Cyber-Physical Systems (CPS) for Material Handling

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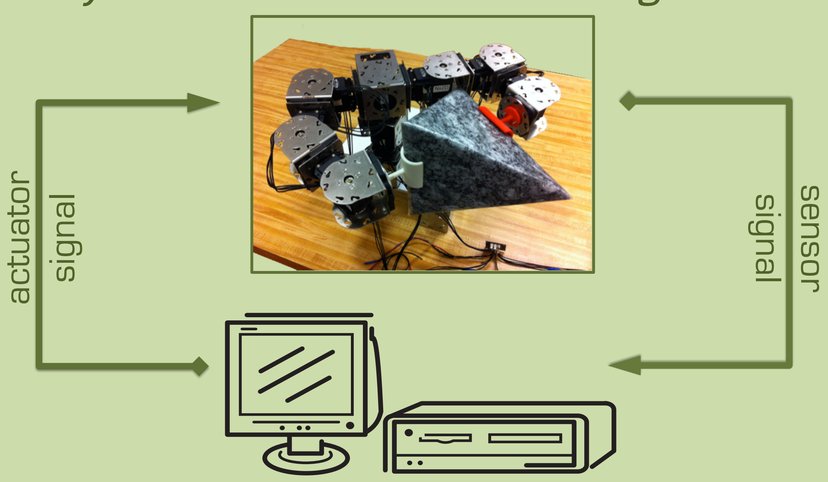
Material Handling by CPS

: Physical Plant + Control Algorithm

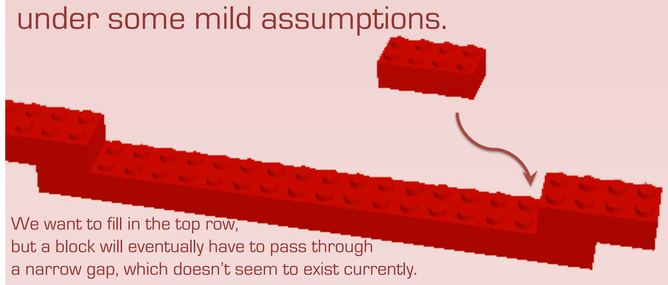


Proposed Research

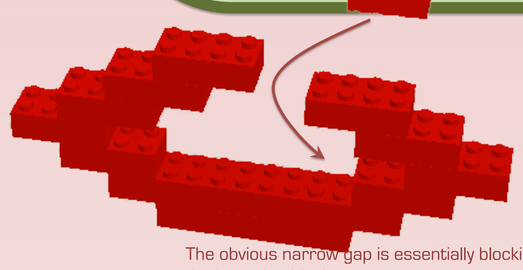
for the "*Material*" side
: Autonomous Robotic Assembly

Mathematics and Theory

With identical, rectangular building blocks moving on the plane, every planar structure of the common brick wall pattern can be constructed without reachability concerns (for example, see below), under some mild assumptions.



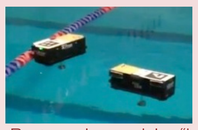
We want to fill in the top row, but a block will eventually have to pass through a narrow gap, which doesn't seem to exist currently.



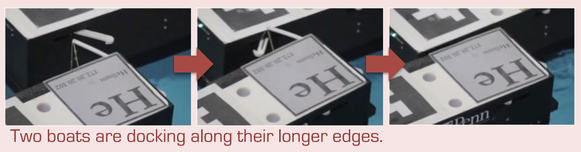
The obvious narrow gap is essentially blocking the incoming block.

The fact facilitates the design of involved CPS: the system doesn't have to address peg-in-hole assembly. Moreover, the brick pattern is structurally sound.

Design and Algorithm



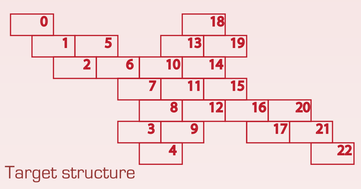
Rectangular modular "boats"



Two boats are docking along their longer edges.

Hardware: Modules are only required to mechanically dock with others along their "longer" edges, like the LEGO blocks; we can also prove the completeness of the idea.

Software: Our software is based on graph theory and supports distributed assembly.



Target structure

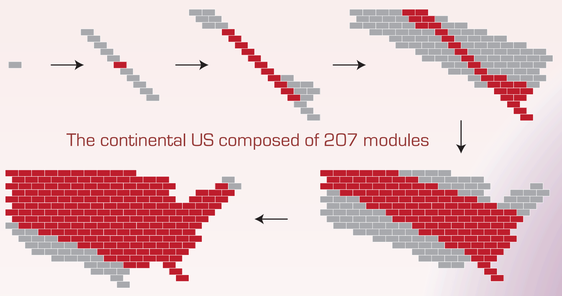
Assembly plan as a directed acyclic graph

Traversing the graph in a distributed manner

Implementation

Landing platform for an aerial vehicle

Bridge for a ground vehicle



The continental US composed of 207 modules

"Assembling by software that implements provably correct algorithms and hardware that is mathematically complete."

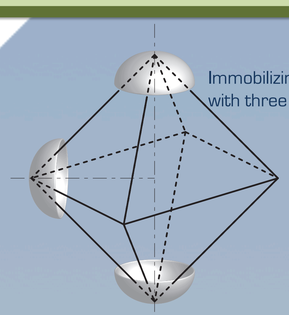
ⓘScan the QR code to watch a video.

Proposed Research

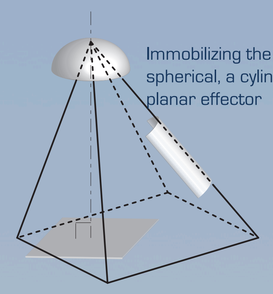
for the "*Handling*" side
: Autonomous Robotic Grasping

Mathematics and Theory

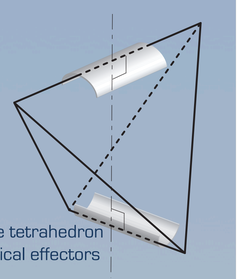
Theorem: Every polyhedron can be immobilized by at most three appropriately concave effectors, which can be as simple as the planar, cylindrical, and spherical effectors below.



Immobilizing the octahedron with three spherical effectors



Immobilizing the pyramid with a spherical, a cylindrical, and a planar effector

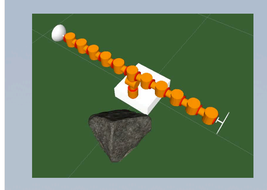


Immobilizing the tetrahedron with two cylindrical effectors

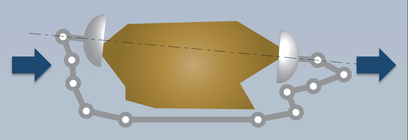
Moreover, the grasps can be acquired in a stable manner by controlling a Lyapunov function defined on the configuration of the effectors; this facilitates the design of involved CPS in that we do not need instantaneous situational awareness.

Design and Algorithm

Whole-arm graping for modular robot systems

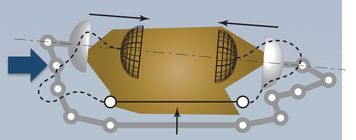


Two-armed robot outfitted with the curved end-effectors



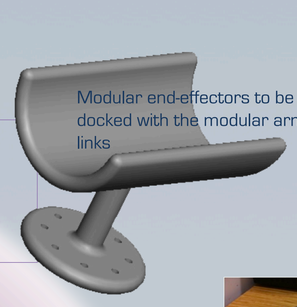
Stage 1: "Preshaping" for a cage by ordinary motion planning

The resultant preshape



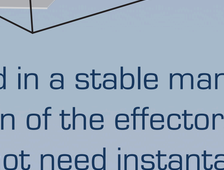
Stage 2: "Squeezing" for a stable grasp *by our energy-based approach*

Implementation

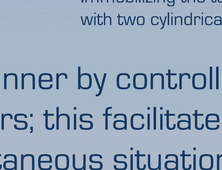


Modular end-effectors to be docked with the modular arm links

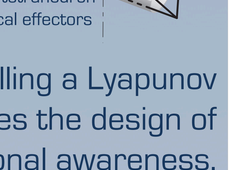
Modular two-armed robot



4-by-2 arm configuration



3-by-3 arm configuration



2-by-4 arm configuration

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Related Research in Our Group *and* Potential Impacts on Industry

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Photo courtesy: wikimedia.org, Elizabeth Beattie, Nick Eckenstein, Justin Thomas, Denise Wong