Optimal synthesis of cascaded loop controllers with saturation using Ant Colony Optimization

Maude-Josée Blondin, Prof. Pierre Sicard
Université du Québec à Trois-Rivières, GREI
blondmau@uqtr.ca
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« Introduction »
Many methods and rules have been proposed for tuning Proportional-Integral-Derivative (PID) controllers:

- Ziegler-Nichols
- Frequency response methods
- Pole placement

**Problematic** : Rules typically respond to particular performance criteria and do not take into account controller saturation, and rely on a time separation argument in complex systems.

**Proposition** :

ACO based methodology applied to a motion system with flexible coupling for tuning controllers in presence of saturation.
「Industrial grinder EMR and control structure」
«Optimal synthesis of cascaded loop controllers with saturation using Ant Colony Optimization»

- Studied system -
leads to a cascade control loop with 5 controllers
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- EMR of the industrial grinder -

EMR #1
hypothesis are required to reproduce the standard 1½ axis industrial controller structure
we evaluate independently driving torque \( T_T \) and \( \Delta T \); we assume external motor velocity reference, set to its final value.
PI current practical control structure
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- Inversion-based control of the system -

Position practical control structure

Simplification for positioning problem:
reference motor velocity generation (model dependent) is simplified by using its steady state value.
«Ant Colony Optimization (ACO)»
Inspired by the behavior of ants

- Tendency of taking the shortest road facing multiple paths to a food source
- Communication via their environment by depositing traces of pheromones

Illustration of ACO with Traveling Salesman Problem:
Find the shortest path connecting several cities

Decision rule:

\[
p_{ij}^k(t) = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta}{\sum_{l \in N_i} [\tau_{il}(t)]^\alpha [\eta_{il}(t)]^\beta}
\]

\(\eta_{ij}\) is the inverse distance between cities \(i\) and \(j\)
**Update of pheromone matrix**

\[
\tau_{ij}(t + 1) = \tau_{ij}(t) + \sum_{k=1}^{m} \Delta \tau_{ij}^k(t) \quad \forall (i,j) \in L
\]

Quantity of deposited pheromones is function of the quality of the solution (total length \(L\) of path):

\[
\Delta \tau_{ij}^k(t) = \begin{cases} 
1/L^k & \forall (i,j) \in L \\
0 & \text{otherwise}
\end{cases}
\]

Evaporation process is used to avoid unlimited accumulation of pheromones and to allow forgetting previous bad decisions:

\[
\tau_{ij}(t + 1) = (1 - \rho)\tau_{ij}(t) + \frac{1}{L(t)} \quad \forall (i,j) \in L
\]
«ACO application for PID parameter tuning with anti-windup management»
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- Simulation environment -
Performance criterion = $f(y^*, y, u, t)$

$I_{Error} = \int_0^{T_s} |e(t)| \, dt + \sigma \int_0^{T_s} e_d(t) \, dt$

$e_d(t) = \begin{cases} |e(t)| & \text{during response overshoots} \\ 0 & \text{otherwise} \end{cases}$
«Results»
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- ACO results -

- IAE index
- Modified IAE index
- Sequential tuning

Position (rad) vs. Time (s)
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- Convergence rate of ACO for the modified IAE with saturation -

EMR’13, Lille, Sept. 2013
Conclusion
EMR representation:
- two EMRs of the same system may lead to very different control structures
- the 1 ½ axis control structure can be improved with other choices for the distribution criterion
- EMR allows to highlight anti-windup management strategies

ACO method:
- fills a gap for adjusting control structures with saturation and multi-loop control structures, for various types of controllers
- performance criterion can be adapted to a specific application and constraints
- can handle a large number of parameters to be adjusted
New developments
- New developments -

- Development of performance criteria for handling hard and soft constraints [M.-J. Blondin and P. Sicard, EPE 2013]

- Development of strategies for multi-degrees of freedom controllers [M.-J. Blondin and P. Sicard, EPE 2013]

- Strategies to reduce the execution time of the ACO: combine ACO with local search algorithm (Nelder-Mead) [M.-J. Blondin and P. Sicard, IEEE IECON 2013]
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«BIOGRAPHIES AND REFERENCES»
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- Authors -

Maude-Josée Blondin
Master student in electrical engineering
Université du Québec à Trois-Rivières, Canada

Research topics: Optimization, metaheuristics, control.

Prof. Pierre SICARD, Ph.D.
Université du Québec à Trois-Rivières, Canada

PhD in Electrical Engineering, Rensselaer Polytechnic Institute, Troy NY, USA (1993)
Research topics: energy conversion, energetic and inverse based control methods, tractions systems, real-time simulation and control.

M.-J. Blondin, and P. Sicard, "ACO Based Controller and Anti-Windup Tuning for Motion Systems with Flexible Transmission," 2013 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE’13), Regina, Saskatchewan, Canada, 5-8 May 2013.

M.-J. Blondin, and P. Sicard, “Combined ACO Algorithm — Nelder-Mead Simplex Search for Controller and Anti-Windup Tuning for a Motion System with Flexible Transmission,” IEEE IECON, Vienna, Austria, 10-13 November 2013 (in press)

