NCSbench Demo: Open-Source Benchmarking Platform for Networked Control Systems

Samuele Zoppi[1], Onur Ayan[1], Fabio Molinari[2], Zenit Music[2],
Sebastian Gallenmüller[3], Georg Carle[3], Wolfgang Kellerer[1]

[1]Chair of Communication Networks, TUM, Germany
[2]Control Systems Group, TU Berlin, Germany
[3]Chair of Network Architectures and Services, TUM, Germany

Project Motivation

- Networked control systems (NCS) are highly affected by packet loss and delays [1]
- Network-induced effects are well investigated with **theoretical models**
- A hardware platform is needed to obtain measurements of a **practical NCS**
- **NCSbench**: open-source implementation of a LTI Networked Control System [2]
- Sandbox measurement platform developed for:
  1. Easy and cheap **reproducibility**
  2. Implementation and **evaluation** of novel control algorithms and networks
  3. Performance **comparison** of different NCS implementations (benchmarking)

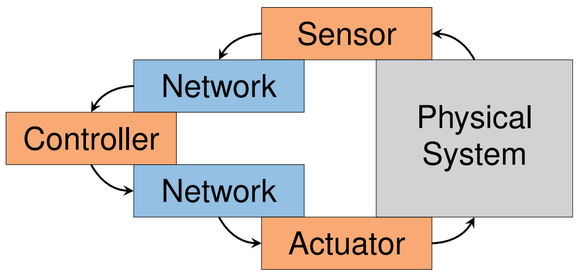

Fig. 1: NCS system model.

Fig. 2: NCSbench platform.

NCSbench Implementation and Measurements

- Hardware: Lego Mindstorm EV3®, 1 multi-purpose PC, any TCP/IP network connection
- Software: python source code, Linux
  ⇒ advanced control logic [3]
  ⇒ modular implementation
- Open source: www.github.com/tum-lkn/NCSbench
  ⇒ step-by-step setup instructions

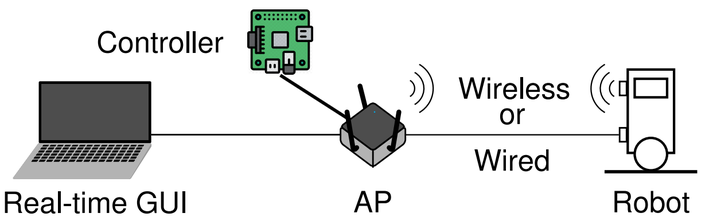

Fig. 3: Experimental demonstration setup.

KPI Measurements

- Organized using a novel architecture for practical NCS (Fig. 4)
  ⇒ aids the **investigation** of critical problems
  ⇒ allows the **performance analysis** of each component
- The Key Performance Indicators (KPIs) of the NCS are measured:
  1. **System delays** (Fig. 5)
     ⇒ processing delay of controller ($d_{\mathrm{P,C}}$), sensor ($d_{\mathrm{P,S}}$), and actuator ($d_{\mathrm{P,A}}$)
     ⇒ average network delay (d_{N})
  2. **Quality of Control** (Fig. 6)
     ⇒ Sensors: vertical angle and motors' position
     ⇒ Actuator: motor's voltages

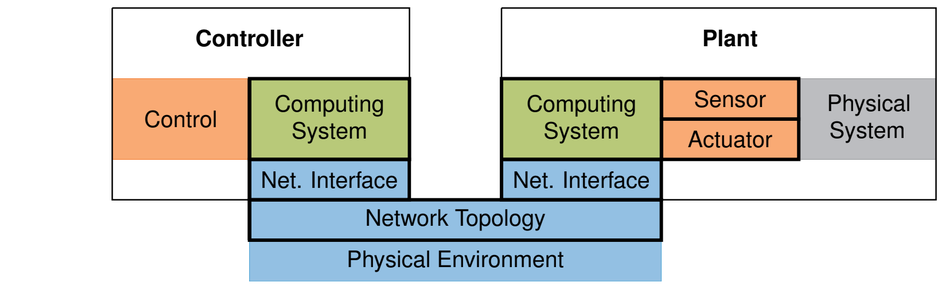

Fig. 4: NCS measurement architecture.

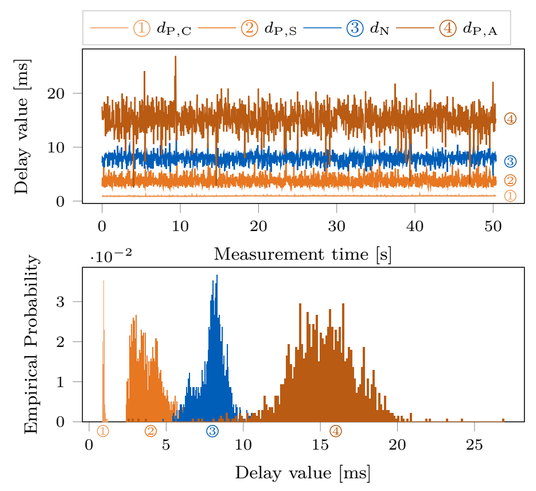

Fig. 5: Evolution of the system delays.

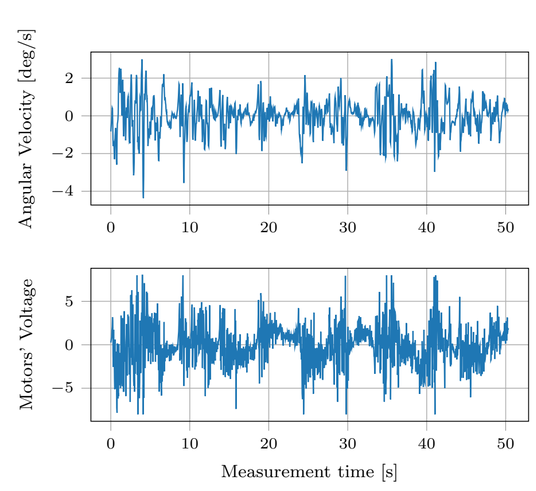

Fig. 6: Evolution of the Quality of Control.

Demonstration

- Robot's sensor and actuator are connected to the RaspberryPi controller
  ⇒ exchange of **control information**
- Controller is connected to the real-time GUI
  ⇒ **KPI measurements** are sent for visualisation
- The GUI visualize the real-time performance of the each NCS component

Conclusions

- NCSbench is **easy to reproduce** thanks to documented open-source SW and cheap HW
- Each element of the architecture can be **extended** or changed
- The KPIs capture the **real-time performance** of all the NCS components

Future Work

- Robot improvement with new hardware (RaspberryPi, sensors, actuators)
- Benchmarking of new control logics (non-linear control) and network technologies (Bluetooth, WSN, 5G)

[1] L. Zhang, H. Gao, and O. Kaynak. "Network-Induced Constraints in Networked Control Systems—A Survey". *IEEE Transactions on Industrial Informatics*, Feb 2013.

[2] S. Zoppi, O. Ayan, F. Molinari, Z. Music, S. Gallenmüller, G. Carle, and W. Kellerer. "NCSbench: Reproducible Benchmarking Platform for Networked Control Systems". In *2020 IEEE 17th Annual Consumer Communications & Networking Conference (CCNC)*.

[3] Z. Music, F. Molinari, S. Gallenmüller, O. Ayan, S. Zoppi, W. Kellerer, G. Carle, T. Seel, and J. Raisch. "Design Of a Networked Controller For a Two-Wheeled Inverted Pendulum Robot". In *8th IFAC Workshop on Distributed Estimation and Control in Networked Systems*, 2019.