

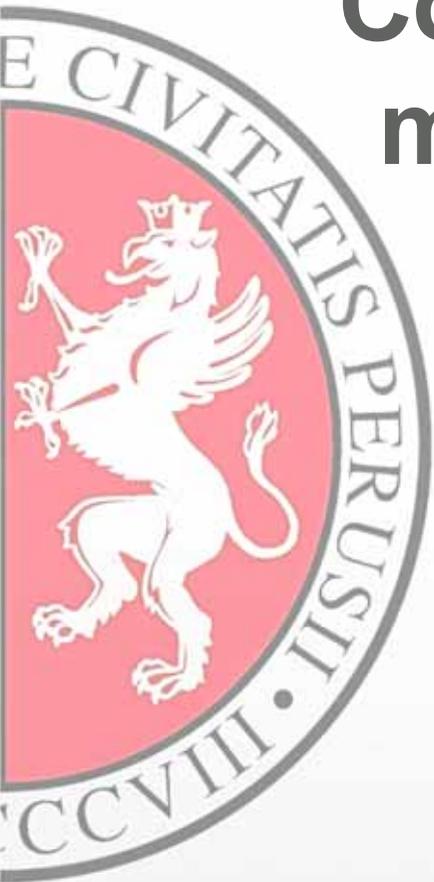
Controllo di processi di additive manufacturing per produzione di componenti in ambito aerospace

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Ing-Ind/16, Tecnologie e sistemi di lavorazione

Dipartimento di Ingegneria Università degli Studi di Perugia



From design to fabrication

Progettazione

Design ottimizzato progettazione
Caratteristiche dei materiali



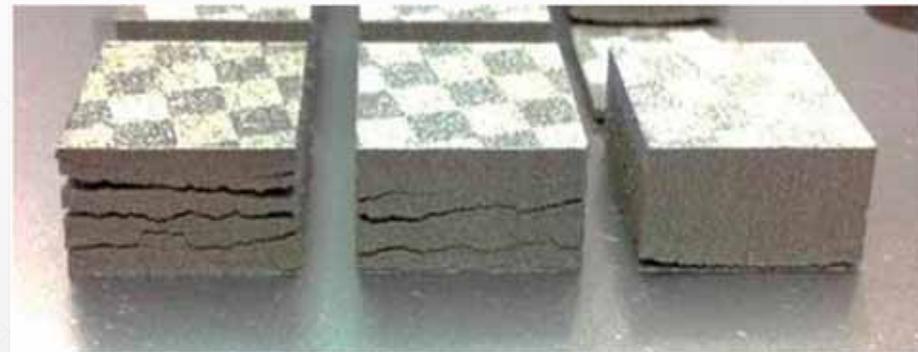
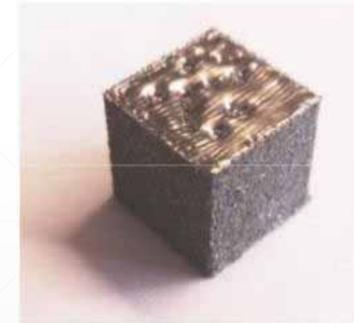
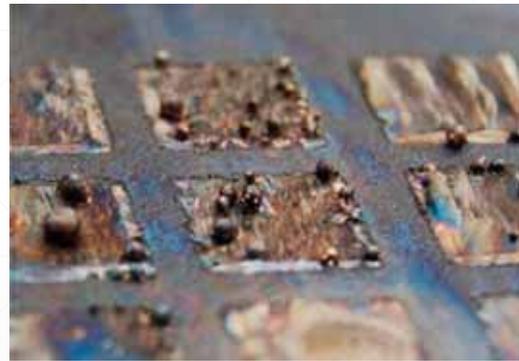
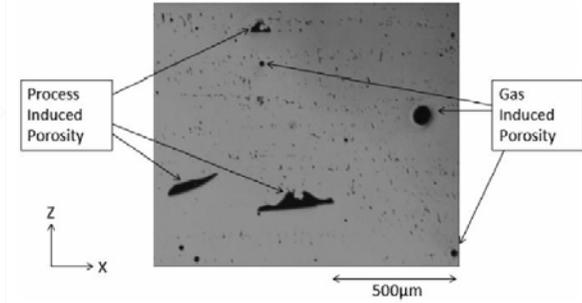
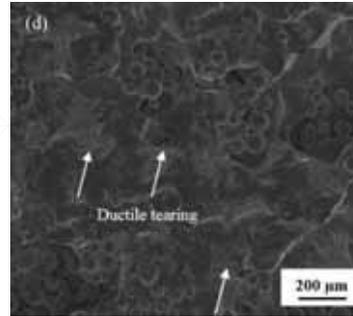
Fabrication & QA



- Parametri di processo
(set and measured)
- Materiali utilizzati
- **Processo di fabbricazione**



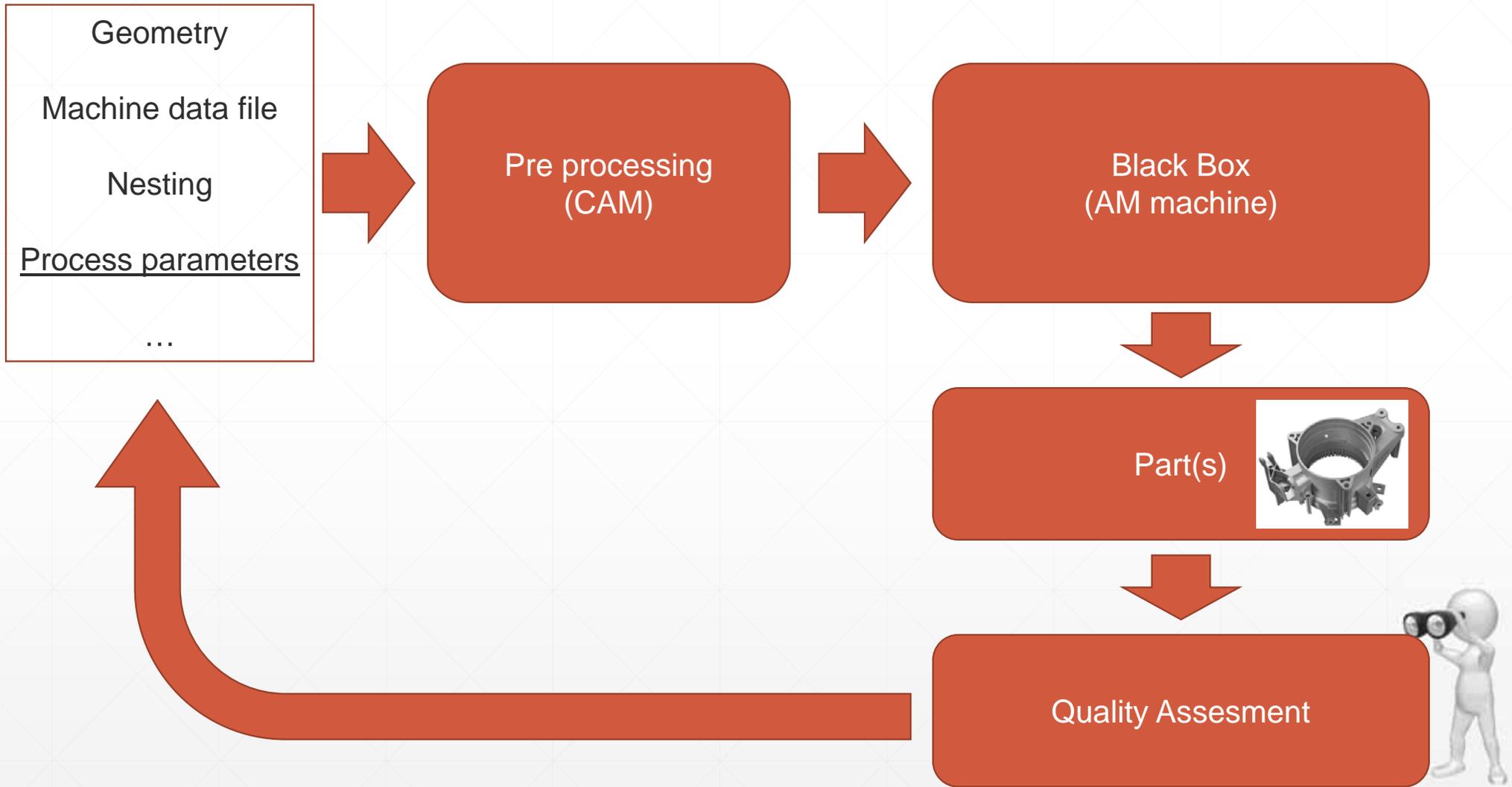
Caratteristiche e difetti



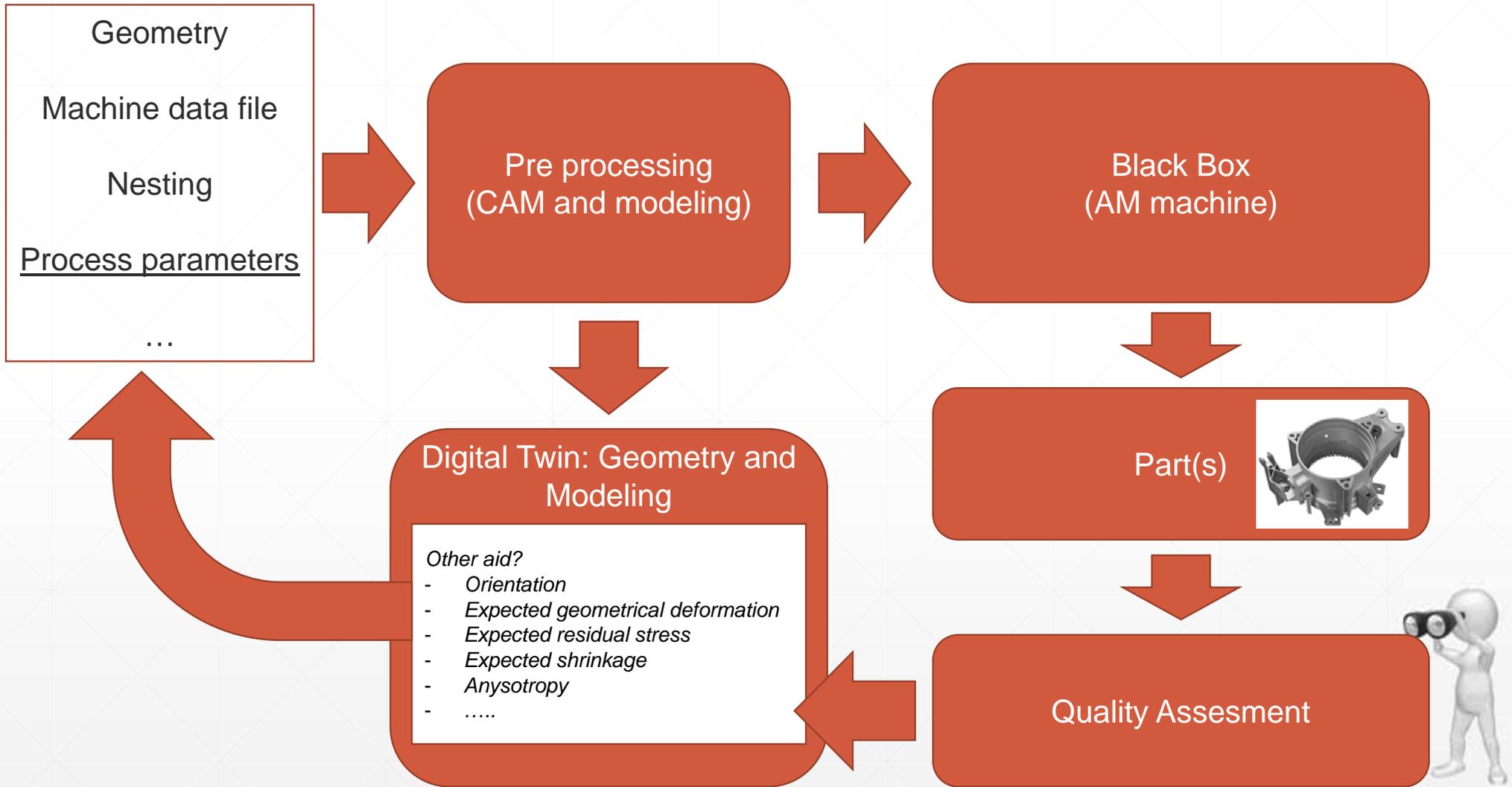
Defects scale



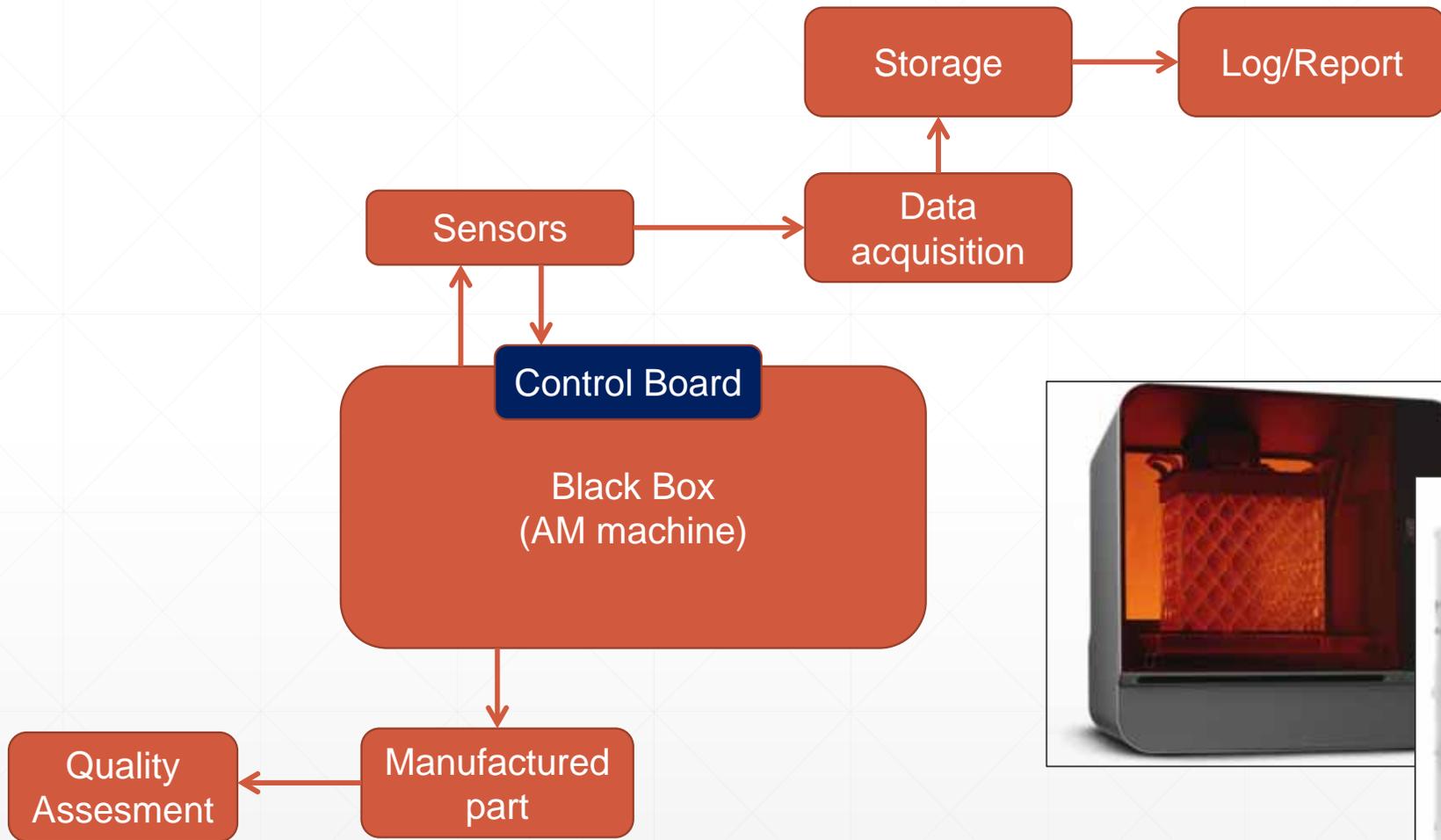
Process monitoring



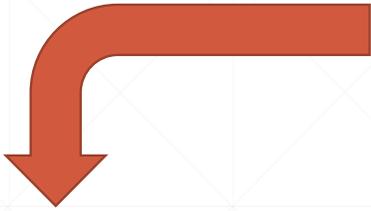
Process monitoring



Process monitoring, standard configuration



Process monitoring



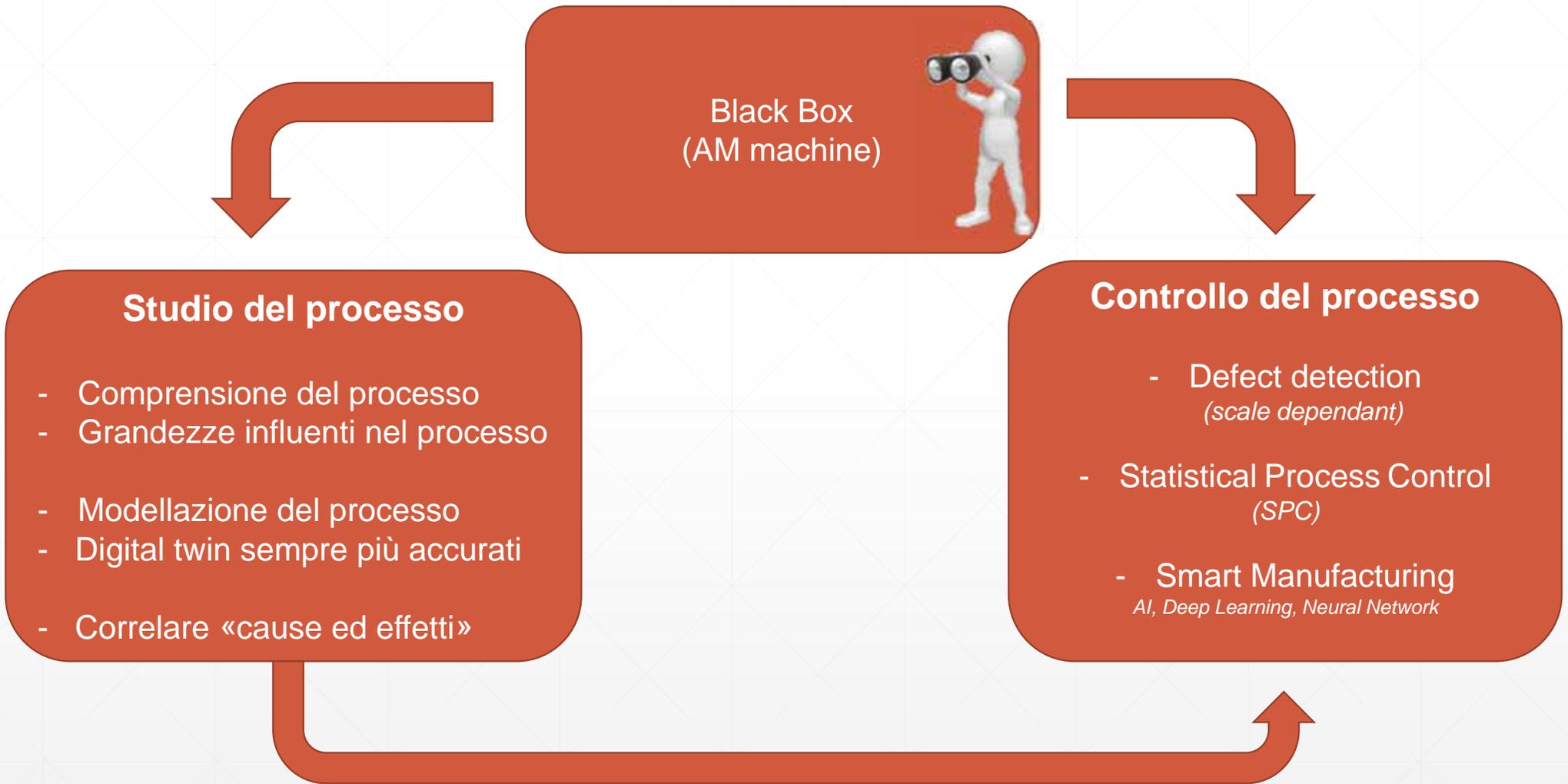
Black Box
(AM machine)



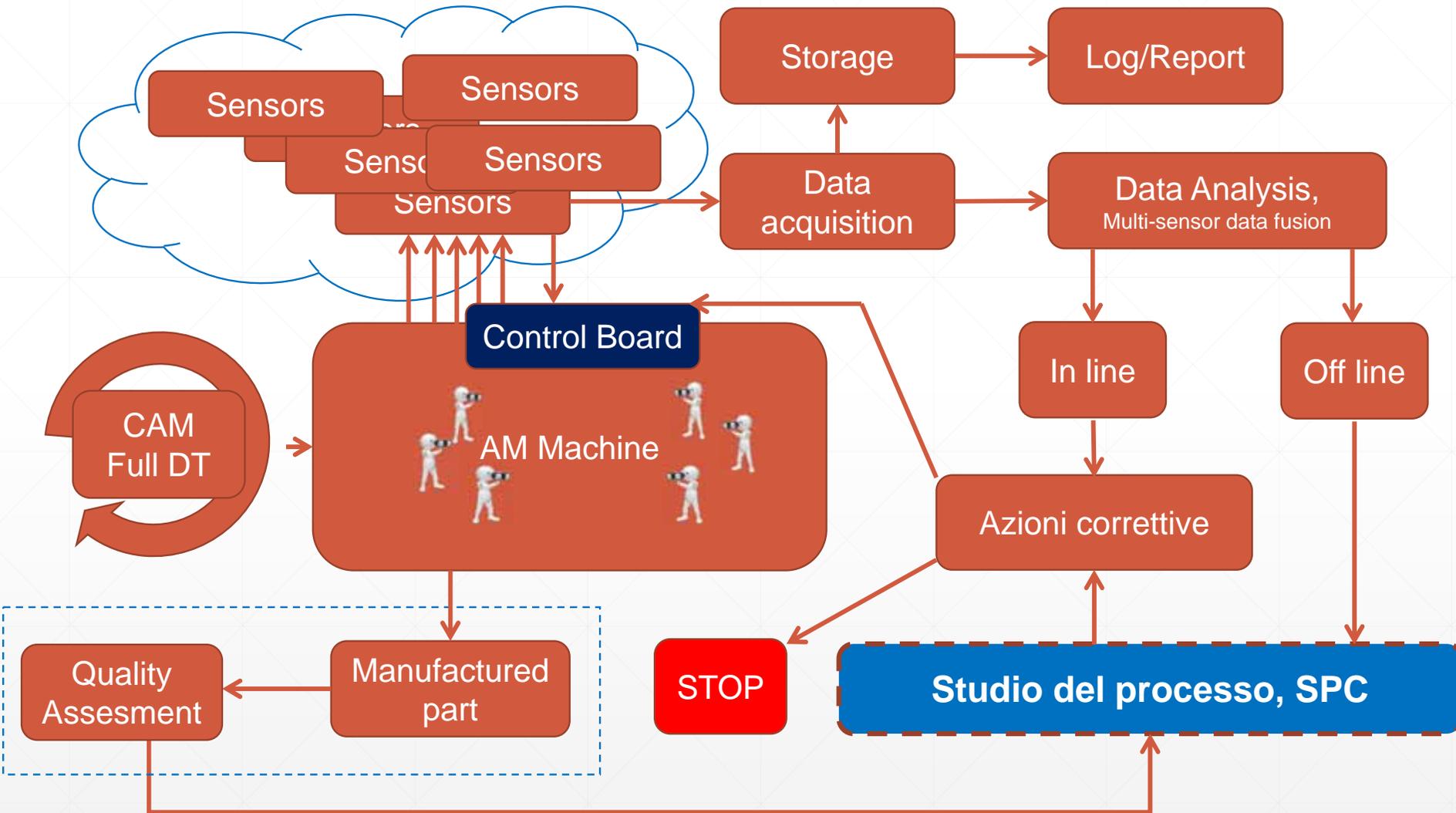
Studio del processo

- Comprensione del processo
- Grandezze influenti nel processo
- Modellazione del processo
- Digital twin sempre più accurati
- Correlare «cause ed effetti»

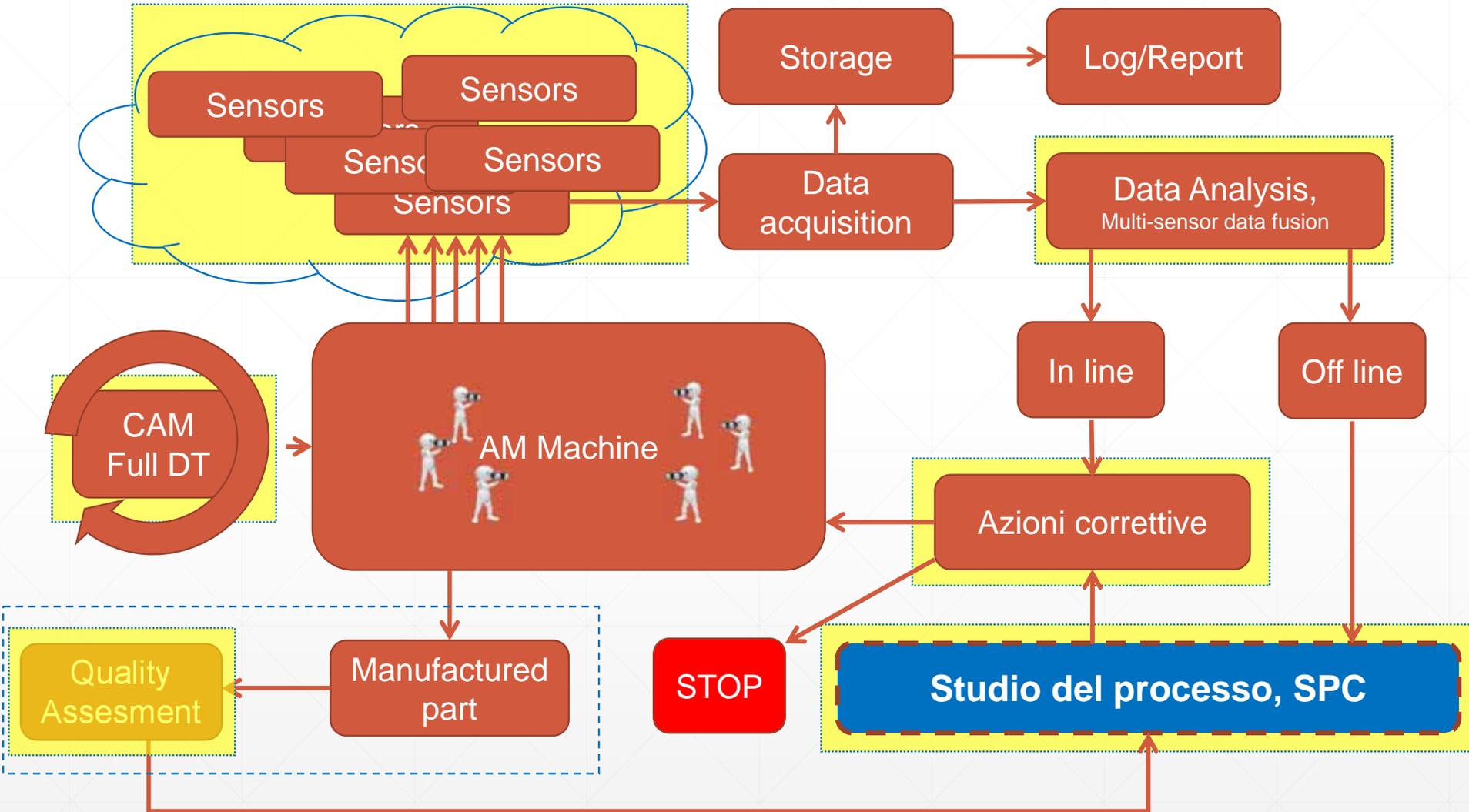
Process monitoring



Process monitoring and SMART manufacturing



Process monitoring and SMART manufacturing



Process monitoring and SMART manufacturing

Obiettivi:

- Sistemi di modellazione predittivi della presenza (probabilità) di difetti localizzati e/o distribuiti (*FDT, Modeling, Data mining*)
- Sistemi capaci di «flaggare» regioni delle parti al di fuori del controllo di processo (*SPC*)
- Sistemi capaci di reagire attivamente per mantenere il processo sotto controllo (*SMART manufacturing*)
- Sistemi capaci di identificare difetti geometrici «in-process»
- Garantire la conformità della parte

Svantaggi

- Complessità della macchina, costi (?)

Process monitoring, Sensor classification

Tecnologie AM

SLM, SLS, EBM, DMD, JF, FFF, mFFF etc...

...ogni tecnologia ha le proprie caratteristiche e necessità di sistemi di monitoraggio dedicati.

CLASSIFICAZIONE

Sensori basso livello

- Temperatura (*con e senza contatto*)
- Power (*optical, electric, thermal*)
- Posizione, velocità, accelerazione
- Forza (*load cells*)
- Shock (*Acoustic emission*)
- Pressione
- Flow (*gas, powder, filament, resin*)

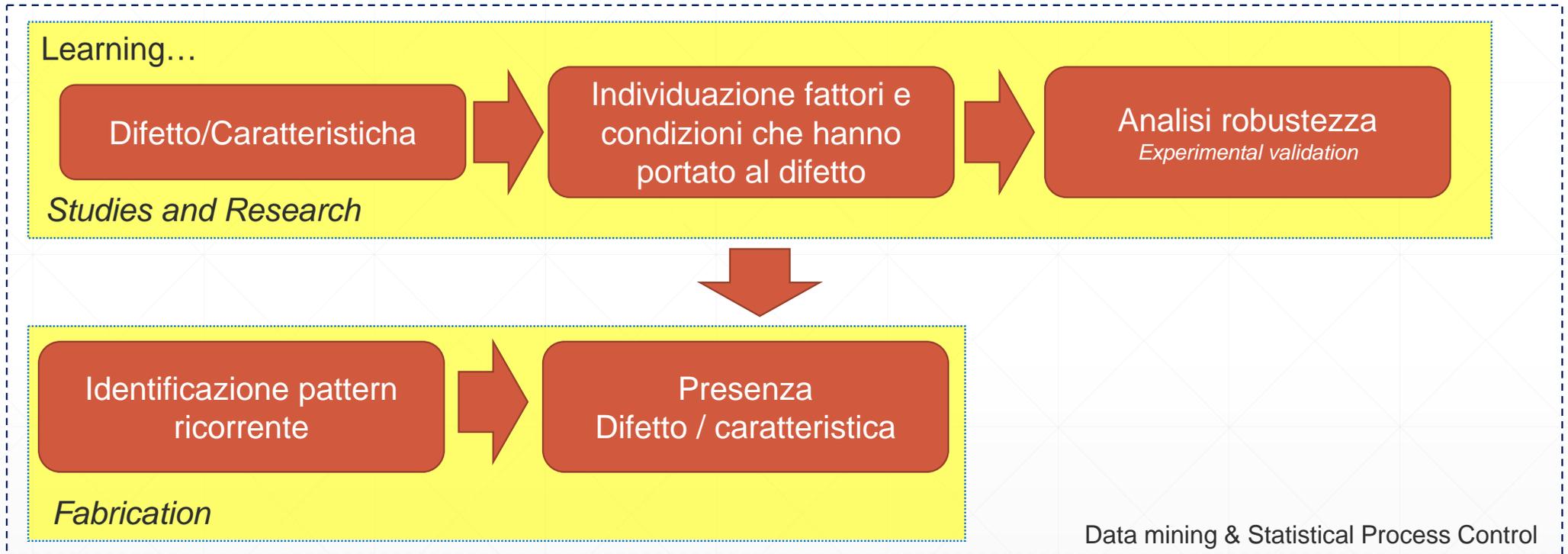
Grandezze osservate SENZA interrompere il processo

Sensori alto livello

- Imaging, Im (*VIS and IR field*)
- Surface Topography, ST
- Optical tomography, OT

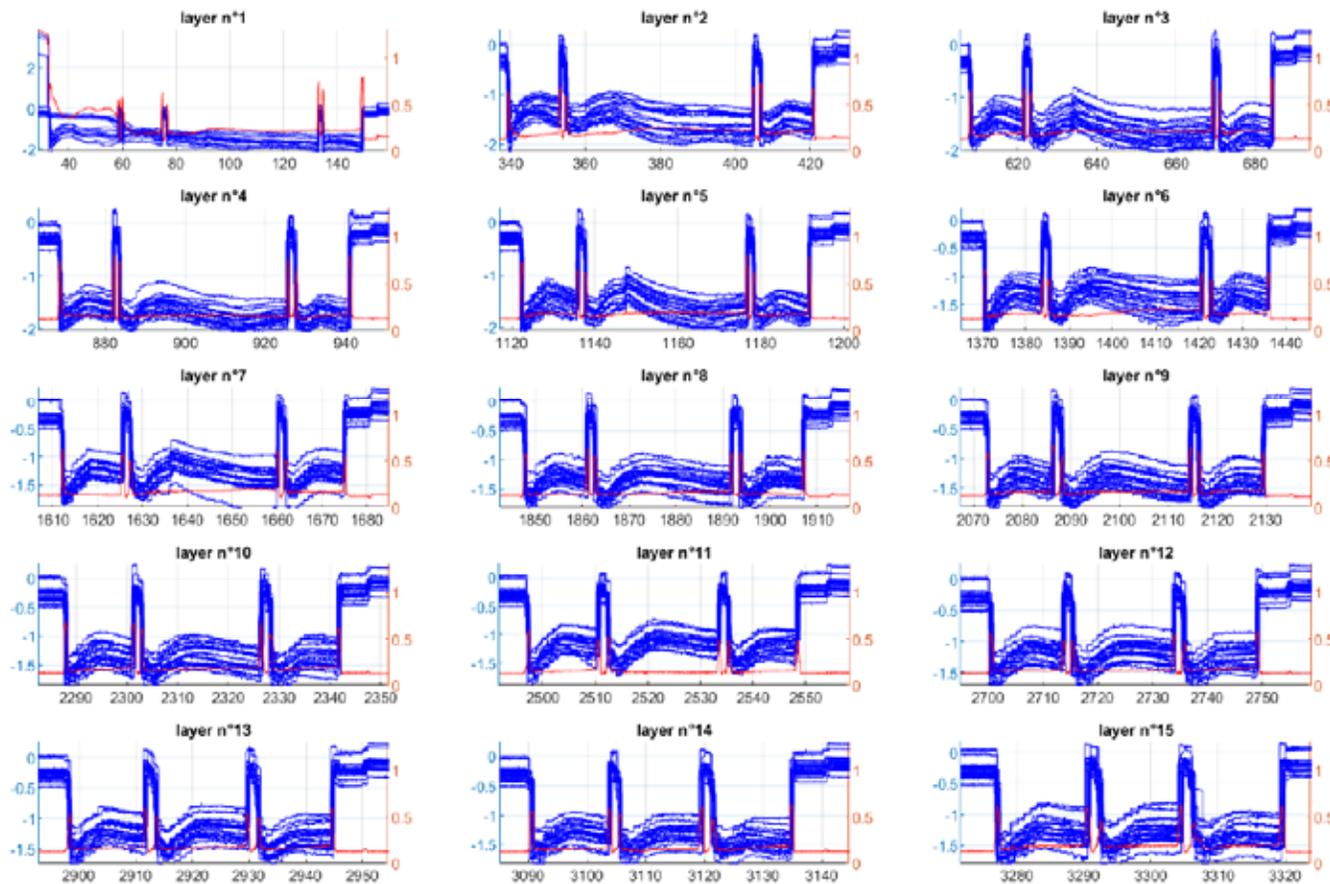
Acquisizione in cui può essere necessario interrompere il processo

Approcci al monitoraggio ed al controllo di processo



Approcci al monitoraggio ed al controllo di processo

Cella A, filament pressure



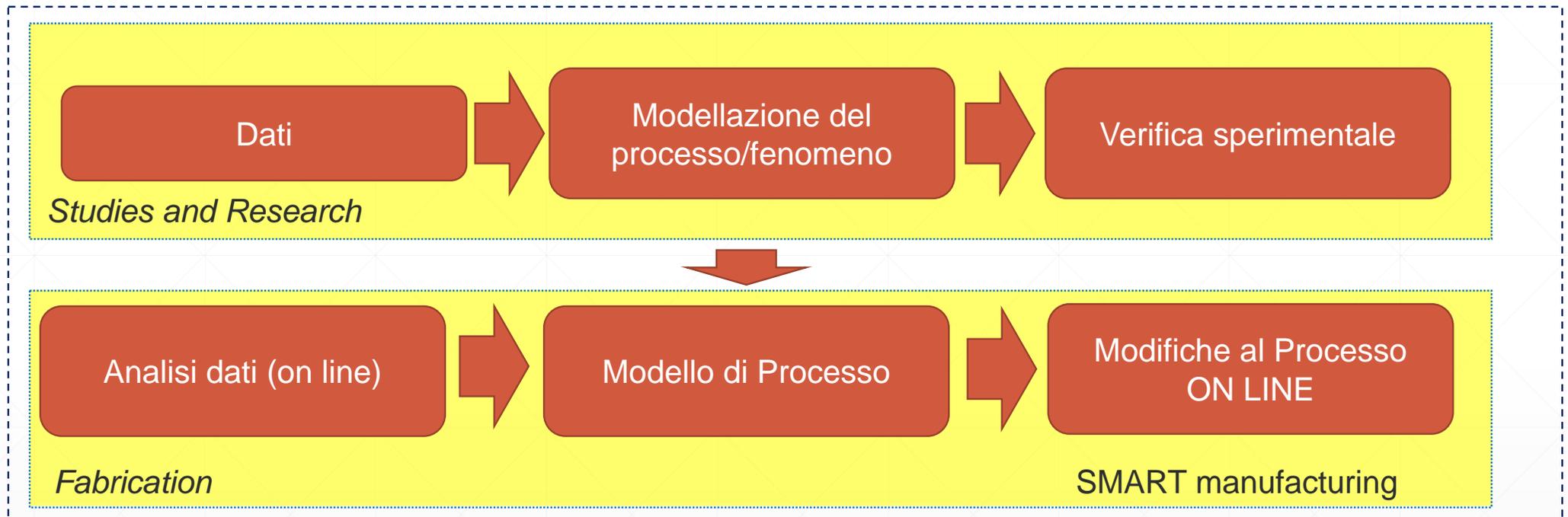
Statistical Process Control

Ricerca di regioni di «sicurezza» che garantiscono la «correttezza» del processo

Individuazione regioni al di fuori del controllo:

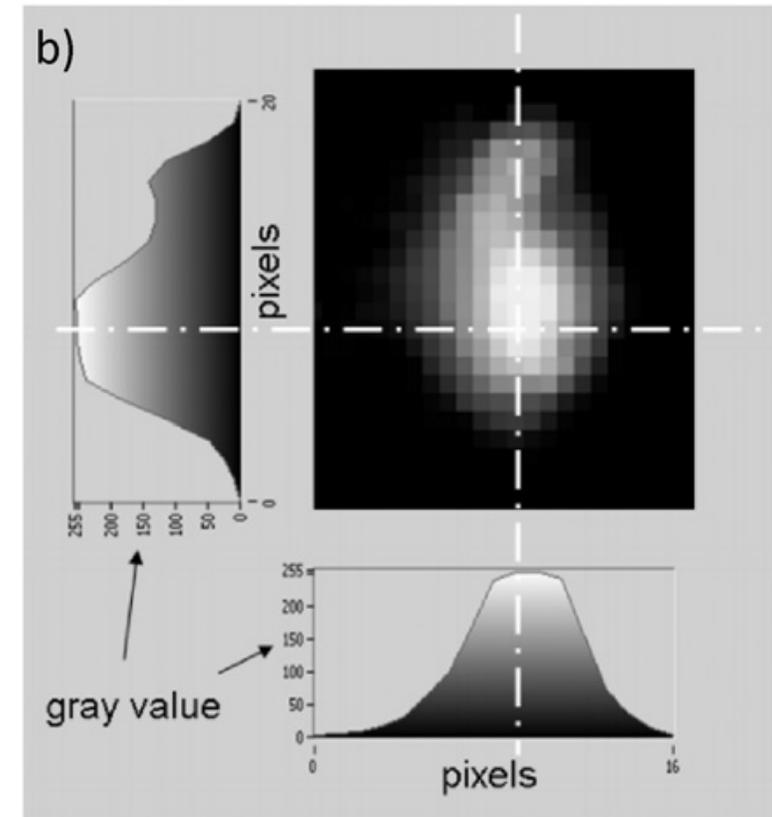
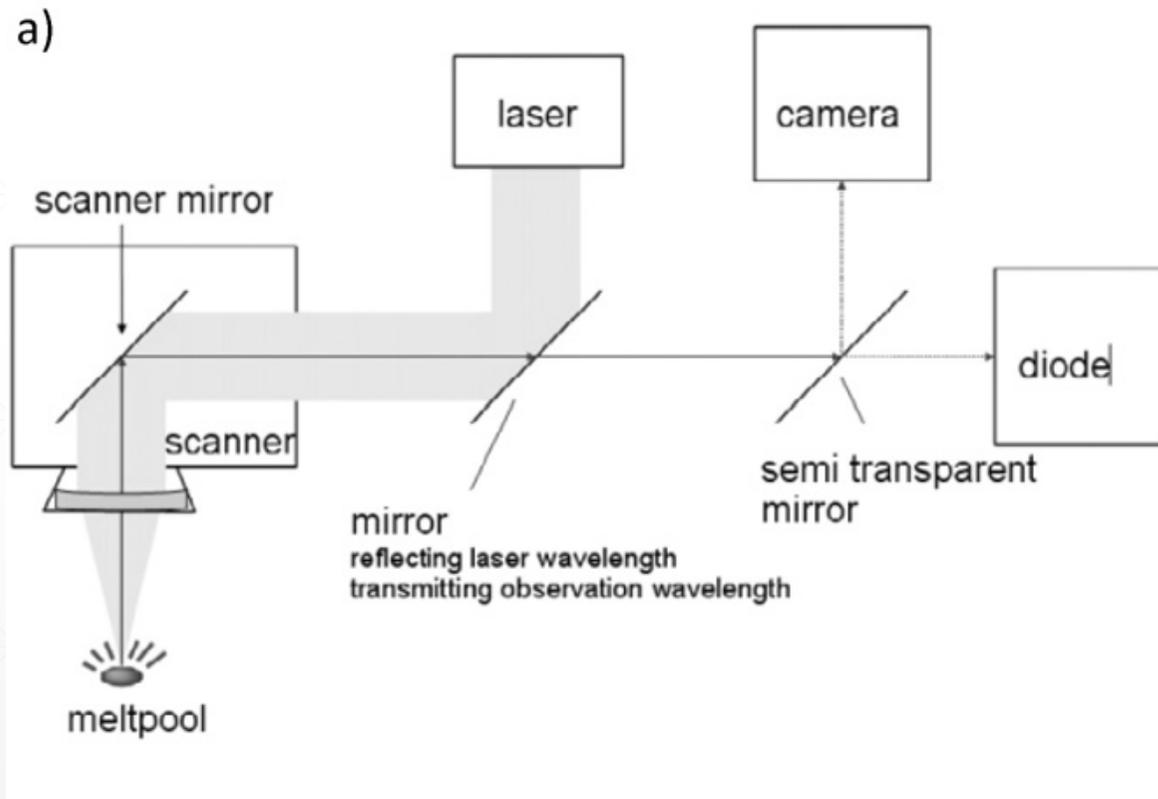
Accettabile?
Non Accettabile?

Approcci al monitoraggio ed al controllo di processo



Machine sensorization: examples SLM, SLS

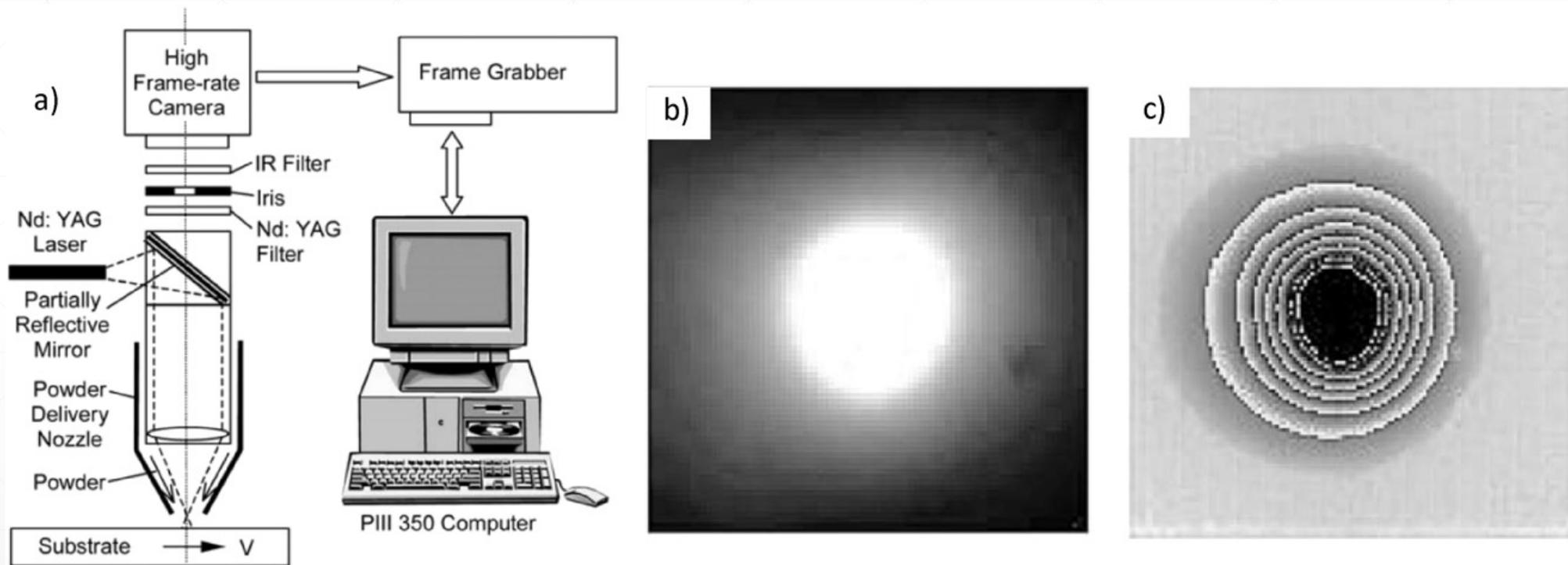
Quality control of laser and powder bed-based Additive Manufacturing (AM) technologies, Berumen



Sistema di visione COAX con la sorgente di potenza

Machine sensorization: examples SLM, SLS

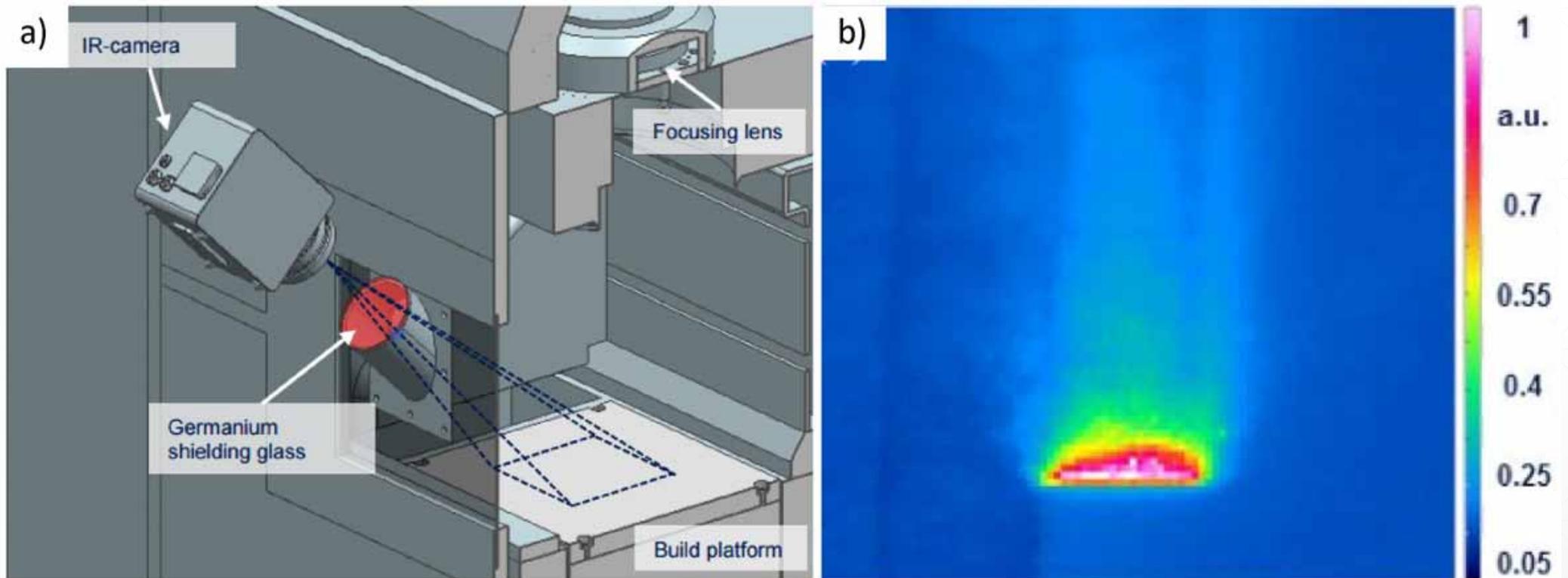
Sensing, modeling and control for laser-based additive Manufacturing, D. Hu,



Sistema di visione COAX con la sorgente di potenza

Machine sensorization: examples SLM, SLS

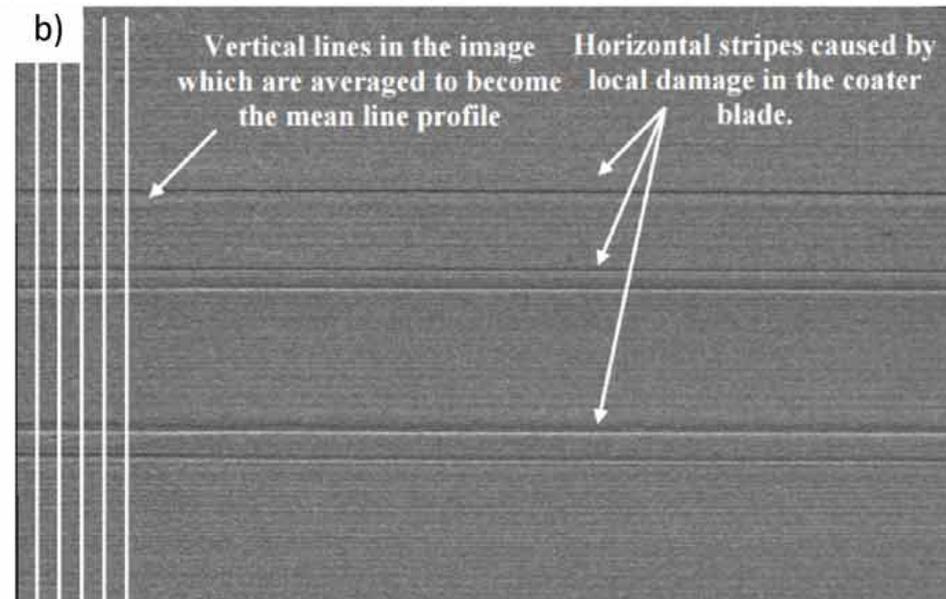
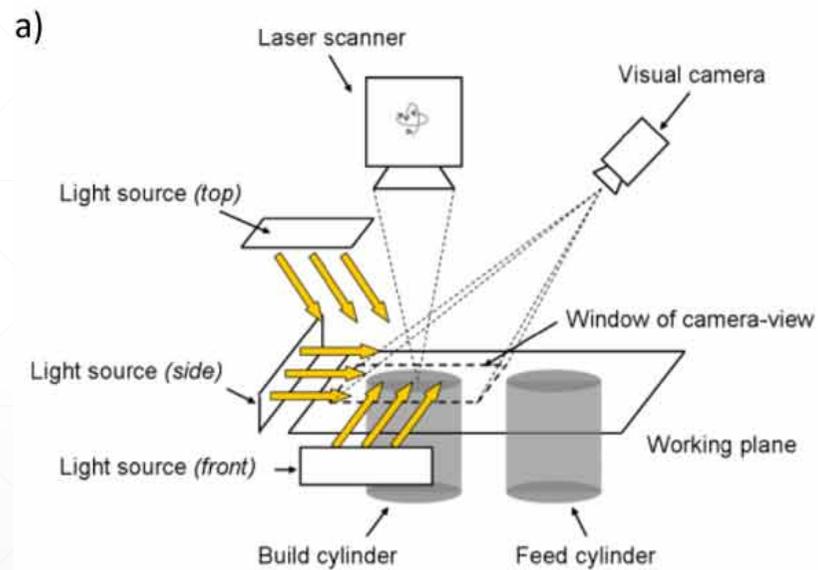
Thermography for monitoring the selective laser melting process, H. Krauss



Sistema di imaging IR

Machine sensorization: examples SLM, SLS

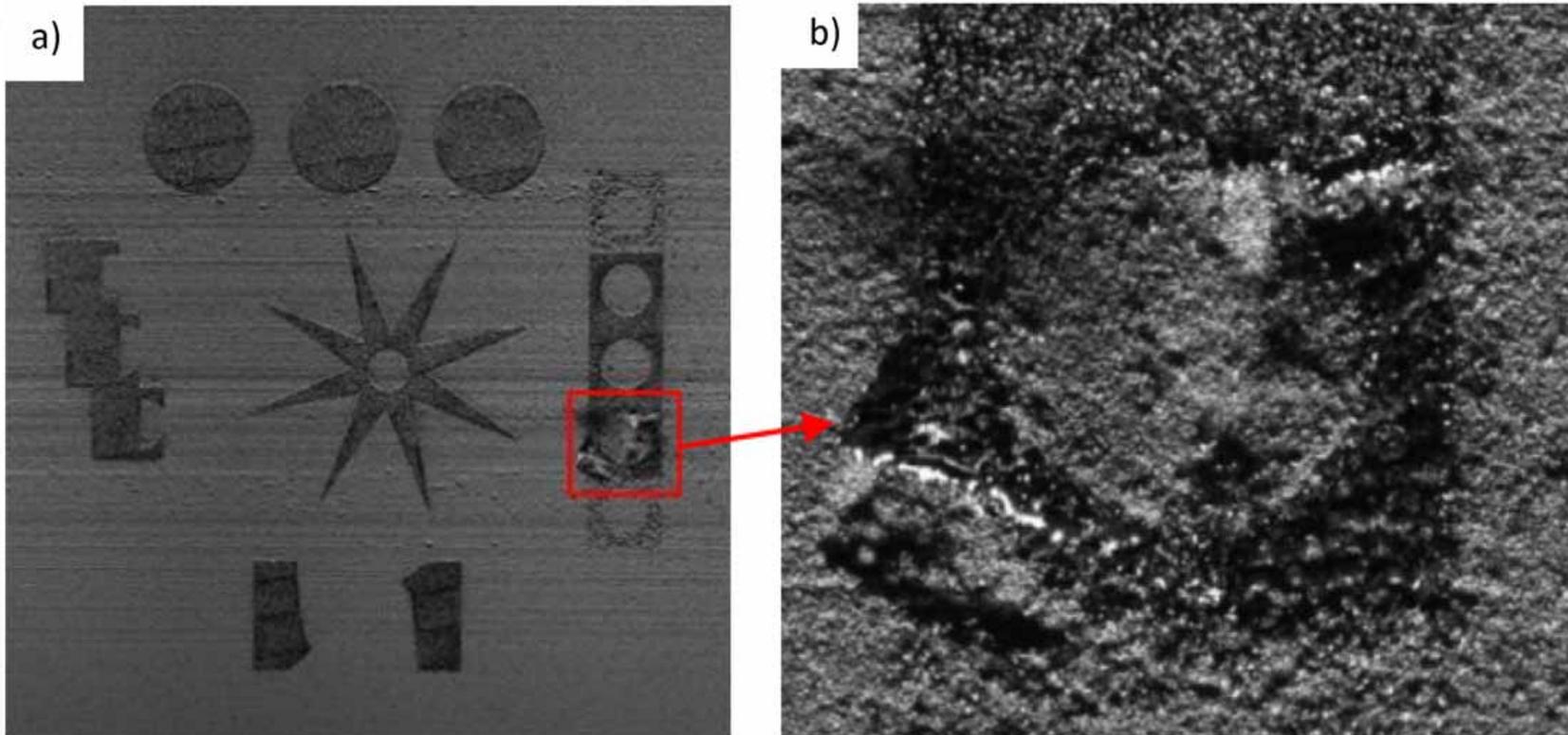
Online quality control of selective laser melting, T. Craeghs,



Sistema di imaging VIS

Machine sensorization: examples SLM, SLS

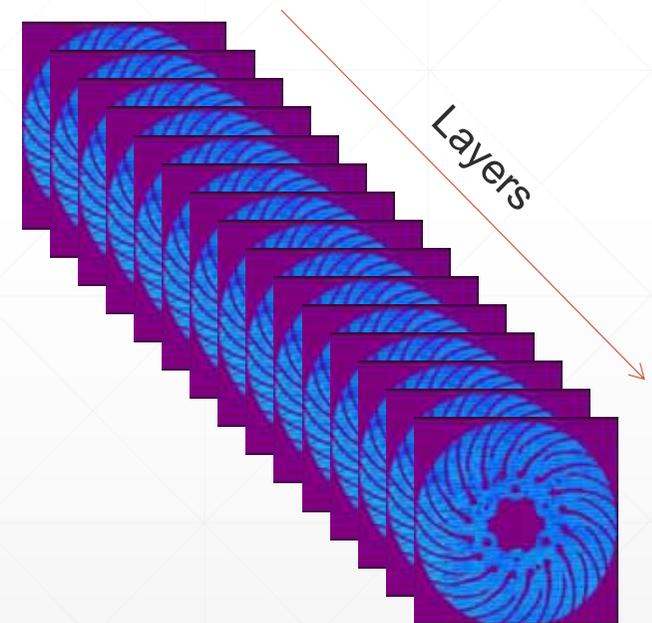
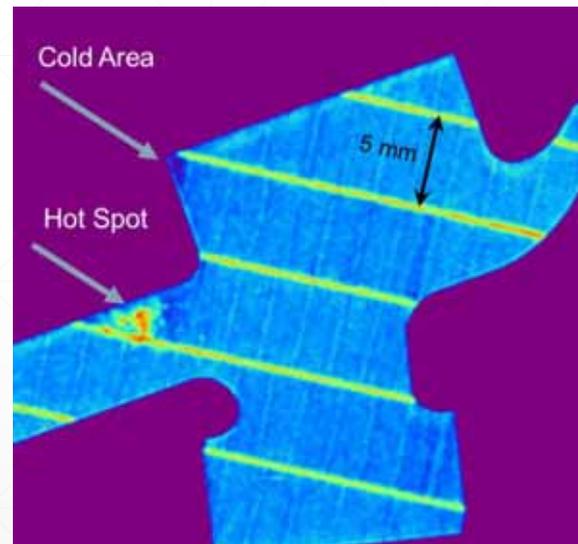
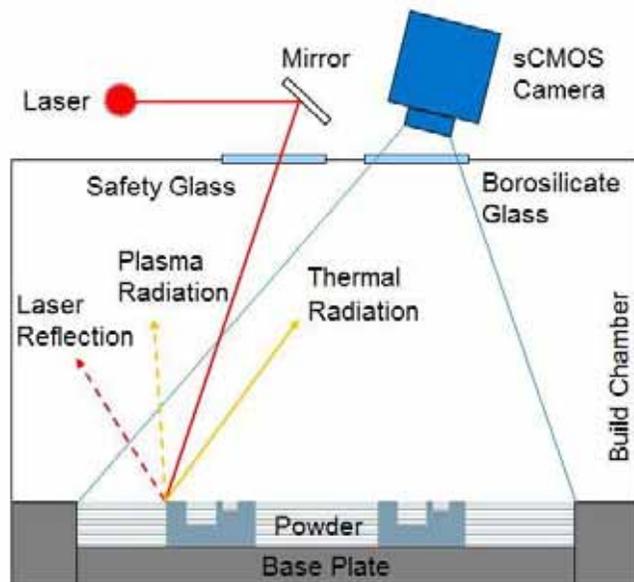
Design of an optical system for the in situ process monitoring of selective laser melting, P. Lott



Sistema di imaging VIS

Machine sensorization: examples SLM, SLS

Process Monitoring of Additive Manufacturing by Using Optical Tomography, J. Bamberg



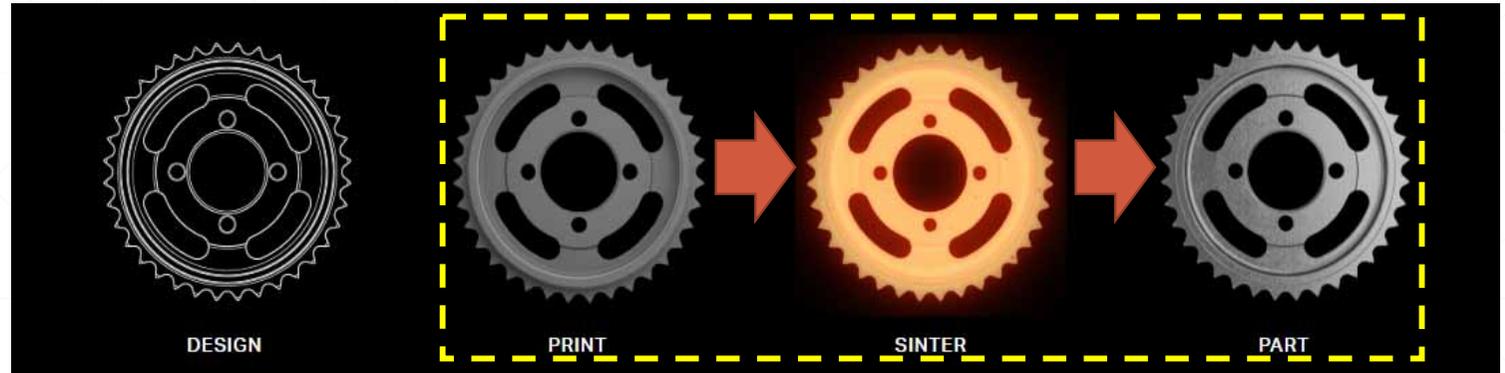
Sistema di imaging VIS ed Optical tomography

Trasferimento tecnologico

EOS monitoring solutions available EOS M 400

Monitoring Solution	EOS M 290	EOS M 400	EOS M 400-4	EOSINT M 270/M 280	EOS M 100
EOSTATE System	X	X	X	X	
EOSTATE Laser	X	X	X	X	
EOSTATE PowderBed	X	X	X		
EOSTATE Exposure OT	X				
EOSTATE MeltPool	X				
EOSTATE Modul Quality Assurance	X	X	X	X	
EOSTATE Modul Controlling	X	X	X	X	
EOSTATE Modul Machine Park	X	X	X	X	

Fused Filament Fabrication: from Polymers to Metals



3D PRINTED METAL PART

CAMSHAFT SPROCKET

The strength and surface hardness of 17-4 PH stainless steel enables 3D printing functional toothed parts, like this camshaft sprocket.

Typical Machined Cost	\$279.06
Markforged 3D Printed Cost	\$12.56
Savings	96%

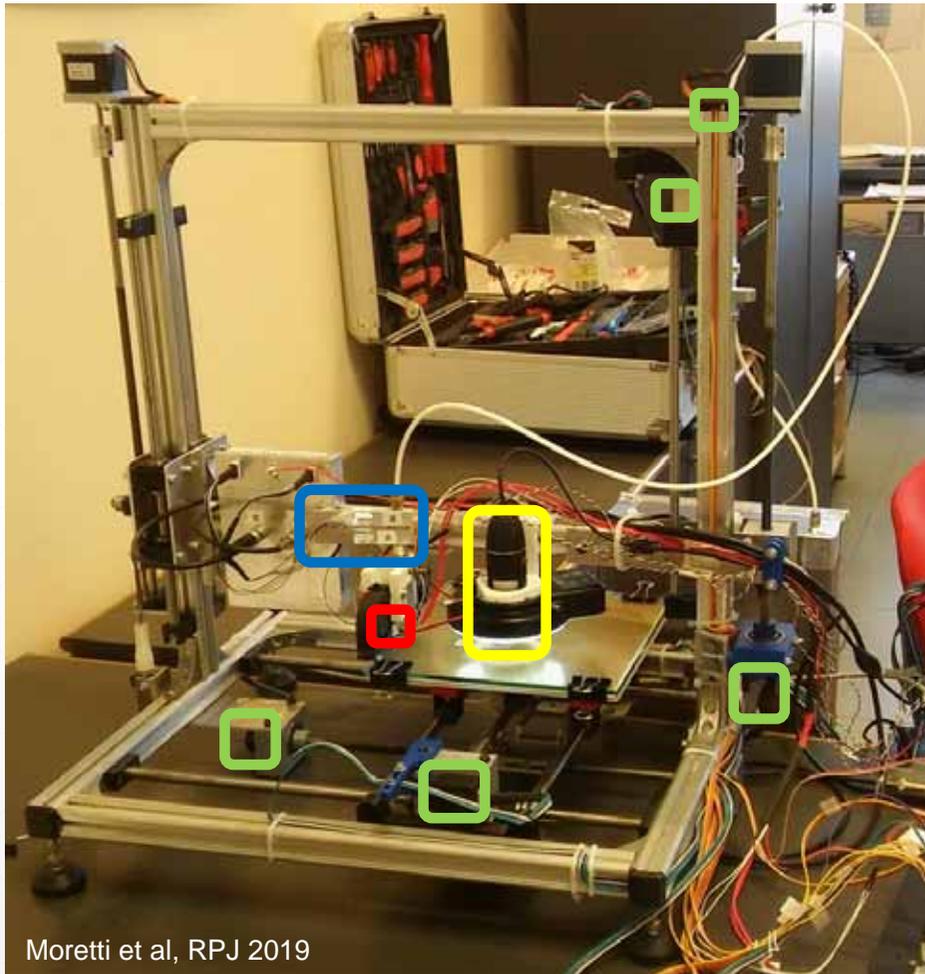
Impeller Sprocket Bracket

- *Inconel Alloy 625*
- *H13 Tool Steel*
- *D2 Tool Steel*
- *A2 Tool Steel*
- *17-4 pH Stainless Steel*

- *Ti-6Al-4V (Beta)*



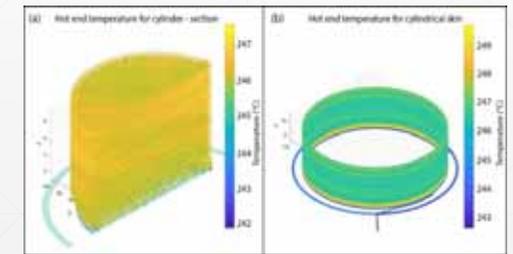
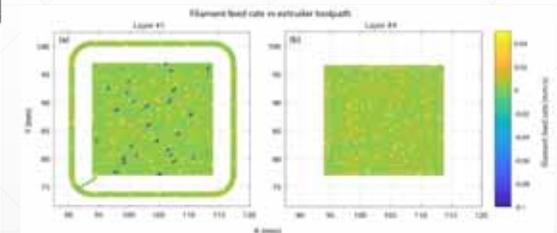
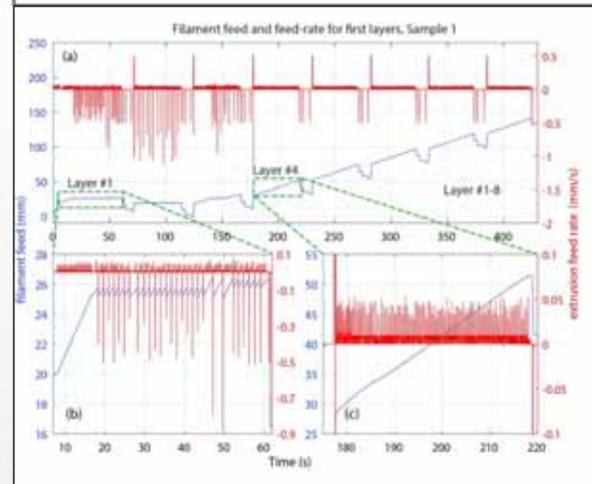
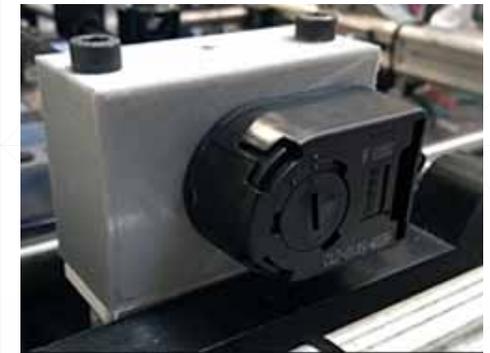
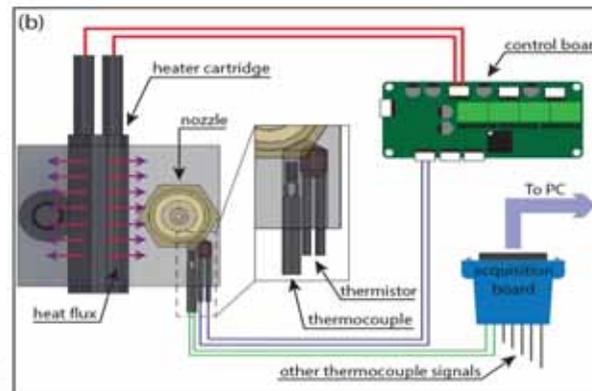
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Moretti et al, RPJ 2019

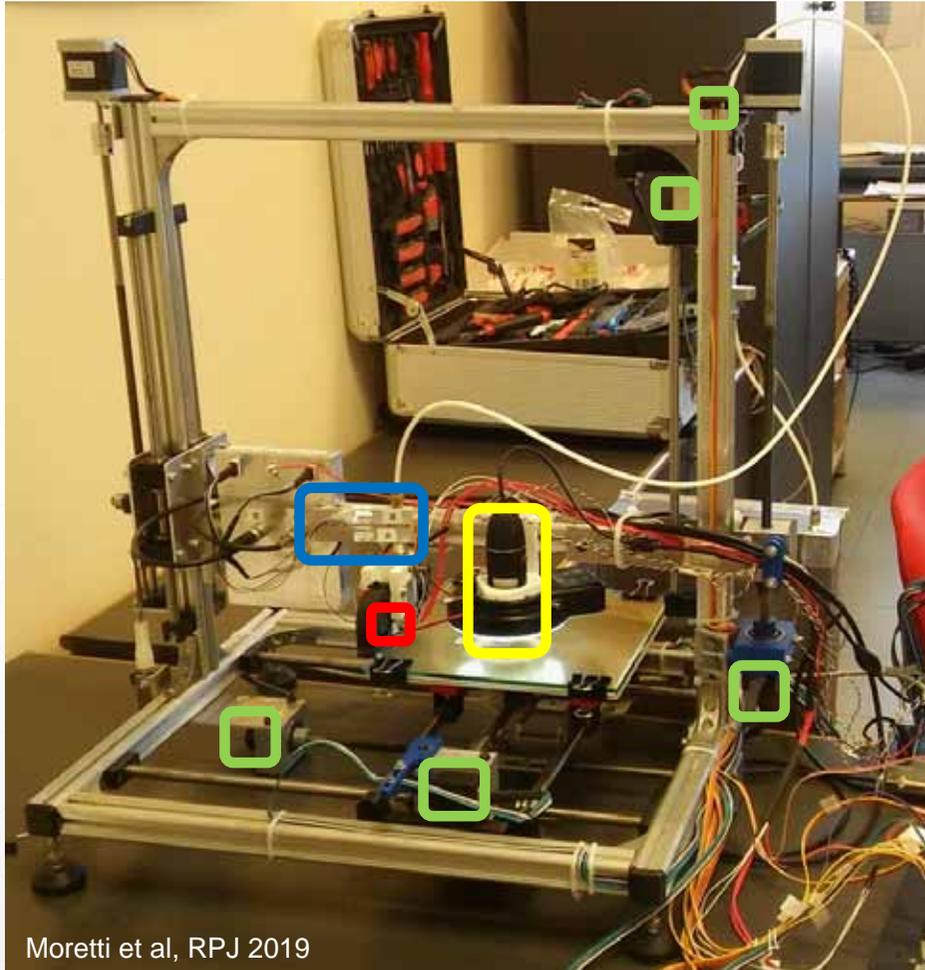
Full process monitoring, low level sensors and imaging VIS

- **Multi-sensor data fusion (time and space domain)***





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Moretti et al, RPJ 2019

Full process monitoring, low level sensors and imaging VIS

- *Multi-sensor data fusion (time and space domain)**
- *On line geometry reconstruction, OT (2.5 D)**
- *On line shape and dimensional errors, SmED (imaging)**
- *Data mining and Statistical Process Control*
- *Extrusion process modeling (multi variable)*

Developments

- *On line Full 3D geometry reconstruction*
- *On line Thermal imaging*
- *Surface Topography*
- *Defect detection (low level sensors)*
- *Deep learning (imaging and low level sensors)*
- *Geometrical Digital Twins*
- *SMART machines*



Grazie per l'attenzione

