Skill-based Layered Control Architecture for the Robotic Manipulation of Amorphous Materials

Louis Hanut[1,4], Yurui Du[2], Renaud Detry[1,2], Herman Bruyninckx[1,3,4]
[1] Department of Mechanical Engineering, KU Leuven, 3001 Heverlee, Belgium
[2] Department of Electrical Engineering (ESAT), KU Leuven, 3001 Heverlee, Belgium
[3] Mechanical Engineering, TU Eindhoven, 5600 MB Eindhoven, The Netherlands [4] Flanders Make@KU Leuven, Belgium
Email: louis.hanut@kuleuven.be

The construction sector keeps growing, demanding more resources and workforce. Many associated tasks involve the manipulation of amorphous materials (i.e. materials that have no fixed shape like sand, wet concrete ...) [1]. Robotic manipulation of such materials is an under-researched problem that presents various challenges. Because their properties are difficult to model exactly (depend on the material composition, environmental conditions), emergent effects are observed during interaction with amorphous materials. These emergent effects also increase the perception complexity and therefore the uncertainty of the robot's belief about the material state.

To enable a robotic system to manipulate amorphous materials, our approach is based on 3 elements answering the above-mentioned challenges: skills, a layered control architecture and adaptation. The skills allow, within the layered architecture, to integrate task knowledge and therefore help the system estimating its effects on the material. Adaptation is crucial for robustness against emergent effects.

1 System architecture description

Skills are defined as parametrized procedures that can be composed to reach the task objectives [2]. Skills are a way to integrate (task) knowledge in the robotic system. They are more than motion primitives, they involve interacting control, perception and world model. For instance, the robot can estimate the expected effects of his actions on the perception and world state.

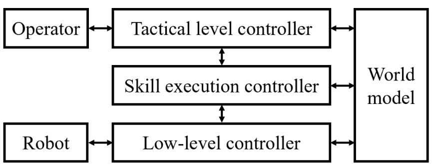

Figure 1: Layered control architecture schematic

The system architecture is shown in Fig. 1. It contains three **layers** that support the skill-based approach. The *Low-level controller* (bottom layer) is responsible to track setpoints at the joint-level. One level higher, the *Skill execution controller* is handling the skills execution as Finite State Machines. Finally, the *Tactical level controller* coordinates the planning of skills towards the task objective. This layer is deciding which skill should be executed with which parameters depending on the current world model state.

Adaptation can take place at the low-level, modifying the skill execution to respect constraints (e.g., robot maximum tolerated force) [3]. At a higher level, adaptation of the skill plan compensates emergent effects.

2 Use case - Sand surface leveling

To demonstrate how this control framework can be applied to amorphous materials manipulation tasks, we defined a sand leveling task (setup presented in Figure 2). In this demonstration, the tactical level control was shared with a human operator that could choose the type of skill (stripe removing or hill flattening) to use next.[1]

Figure 2: Experimental setup (top view)

3 Conclusion and future work

In this work, a control framework was developed to enable the robotic manipulation of amorphous materials. A sand leveling use case shows how the skill approach and layered architecture can tackle the amorphous material challenges. As future work, we plan on automating the skill planning and parametrization.

References

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[1] Use case video available at: https://youtu.be/Q7UosuRZx60