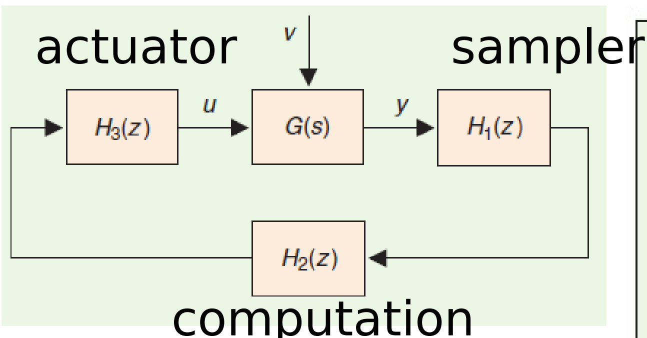
How Does Control Timing Affect Performance?
Analysis and Simulation of Timing Using Jitterbug and TrueTime

Jitterbug

- Jitterbug
  - A MATLAB-based toolbox that computes a quadratic performance criterion for a linear control system under various timing conditions
  - Using the toolbox, one can easily and quickly assert how sensitive a control system is to delay, jitter, lost samples, etc., without resorting to simulation.

Example of a cost function computed using Jitterbug



$$J = \lim_{T \to \infty} \frac{1}{T} \int_0^T \left(y^2(t) + u^2(t) \right) dt.$$

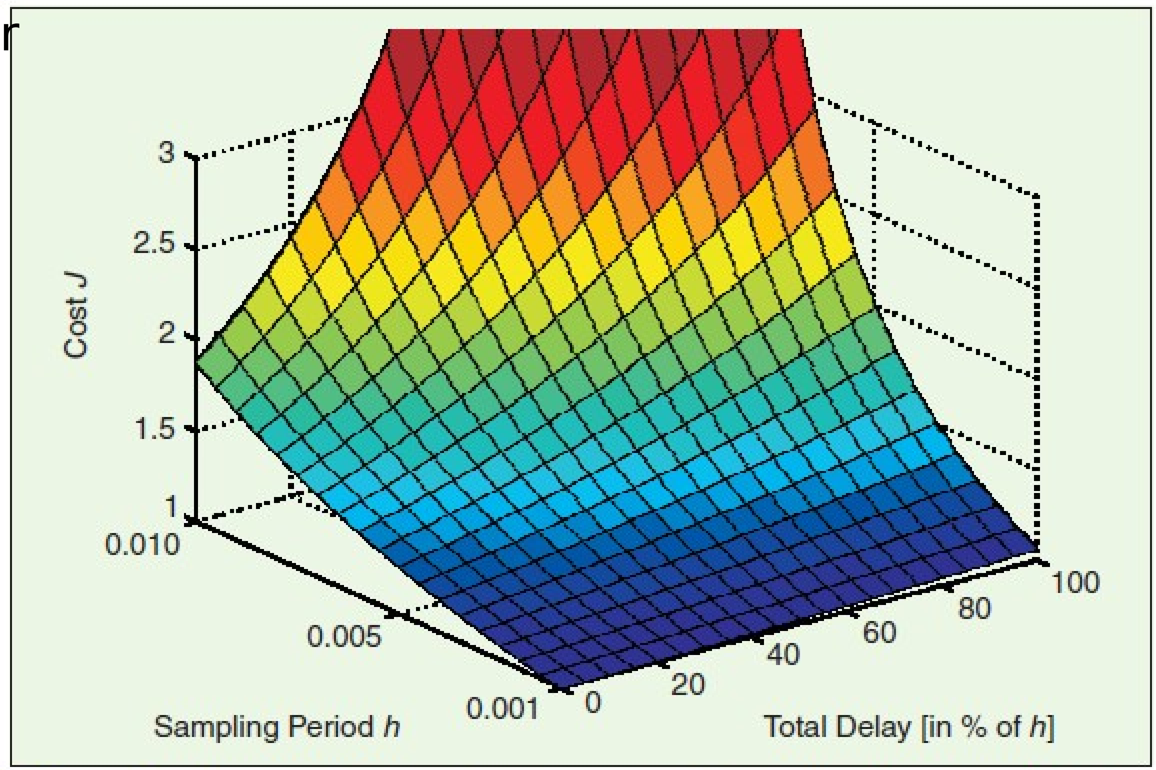


Figure 4. *Example of a cost function computed using Jitterbug. The plot shows the cost as a function of sampling period and delay in the networked control system example.*

- Analysis using Jitterbug can be used to quickly determine how sensitive a control system is to slow sampling, delay, jitter, and so on.
- For more detailed analysis as well as system wide real-time design, the more general simulation tool TrueTime can be used.

TrueTime

- TrueTime
  - facilitates simulation of the temporal behavior of a multitasking real-time kernel executing controller tasks
  - TrueTime makes it possible to study more general and detailed timing models of computer-controlled systems
  - not restricted to the evaluation of a quadratic performance criterion but can be used to evaluate any time-domain behavior of the control loop

TrueTime blocks

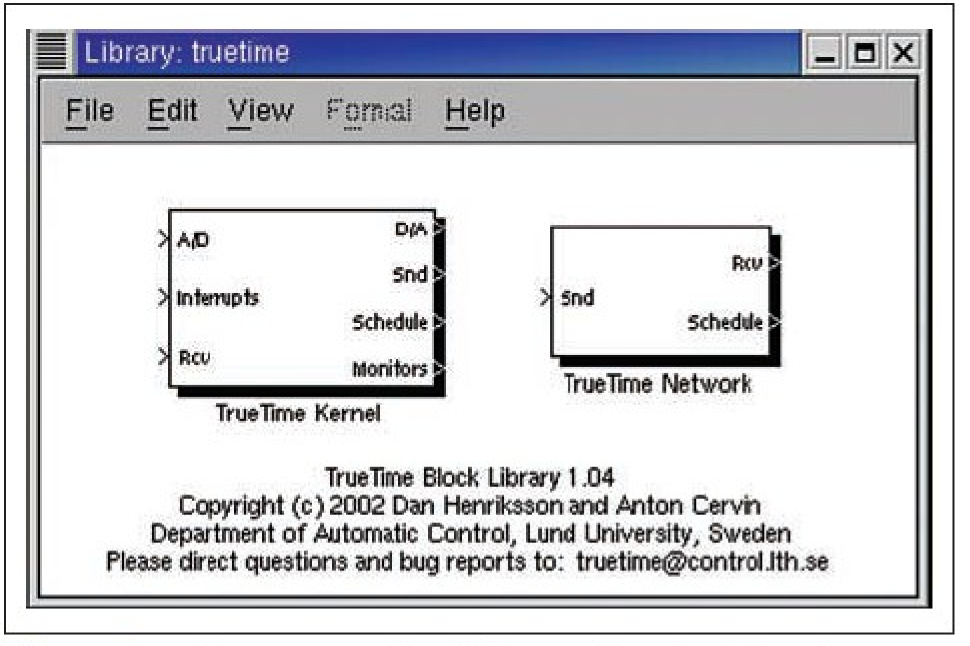
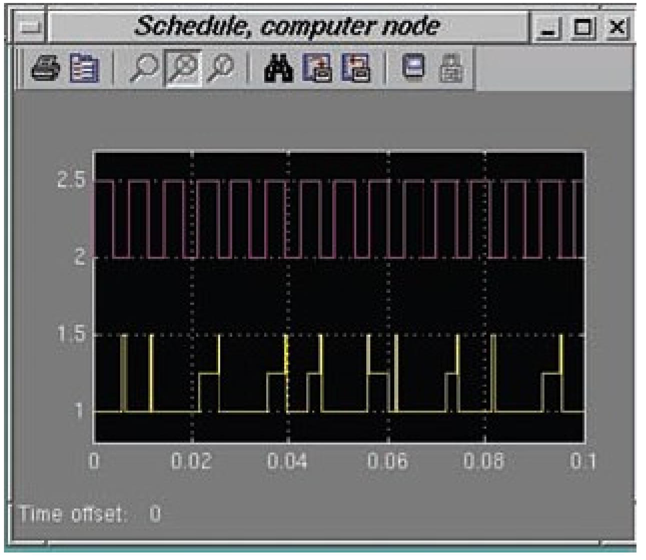


Figure 8. *The TrueTime block library. The Schedule and Monitor outputs display the allocation of common resources (CPU, monitors, network) during the simulation.*

- If context switching is simulated, the graph will also display the execution of the kernel.
  - If the signal is high, it means that the task is running.
  - A medium signal indicates that the task is ready but not running (preempted), whereas a
  - low signal means that the task is idle.



Example 1

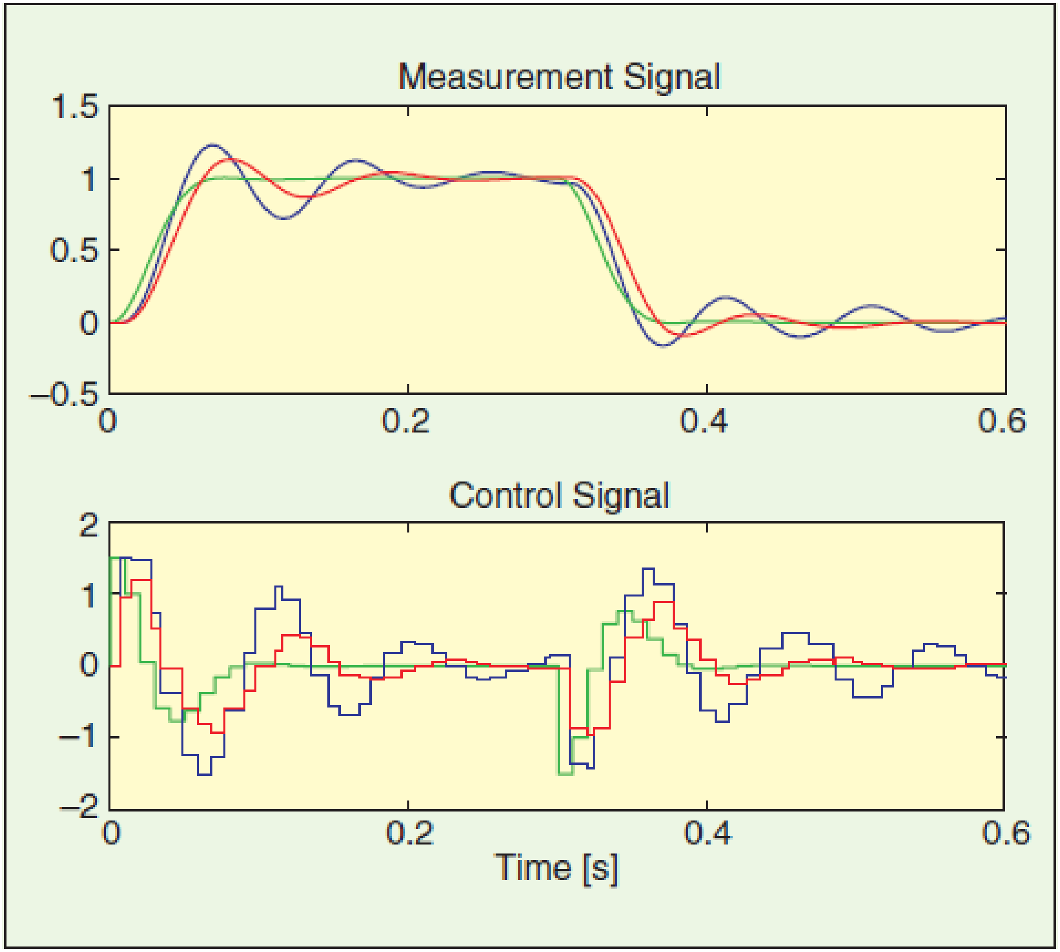


Figure 15. *Control performance for the networked control system in the ideal case (green), with interfering network messages and an interfering task in the controller node without compensation (blue) and with delay compensation (red).*

Example 2

- ***Feedback Scheduling***

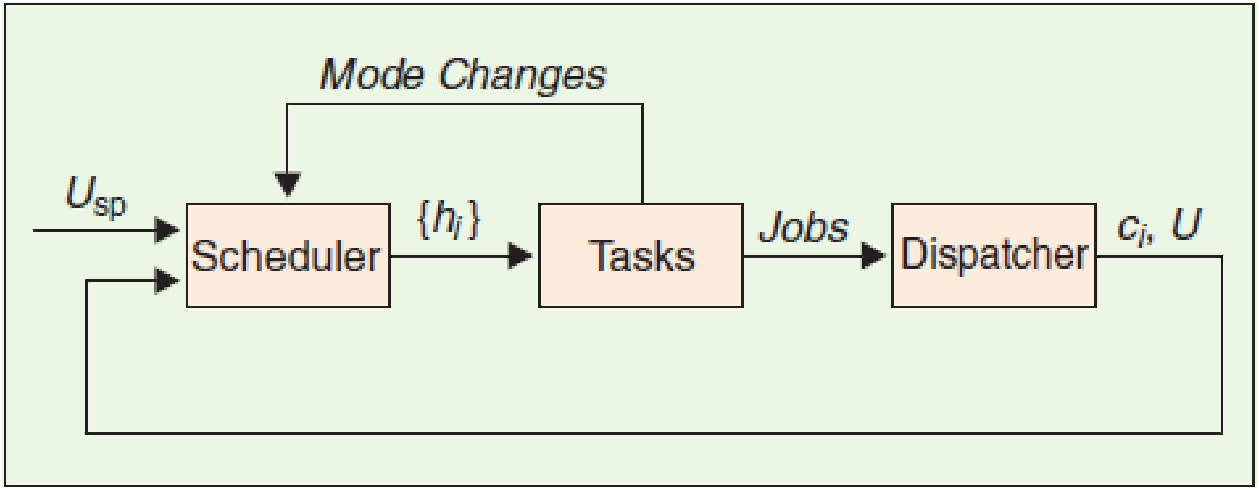


Figure 17. *The feedback scheduling structure.*

Conclusion

- Choices made in the real-time design will affect the control design and vice versa.
- 1. network protocol -> delay pattern
- 2. bandwidth requirements in the control loops -> the choice of CPU and network speed

Conclusion

- Jitterbug allows the user to compute a quadratic performance criterion for a linear control system under various timing conditions.
- TrueTime facilitates event-based cosimulation of a multitasking real-time kernel containing controller tasks and the continuous dynamics of controlled plants

Joint Design of Control and Communication in Wireless Networked Control Systems: A Case Study

A. Chamaken, L. Litz, member IEEE

3 approaches to joint design

- 1. comm. System selected (QoS)-> improve control sys.
- 2. controller selected (QoC)-> design comm. Sys.
- 3. joint design

Framework

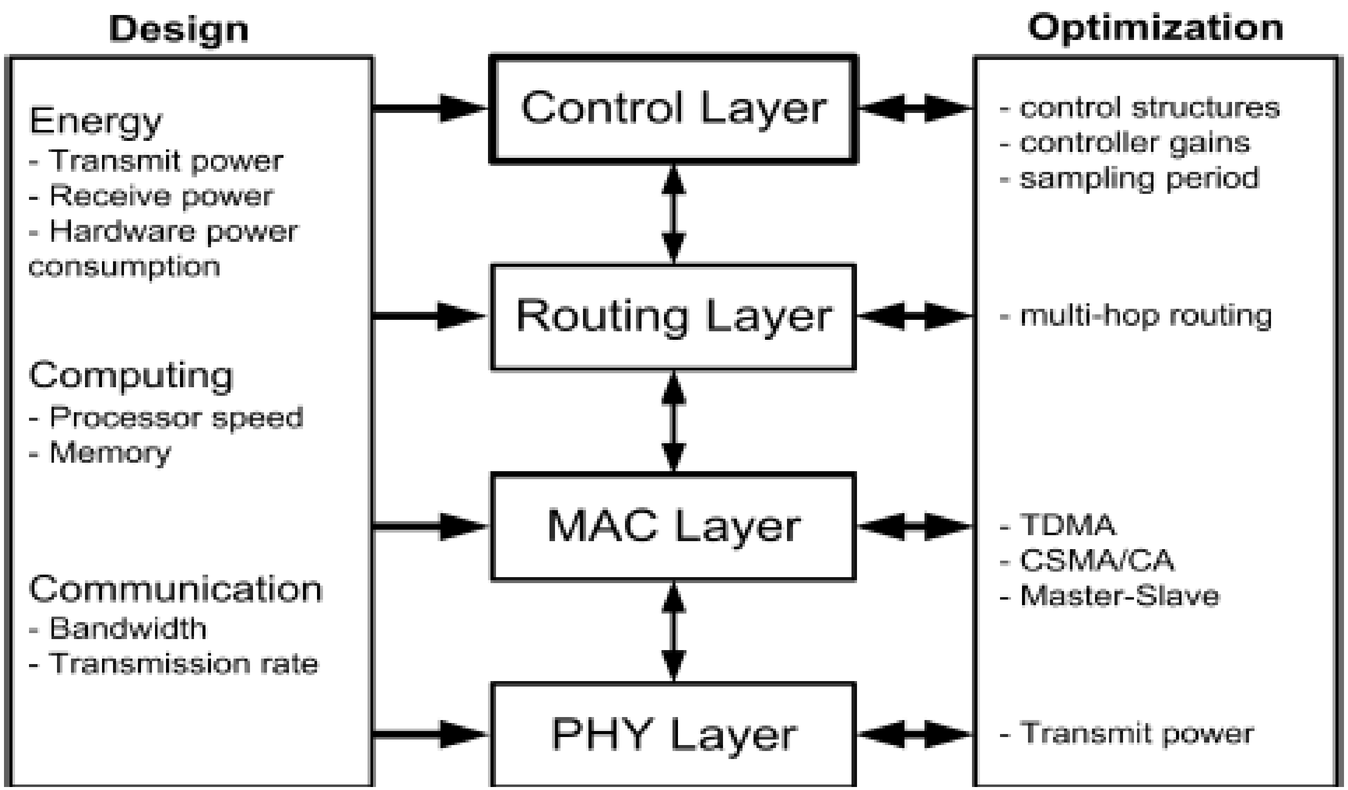


Fig. 2. Framework for the joint design of control and communication

INVERTED PENDULUM BENCHMARK

- Control Structures
  - Cascaded controller
  - State Feedback controller
- Communication Structure (3 different MAC protocols are implemented at the Data Link layer)
  - TDMA
  - CSMA/CA
  - Master-Slave (MS) poling protocol

Simulation Setup

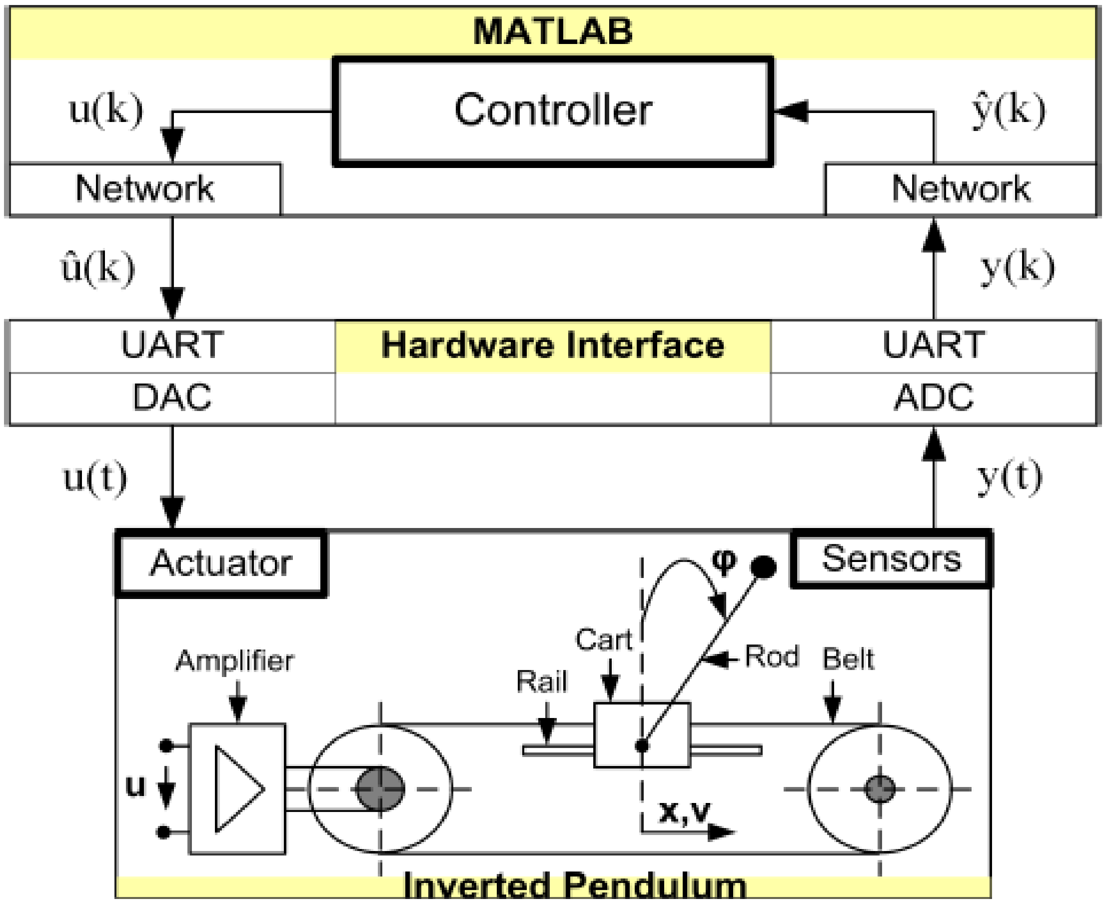


Fig. 3. HiL inverted pendulum network simulator

WNCS Network Configuration

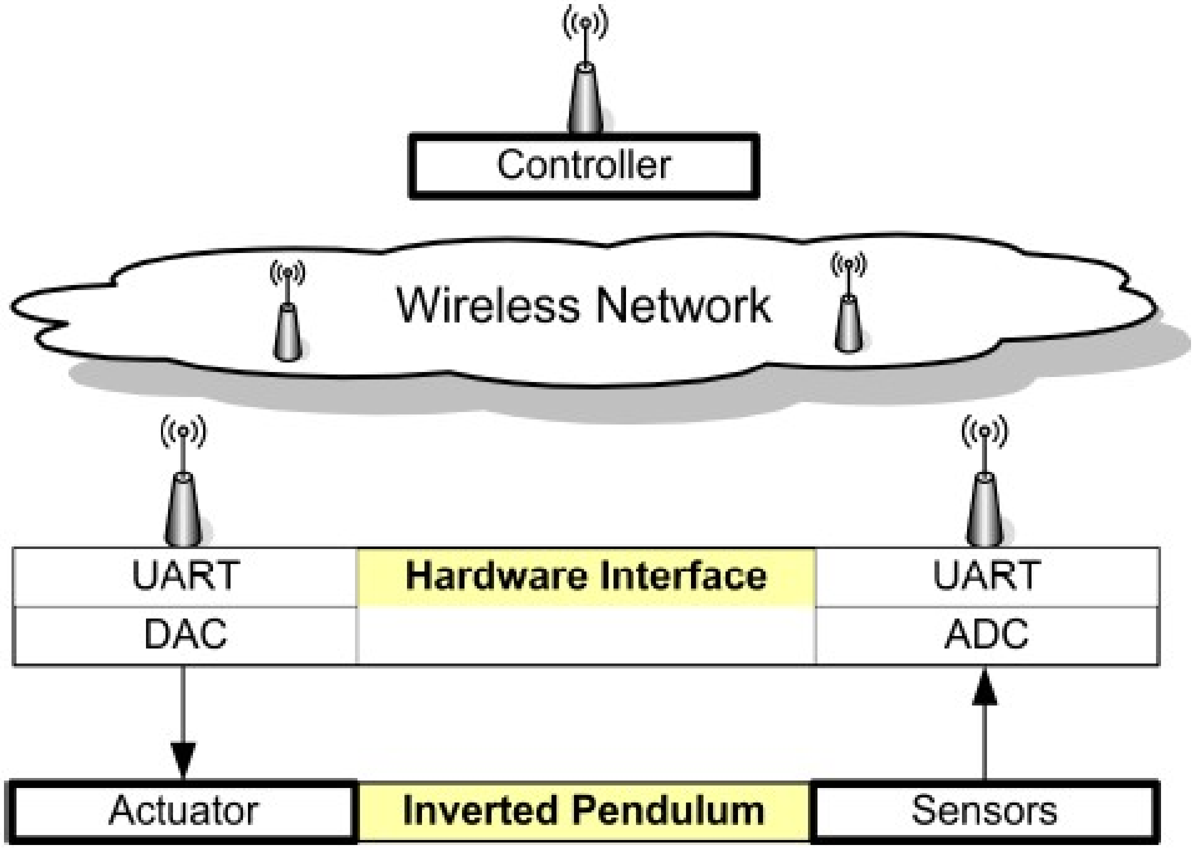
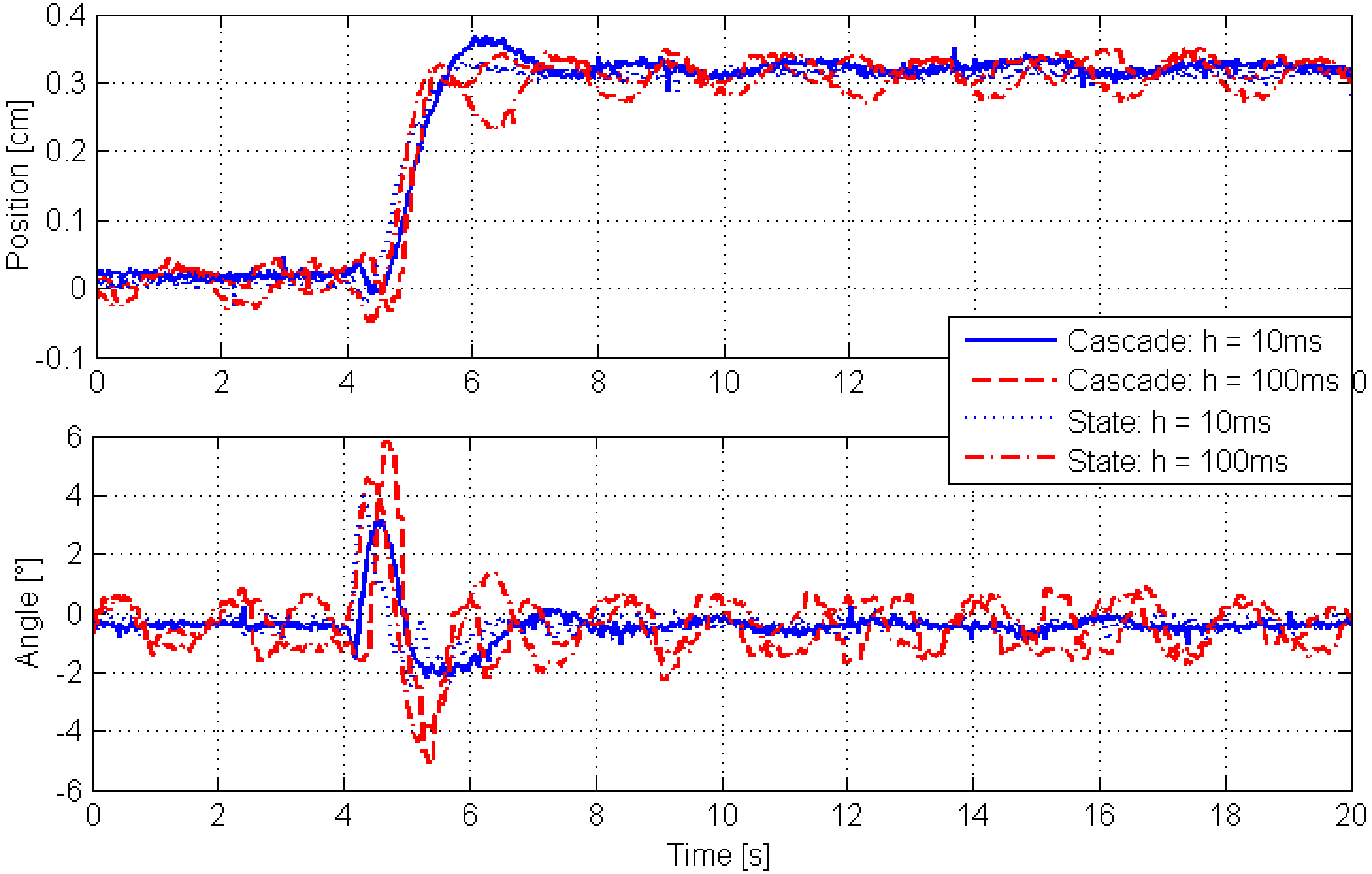
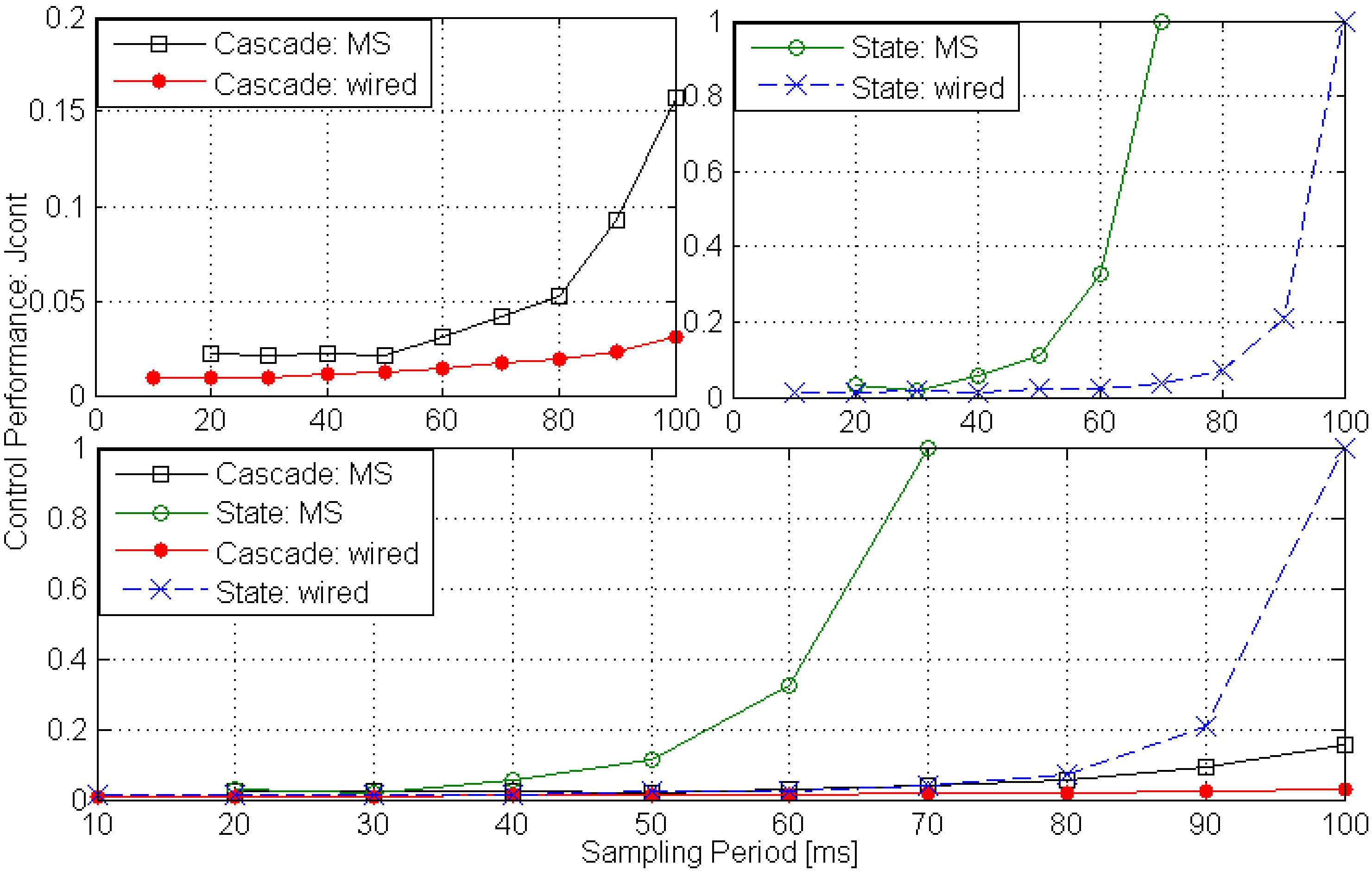


Fig. 4. Experimental setup and network configuration

Result –step response for wired case



Result 2



Control performance evaluation for the wired case and wireless case (TDMA) with the cascaded and the state feedback controller

Result 3

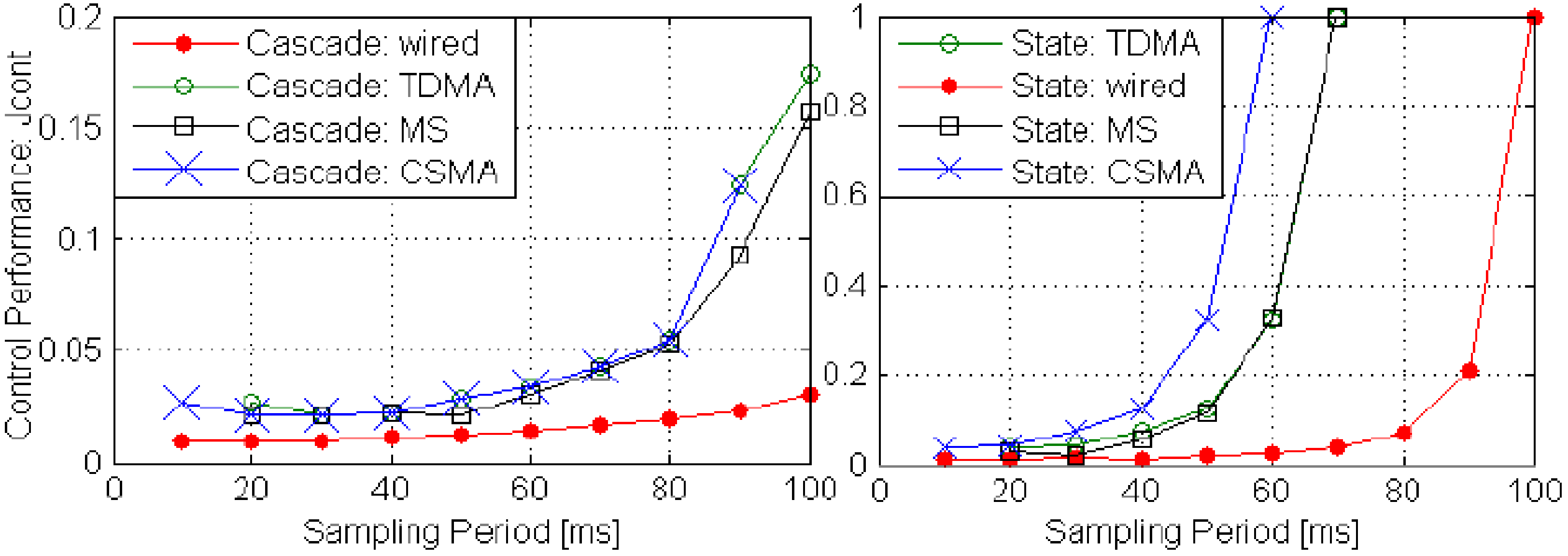


Fig. 7. Control performance evaluation for the wired case and wireless case (TDMA, CSMA, MS) with the cascaded and the state feedback controller

H: sampling time.

Tao: delay.

Ro: The maximum packet dropout rate at which stability is still guaranteed, measured at the maximum sampling period with maximum transmission delay.

Parameters	State	Cascade
HiL Simulation: Wired		
h_{min}[ms]	2	4
h_{max}[ms]	120	100
τ^{n}_{max}[ms]	118	94
ρ^{n}_{max}[%]	20	10
Experiement: TDMA		
τ^{n}[ms]	10	10
ρ^{n}[%]	<2	<2
Experiement: CSMA		
τ^{n}_{min}[ms]	8	8
τ^{n}_{max}[ms]	20	20
ρ^{n}[%]	<5	<5
Experiement: MS		
τ^{n}[ms]	20	20
ρ^{n}[%]	<1	<1

TABLE I

MEASURED SAMPLING PERIOD BOUNDS (WIRED CASE), AVERAGE TRANSMISSION DELAY AND PACKET DROPOUT RATES (WIRELESS CASE)

CONCLUSION

- implemented two control structures
- showed how optimal controller parameters can be obtained using a HiL simulator based on real process data.
- Three different MAC protocols were implemented and used in conjunction with the two control structures to stabilize the inverted pendulum.

Design the Remote Control System With the Time-Delay Estimator and the Adaptive Smith Predictor

Chien-Liang Lai and Pau-Lo Hsu, *Member, IEEE*

NCS AND TIME-DELAY MEASUREMENT

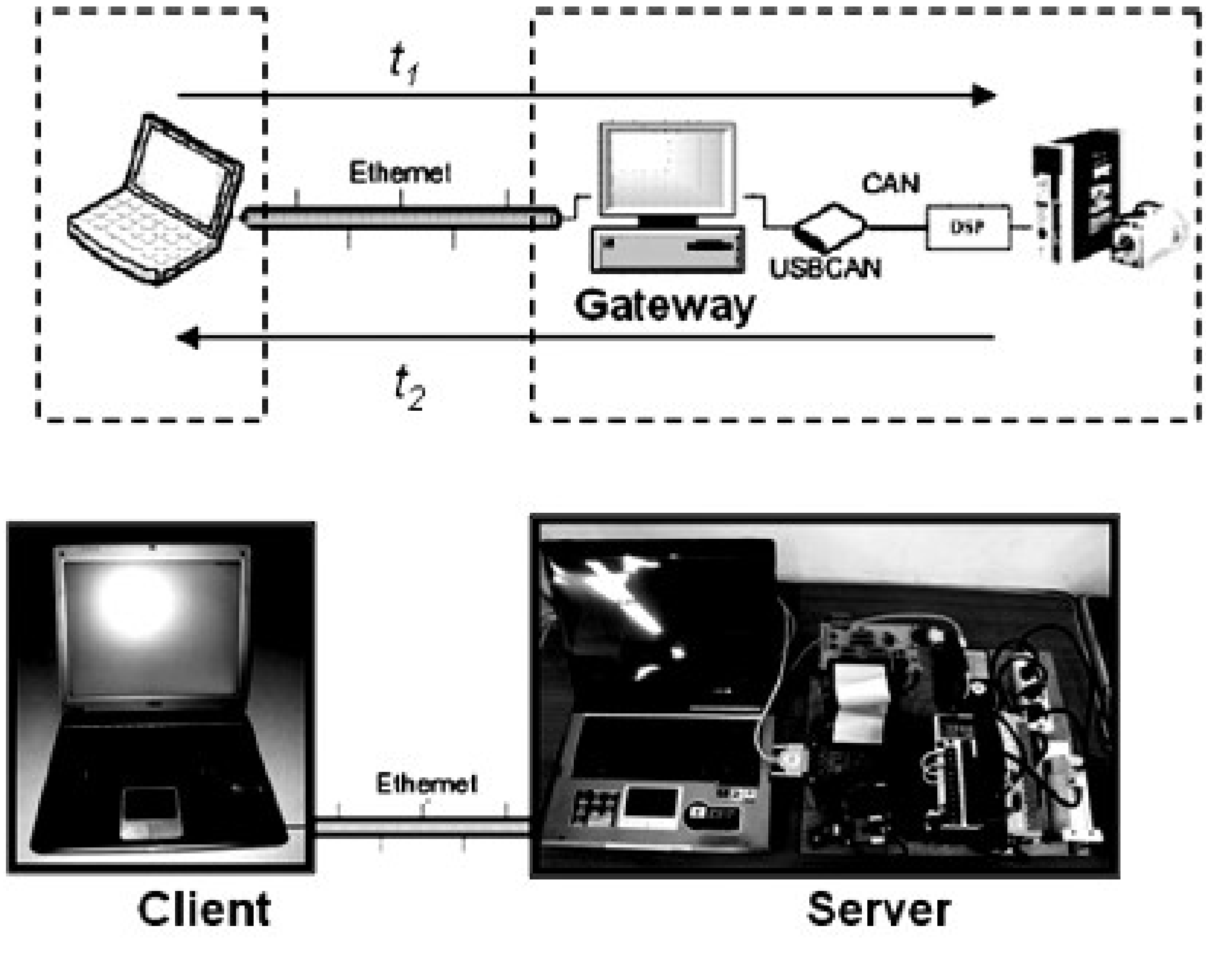


Fig. 2. The experimental setup.

NCS

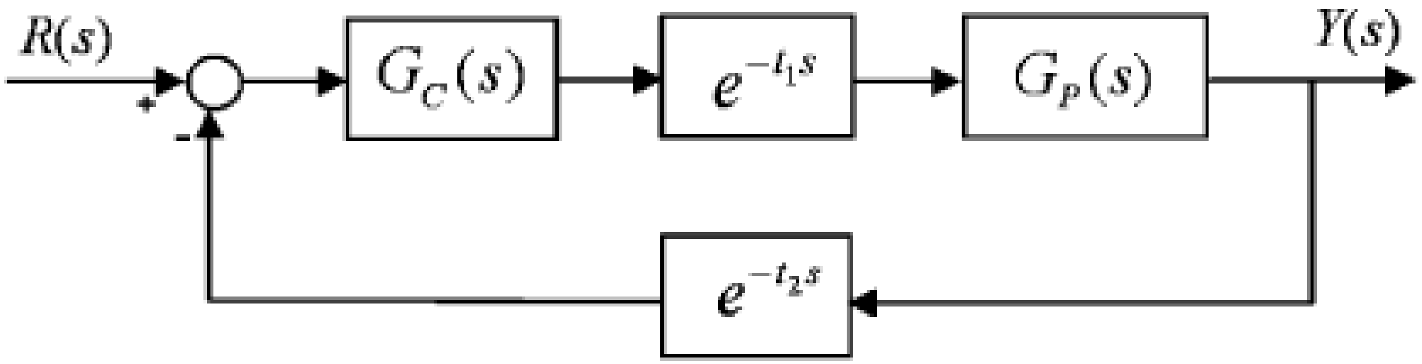
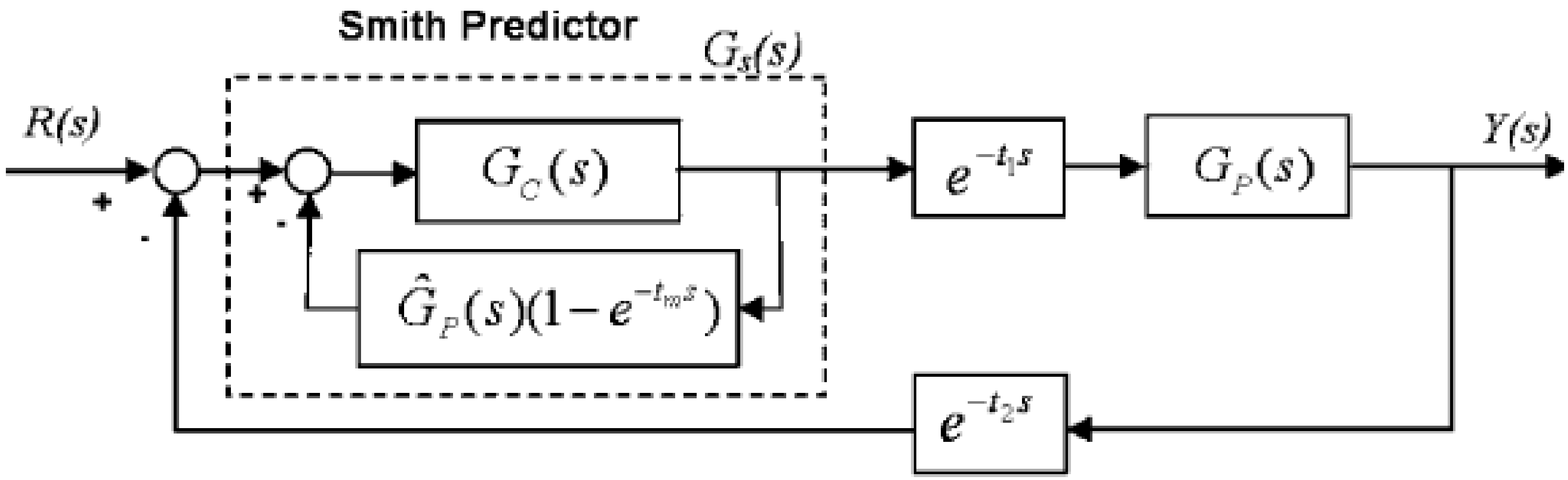
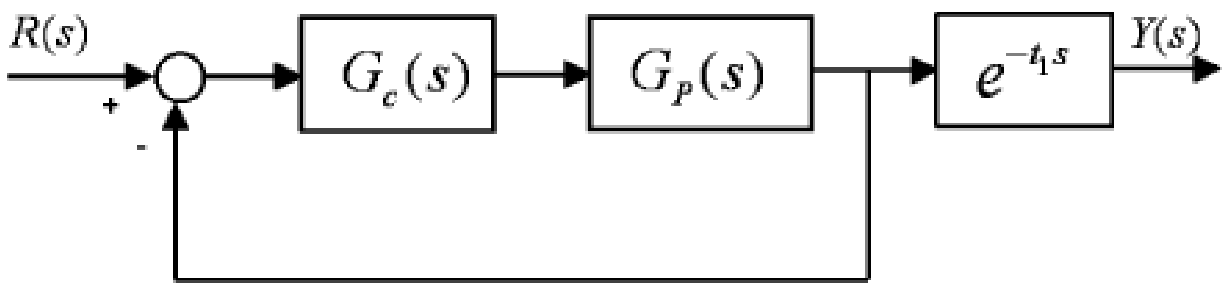


Fig. 5. The simplified block diagram of NCS.

NCS with Smith predictor

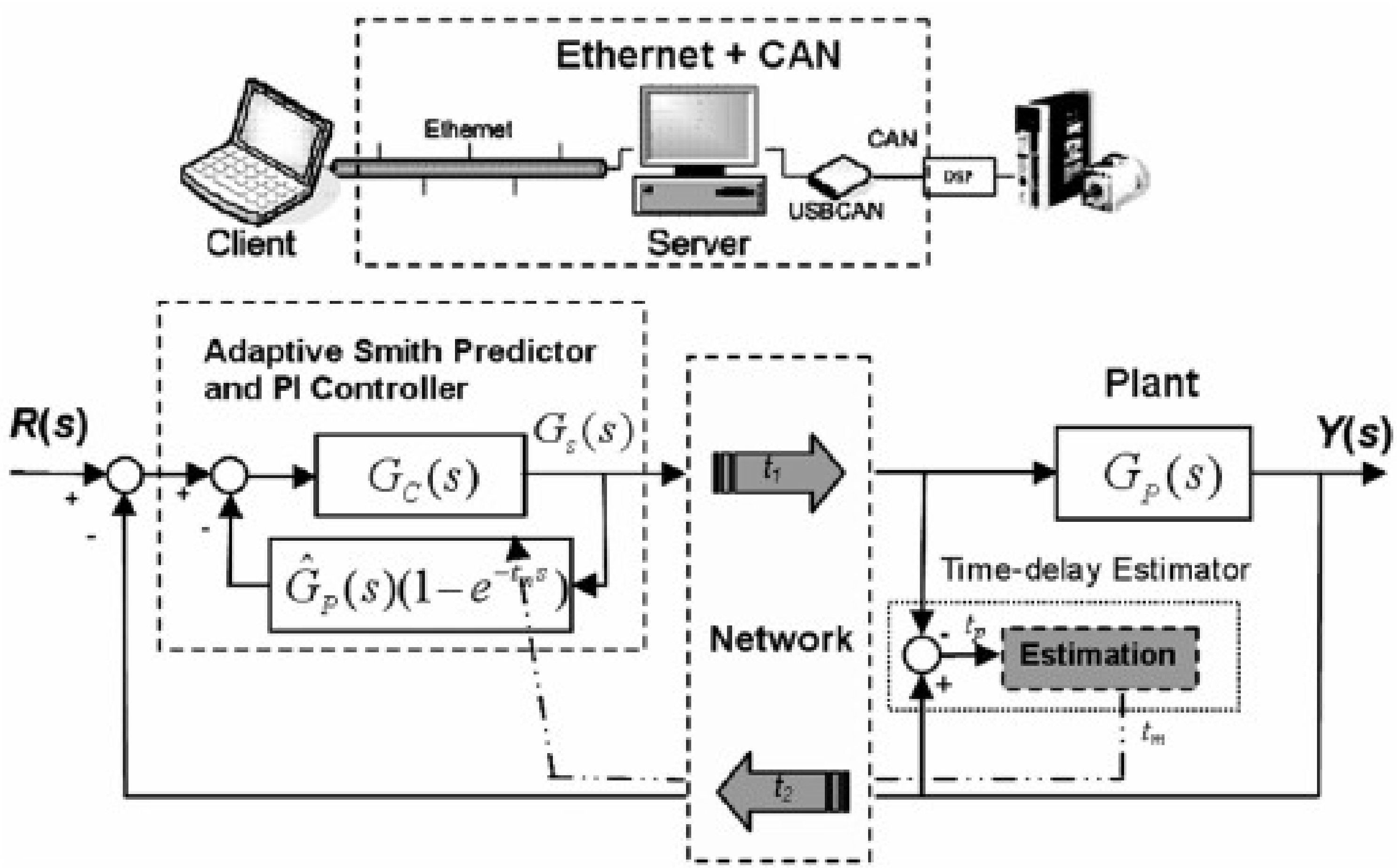


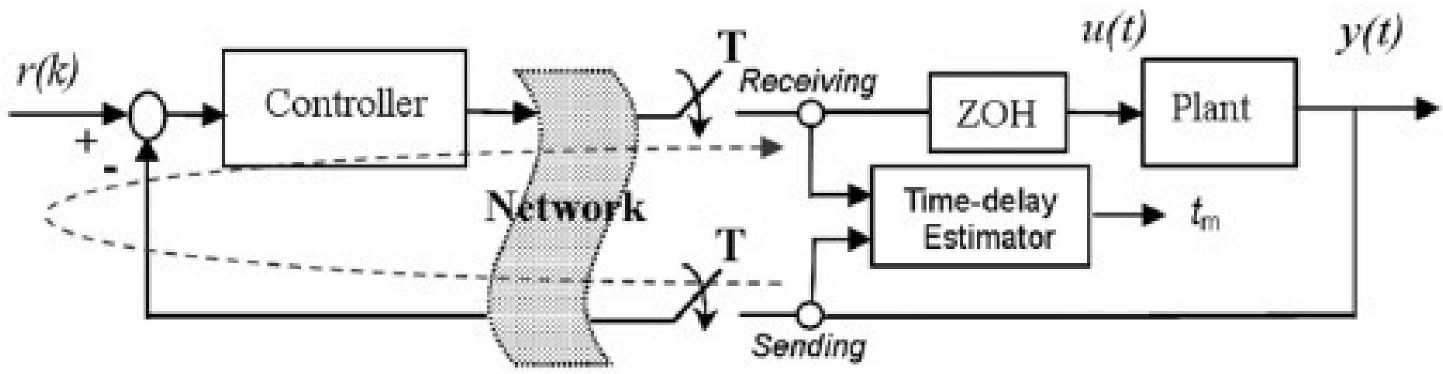
(a)



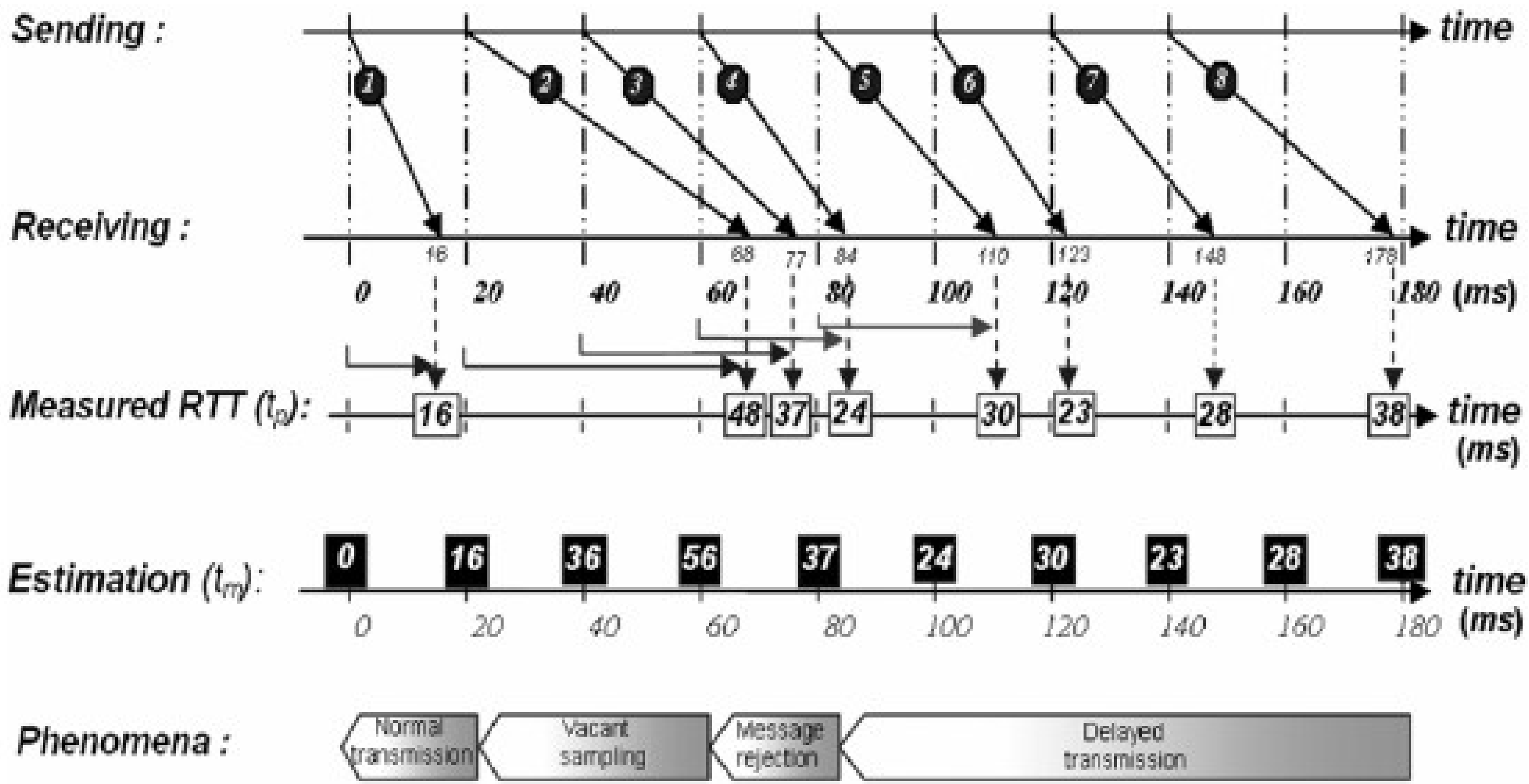
(b)

adaptive Smith predictor with a PI controller




r(k)
+
-
Controller
Network
T
Receiving
ZOH
u(t)
Plant
y(t)
Time-delay Estimator
t_m
T
Sending

(a)


Sending :
time
1
2
3
4
5
6
7
8
Receiving :
time
16
68
77
84
110
123
148
178
0
20
40
60
80
100
120
140
160
180
(ms)
Measured RTT (t_p):
16
48
37
24
30
23
28
38
time (ms)
Estimation (t_m):
0
16
36
56
37
24
30
23
28
38
time (ms)
0
20
40
60
80
100
120
140
160
180
Phenomena :
Normal transmission
Vacant sampling
Message rejection
Delayed transmission

Results

- To be understood…

Conclusion

- an algorithm is proposed by sending the measurement of each frame at the half sampling period to achieve online estimation of the delay time of the proposed NCS
- The adaptive Smith predictor is adopted with the online estimated time-delay to achieve improved performance of NCS
- The present remote controller may present a larger overshoot because an initial estimation error may exist.