Cyber-Physical Systems for Material Handling

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Background and Motivation

Automated material handling is relevant to a wide range of applications including manufacturing, disaster response, space exploration, and assisted living. Cyber-physical systems (CPS) technology can provide one way to approach the problem, that is, designing computational algorithms that address physical interactions involved in the tasks. With current CPS technology, however, there are considerable challenges in meeting the safety and reliability requirements of material handling in a real world setting where complicated dynamic interactions necessitate carefully synchronized time-triggered behaviors for the successful completion of the task. As a consequence, for example in robotic grasping, most practical solutions involve specially designed hardware (end-effectors) and control algorithms that are customized only to the specific object to be handled or grasped.

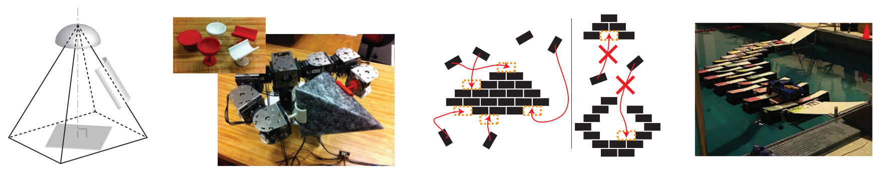
Proposed Research

My vision is to realize automated material handling with guaranteed safety and reliability in a wide range of operating conditions. I propose to begin with two specific problems: autonomous object grasping and self-assembly with standardized modules. For the grasping problem, we presented techniques allowing robots to grasp objects with at most three simple (planar, cylindrical, or spherical) effectors[1]; moreover, the grasps are acquired in a stable manner, so we can disregard the complicated dynamics of the object and the effectors interacting with each other (Fig. 1a, b). For the assembly problem, we presented an assembly planning algorithm for constructing planar structures with simple rectangular modules in a distributed manner[2]; the resultant plan allows us to avoid peg-in-hole scenarios

[1] J. Seo, M. Yim, and V. Kumar, "Restraining objects with curved effectors and its application to whole-arm grasping," in *The 16th International Symposium on Robotics Research (ISRR)*, IFRR, 2013.

[2] J. Seo, M. Yim, and V. Kumar, "Assembly planning for planar structures of a brick wall pattern with rectangular modular robots," in *Automation Science and Engineering (CASE), 2013 IEEE International Conference on*, IEEE, 2013.

that can be involved with complicated dynamic interactions (Fig. 1c, d). The ideas suggest that clever design can relieve computational algorithms of the need for instantaneous situational awareness; in all these cases, I have designed software that implements provably correct algorithms that work with the designed hardware.



(a) (b) (c) (d)

Figure 1: (a) The pyramid cannot translate or rotate at all because of the planar, the spherical, and the cylindrical effector. (b) The two-armed robot is stably grasping the "rock" with the two cylindrical end-effectors. (c) Constructing a planar structure of a brick wall pattern in a distributed manner; we want to avoid peg-in-hole cases, where the module has to pass through the narrow gap, as shown in the right panel. (d) The rectangular "boats" were assembled into the bridge.

My proposed work will address the extension of these ideas to more complex applications with a wider range of operating conditions. For the grasping work, I further propose to address the mechanical properties of materials; ultimately, the algorithm is expected to coordinate haptic sensing and actuating with timely closed-loop interactions. For the assembly work, I further propose to address more general goal shapes by enabling forming topological holes and building on existing structures; the algorithm will also aim at constructing mechanisms such as an articulated robot arm.

Potential Impacts to Cyber-Physical Systems

Autonomous grasping adaptive to material properties will be useful for many applications requiring CPS ranging from handling soft tissue in surgery to moving rigid rocks on the Martian surface; the modular end-effectors (Fig. 1b) can also be used as modular feet that allow a legged CPS to stably walk on uneven terrain. CPS for self-assembling arbitrary structures and mechanisms will provide an advantage for operational fabrication support for the storage, movement, control, and protection of materials, allowing Kiva Systems-like operations even in an unstructured environment. Based on the ideas, I ultimately envision programmable machines for material handling that can reconfigure themselves as needed in order to optimally interact with physical objects and environments.