Collaborative Control Theory for Robots

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Robot Collaboration

• Collaboration revolution

• Co-Ro-Bots – Robot; Agent

• Collaborate: Why? Who? How?

  Nature of Robot Collaboration: Alliance vs. adversary

• CCT; Design recommendations for collaboration support

• Emerging trends
  • Evolutionary robotics
  • Bio-inspired robotics
  • Nano-robots
  • Social robotics
  • CI, Collaborative Intelligence
Why is collaboration needed? For better effectiveness & success

Evolution of automation in mobility and navigation
(Ollero, Springer Handbook of Automation 09)

Ergonomics, work optimization: Stronger, safer, faster, more precise, reach further
How to collaborate?

R:R:R, H:R:R

Optional Task Collaboration

Level of Resource Sharing
Service load: (a) high, (b) low

Mandatory Task Collaboration

HBIR2 (Nof) Ch 32 Robot Ergonomics: Optimizing Robot Work

PARO, therapeutical seal robots (AIST)

AIBO, robotic pet (Sony)

MEL, Conversational penguin robot (MERL)

Leonardo, media robot (MIT)
Cooperate vs. Collaborate

Both: share space; time; information; knowledge; tools; capacity. In collaboration, share also in tasks execution.

Cooperating robots: “I can see what you cannot”

Collaborating robots: Master-slave model

From rigid to bi-inspired control models:
- Autonomous / autonomic units (agents)
- Adaptability, evolutionary,
- Survivability (of fittest)
- Autonomous, collaborative systems
- Scalability, agility
**How?** Comm. → Coordinate → Cooperate → Collaborate

**H:R:R in sensor networks: Response quality by CCT logic**

Co. to win: W-W; ZSG; MSG

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Pheromone strategies with alarm response times achieved

de Fereitas et al. Coordinating aerial robots and sensors for intelligent surveillance.

*IJCCC* 10, 52-70
<table>
<thead>
<tr>
<th>Design Principle</th>
<th>Brief Definition</th>
<th>Robots/Agents</th>
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<tbody>
<tr>
<td>1. <strong>CRP</strong> I+II Collaboration Requirement Planning</td>
<td>Effective e-collaboration requires advanced planning and on-going re-planning</td>
<td>Operation plan and seq.; Adapt</td>
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<tr>
<td>2. <strong>Parallelism &amp; KISS</strong> Parallelize and “Keep it simple, system!”</td>
<td>Optimally exploit the fact that work in cyber work-spaces and human work-spaces can and must be allowed to advance in parallel</td>
<td>Optimize DOP, {R}, TAP; KISS for H, R</td>
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<td>3. <strong>CEDP</strong> Conflict &amp; Error Detection and Prognostics</td>
<td>Minimize cost of resolving conflicts among collaborating agents by automated CSS, collaboration support systems</td>
<td>Id., detect, prevent, resolve errors, conflicts</td>
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<td>4. <strong>FTT</strong> Fault-Tolerance by Teaming</td>
<td>Fault-tolerant collaboration can yield better results by a team of weak agents, than a single optimized and even flawless agent</td>
<td>Sensors and robots networks</td>
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<tr>
<td>5. <strong>JLR</strong> Join/Leave/Remain in a CNO network</td>
<td><strong>An agent:</strong> Decide when/ why to JLR a CNO by monitoring total participation gains/ costs. <strong>A CNO:</strong> Same, including more coordination, re each member</td>
<td>Dynamic team optimization</td>
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<td>6. <strong>LOCC</strong> Lines of Command and Collaboration</td>
<td>Evolutionary mechanisms of interaction and organizational learning for effective ad-hoc decisions, improvisation, on-the-spot contact creation, best matching protocols pairing planners with executors</td>
<td>Alerts, backup and best matching TAPs</td>
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Nof, *ARC 07*; Velasquez & Nof, *SHBA 09*
Group/Swarm robotics

Model based control, MPC (Model Based Predictive Control) used for formation control. MAS, Multi Agent distributed control applies to autonomous agents.
Collaborative parallelism

PIEM (centralized optimization algorithms) and DPIEM (optimization with distributed protocols) for planning the communication and coordination trade-offs in collaborative design, mfg., logistics, operations with parallelism.

Summary: Local and Integrated Teams [Ceroni,00]

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<tr>
<th></th>
<th>$\Phi$</th>
<th>$\Pi$</th>
<th>$T$</th>
<th>No. of Sub-tasks</th>
</tr>
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<tr>
<td><strong>Local Teams</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(A+B)</td>
<td>1.984</td>
<td>1.4239</td>
<td>0.5607</td>
<td>52</td>
</tr>
<tr>
<td><strong>Team A</strong></td>
<td>1.390</td>
<td>1.0350</td>
<td>0.3558</td>
<td>16</td>
</tr>
<tr>
<td><strong>Team B</strong></td>
<td>0.593</td>
<td>0.3889</td>
<td>0.2049</td>
<td>36</td>
</tr>
<tr>
<td><strong>Integrated</strong></td>
<td>1.807</td>
<td>1.1666</td>
<td>0.6404</td>
<td>26</td>
</tr>
</tbody>
</table>

Optimize the DOP, Degree of Parallelism.
The Principle of Conflict Resolution in Collaborative e-Work
[Huang and Nof, 99; Chen and Nof, 09]

- Minimize the cost of resolving conflicts among collaborating agents by automated CSS (collaboration support systems)
- Beyond reducing information and task overloads, agents must be designed to automatically prevent and overcome as many errors and conflicts as required to be effective

Conflict & Error Detection Agents (CEDA) and Protocols (CEDP) are assigned to Network $N_0(t)$

Ex. Elimination of faults in inspection, testing, security
Increases exponentially when human communications and operations are applied (assuming $q=0.2$)

Reaches an upper bound when IT is Applied (assuming $q=0.0$)

$q = \%$ of human involvement

$S = \text{rate of conflicts}$
Collaborative fault-tolerance TAP design in sensor/agent networks

Principles 1-6 at work:
Alternative MEMS and nano sensor arrays / networks optimized along an artery for measurement and control

Faulty sensors routed communication by a time-based control [Jeong, 2006]

TAP: Task Administration Protocols for complex workflow
Summary, Emerging Trends, open challenges

1. **CCT contributions** continue and expand in networks of supply, knowledge supply, decision and policy making, healthcare delivery, cyber security, physical security, etc.

2. **Modeling for CCT**: Network theory; Network-aware models; bio-inspired models; swarm intelligence; game theory models (bargaining)

3. **Collaborative Intelligence**, CI

4. Collaborating with **humanoids**
Collaboratorium quality impact: How well it facilitates

1. Significantly accelerated and better synthesis and integration of knowledge and discoveries;
2. Understanding the dynamics of interactive-collaborative work;
3. Timely delivery of critically needed discoveries and shared knowledge.
Abstraction Scheme for Collaborative Visualization
Co – Viz / Co-insight Approach (Ozsoy, 10)

Application

Simulations, DataSets, Results

DATABASE

Analytics Abstraction Layer

Visualization Abstraction Layer

Work Group

Collaborative Understanding

Customized output for each distinct collaborator

Feedback from different perspectives
Collaborating with Humanoids

Dancing with humanoids

Socially interactive humanoid robots

Springer Handbook of Robotics, 08
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