End-of-Life Disassembly as a Benchmark for Active Perception in Robotic Manipulation

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***Abstract*— Active perception is central to robotic manipulation under uncertainty, yet the field lacks benchmarks that demand this coupling in realistic settings. We argue that end-of-life (EOL) disassembly naturally exhibits the properties required of such a benchmark: hidden defects, occlusion, and instance-specific variation that force a robot to gather information through physical interaction. We formalize this view as a POMDP and present a 3D-printable replica of an angle grinder, designed as a benchmark for EOL disassembly. We validate the benchmark by demonstrating a system that actively reasons about stuck or missing parts from interaction feedback and completes disassembly tasks under these uncertainties.**

I. INTRODUCTION

Active perception is widely recognized as essential for manipulation under uncertainty. A robot may need to remove a cover to inspect hidden components, or probe a fastener to determine whether it is stuck. Despite growing interest, the field lacks practical industrial benchmarks that require the tight coupling of information gathering and physical interaction in realistic, reproducible settings. Without such benchmarks, it is difficult to systematically compare active perception strategies or measure progress. Building on prior work on robotic disassembly systems [1], disassembly planning [2], and industrial disassembly under real-world conditions [3], we argue that end-of-life (EOL) disassembly fills this gap. Consider a product arriving for recycling: a robot might know theCAD model, but the physical instance of the product may deviate substantially: screws may be corroded, parts may be missing, or previous repairs may have altered the internal structure. These deviations can be hidden behind outer components and become observable only through disassembly or interaction. In this paper, we extend this line of work with three contributions: We argue that EOL disassembly can be viewed as a POMDP in which every manipulation action also serves as an information-gathering action, making it a natural active perception benchmark. We present a 3D-printable angle grinder replica with configurable EOL conditions as a reproducible physical benchmark for this domain. We validate the benchmark by demonstrating a system that actively reasons about stuck and missing parts based on interaction feedback on the benchmark to successfully complete the disassembly task.

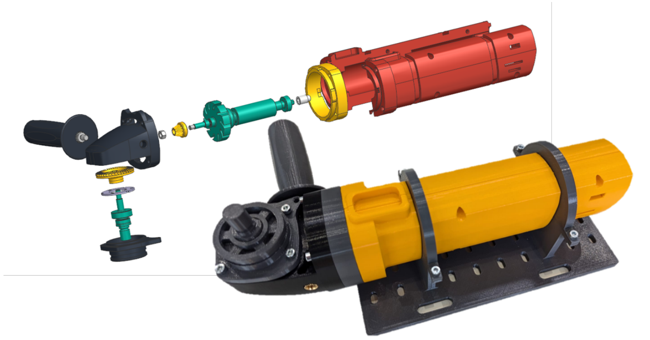

Fig. 1. The 3D-printable angle grinder benchmark in its fully assembled state alongside an exploded view. The replica preserves the part topology, fastener types, and layered occlusion structure of the original angle grinder.

II. EOL DISASSEMBLY AS AN ACTIVE PERCEPTION PROBLEM

What makes a domain a good benchmark for active perception [4]? We identify two necessary properties and show that EOL disassembly exhibits both. The first is *action-dependent observability*: the information a robot needs to plan is hidden and can only be revealed by acting on the world. In EOL disassembly, the relevant uncertainty is not sensor noise but *latent product state*—which parts are present, which fasteners are stuck, which removal paths remain possible. These variables strongly affect the optimal strategy but are initially unobservable because internal components are occluded by outer housings. Determining whether an internal part is damaged may require first removing obstructing components unrelated to the final target. Inspection is therefore inherently interleaved with manipulation. The second is *dual-role actions*: every manipulation simultaneously changes the world and generates information. Removing a cover alters the product state *and* exposes previously hidden subassemblies. A failed unscrewing attempt changes nothing physically but reveals that the fastener is likely stuck. This duality means that planning must reason about both task progress and information gain. These properties map directly onto a POMDP $\langle S, A, T, R, O, Z, \gamma \rangle$. The hidden state encodes how the part is altered from the nominal product. The observation model captures direct sensor readings (e.g., a depth camera detecting part presence after cover removal) and action feedback (e.g., a failed pull indicating blockage). This formalization provides a principled basis for comparing active perception strategies in disassembly: different policies correspond to different ways of balancing

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exploitation (task progress) and exploration (information gathering).

III. A 3D-PRINTABLE BENCHMARK ASSEMBLY

Arguing that EOL disassembly is a suitable benchmark domain is only useful if researchers can actually evaluate algorithms on a shared, reproducible test object. Real EOL products vary uncontrollably between instances, making systematic comparison difficult. We address this with a fully 3D-printable benchmark assembly modeled after a real angle grinder (Fig. **??**). The replica faithfully reproduces the original product's part topology, fastener layout, and layered housing structure. Parts are interchangeable between the 3D-printed replica and the real product (Fig. 3), and the benchmark was validated to exhibit equivalent disassembly behavior, meaning that the same tools, sequences, and failure modes apply. The design follows four principles: internal subassemblies are hidden behind covers that must be removed before inspection; parts can be omitted, swapped, or tightened to simulate missing components or stuck fasteners; screws and friction-held parts require different tools and sensing modalities; and all components print on standard FDM printers. By controlling which deviations are introduced, researchers can systematically vary the difficulty of the active perception problem.

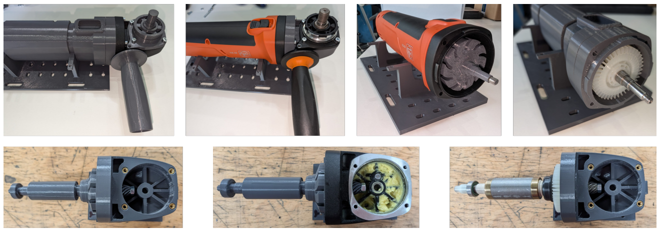

Fig. 3. Parts are interchangeable between the 3D-printed benchmark and the real angle grinder, validating that the replica faithfully reproduces the relevant mechanical and structural properties.

IV. VALIDATION: ACTIVE REASONING UNDER UNCERTAINTY

The previous sections argued that EOL disassembly has the right properties for an active perception benchmark and presented a reproducible test object. To show that the benchmark elicits the intended behavior, we implemented a POMDP-based disassembly system. We evaluated it on the angle grinder replica as well as a real electric motor used in [2]. The system operates on a robotic disassembly cell with a depth camera and interchangeable tools (grippers, screwdrivers, milling end-effectors). The belief about hidden EOL conditions is updated online based on visual observations and action outcomes. When an unscrewing attempt fails, the system can infer that the fastener may be stuck and adapt by switching to destructive removal or rerouting the disassembly sequence (as shown in Fig. **??**). This shows that the benchmark successfully captures the core active perception challenge: the robot must gather information through interaction, update its beliefs, and adapt its strategy online to complete the task under uncertainty.

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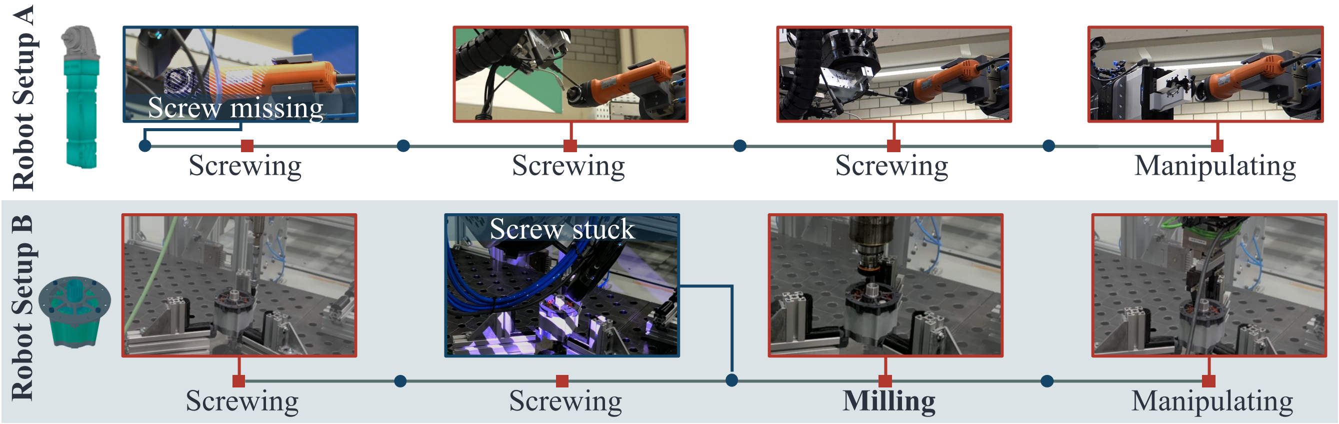

Fig. 2. Validation results showing that the active perception system can successfully adapt to unexpected conditions (e.g., a stuck or missing fastener) by updating its belief and replanning, outperforming deterministic baselines that fail to recover.