Imposing a Weight Norm Constraint for Neuro-Adaptive Control

IEEE European Control Conference (ECC) 2025

Myeongseok Ryu[1], Jiyun Kim[2], and Kyunghwan Choi[1]

[1]Department of Mechanical and Robotics Engineering
Gwangju Institute of Science and Technology

[2]AI Graduate School
Gwangju Institute of Science and Technology

June 7, 2025

Outline

1. **Background and Contributions**
   - Introduction to Neuro-Adaptive Control
   - Literature Review
   - Research Objectives
2. **Proposed Method**
   - Problem Formulation
   - Adaptation Law Derivation
   - Stability Analysis
3. **Numerical Validation**
   - Simulation Setup
   - Simulation Results
4. **Conclusion**
   - Conclusion and Future Work

Outline

1 Background and Contributions
- Introduction to Neuro-Adaptive Control
- Literature Review
- Research Objectives

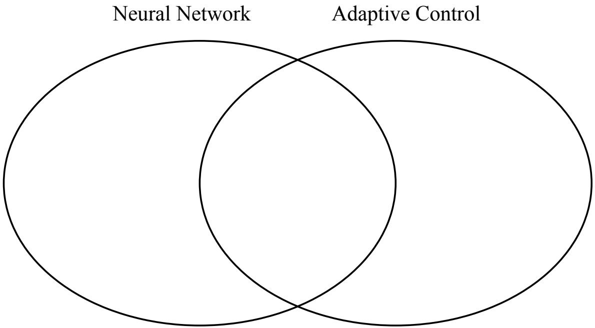
2 Proposed Method

3 Numerical Validation

4 Conclusion

Neuro-Adaptive Control

- **Neuro-adaptive control** (NAC) is a control strategy that combines **neural networks (NNs)** with **adaptive control** [1].
- Features of both **NNs** and **adaptive control** can be found in NAC.



Advantages of Neuro-Adaptive Control

- **Adaptability**: NAC adapts to changing environments and system dynamics.
- **Stability Guarantee**: The closed-loop stability is ensured using *Lyapunov stability theory*.
- **Online Learning Capability**: NAC adapts in *real-time* to new data with stability guarantees.
- **Robustness**: NAC handles *uncertainties and disturbances* effectively with adaptive control techniques.

Challenges

- **Optimality**: In general, the adaptation laws are driven with respect to the tracking error, which may not guarantee optimal performance.
- **Unpredictable Amplitude of Control input**:
  - The maximum amplitude of the NN weights is not predictable.
  - This can result in unpredictable amplitude of the control input, which may lead to control saturation.
- **Parameter Dependency**:
  - The performance of the NAC is highly dependent on the choice of parameters, such as learning rate and NN architecture.

Literature Review

In general, the NN outputs are bounded by limiting the maximum amplitude of the NN weights.

1. **Projection Operator**
   - Cats
   - Dogs
   - Birds

2. **ϵ-modification, and σ-modification**
   - Cats
   - Dogs
   - Birds

Research Objectives

Objective 1: Optimality

- Formulate a constrained optimization problem to minimize the tracking error.
- Guarantee the stability of the system and the NN weights.

Objective 2: Stability

- Derive an adaptation law that guarantees the stability of the system.
- Ensure that the NN weights remain bounded during operation.

Objective 3: Boundedness of

- Ensure the controller is robust to uncertainties and disturbances.
- Validate the proposed method through numerical simulations.

Outline

1 Background and Contributions

2 Proposed Method
- Problem Formulation
- Adaptation Law Derivation
- Stability Analysis

3 Numerical Validation

4 Conclusion

Objectives:

- Minimize the tracking error by adapting the NN weights $\widehat{\boldsymbol{\theta}}$.
- Guarantee the stability of the system and the NN weights $\widehat{\boldsymbol{\theta}}$.

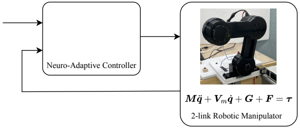


Figure: Architecture of the constrained optimization-based neuro-adaptive controller (CONAC).

Notations: $\boldsymbol{M}$: Inertia matrix, $\boldsymbol{C}$: Coriolis matrix, $\boldsymbol{G}$: Gravity vector, $\boldsymbol{\tau}$: Control input, $\boldsymbol{q}$: Joint position, $\widehat{\boldsymbol{\theta}}$: Estimated NN weights.

Outline

1. Background and Contributions
2. Proposed Method
3. **Numerical Validation**
   - Simulation Setup
   - Simulation Results
4. Conclusion

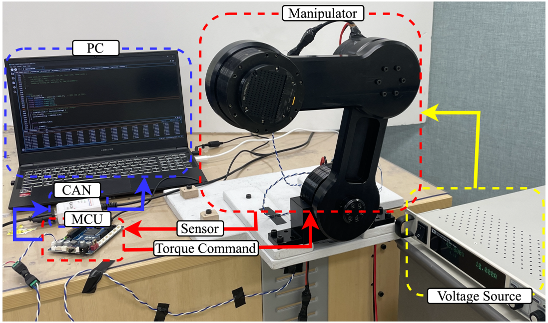
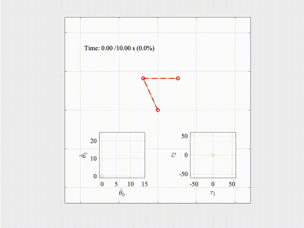


Figure: 2-Link Robotic Manipulator

Notations: $\boldsymbol{q}$: Joint position, $\dot{\boldsymbol{q}}$: Joint velocity, $\boldsymbol{\tau}$: Control input, $\boldsymbol{M}$: Inertia matrix, $\boldsymbol{C}$: Coriolis matrix, $\boldsymbol{G}$: Gravity vector.

Representative Simulation Results



Box-and-Whisker Plots

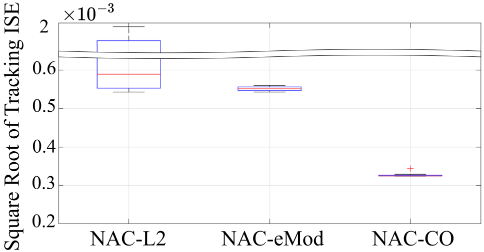


Figure: Parameter dependencies of the proposed method.

Table: Largest cities in the world (source: Wikipedia)

City	Population
Mexico City	20,116,842
Shanghai	19,210,000
Peking	15,796,450
Istanbul	14,160,467

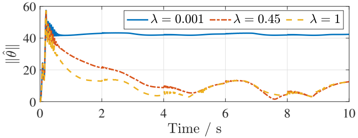


Figure: Weight norms of NAC-L2

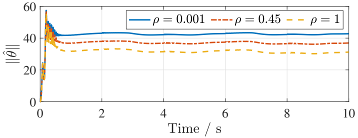


Figure: Weight norms of NAC-eMod

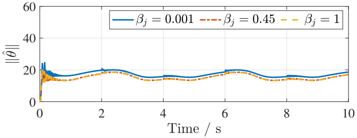


Figure: Weight norms of NAC-CO

The weight norms of the proposed method (NAC-CO) are bounded, while ...

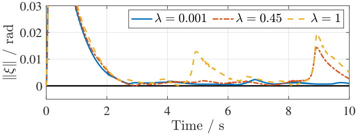


Figure: Tracking error of NAC-L2

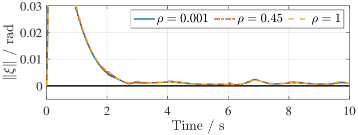


Figure: Tracking error of NAC-eMod

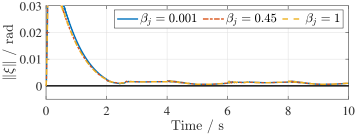


Figure: Tracking error of NAC-CO

The Tracking error ...

Outline

1 Background and Contributions

2 Proposed Method

3 Numerical Validation

4 Conclusion
- Conclusion and Future Work

Conclusion

Flux theme comes with three pre-defined block style collections.

Default

Block content.

Alert

Block content.

Example

Block content.

Thank you for your attention!

References I

[1] J. A. Farrell and M. M. Polycarpou, *Adaptive Approximation Based Control: Unifying Neural, Fuzzy and Traditional Adaptive Approximation Approaches (Adaptive and Learning Systems for Signal Processing, Communications and Control Series).* **USA: Wiley-Interscience, 2006.**