Self-Assembly and Self-Repair of Structures with Stability and Resource Constraints

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Vision

- Self-Assembly
- Self-Reconfiguration
- Self-Repair

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Computational Materials

DISTRIBUTED
AMORPHOUS
SCALABLE

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Challenges

• How to maintain *stability* during self-assembly in air?
• How to limit sensing, actuation and computation *resources*?
• How to *self-repair*?

Distributed Flight Array, Raffael d’Andrea, ETH

Superbot, Wei Min-Shen, USC

3 year grant, start April 1st, 2012
1. Stability

• Which *path* to choose to reach a desired configuration?
  – Basic physics
  – Wind, turbulences, vibrations, etc.
  – Sensor/Actuator limitations

• Adding restraints?
Example
Approach

• Combination of
  – Discrete search
  – Dynamical Simulation
  – Full physics, realistic simulation

Gazebo / ODE

Frame3DD

100 x

10000 x
Valid Assembly Sequences:
1,2,3,4,5,6,7,8
1,2,3,4,5,6,8,7
1,2,3,4,5,7,6,8
1,2,3,4,6,5,7,8
1,2,3,4,6,5,8,7
1,2,3,4,6,8,5,7
Tee Structure Assembly Graph Nodes

Analysis Sequences:
1
1, 2
1, 2, 3
1, 2, 3, 4
1, 2, 3, 4, 5
1, 2, 3, 4, 6
1, 2, 3, 4, 5, 6
1, 2, 3, 4, 5, 7
1, 2, 3, 4, 6, 8
1, 2, 3, 4, 5, 6, 7
1, 2, 3, 4, 5, 6, 8
1, 2, 3, 4, 5, 6, 7, 8
Other Structures

Tee

Bridge

2D w/ Hole

2D w/ enclosed

Valid Assembly Paths | Graph Nodes to analyze
--- | ---
6 | 12
78 | 60
452 | 76
7985 | 243

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Frame3DD FEA: Partial Bridge

![Analyzed Structure]

- Undeformed
- Deformed

Cubelet Build Path: Build Step = 8 (in-lbf-s)
analysis file: InputFiles/input8.inp  deflection exaggeration: 1000.0  load case 1 of 1
Discussion: Stable Paths

• Fast heuristics needed for discrete search
  – Encode basic physics
  – Encode geometric constraints
• Identification of “critical” elements that need restraints
• Frame3DD -> arbitrary physics
  – From static assemblies to flying and swimming
2. Resources

• How to limit the number of building blocks with actuation, sensing, and computation?
  – Weight
  – Cost

• Approach: “Intelligent Scaffolds”
Approach: Intelligent Scaffolds

- Scaffolds (red) coordinate construction
- Three Scaffold blocks can construct any computable structure
Intelligent Scaffolds
Discussion: Resources

• Intelligent scaffold allow trade-off between number of actuated modules (from 3 to N) and assembly time

• Need new algorithms that use *some* computation & communication in otherwise passive blocks
3. Self-Repair

• Challenge:
  – Detect damage
  – Execute repair

• Approach:
  – Graph grammars
  – Graph rewriting rules

\[ \phi_{fi} : X \ A \Rightarrow Y \ - \ Z \]

\[ \phi_{ri} : Y \ - \ Z \Rightarrow X \ A \]
3. Self-Repair

• Generate graph grammars to monitor and repair structural integrity

• Embed monitor and repair rules into material

A-B, A-C, B-C, B-A, C-A, C-B
Discussion: Self-Repair

• Requires additional sensing, computation, and communication

• Find right trade-off between
  – Speed of detection/repair
  – Additional resources to embed
Outlook

• From simple physics to (simple) flight dynamics
• Study self-assembly, reconfiguration, and repair in realistic simulation
• Perform preliminary experiments in 2D and 3D

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