Quantifying Morphological Computation of Soft Robotic Hands

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Soft manipulators realize complex grasping behavior with simple control, as demonstrated by research with compliant and soft hands [1], [2], [3]. To understand the contribution of compliance to the resulting behavior, it is helpful to compare a soft manipulator with a rigid robotic hand. For the latter, in most applications, the joint space trajectory is controlled explicitly. In contrast, soft hands allow for a much coarser control scheme where the exact joint trajectories are not determined a priori but result from the interactions between hand and environment. For example, the RBO Hand 2 [4] (left hand in Fig. 1) grasps objects by applying a low dimensional actuation signal. The observed grasping behavior, however, is determined by a combination of control and interactions of the hand with the object/environment. The contribution of this interaction to overall behavior is referred to as *morphological computation* (MC) [5].

In this work, we evaluate MC measures as a possible benchmark for soft hands. We determine the amount of MC during grasping with three different hand morphologies (shown in Figure 1) and three different motion primitives (Controller 1 to 3) that varied slightly in their wrist frame and finger pressure trajectories. We employ an information-theoretic quantification of MC [6], which we previously evaluated on muscle models before [7]. We perform our experiments in a grasping simulator based on SOFA [8].

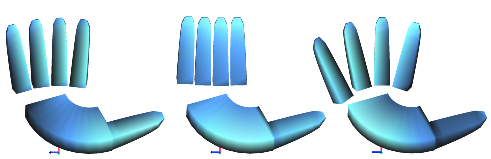

Fig. 1. Three hand shapes were used for evaluation

Figure 2 shows one of 9000 simulations we performed. The measure $\mathrm{MC_{MI}}$ was similar for each hand/controller combination and averaged to 11.35 bit out of the maximum attainable limit 18.7 bit. Without considerations of physical interactions (i.e. control determines the entire behavior and penetrations are allowed), $\mathrm{MC_{MI}}$ drops to 3.64 bit, demonstrating the significant contribution of physical interactions enabled by soft hands.

An analysis of the contribution of each time step to $\mathrm{MC_{MI}}$ (Figure 3) shows that failed and successful grasps (solid lines) mainly differ from unsuccessful ones (dashed lines) in the hold phase. This is reasonable, because the hand stops to interact with a dropped object in that phase.

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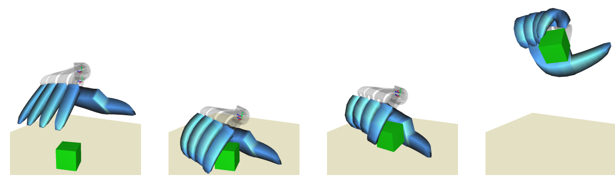

Fig. 2. Simulated grasp strategy (object shape and location vary)

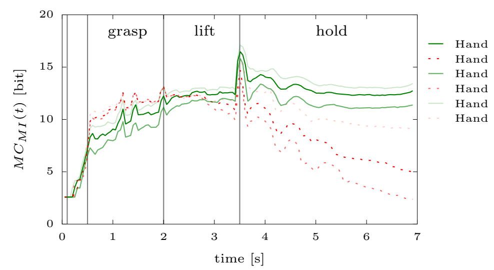

Fig. 3. This diagram shows the contribution of each phase to the MC_{MI} score (success: green/solid line; failure: red/dashed line)

Our results indicate that $\mathrm{MC_{MI}}$ and related measures are promising candidates for the development of benchmarks for underactuated and soft hands. $\mathrm{MC_{MI}}$ reflects intuitively the complexity of the behavior that is not caused by control. We omitted results that show that there is MC that contributes to success but also MC that does not. To develop functional benchmarks, we have to devise measures that can separate these two. Such a measure would enable MC-guided automated design of soft hand morphologies.

References

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