Machine Tool Sensorization to Improve the Performances

Sensori e Data Fusion nelle Lavorazioni Meccaniche

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Marco Grasso

Supervision: *Bianca Maria Colosimo*
Area 2 Person in Charge:
Giovanni Moroni

MUSP
Macchine Utensili e Sistemi di Produzione

POLITECNICO MILANO

High Performance Manufacturing

High Performance Manufacturing & Intelligent Machine Tools

What?

- ***Autonomy***
- ***Automated supervision***
- ***Adaptive control***
- ***Condition-based maintenance***
- ***Waste and defect reduction***
- ***High quality***
- ***High productivity***
- ***Machine to machine, etc.***

How?

Sensors → ***Machine Tool Condition Monitoring***

Process Quality/Stability Monitoring

→ ***Diagnostics & Prognosis***

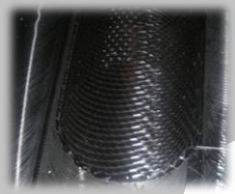
Error mitigation / suppression

Maintenance

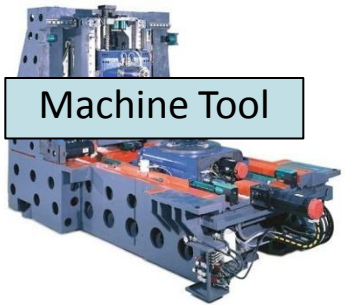
The Intelligent Machine Tool?



Tool chipping
Tool breakage


Bearing damage
Vibrations

Performance Monitoring

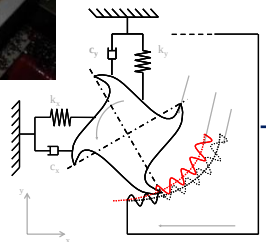

Machine Tool

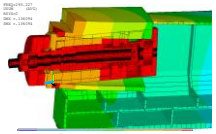
Sensors

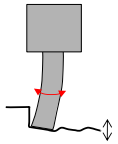
Data Acquisition & Signal Processing

Feature extraction / selection

Process







Machine - Process Model
Experimental Characterization

Decision Making

Adaptive Control & Process Optimization

Available vibration mitigation strategies (Spindle speed variation, Speed Tuning, Feed Tuning)

Background process knowledge

Product specifications
Technological constraints
Productivity Goals

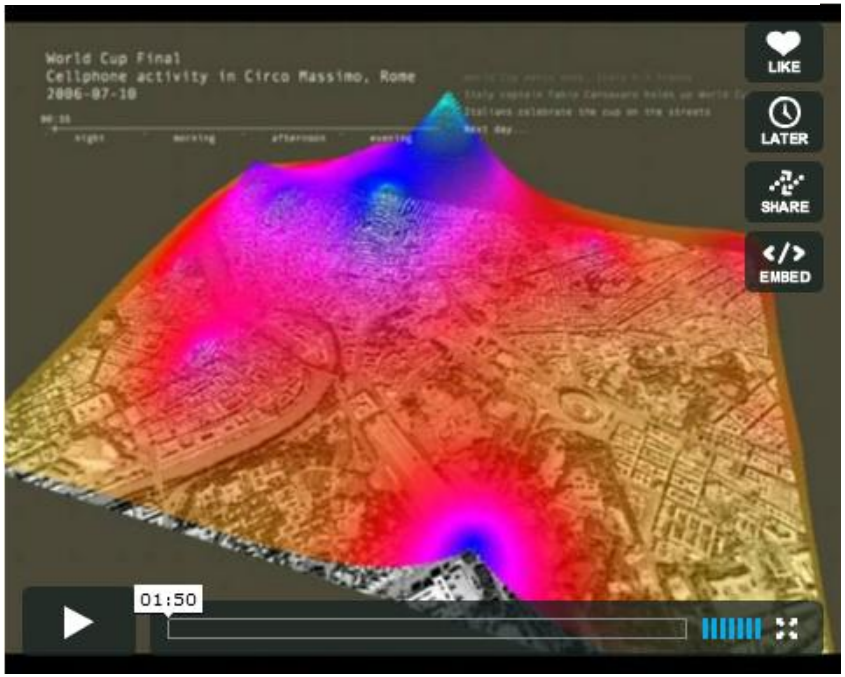
How to improve the performances?

1 The first ingredient: **SENSORS**

Our everyday life depends on sensors (*smart-phones, tablets, vehicles, controllers, etc*.)
Devices we use every day are equipped with any kind of sensor
Everyone of us can be a sensor node of a global network

Google – Real-Time Traffic monitor

SenseAble City – MIT Lab



How to improve the performances?

1 The first ingredient: **SENSORS**

What about Machine Tools?

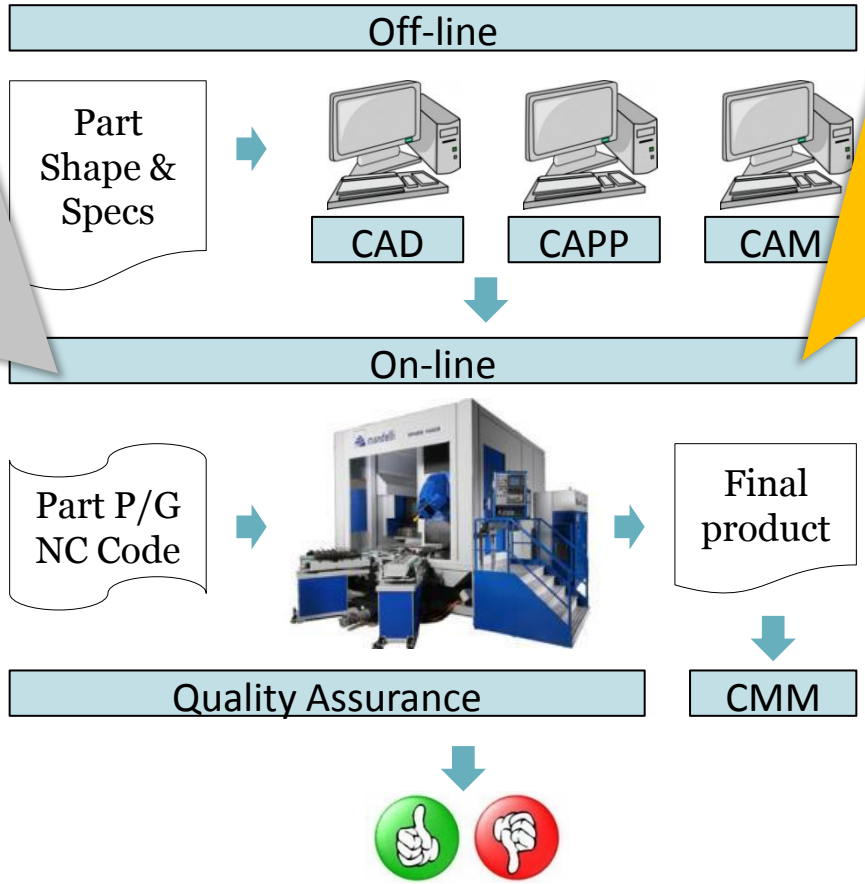
The current situation

Machine Tools are sold "naked"

Process Monitoring on Final Product

In-process monitoring rarely performed (external toolkits)

Adaptive control rarely used



Intelligent Machine

More effective usage of already available sensors

Integration of additional sensors

Data fusion

Efficient/robust signal processing

Integrated adaptive control

Machine to Machine

How to improve the performances?

1 The first ingredient: **SENSORS**

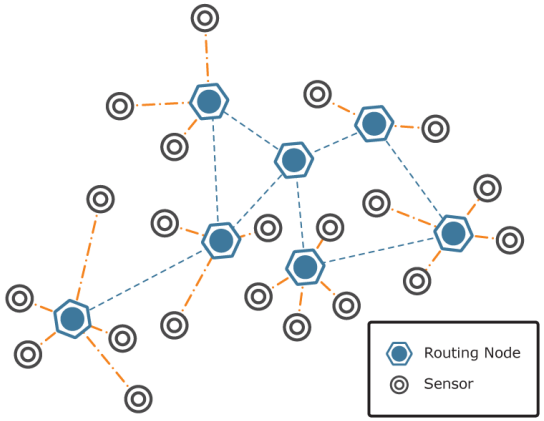
Which type of sensors?

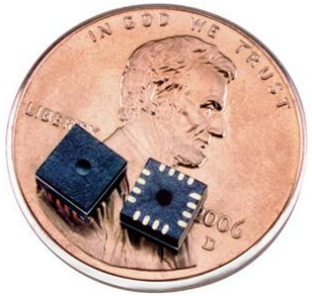
A single highly informative data source may be difficult to have in industrial applications.

It implies high costs, high intrusivity, complex installation, …
A better approach:

Distributed Data Sources

Low-cost sensors	Non-intrusive sensors
Smart sensors	Wireless Communications
Autonomous sensors	Sensor Networks
Optical sensors	Etc…





How to improve the performances?

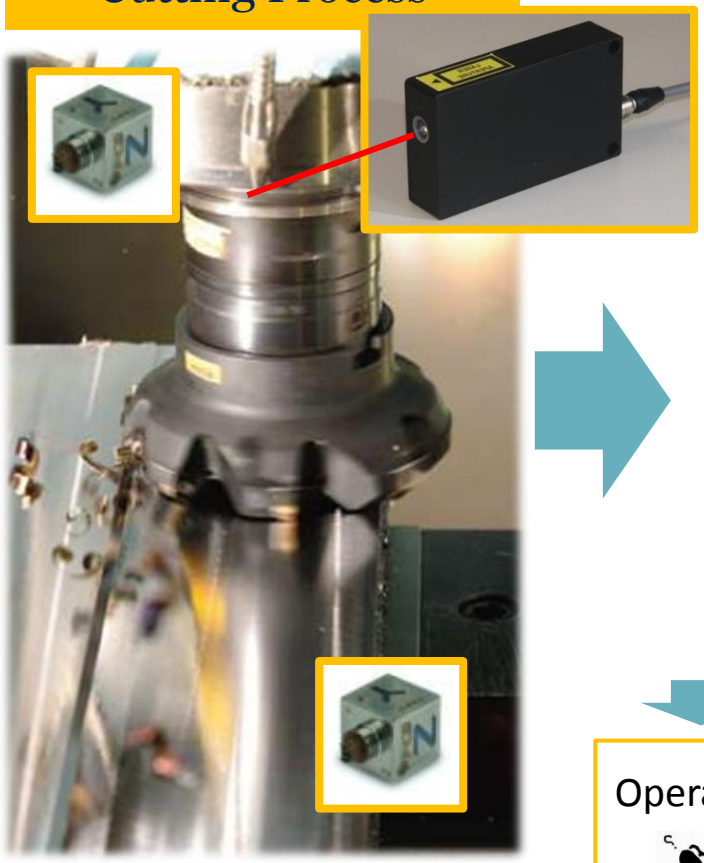
1 The first ingredient: **SENSORS**

Operator

Is there a problem?

Intervention

Cutting Process



In-Process Monitoring

Sensors
(vibration, force, acoustic emission, lasers, etc.)

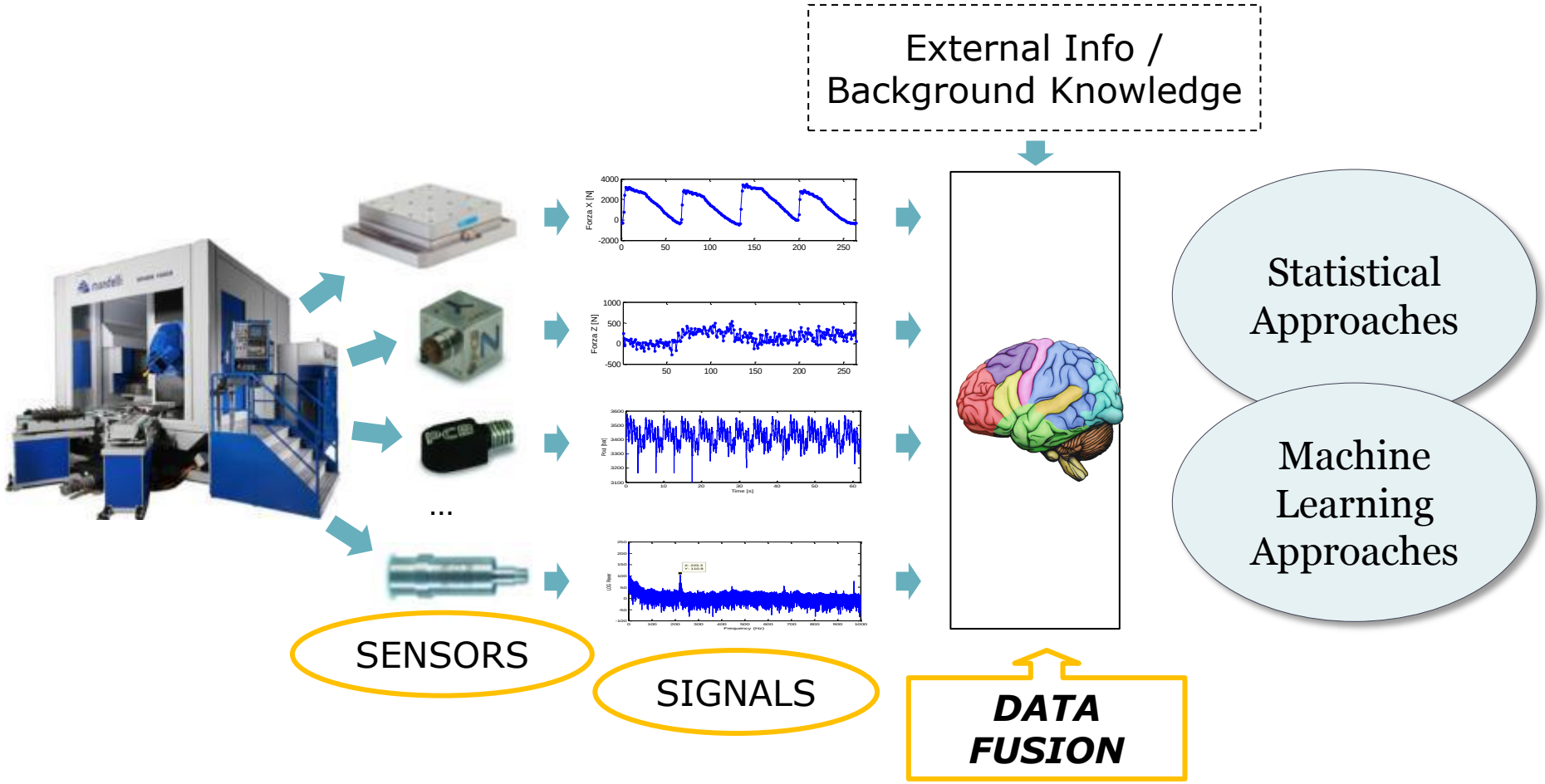
Is there a problem?

- Operator
- Adaptive Control
- Remote supervision

How to improve the performances?

2 Sensors alone do not transform a “stupid” machine into an “intelligent” machine
The second ingredient: **SIGNAL ANALYSIS and DATA FUSION**

How to combine information from multiple sources?



How to improve the performances?

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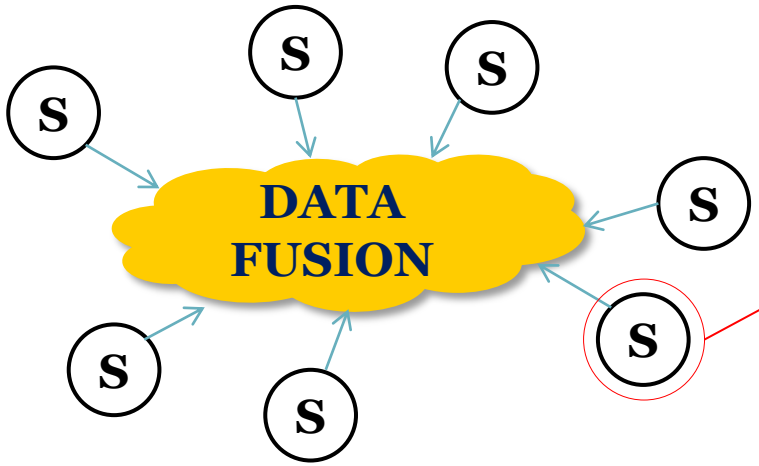
Data Fusion

Combination of data made available by different sources, in order to provide a better understanding of a given process, phenomenon, system, etc.



Information from single sensor:

- incomplete
- affected by uncertainty
- dependent on working conditions
- not fully reliable (sensor faults)

Benefits

- More **complete characterization** of phenomena
- **Robustness** with respect to disturbances and changing working conditions
- More **effective** use of available data
- More **efficient** use of available data
- Higher decision making **reliability**
- **Uncertainty reduction** in inference processes

How to improve the performances?

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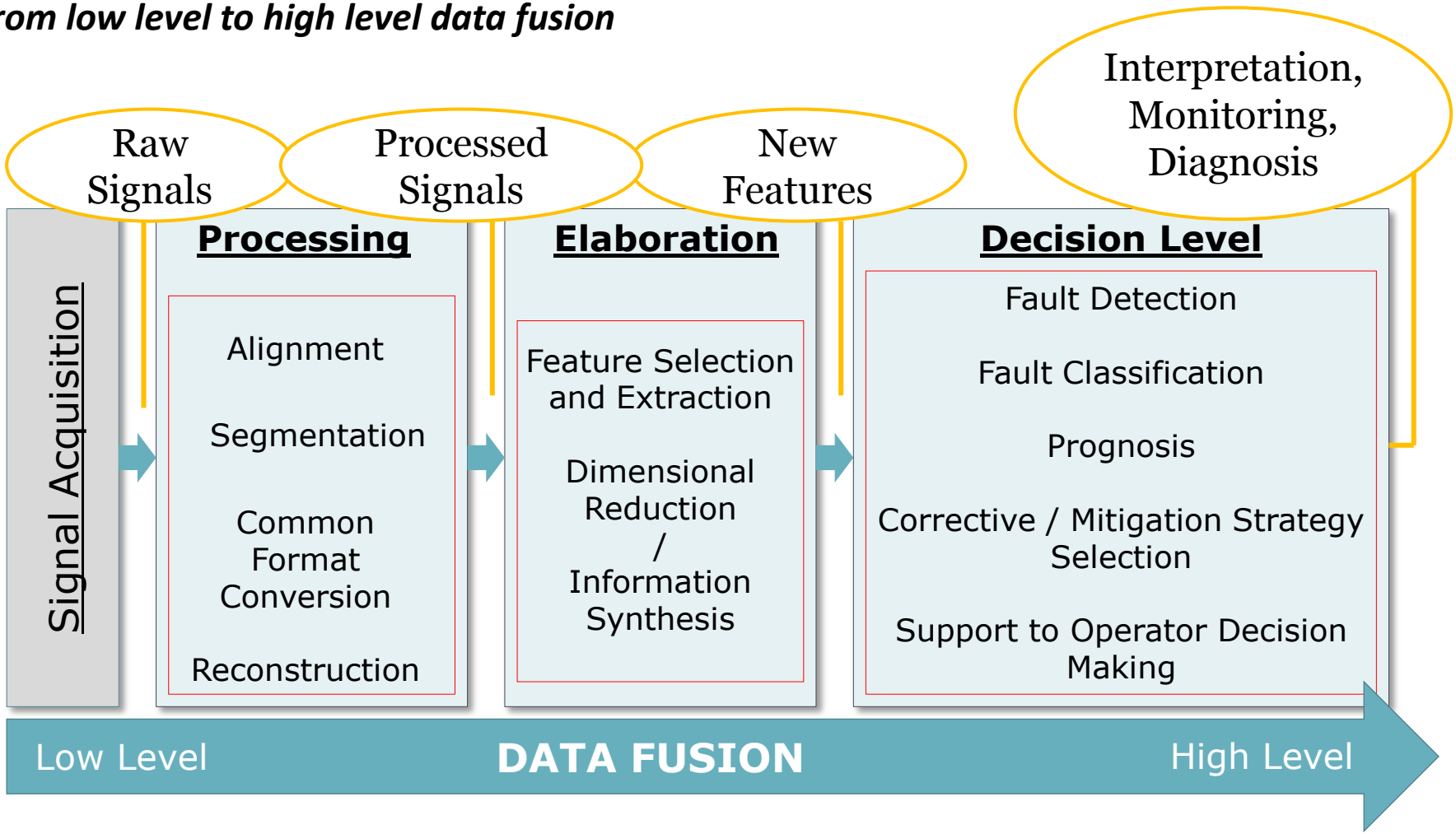
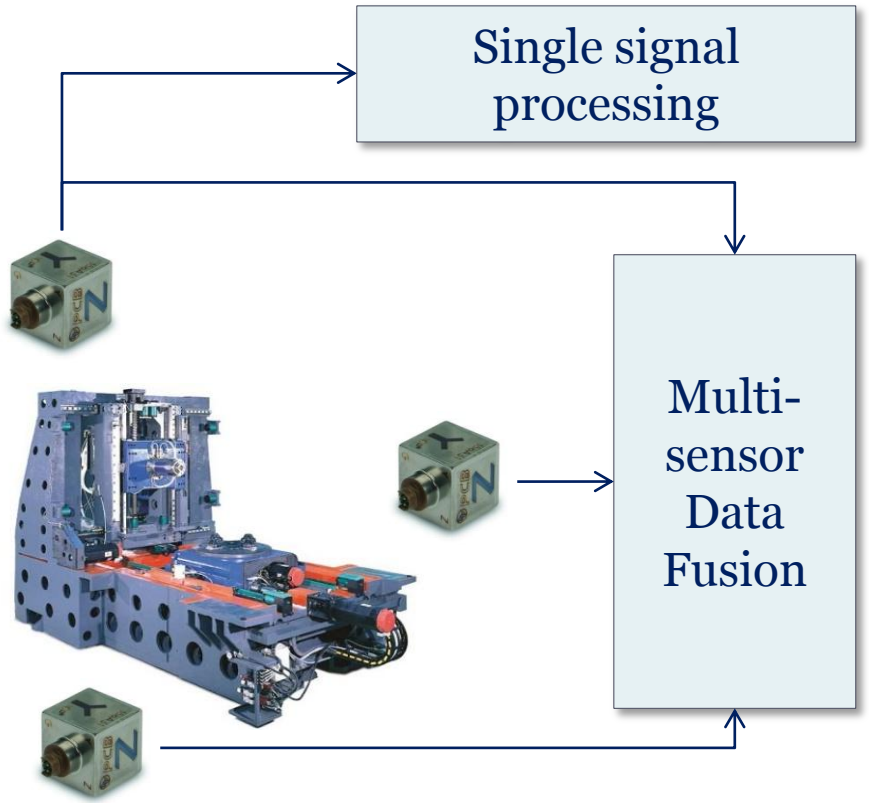
From low level to high level data fusion

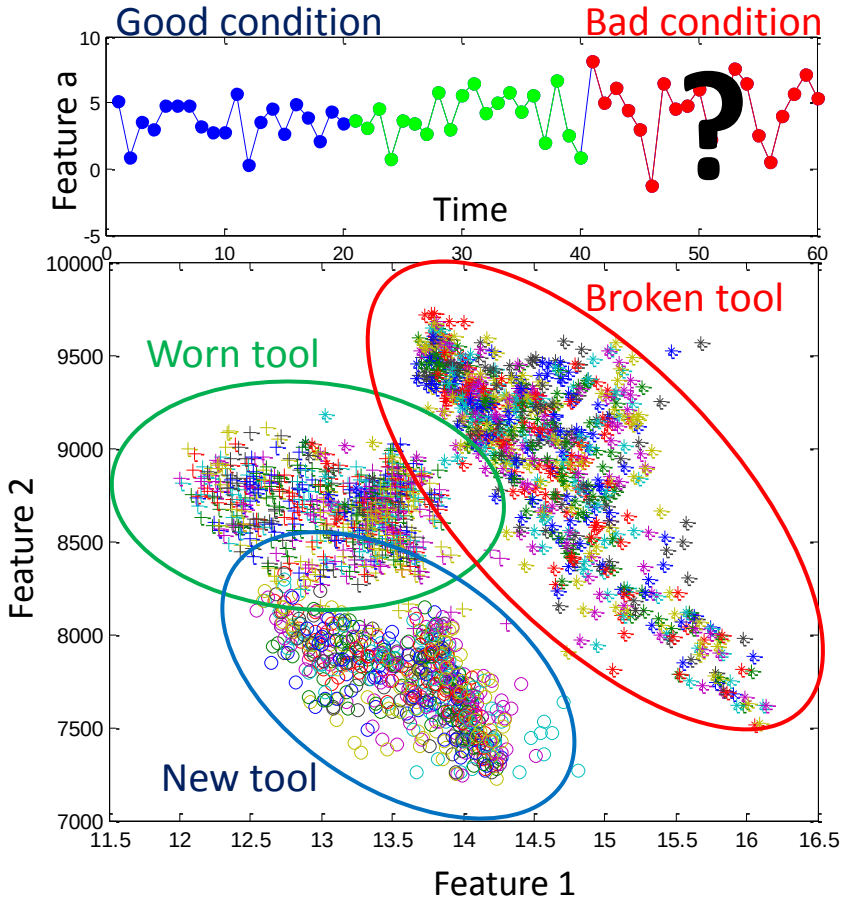


How to improve the performances?

2 Sensors alone do not transform a “stupid” machine into an “intelligent” machine
The second ingredient: **SIGNAL ANALYSIS and DATA FUSION**

Fusing multiple information sources may provide a better interpretation of a phenomenon



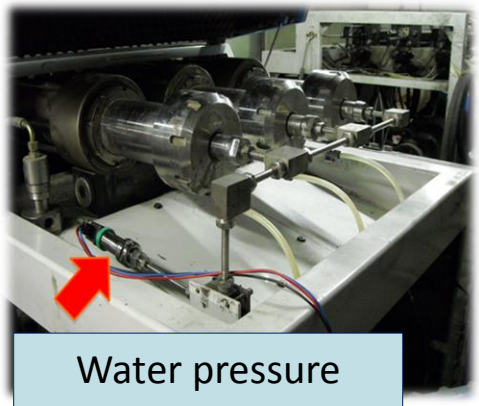


Examples of MUSP activities

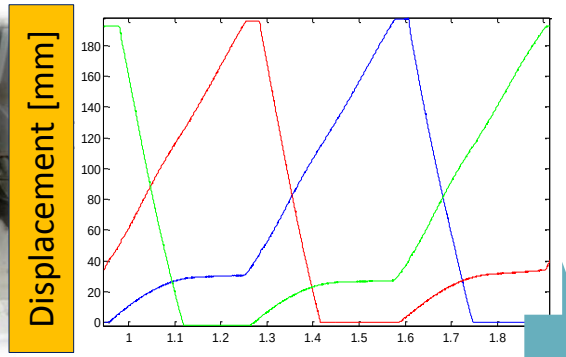
2 Sensors alone do not transform a “stupid” machine into an “intelligent” machine
The second ingredient: **SIGNAL ANALYSIS and DATA FUSION**

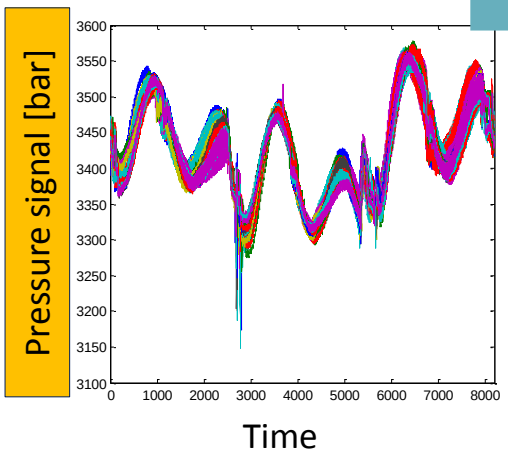
An example: *Health condition monitoring of Ultra High Pressure pump in Water Jet cutting*

Plunger displacement sensors



Water pressure sensor

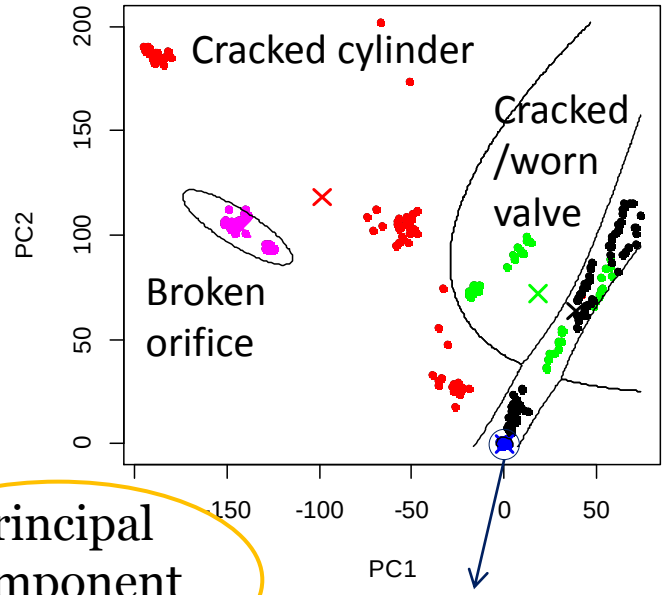




Data Fusion

Information synthesis

Fault Classification



Principal Component Analysis

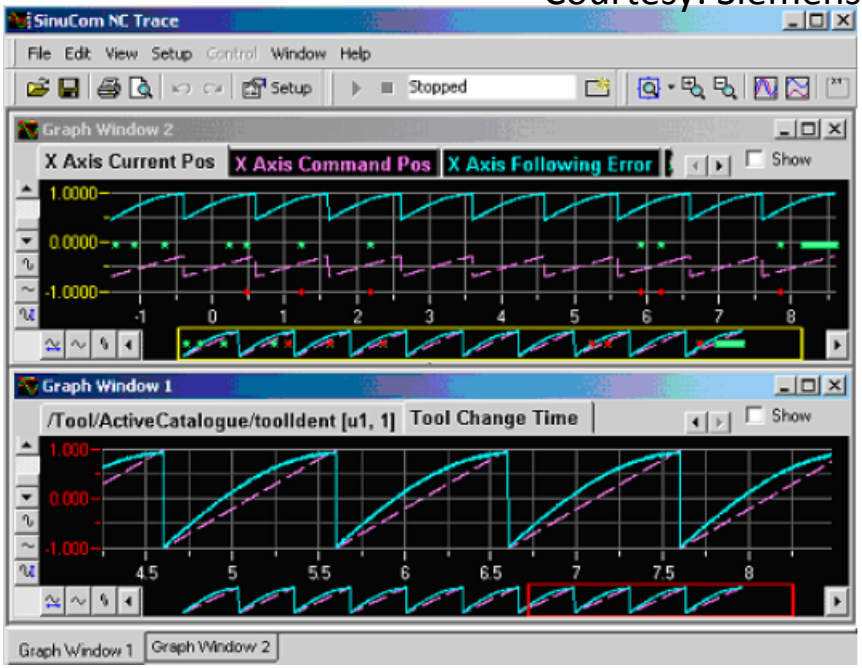
Normal working condition

How to improve the performances?

3 External sensors should be integrated with information already available on-board
The third ingredient: **ON-BOARD DATA AVAILABILITY and INTEGRATION**

- On-board data provide fundamental information for monitoring and adaptive control
- They could allow **monitoring** capability **without added sensors**
- **Integration** is mandatory to allow closing the loop for **adaptive control**

Courtesy: Siemens



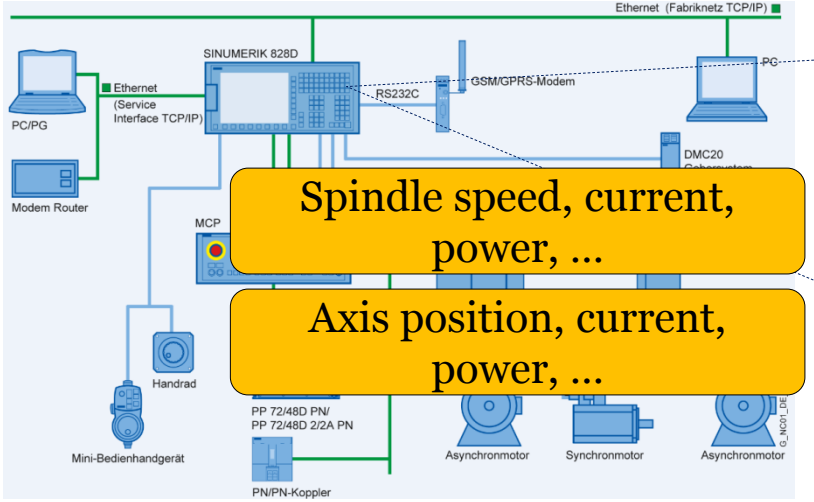
- Axis position (current and command)
- Position errors
- Axis speed
- Axis torque
- Axis current & power
- Spindle speed
- Spindle torque
- Spindle current & power
- State triggers
- Etc.

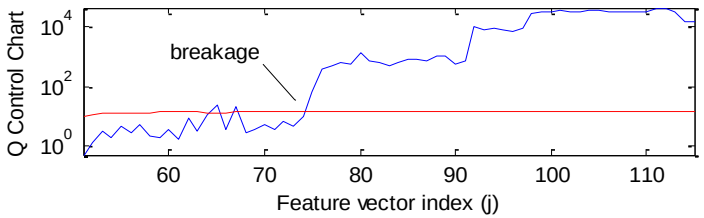
How to improve the performances?

3 External sensors should be integrated with information already available on-board
The third ingredient: **ON-BOARD DATA AVAILABILITY and INTEGRATION**

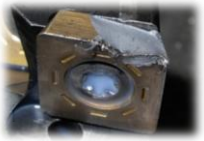
An example: usage of drive signals for tool condition monitoring (in milling)

Courtesy: Siemens

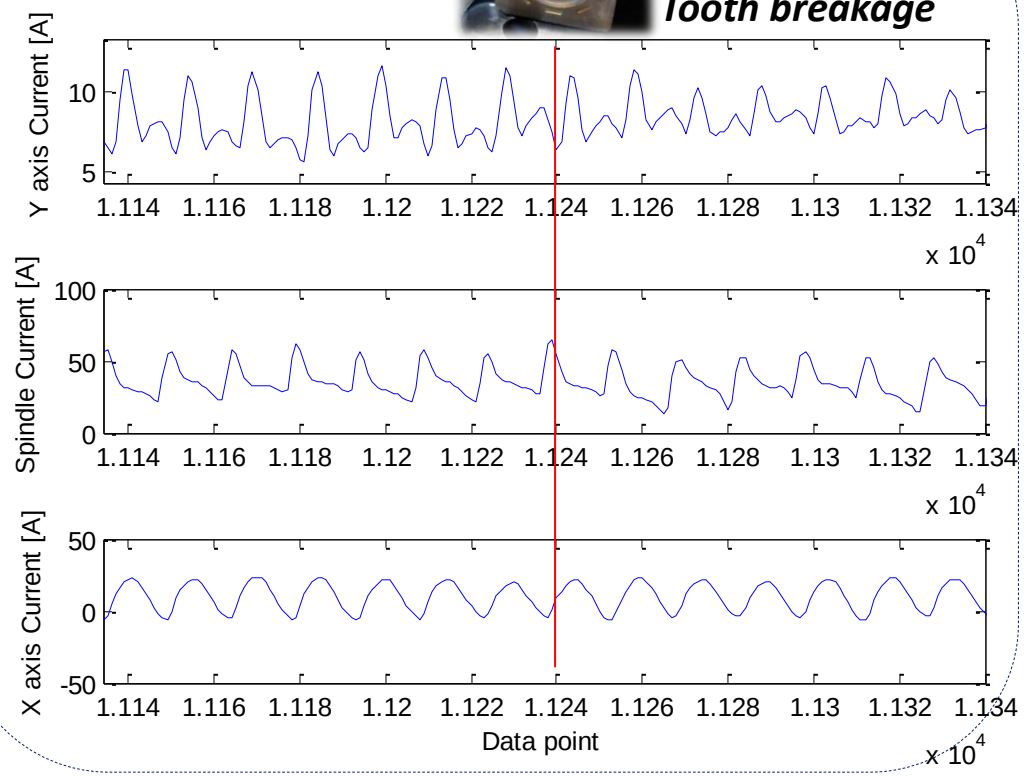




Fault detection without external sensors!

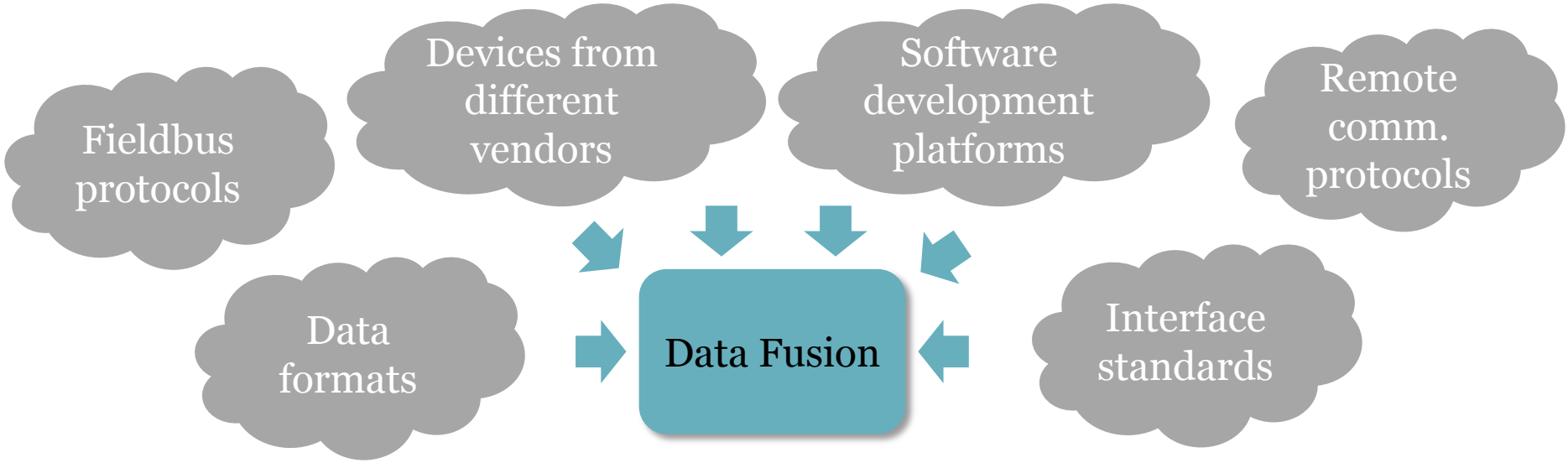


Tooth breakage



How to improve the performances?

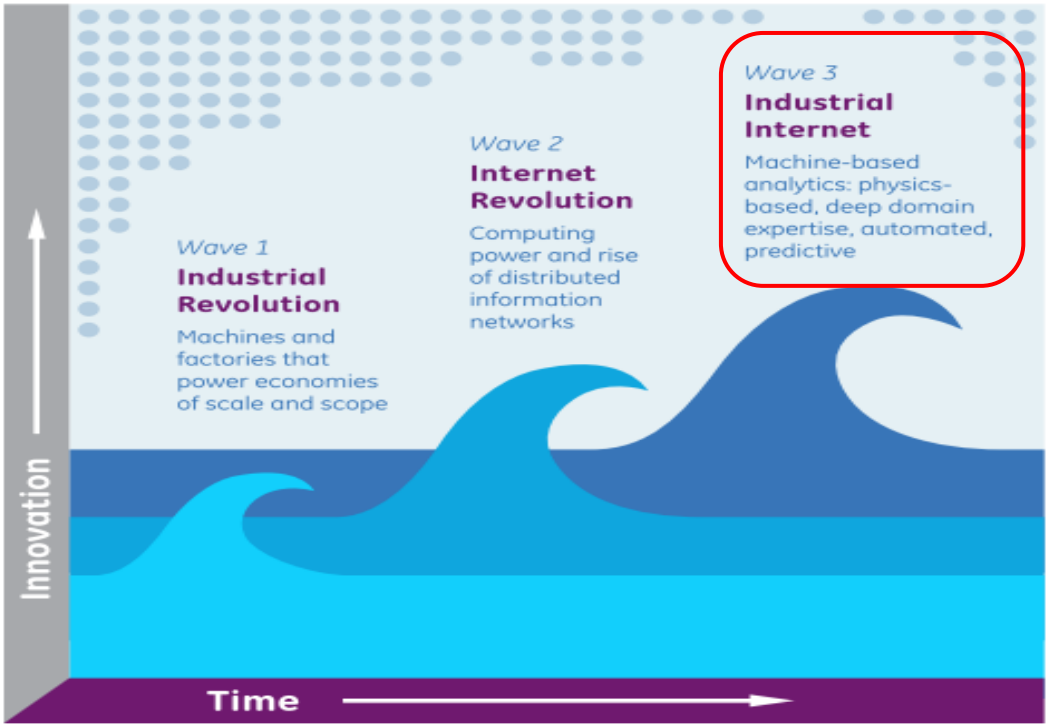
4,5,... The recipe is not complete.
Several open issues must be faced with:



- Need for **data accessibility**
- Need for **open architectures**
- Need for **standardization and interoperability**
- Need for **extendibility and portability to and from different platforms,** etc…

Conclusions - the innovation waves

The future of industrial automation (*mechatronics 2.0*?)



Source: General Electric report – November 2012

How to react to the next wave?

Conclusions

The seven zeros

1. Zero defects
2. Zero (excess) lot sizes
3. Zero setups
4. Zero breakdowns
5. Zero (excess) handling
6. Zero lead-time
7. Zero surging

Usage of sensors is a fundamental step towards the Factory of the Future

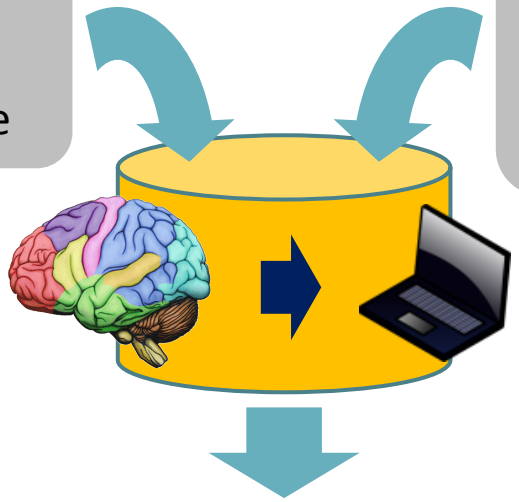
In-process measures will be more and more available:

- Vision
- IR
- Current, power, voltage
- Forces
- Torques
- Vibrations
- Displacements
- Sound emissions
- Ultrasounds
- Acoustic Emissions
- Temperature
- Pressure
- Flow
- Etc…

What's next?

We need to achieve the industrial implementation of sensor-based tools

- End user experience
- On-field know how
- Background knowledge



- Monitoring algorithms
- Empirical models
- Machine learning
- Data fusion, etc…

Final goal: **Transfer of experience, know-how, knowledge into machine automation and smart toolkits**

We need to broaden our industrial collaborations to collect that experience, know how and background knowledge
END USER experience is a fundamental resource to actually move to the Smart Factory

Recent and On-going projects

Related to sensorization, data fusion & process monitoring

High Performance Manufacturing Framework: MIUR Partner: MUSP Consortium + national network	***MILL4D*** Framework: Regione Emilia Romagna Partner: Capellini, ITIA-CNR
Michelangelo Framework: MIUR Partner: ITIA-CNR + international network	***Tecnopolo*** Framework: Regione Emilia Romagna Partner: MUSP Consortium
Tapping Process Monitoring Framework: Direct Contract Partner: Marposs/Artis	***STEMMA*** Framework: Regione Emilia Romagna Partner: MUSP Consortium
AcquaControl Framework: Regione Lombardia Partner: Tecnocut, Altag, Polimi,…	***MuProD*** Framework: Factory of the Future Partner: Polimi + international network
EROD Framework: Industria 2015 Partner: Jobs, BIESSE, Polimi ,…	
…	

Thanks for your attention

Info:
marco.grasso@musp.it
biancamaria.colosimo@polimi.it

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