Monitoring and Fault Detection in Networked Control Systems

Thomas Gustafsson

Luleå University of Technology
Department of Computer Science and Electrical Engineering
Systems and Interaction
SE-971 87 Luleå
SWEDEN

tgu@ltu.se
Overview

- FDI - Fault detection and isolation
- NCS - Networked Control Systems
- FDI and NDC
- Some suggestions and current research
- Open problems
Model based Fault detection

The residual generator is usually model-based as the estimator includes a model of the process.

Fault isolation can be achieved with multiple residual generators.
Fault detection

One of the aims for fault detection and isolation is to provide the information needed for predictive maintenance or condition maintenance.

Fault detection could also be part of a Fault tolerant control system.
Fault isolation in induction machines
Fault isolation in induction machines

Process

Input

Detector

Alarm?

Output

Short circuit Estimator

R1

Increased Resistance Estimator

Rn

Detector
Residual evaluator

Constant threshold

Dynamical threshold

Evaluation signal

Fault occurring
Networked Control System

- Feedback control system
- Closed via a serial communication channel (Network)
- Network possibly shared with other nodes outside the control system
Why use a NCS?

- Sensors and controllers are distributed.
- Pervasive mixed data flow.
  - Time-critical data, including
    * periodic variables, e.g. sample data used for updating controller output.
    * aperiodic(event) variables, e.g. alarm and device status signal.
  - Non-critical data (message)
    * include system or nodes initialization and installation information.
    * network supervision and diagnosis.
    * interaction with high level systems.
Example: Flexible Manufacturing

Factory Level
Management & Logistic of the Local Production Site

Cell Level
Co-ordination Control Logic & Supervision of Cell-Behavior

Component Level
Control Logic & Machine-near Supervision

MES
Real-Time Control
Example: ICT challenged rural/remote areas

- Disruption of links and network partitioning is the rule rather than the exception!
- Continuous, synchronous communication is not feasible!
- Contemporaneous end-to-end path between source and destination may never exist!

Harsh and challenging network environments have special communication needs!
Why use a NCS?

Attractive features of serial communication networks

- High transmission speed and quick, efficient bus arbitration (due to transfer of real-time data).
- Capable of transferring time-critical data as well as non-critical message.
- High transmission reliability
- Operability in harsh environment
- Simple installation and maintenance
- Good diagnostic capability
- Inexpensive
The Pros and Cons of the NCS

Advantage of NCS vs. Traditional Point-to-point Interconnected Control System

+ Increase system reliability and testability.
+ Enhance resource utilization.
+ Reduce weight, space, power and wiring requirements.
- Signal delay and distortion due to limited network resource (or finite bandwidth constraint, i.e. at one time only one node can access the network.)
Performance in Networked Control Systems

![Graph showing the relationship between sampling frequency and performance for different control methods: Continuous control, Digital Control, Networked Control, and the impact on stability and acceptability.](image-url)
Fault detection in Networked Control System

Continuous process

D/A

A/D

Residual generator and evaluation

D/A

A/D

D/A

A/D

D/A

A/D
Fault detection in NCS

Signals randomly delayed or missing

Residual generation
Residual evaluation

Input

Process

Output

Alarm

Estimator

Residual

Detection

algorithm

Input

Output
Fault detection in NCS

Residual evaluation

Signals

Y_1

Y_2

Y_3

Y_4

Sample missing

Different order

Time
FD with randomly delayed signals

To not lose detectability we must have knowledge of

- Inter-sample behavior of the process
  - Requires enhanced model of the process
- Time delay of signals
  - Requires time-stamped measurements (increases traffic)
  - Requires synchronization of time over a network (difficult)
- How to deal with missing data

Necessary to find other methods to avoid loss of detectability of faults.
Distributed Fault Detection

Diagram:
- Controller and FDI
- Network
- Actuator
- Sensor
- Process plant
Distributed Control and Fault Detection

Continuous process

A/D and residual generator

A/D and residual generator

A/D and residual generator

Residual evaluation

D/A

D/A

D/A
Current Research Projects

FP6 IP SOCRADES (ABB, LTU, KTH, Schneider, ... )

C4-DTN (CDT¹, ProcessIT Innovations²)

Modeling of complex dynamic systems (HLRC³, ProcessIT Innovations)

- Ad-hoc network in harsh environments.
- Reactive architecture supported by TIMBER
- Model-based sensors and actuators
- Residual generation in sensor and evaluation on aggregated level. Less sensitive to time-delays
- Control under communication constraints

¹http://www.cdt.ltu.se
²http://www.processitinnovations.se/
³Hjalmar Lundbohm Research Center
Traditional (Internet-like) networking

• Infrastructure based and TCP/IP based
  – Mostly fixed (extended to end-host mobility, e.g., cellular networks)
  – Reliable and predictable

• Contemporaneous end-to-end path between source and destination
  – Disruption of links and network partitioning is an exception
  – Low, bounded end-to-end delay
  – Routing is end-to-end, i.e., communication fails in the absence of an existing path to the destination
Hash and challenging network environments

Have special communication needs

- Disruption of links and network partitioning is the rule rather than the exception
- Continuous, synchronous communication is not feasible
- Contemporaneous end-to-end path between source and destination may never exist
Hash and challenging network environments

ICT-challenged rural/remote areas

Interplanetary networks

Wireless sensor networks
Reactive Software Design

Traditional languages for RTOS based design

- lack the notion of time
- lack the notion of parallelism and blocking
- lack automatic memory management

Consequences; a time consuming error prone design methodology

- time has to be encoded by “artificia” process priorities
- parallelism and blocking has to be manually encoded by concepts of threads, semaphores, monitors etc.
- memory has to be manually managed
Timber

Timber\(^4\); a language based on reactive objects is being developed, that

- captures timely behavior of parallel systems intuitively by reactive objects
- solves memory (state) integrity and dead/live locks
- supports dynamic (heap based) memory and garbage collection

Offers a time efficient and robust design methodology through

- modern language design; advanced type checking, object orientation etc.
- system analysis by formal methods; Timber is an executable model

\(^4\)http://www.csee.ltu.se/index.php?subject=timber
• fully self contained; does not rely on RTOS or other external components
Control under communication constraints

Emerging Areas Project, Rotterdam 2003

Problem: Control a distributed system consisting of a large number components of very different nature – such as analog devices, sensors, computers, decision logics – which exchange information through (wireless) networks.

Little effort has been put so far in understanding how communication constraints affect the performance of a distributed control system.

Communication constraints may induce a change in control design principles.

Rigorous analysis of robustness, and guaranteed robustness margins, are sought.
Control under communication constraints

Emerging Areas Project, Rotterdam 2003

The goal is to design sensors, encoders, communication channels and controllers (or estimators) so as to achieve prescribed performances despite of all the constraints and obstacles imposed by the communication channels and in the presence of possible uncertainties and disturbances.

Constraints imposed by the communication channels include:

- bandwidth
- delays (of variable amount)
- quantization errors
- transmission noise
- loss of information
Questions