Robust Control Strategy Using Event-triggered approach for Networked Control System (NCS) with Network Irregularities

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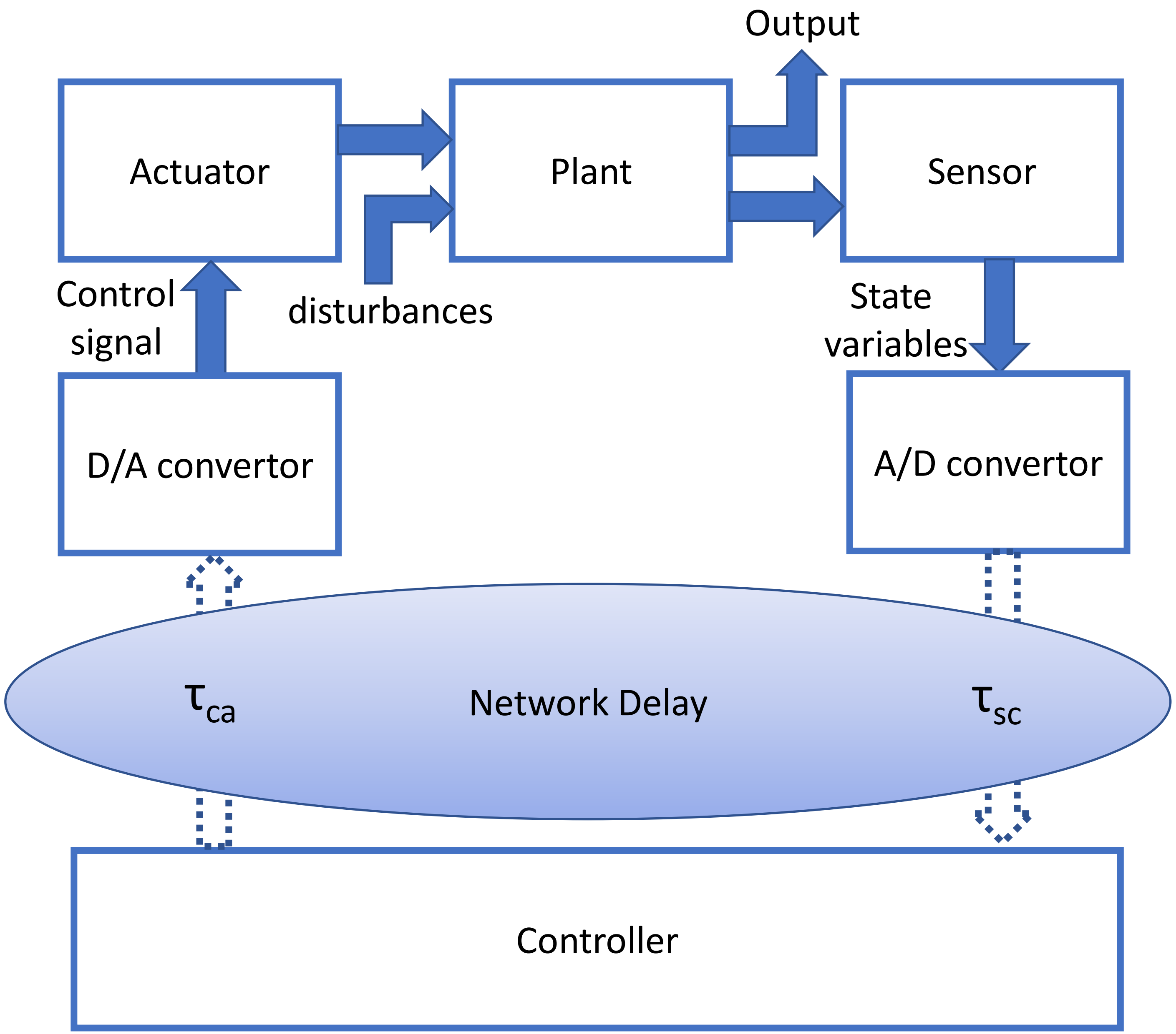
Overview of NCS



Structure of NCS

Shared Structure NCS

- Single network
- Multiple actuators, sensors and controllers

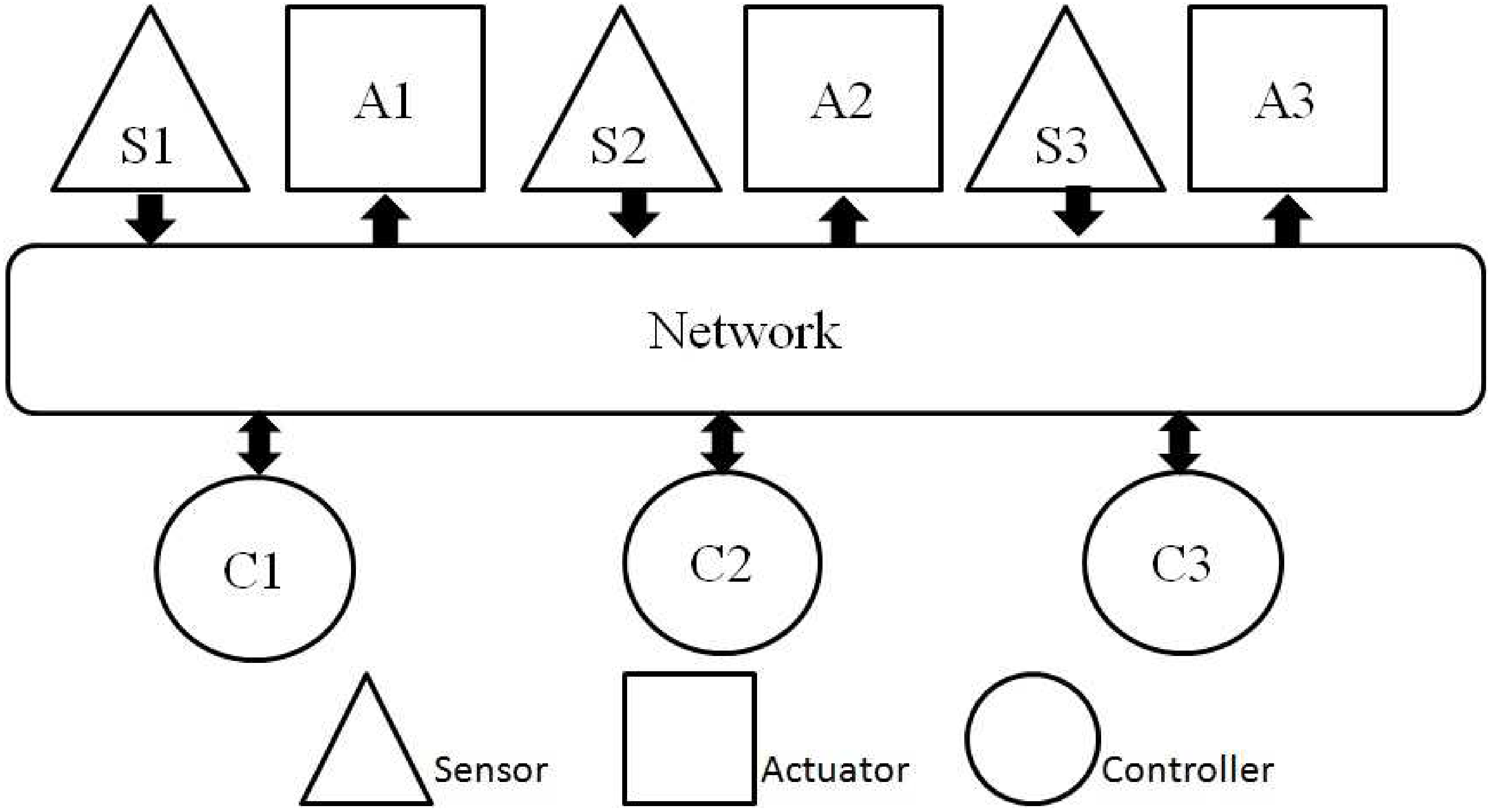
Hierarchical Structure NCS

- Single or multiple network
- Multiple clusters of subsystems consisting of actuators, sensors and controllers
- Concept of Master controller

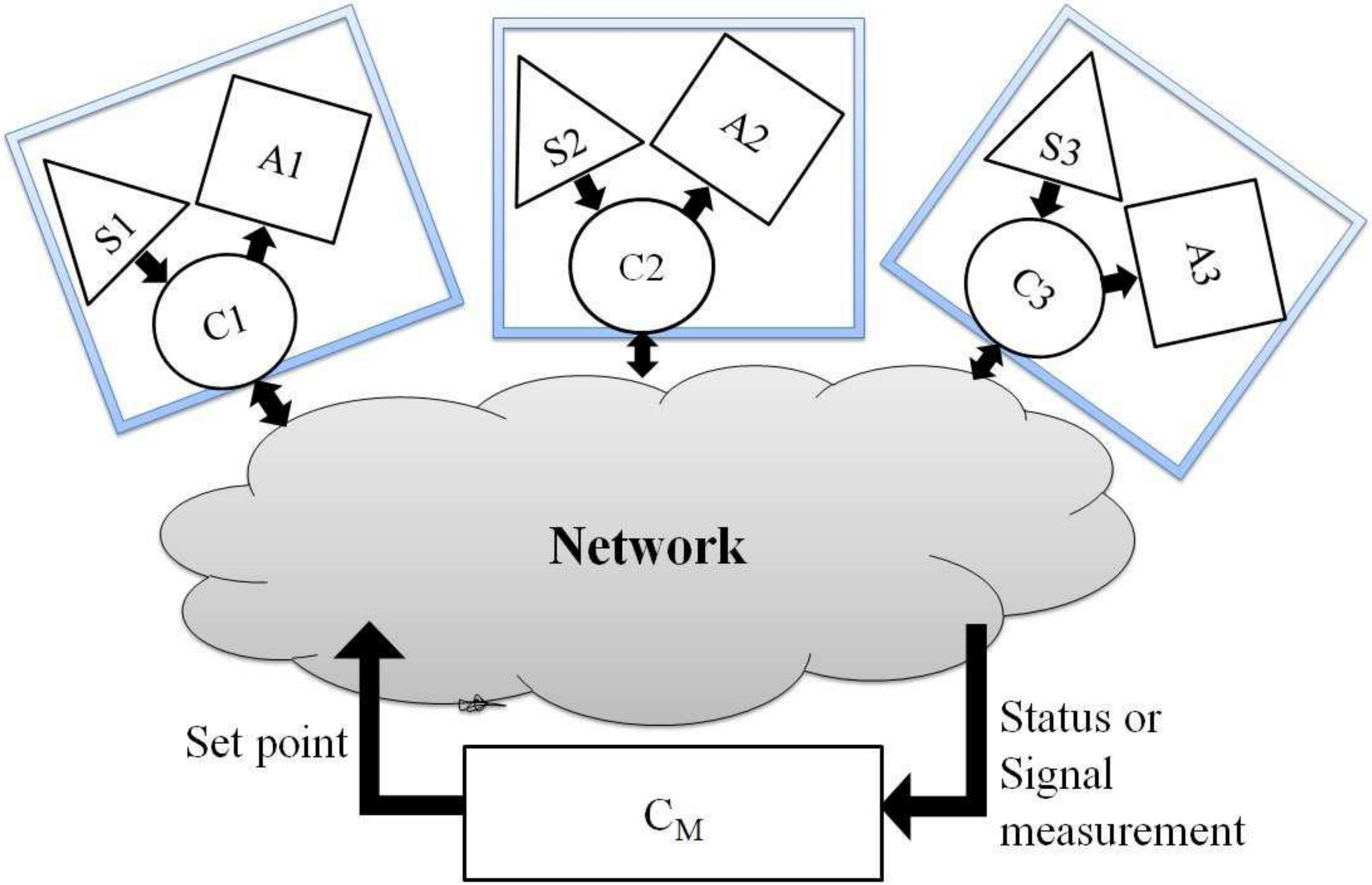
Direct Structure NCS

- Single network
- Single controller connected to sensor and actuator through a network

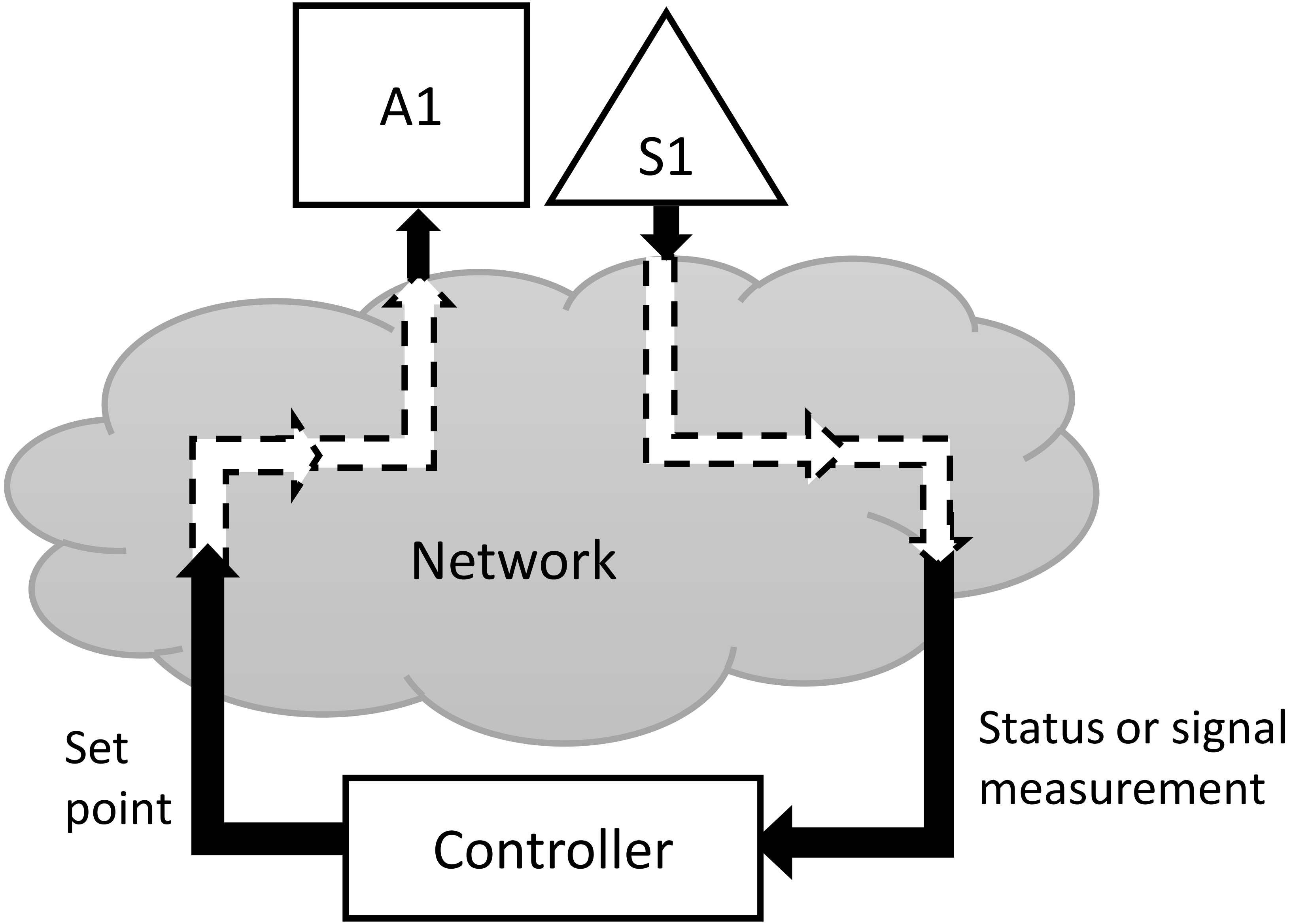
Shared Structure NCS



Hierarchical Structure NCS



Direct Structure NCS



Advantages of NCS

- Effectively reduce the complexity of systems, with nominal economical investments
- Network controllers allow data to be shared efficiently
- It is easy to fuse the global information to take intelligent decisions over a large physical space
- Eliminates unnecessary wiring
- It is easy to add more sensors, actuators and controllers with very little cost and without heavy structural changes to the whole system.

Concerns in NCS

- Networked Delay
- Packet Loss
- Packet Disordering
- Network Utilization
- Security

Objectives

- Design of delay compensators that encompasses the effect of networked delay
- Design of event based sliding surface with networked delay compensation
- Design of event based robust control strategy in the presence of system uncertainties
- Design of event-triggered mechanism that control the flow of data packets in network
- Implementation of proposed protocol on 2-DOF robotic arm

Delays in NCS

SENSOR TO CONTROLLER DELAY

CONTROLLER TO ACTUATOR DELAY

COMPUTATIONAL DELAY

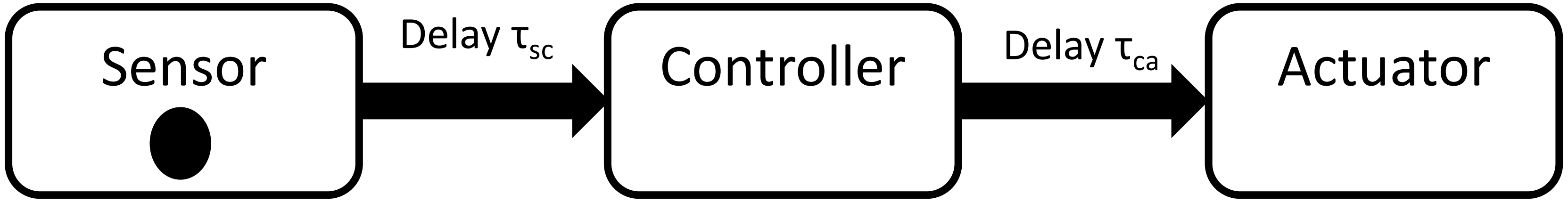
PROCESSING DELAY

Sensor to controller Delay + Controller to actuator Delay = Total network delay

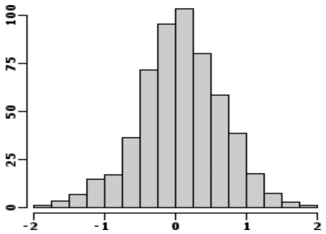
Sensor to controller Delay + Computati-onal Delay + Processing Delay = System delay

Total network delay + System delay = **Total Delay**

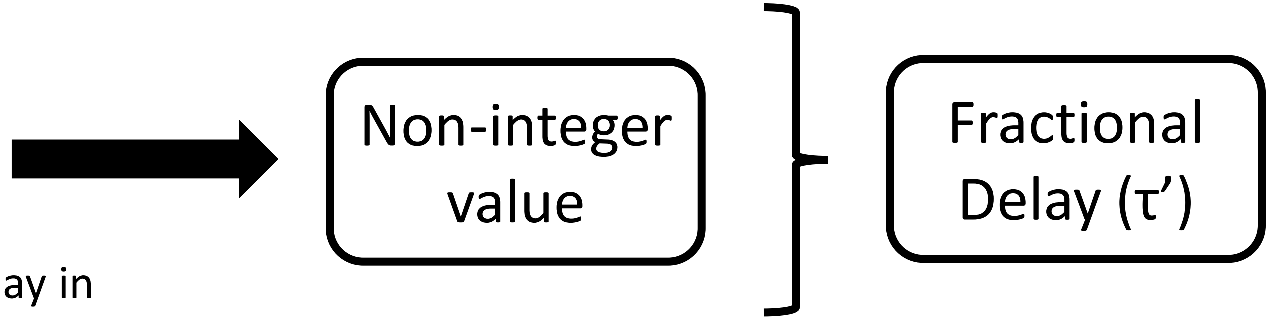
Concept of Fractional Delay



Total Network Delay (τ)



Total Network Delay in discrete domain (τ/h) where h is sampling interval



The nature of both these fractional delay depends on the type of the communication medium.

Recent trends in NCS

Includes the development in the communication protocols and the network topologies that are used for exchanging the information between the source and destination

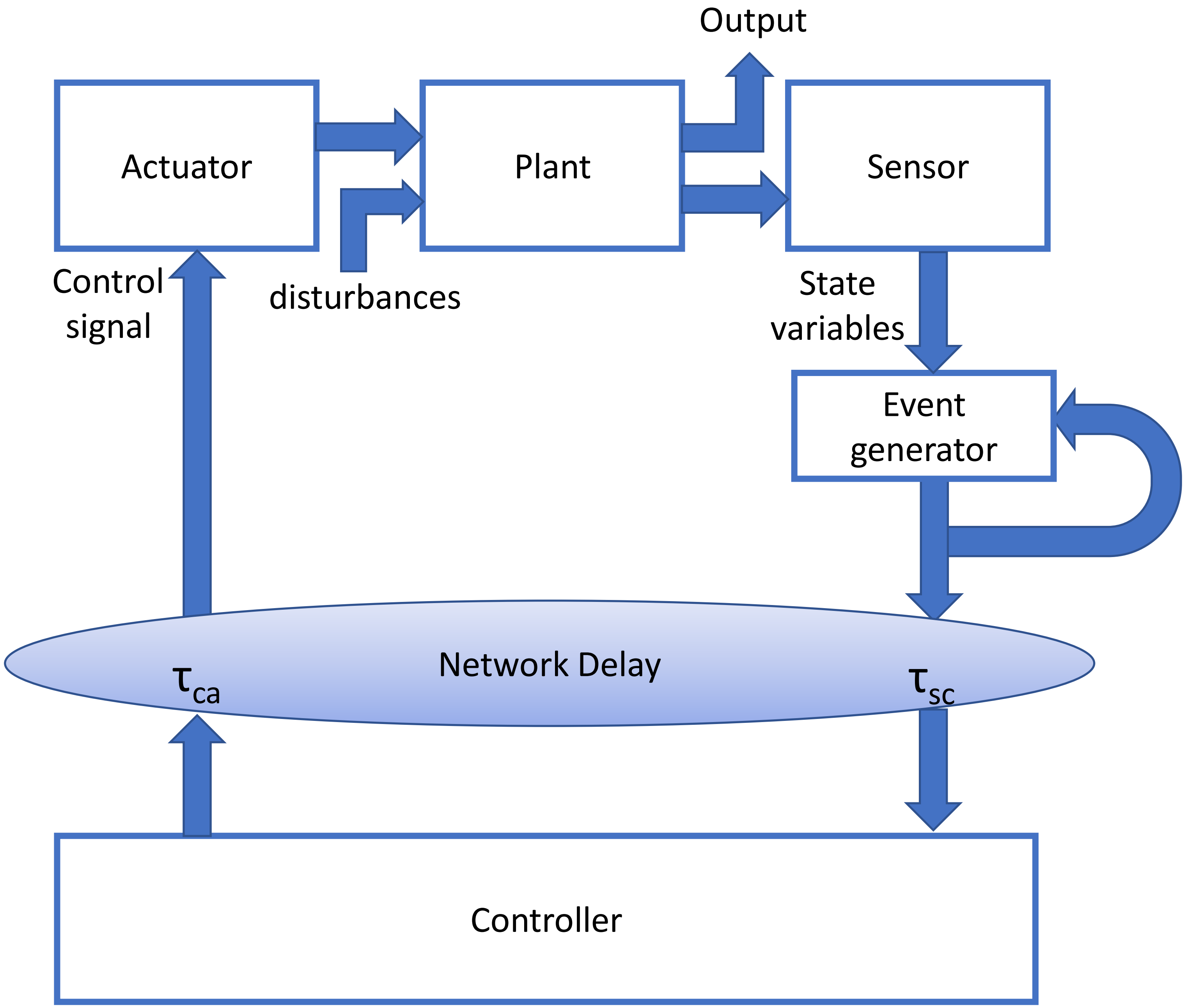
Control of Networks ⇄ **Control over Network**

Development in control strategies in order to overcome the various issues that are existing in the networked control system

Communication process in NCS

Time Driven	The transmission of data packets is always implemented in a periodic manner
Event Driven	The transmission of data packets is always implemented in a aperiodic manner

Event triggered approach in NCS



Basics of Sliding mode control

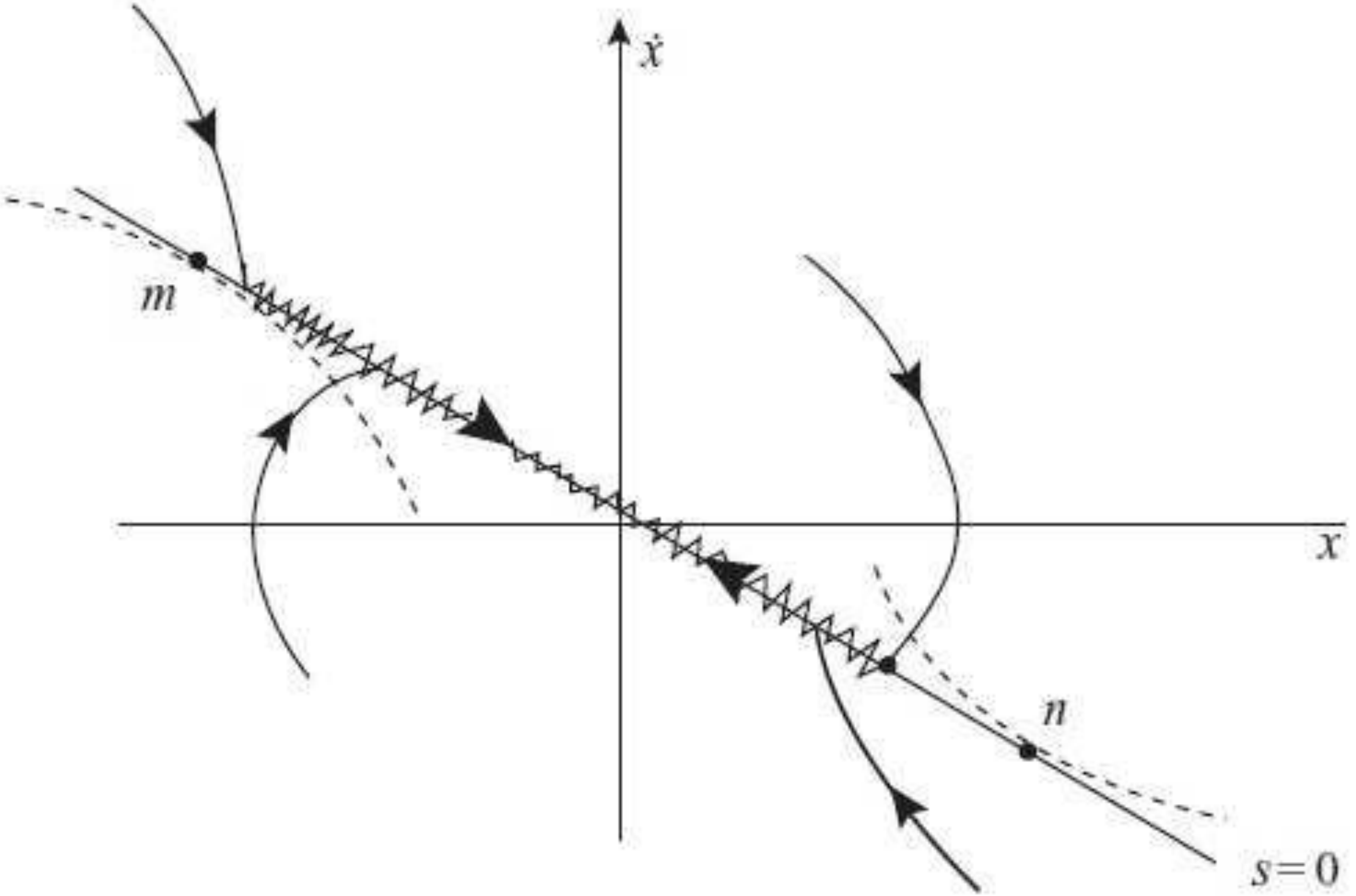
nonlinear control method → Alters the dynamics of system using a discontinuous control signal → This signal forces the system states to slide along the predefined surface called as sliding surface → This represent the controlled system behavior. → Sliding mode control design

- Design of sliding surface and
- Control law that steers the system states to slide along predefined sliding surface over a finite interval of time.

- Conventional example of sliding mode is second order system which is given by,

$$\ddot{x} + a_2\dot{x} + a_1 x = u,$$
$$u = -M_s sign(s),$$
$$s = cx + \dot{x},$$

Basics of Sliding mode control

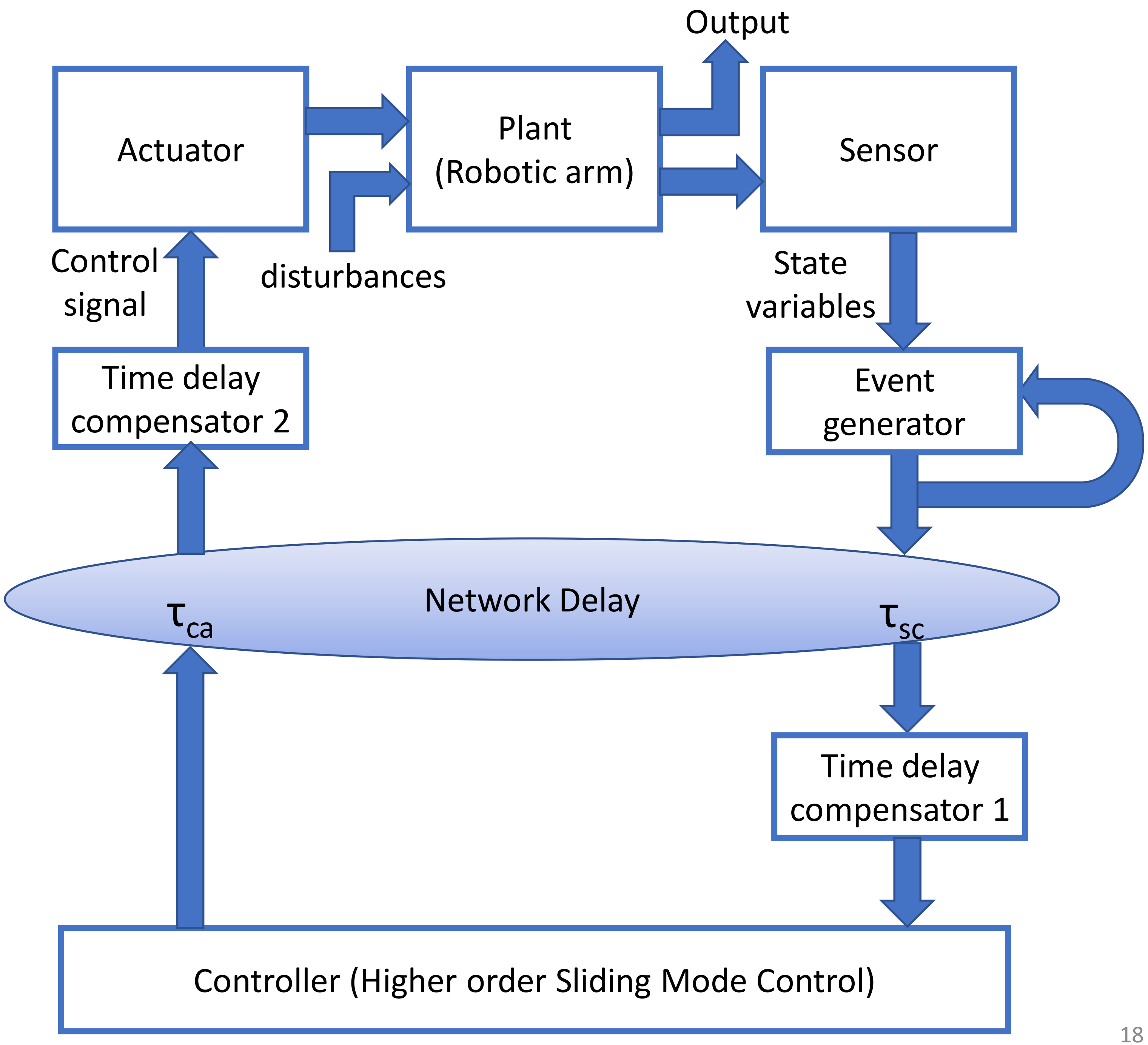


Sliding mode control for second order system

Properties of Sliding mode control

- Lower sensitivity towards plant parameters variations
- Robustness
- The dynamics of the system can be described by a differential equation with lower degree of freedom than the original one
- Relatively easy to apply
- Function of discontinuous state which can be easily implemented using conventional power converters

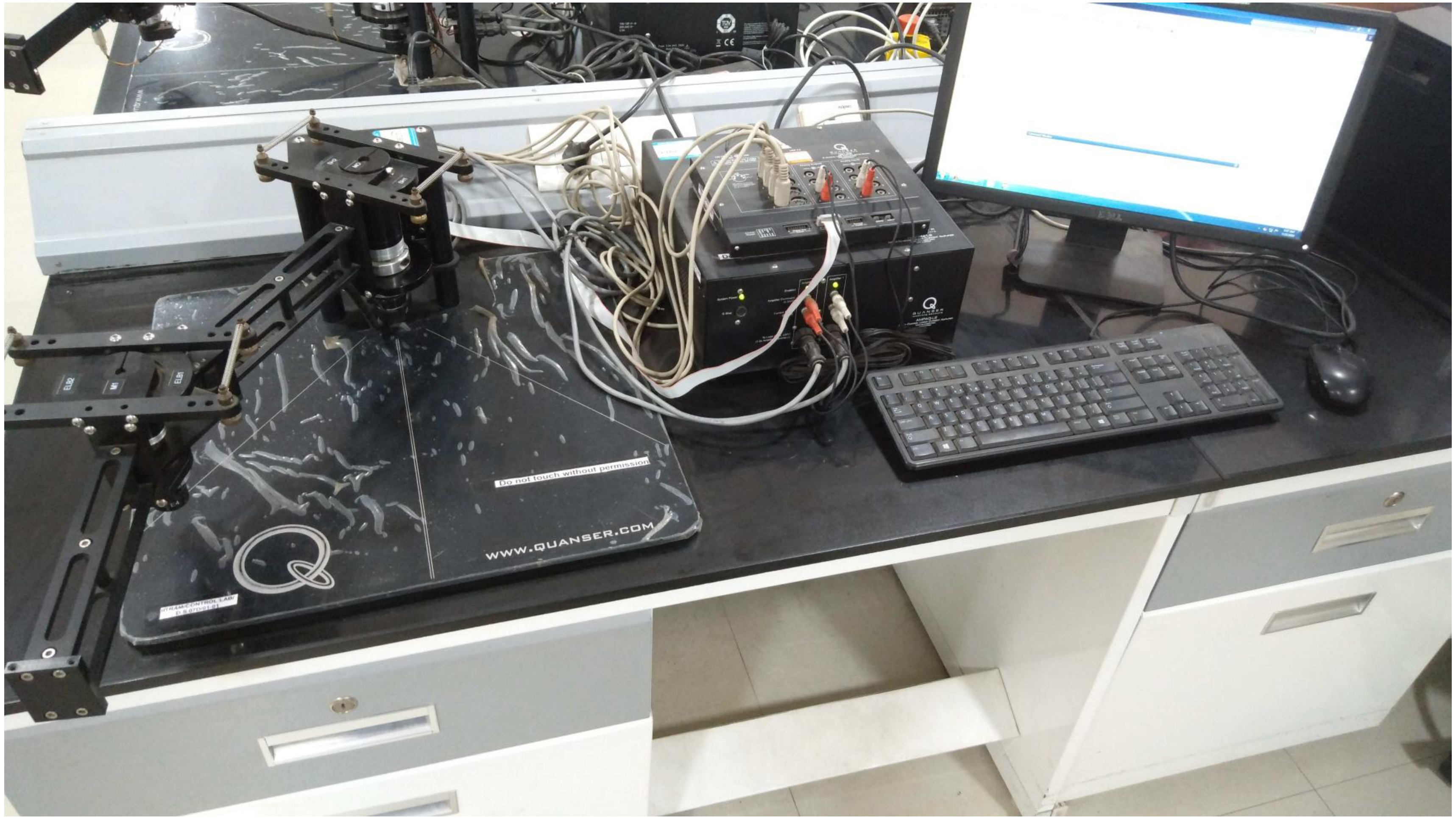
Event triggered approach in NCS



Application 2-DOF Flexible Joint Robotic Arm

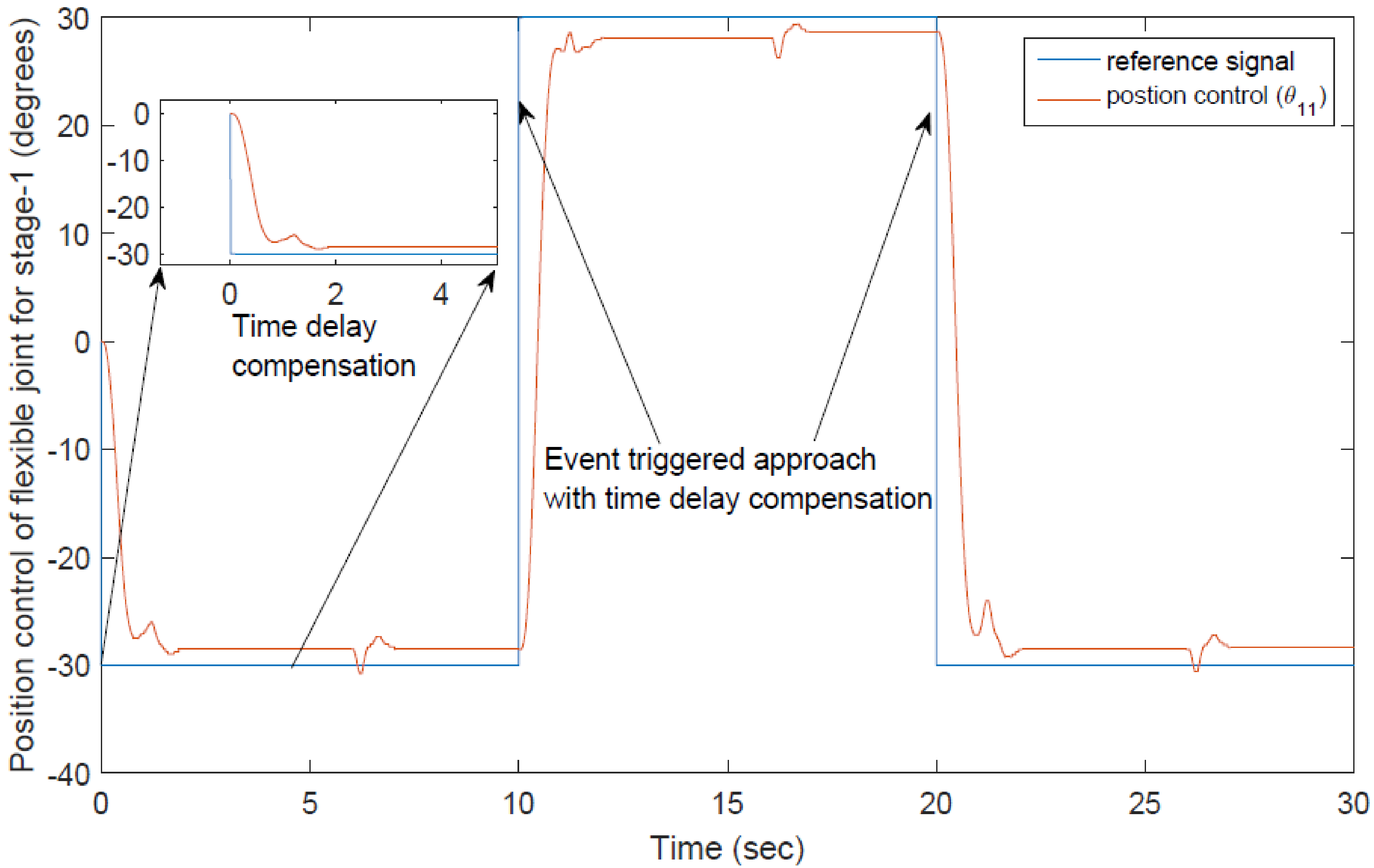
2-DOF Flexible Joint Robot

Experimental setup



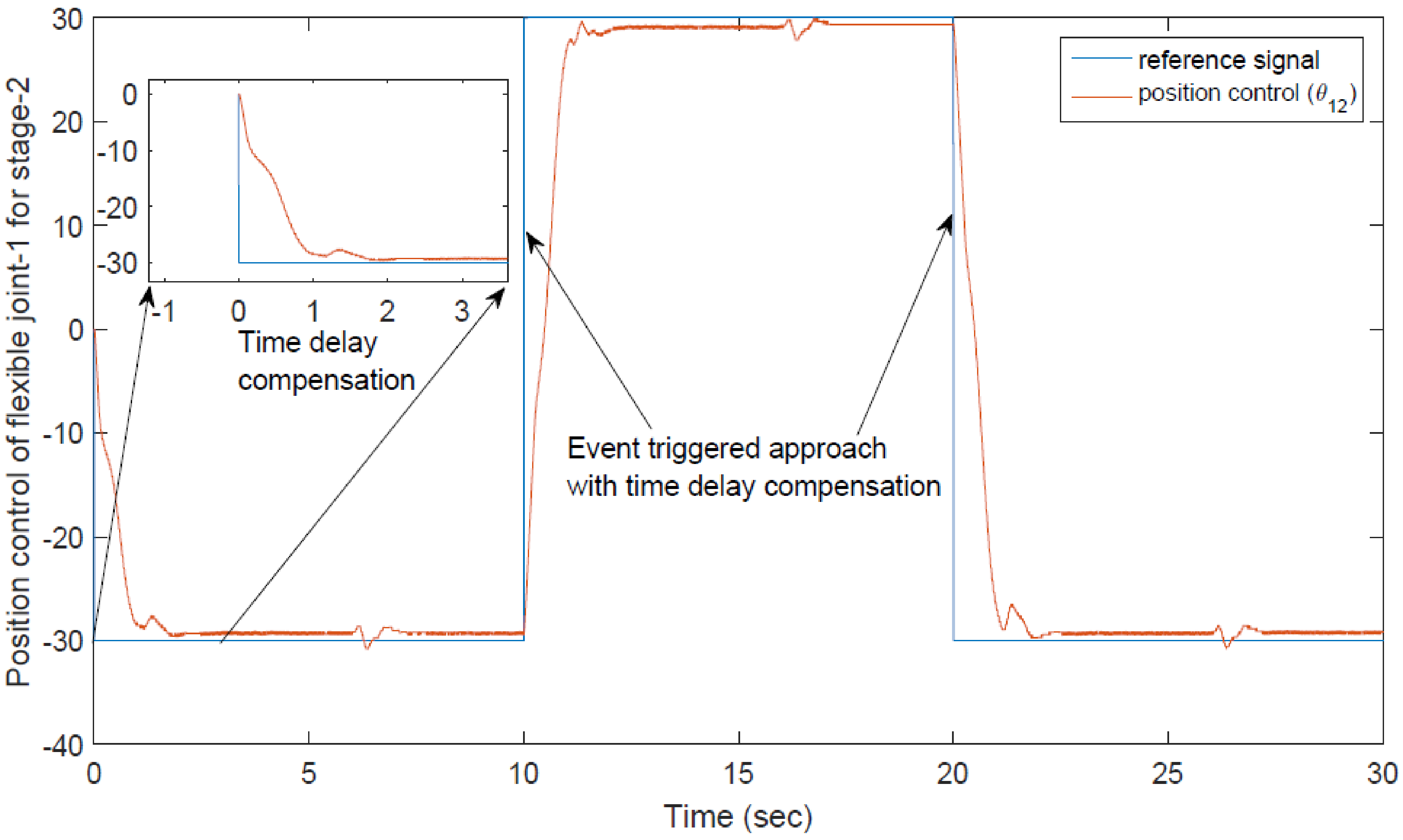
Test-Bed platform of 2-DOF Flexible Joint Robot

Experimental results



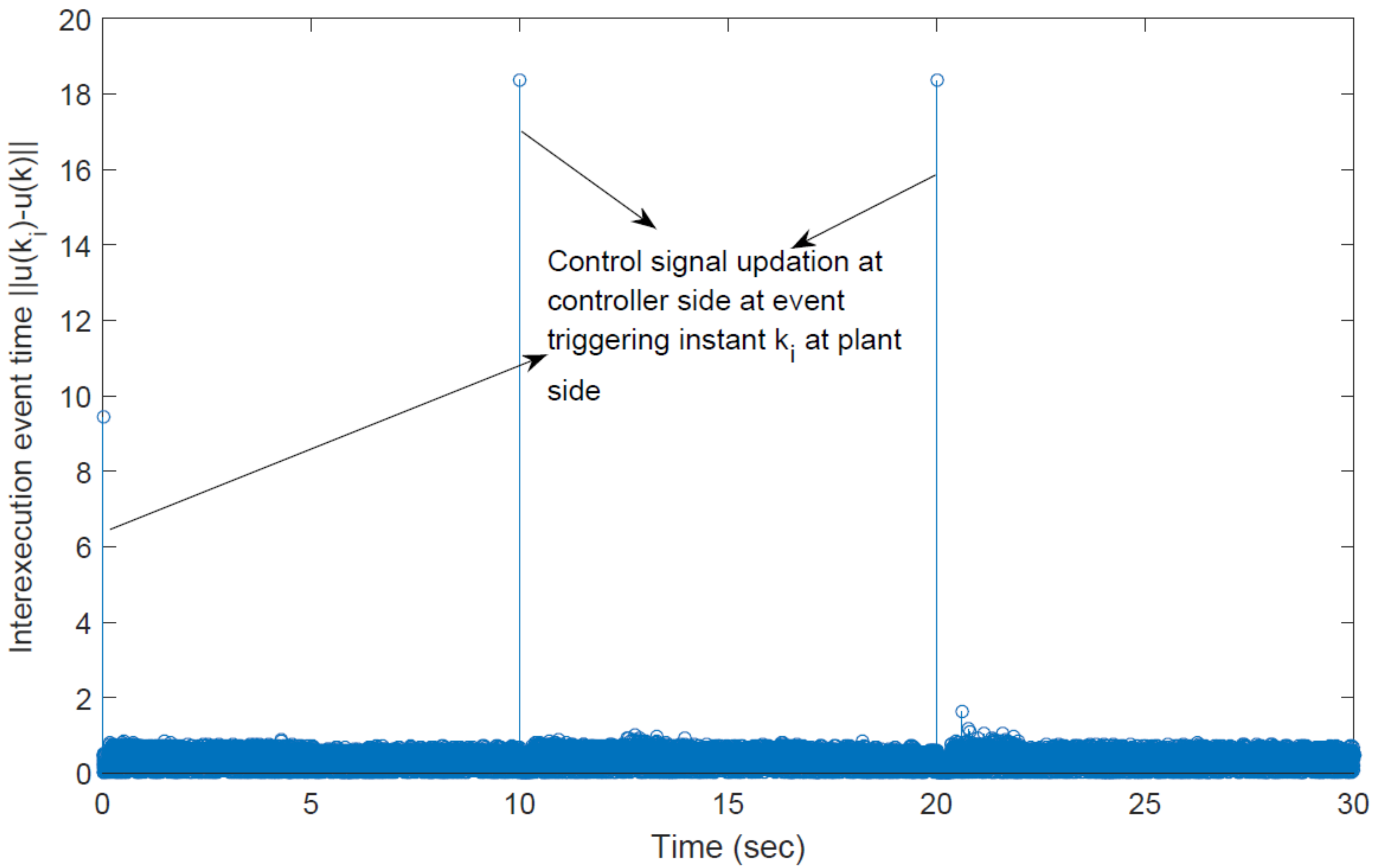
Position control of SFJ for Stage -1

Experimental results



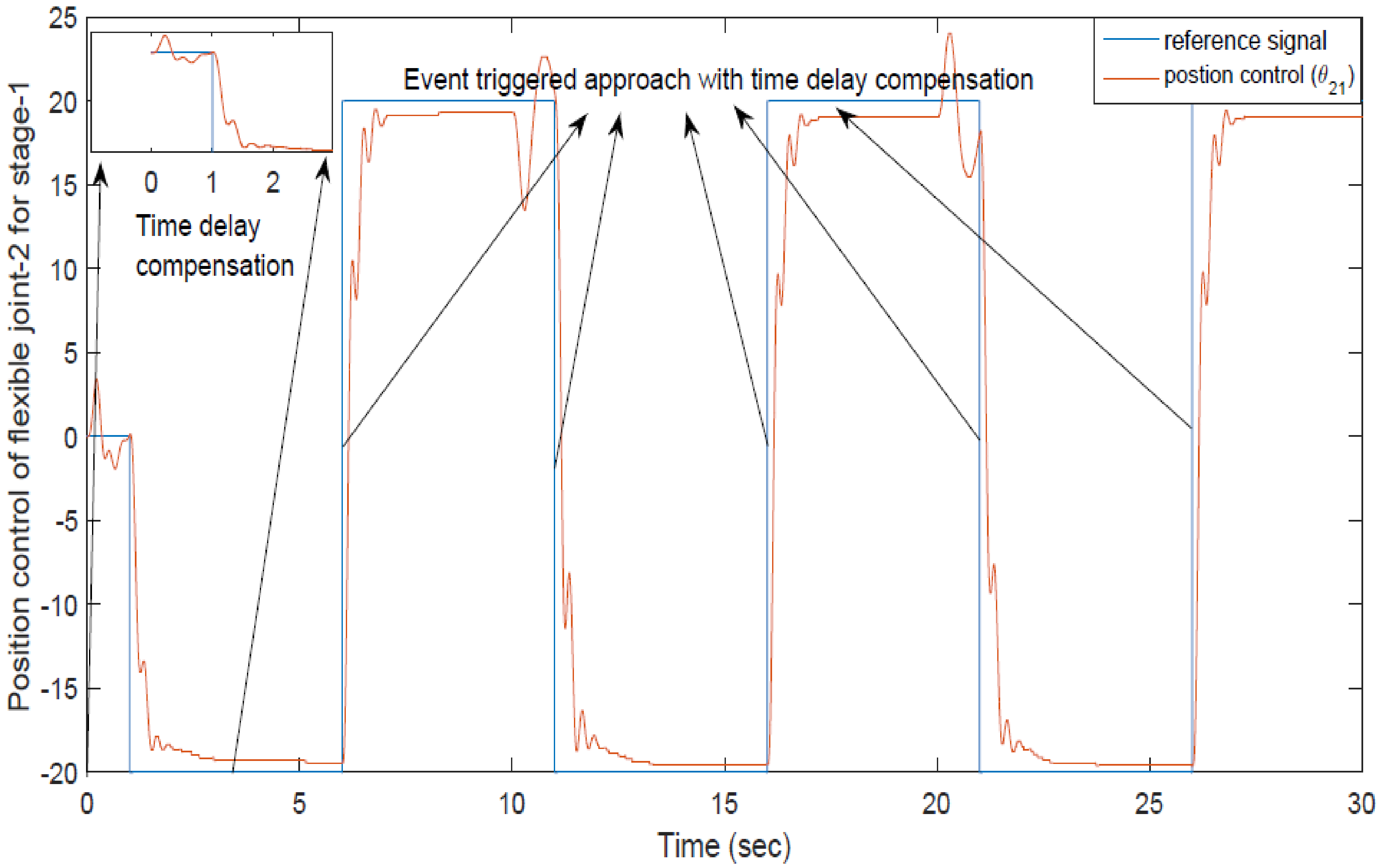
Position control of SFJ for Stage -2

Experimental results



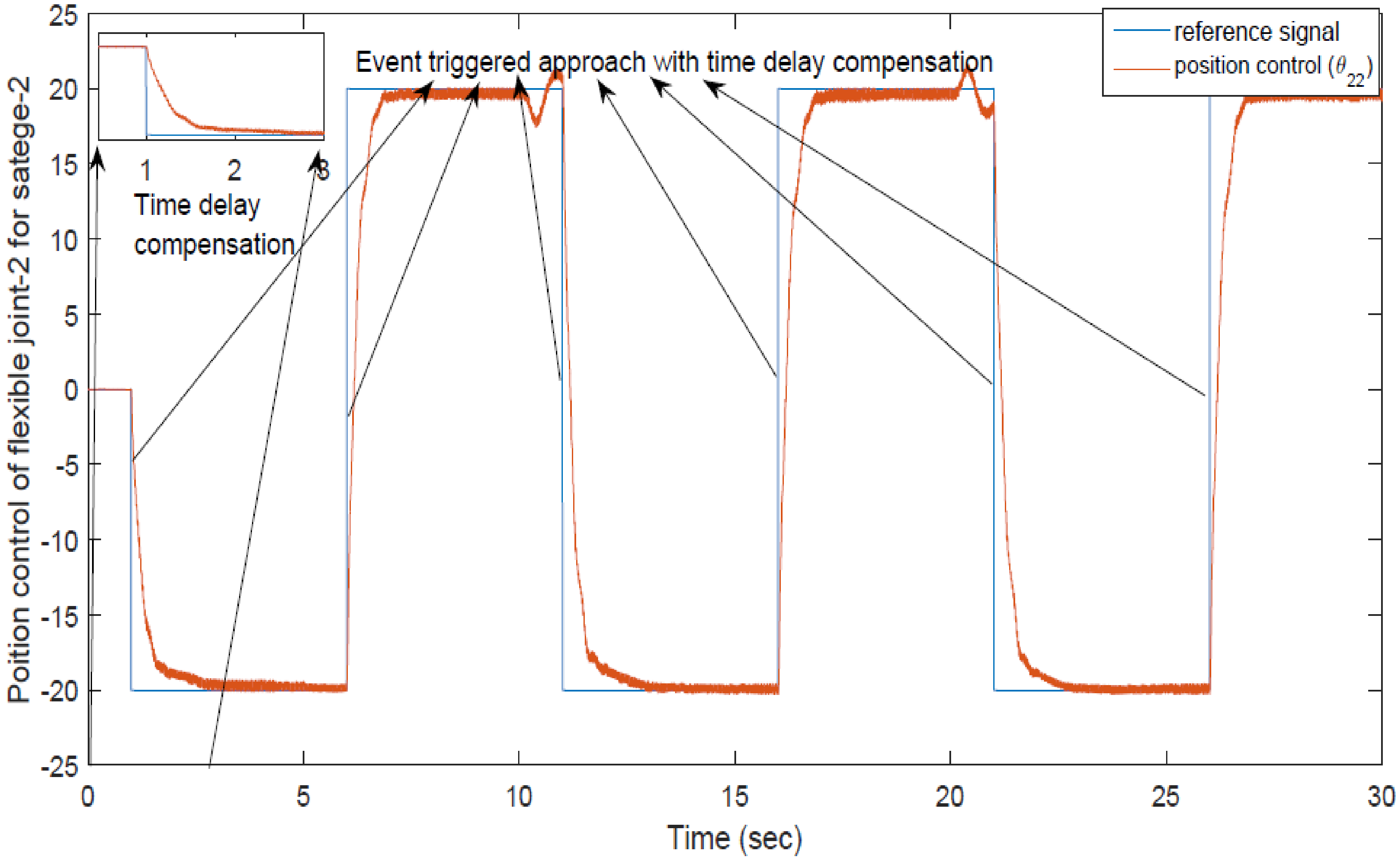
Inter-execution event time of SFJ

Experimental results



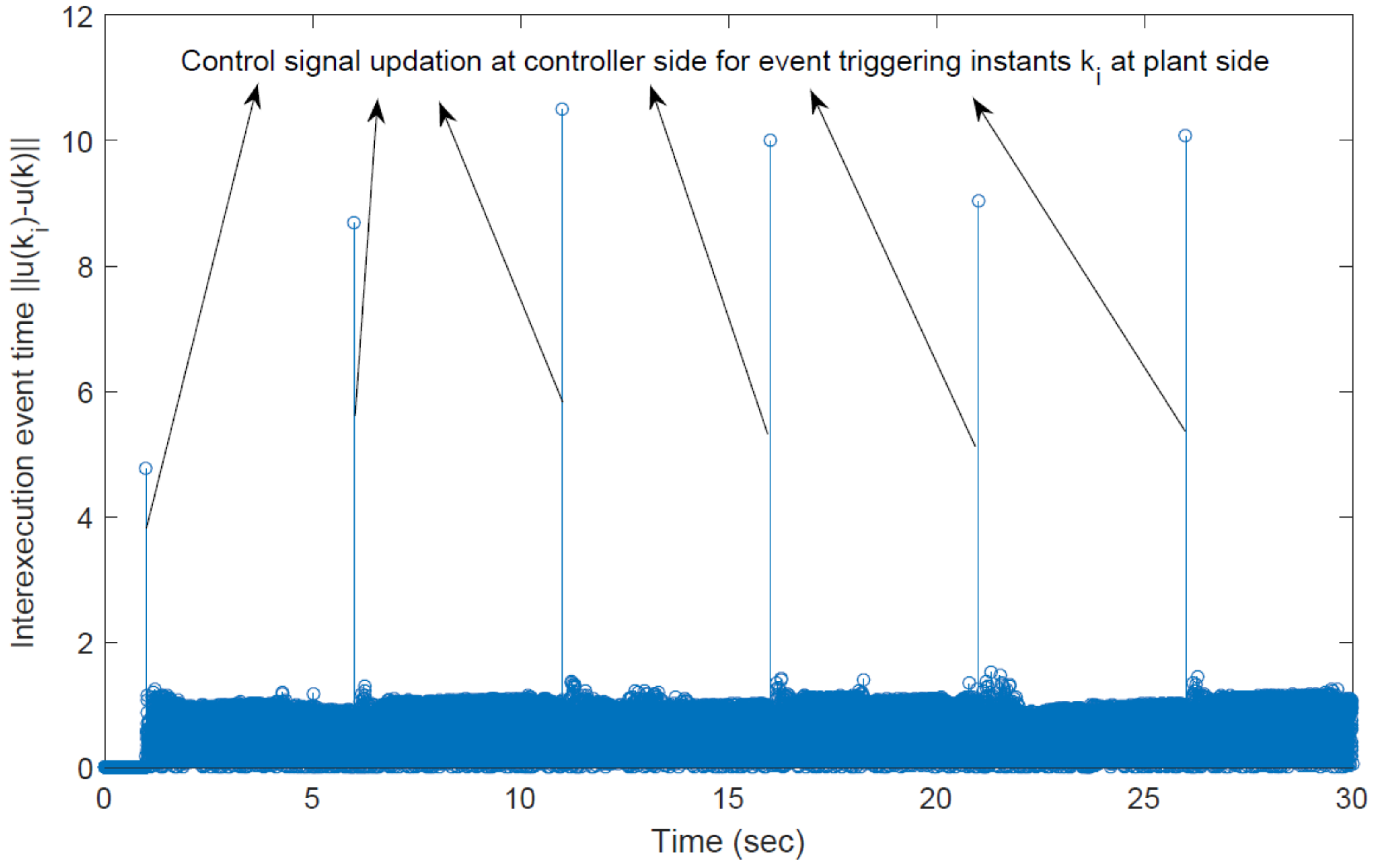
Position control of SFJ for Stage -1

Experimental results



Position control of SFJ for Stage -2

Experimental results



Inter-execution event time of SFJ

Research areas in NCS

- Network Security
- Topology structure
- Packets dropouts
- Sensor or actuator failure
- Scheduling Protocol

Applications in NCS

- Industry 4.0
- Medical sectors such as haptic surgery
- Robotic applications
- Aircraft Industries
- Automobile sector
- Tele-operation
- Military sectors

Insights of my research

- **Dipesh Shah**, Axaykumar Mehta, Keyurkumar Patel and Andrzej Bartoszewicz. "Event-Triggered Discrete Higher-Order SMC for Networked Control System having Network Irregularities", IEEE Transactions on Industrial Informatics. doi no.: 10.1109/TII.2020.2973739, March 2020

- **Dipesh Shah** and A J Mehta**.** "Discrete-Time Sliding Mode Control for Network Control System" published in the book series "Systems, Control and Decision", Springer, March 2018

- **Dipesh Shah** and D M Patel. "Design of Sliding Mode Control for Quadruple-Tank MIMO Process with Time Delay Compensation", Journal of Process Control, Elsevier, Vol. 76, pp. 46-61, 2019

- **Dipesh Shah** and A J Mehta. "Discrete- Time Sliding Mode Controller Subject to Real-Time Fractional Delays and Packet Losses for Networked Control System". International Journal of Control, Automation and Systems (IJCAS), Springer Vol. 15, No. 6, pp. 2690-2703, 2017

- **Dipesh Shah** and A J Mehta. "Fractional Delay Compensation Using Discrete-Time SMC for Networked Control System". Digital Communication Networks, Elsevier, Vol. 3, No. 2, pp. 385-392, 2017

Research Collaborators

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Thank You...
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