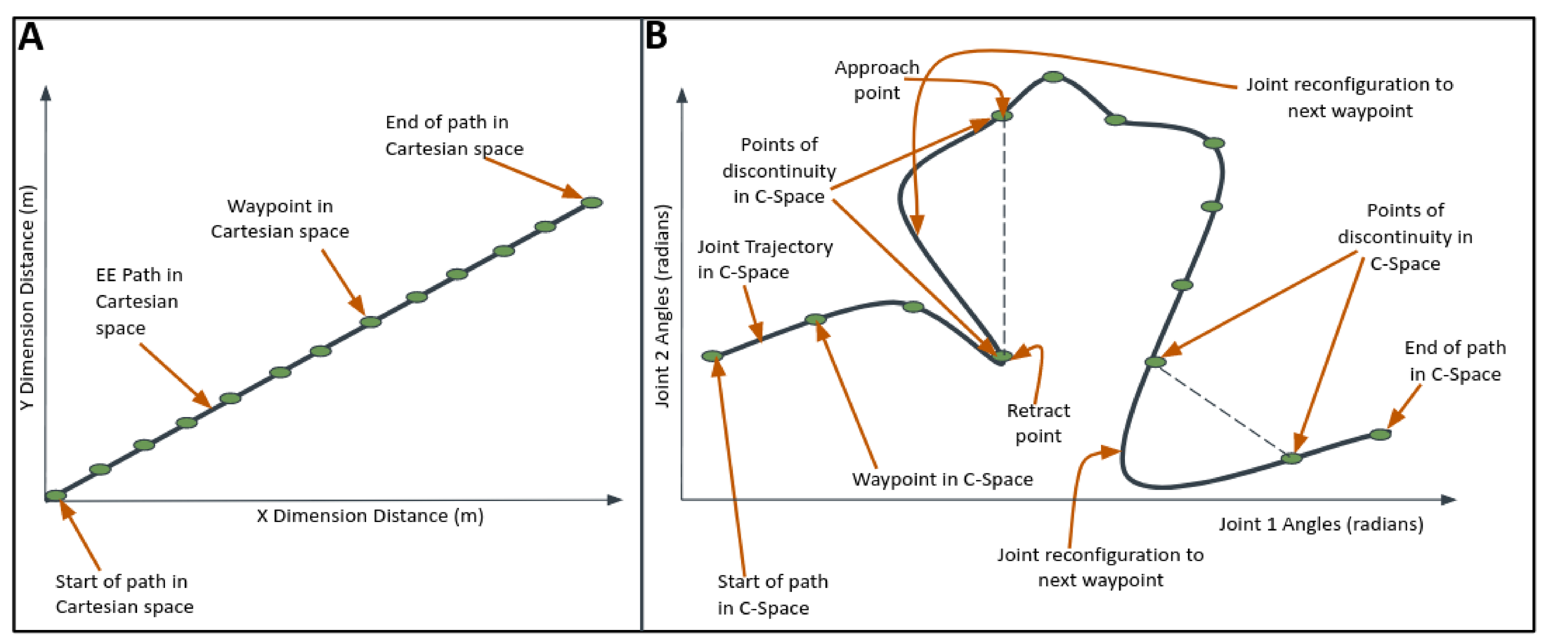


Figure 2: Cartesian path discontinuity in configuration space. **A** shows a straight, continuous EE path. **B** shows a curved line which represents the conceptualization of a joint space trajectory for a simplified 2 DoF manipulator. "C-Space" refers to configuration space. The retraction from the task and the approach to the task occur at the points of discontinuity in configuration space during when the joints are reconfigured.

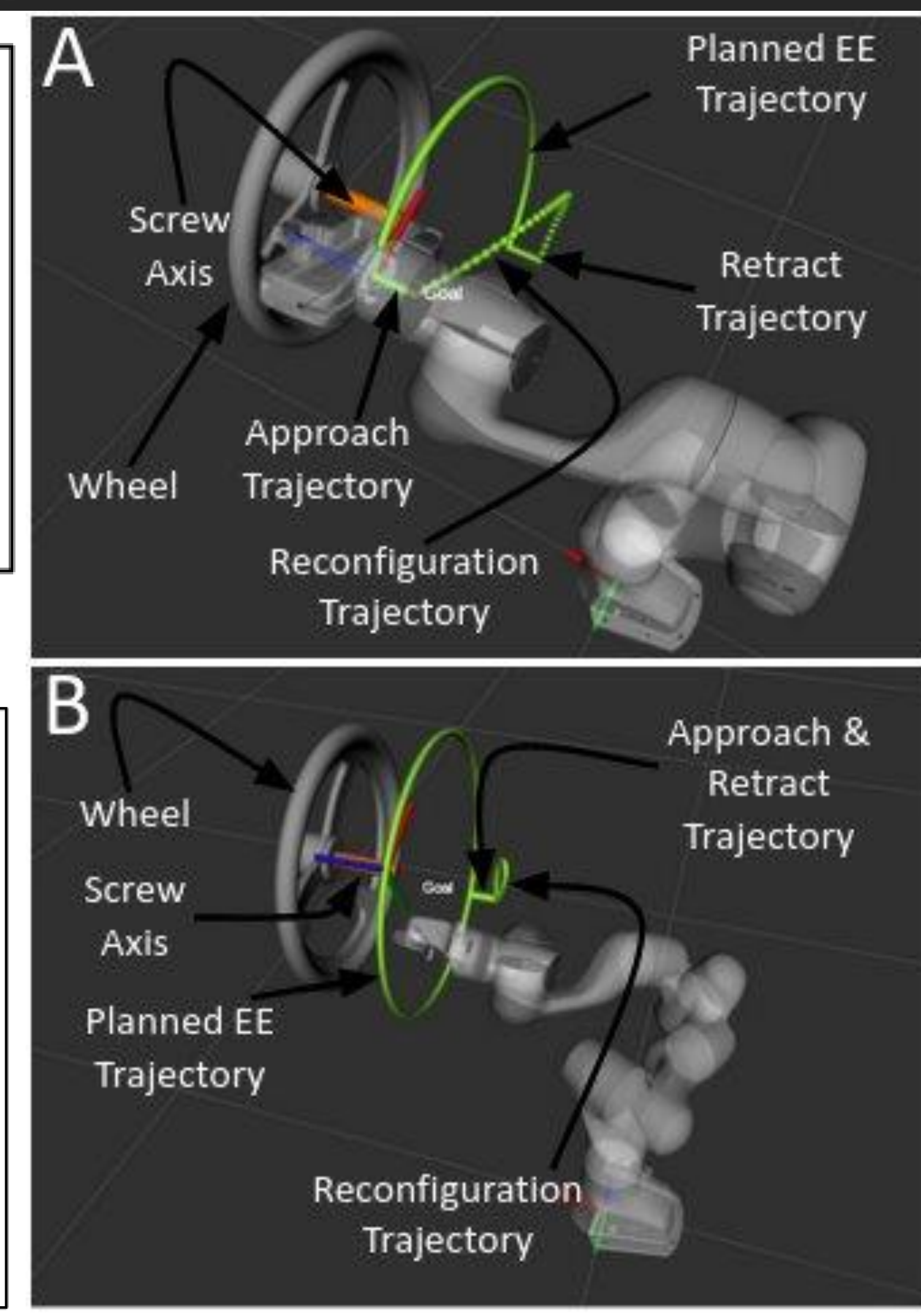


Figure 3: Joint reconfiguration and planned EE trajectory. The robot reconfigures to the start state in **A**, and reconfigures to the next waypoint in **B**.

4. Situational Awareness (SA) Module Highlights

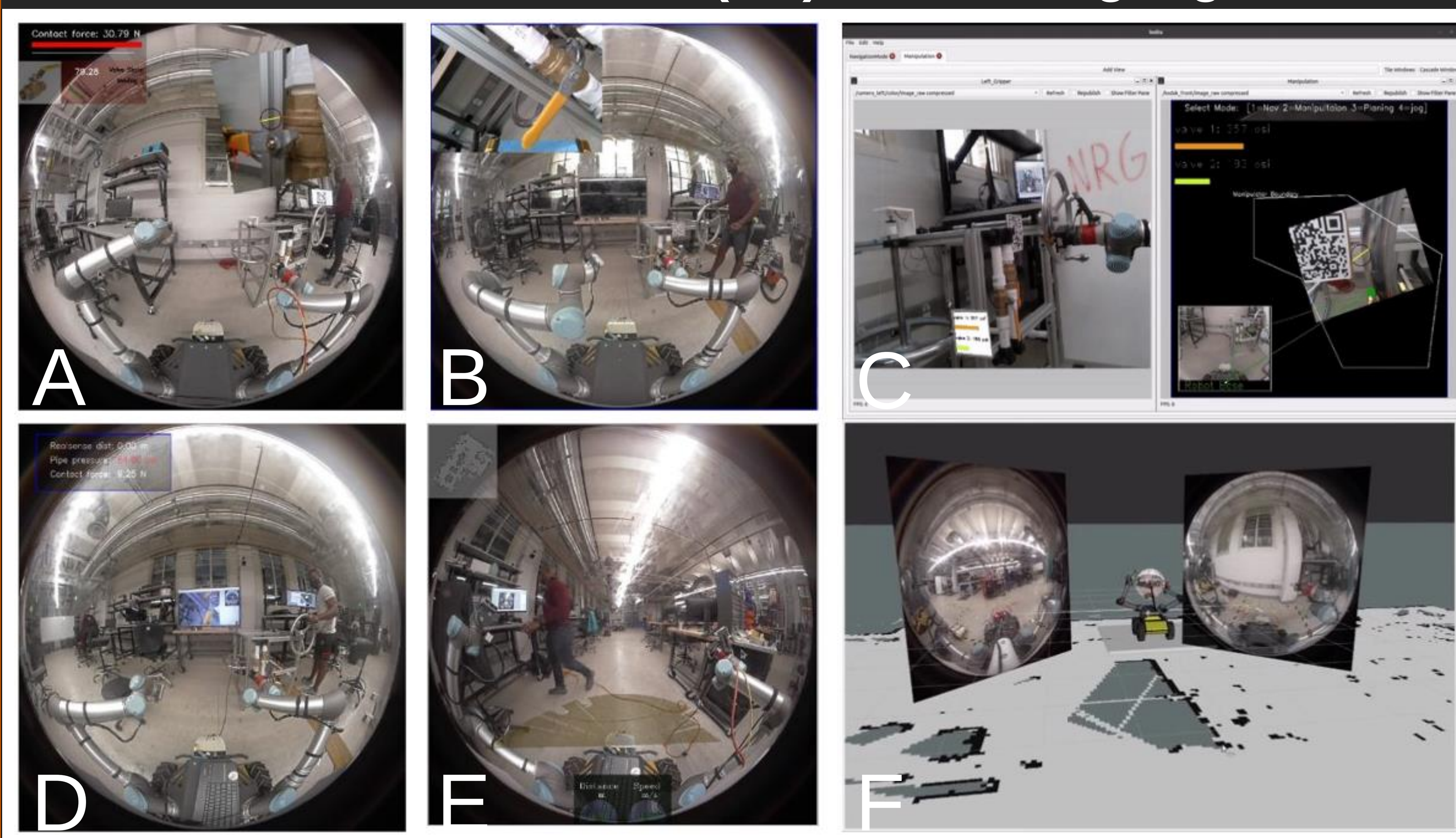


Figure 4 [A] x, y, z contact and resultant force filter. [B] Virtual plane for gripping [C] Manipulation mode window [D] Data filter [E] LiDAR and Dashboard filter [F] Navigation mode in RViz

Uses overlays to address SA challenges such as:

- Depth Perception
- Field of View Enhancement
- Force & Haptic Feedback
- Cognitive Load reduction
- Latency Mitigation

Eliminates the need for high-end computing resources and wearable devices for operators.

5. Methods and Results

- Constrained motion planner study for 360º rotation: **100%** success rate for reconfiguration to the motion start state. **90%** success rate for reconfiguration to the next waypoint.

Planner, Reconfig	BioIK Success	BioIK Time (s)	KDL Success	KDL Time (s)
PRM, Start	100%	9.3 (6.6, 29)	100%	5.88 (4, 25)
PRM, Pose	98%	30.79 (7, 136)	100%	25.0 (5, 47)
RRTConnect, Start	96%	8.92 (7, 10)	100%	5.66 (4, 25)
RRTConnect, Pose	100%	27.35 (8, 70)	100%	22.83 (5, 48)

Table 1. Results for BioIK and KDL for a vertical wheel. Rounded up minimum and maximum values in parentheses.

- SFE setup and joint torques for vertical wheel orientation

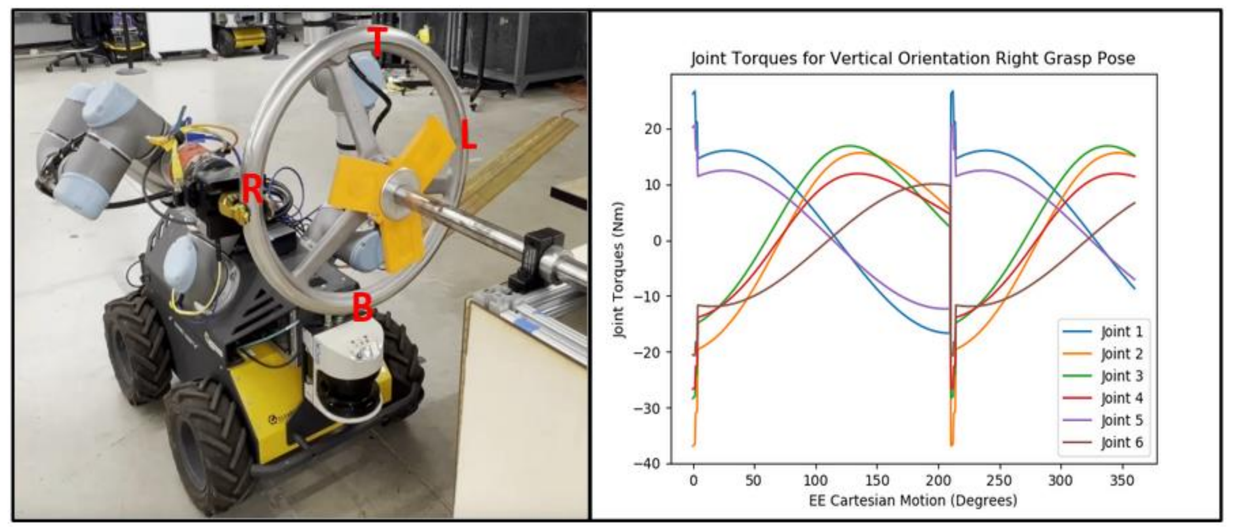
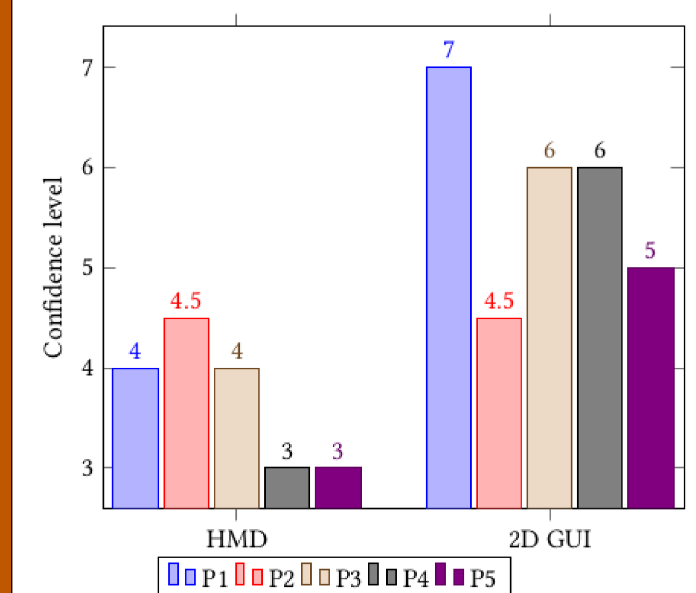


Figure 5. SFE setup and joint torques for vertical wheel orientation.

- SA SAGAT Evaluation Results



The results show superior performance and increased SA levels with the 2D GUI in comparison to the HMD interface.

Figure 6. SAGAT level of confidence rating [1-7]

The framework increases the success rate for contact tasks by considering task wrenches and leveraging the SA module as a fallback.

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