Self-organization in Manufacturing Systems: Challenges and Opportunities

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Agenda

- Introduction and motivation
- Self-organization in manufacturing systems
- Foundations of a biological-Inspired control solution
- Why are not yet adopted by industry?
- Challenges and opportunities
- Conclusions
Motivation for this Work

- Re-configurability and responsiveness are key roles for a company to stay in the business, exhibiting an agile response to the changing conditions through their dynamic re-configuration on the fly.

- **Reconfigurable manufacturing control systems** are based on emergent technologies and impose:
  - modularity, integrability, customization, scalability, convertibility and diagnosability.

- Biology and nature are suitable sources of inspiration for the development of RMS and evolvable systems.

- Applicability of bio-inspired theories to build RMS.
What can Bio-inspired Theories Offer

• Simple individual entities possessing simple behaviors,
  – A small number of rules can generate complex systems.
  – Depending of intelligence and learning skills.

• Swarm intelligence:
  – Emergent collective intelligence of groups of simple and single entities.
  – Alternative way of designing intelligent systems, in which autonomy, emergence and distribution replace centralized control.

• These systems operate in a very flexible and robust way.

• Self-organization, chaos and complexity theories support the operation of non-linear and dynamic processes.
The Self-Organization Concept

**Definition:** Ability of an entity/system to adapt dynamically its behavior to external conditions without external intervention.

The application of self-organization allows the dynamic:

- **Self-configuration** (i.e. adaptation to changing conditions by changing their own configuration without service disruption);
- **Self-optimization** (i.e. tuning itself in a pro-active way);
- **Self-healing** (i.e. capacity to diagnose deviations and take proactive actions to normalize them).

The emergence of the global control is based on:

- Capability of individuals to change dynamically their properties.
- Evaluation if the evolved solution is better than the previous one.
- Important to achieve order and stability.
Bio-Inspired Manufacturing Paradigms

• Some manufacturing paradigms:
  – Bionic Manufacturing Systems (BMS).

• Propose distributed, autonomous and adaptive manufacturing systems.

• Differ in their inherent capability to adapt to changes without external interventions.
Biological-Inspired Control Solution

Local Schedule

OH

logical control

interaction during the re-scheduling

Global Schedule

interaction during the global optimization

Local Schedule

2

logical control

8 30

Local Schedule

2 8

Local Schedule

10 30
Complex Systems from the Individuals

The whole system emerges from the interaction between local entities.

Simple behaviors composed by a set of few simple rules.
Individual Driving Forces: Autonomy Factor

- An intrinsic parameter reflecting the degree of autonomy of a holon.

- Evolves dynamically in order to adapt the holon behavior to changes in the environment where it is placed.

- Regulated by a fuzzy rule-based engine that considers:
  - the reestablishment time ($\tau$),
  - the pheromone parameter ($\rho$).

```plaintext
IF $\rho$ == High AND $\alpha$ == Low
THEN $\alpha$ = High AND ReorganiseIntoNewStructure

IF $\rho$ == High AND $\alpha$ == High AND $\tau$ == Elapsed
THEN $\alpha$ = High AND Reload $\tau$

IF $\rho$ == Low AND $\alpha$ == High AND $\tau$ == Elapsed
THEN $\alpha$ = Low AND ReorganiseIntoNewStructure
```
Global Driving Forces: Spreading Mechanism

- Deposit a pheromone indicating the need for re-organisation
- Propagates the pheromone
- The holons sense the pheromone
- Occurrence of a disturbance
Adaptive Control Working in Practice

Stationary state

Propagation of the disturbance occurrence

Transient state

Evolution to a new structure

Reorganization into a heterarchical structure
Prototype Operation

Ethernet network

 FPS
 PM
 PH
 OH-turn-b

 Windows
 Linux
 Windows XP

 OH-agv
Why Are Not Yet Adopted by Industry?

- New way of thinking.
- Customers and industry want to use proven technology.
- Industry is afraid of the usage of emergent terminology usually associated to these new technologies.
- Investment to implement these emergent approaches.
- Restrictions of some technical issues.
- Use of limited features offered by the bio-inspired theories.
Challenges and Opportunities

• Convincement of people to believe in the concepts,
  – using mature demonstrations to proof that they work as desired, even in severe scenarios.
  – Indicators illustrating the benefits of these approaches.

• Presence of modularity, embodied intelligence, re-configurability mechanisms and interoperability.

• Stability: identify reconfiguration opportunities, while maintaining the system behavior predictable and stable.

• Interoperability in heterogeneous environments.
  – Semantics and ontologies seem to be the answers to this challenge.
Conclusions

• Manufacturing systems are addressing the challenge for reconfigurable and evolvable systems.

• Biological and nature inspired concepts and theories seem suitable for the design of RMS.

• Bio-inspired solution using concepts derived from HMS, swarm intelligence and self-organization, supported by the use of multi-agent principles.

• Some possible reasons for the weak adoption by industry were pointed out.
Thank you!

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