Imaging under challenging conditions

– an application case in steel mills

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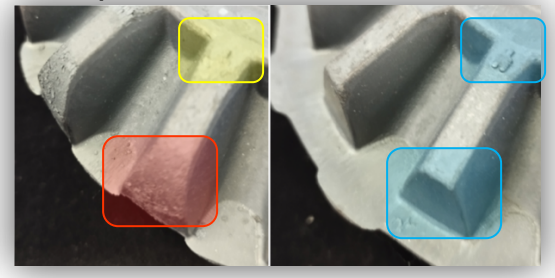
Vision-based inspection in manufacturing

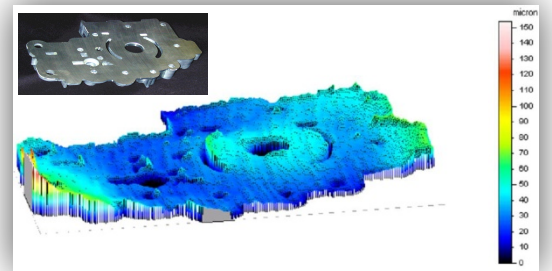
Surveillance/Monitoring

Component/feature check

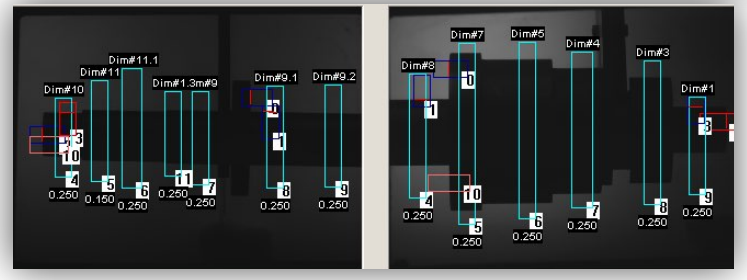


Surface imperfection detection

Shape conformity

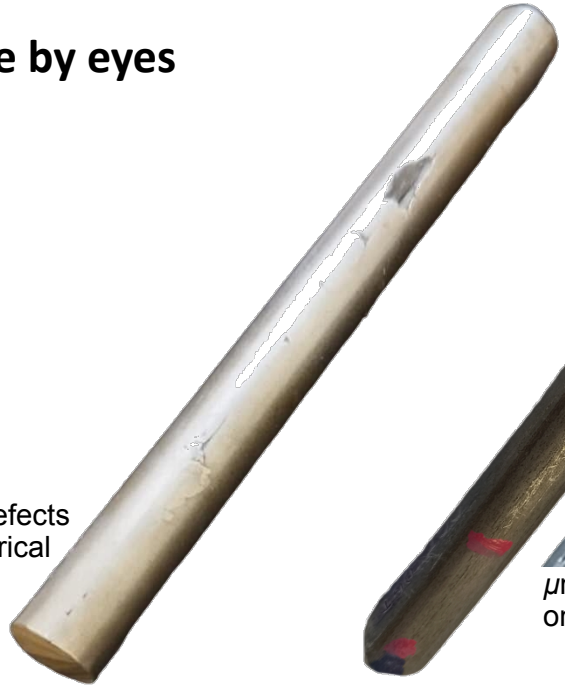


Dimensional measurement

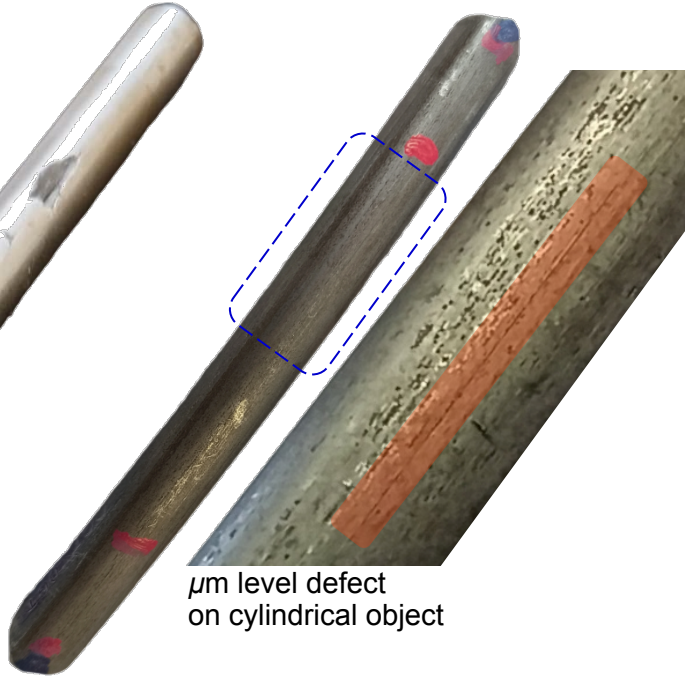


Target of the application

- **Simple geometry – cylinder**
- **Millimeter level – visible by eyes**
- **Could be *µm* level**



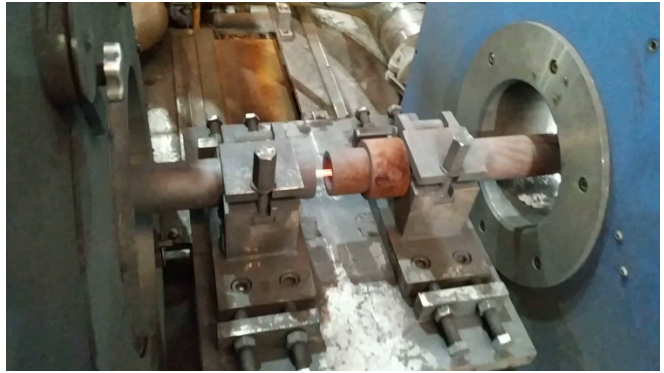
Visible defects on cylindrical object



µm level defect on cylindrical object

Challenging conditions

- **Temperature: 1,000°C ±250°C**
- **Speed: as fast as 112 m/s (400 km/h or 250 mph)**
- **No clean room – spark, smoke, water mist, vapor, dust, oil, vibrations, flame …**



The issue

High degree of variability

- **Potentially leading to constant changes in the resulting images due to**
  - the definition of **surface defects** ;
  - the **surrounding conditions**, and
  - their combinations.

Surface defect, or not

What is a surface defect?

- **Functional imperfection vs. cosmetic blemish**
- **Of any free form**

On the appearance

Blemishes on car engine hood and side fender
(Class A surfaces)

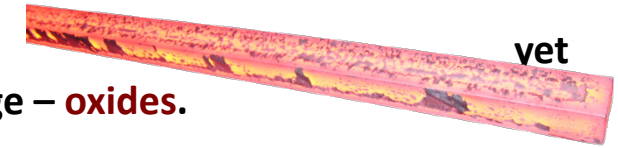
Under the appearance

Raw metal bar
with surface defect

Failures in parts due to
surface defects

It varies from one application, or one defect to another!

Surrounding conditions



- **Temperature is not difficult to overcome in vacuum; yet oxygen in the air may induce arbitrary surface change – oxides.**
- **Speed complicates the issue on imaging and image processing rate, but not far from reachable with today's imaging and computing capability.**
- **However, temperature + speed, and equipment/process to facilitate them lead to further complications:**
  - **Object stability –** precision motion not possible as being hot, fast and soft
  - **Surface uncertainty –**
    - Same defect imaged differently due to varying viewing angle, working distance, etc.
    - Cosmetically and possibly functionally damaged with chemical and/or mechanical mechanisms

Introducing Variability

More surrounding conditions

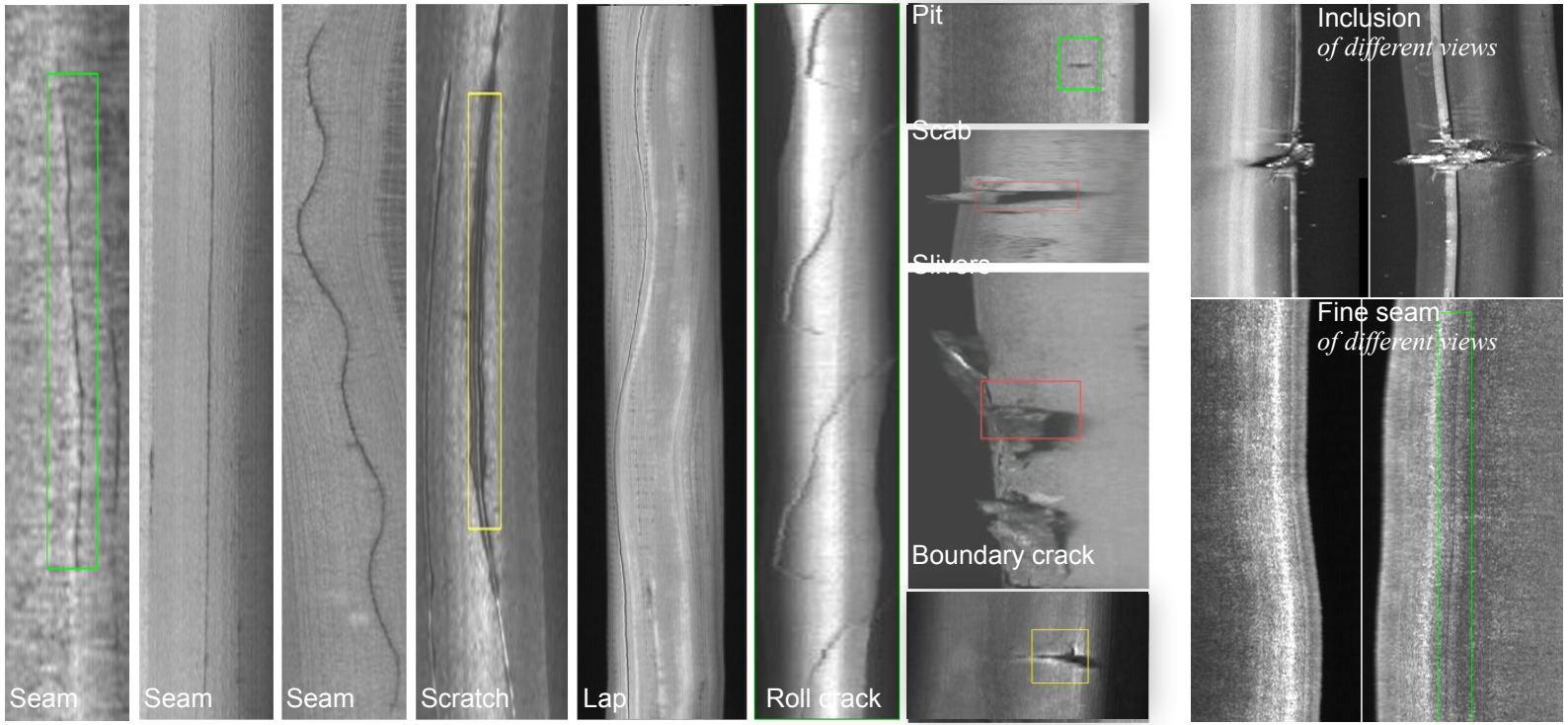
- **Spark, smoke, dust, mist, and more –**
  - **Critical, as "surface defects" are noises to the surface norm**
    - Noise reduction techniques in image processing are inadequate – need to prevent and/or live with noises
  - **Damage to the equipment**
    - Corrosive smoke and mist, damaging spark and water
  - **How to keep the optics clean for hours, days, even weeks.**
- **Catastrophic incidents – survival protection**

Video from *RS Steel Media*

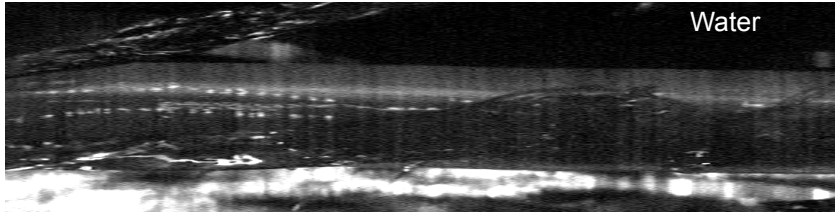
More variability

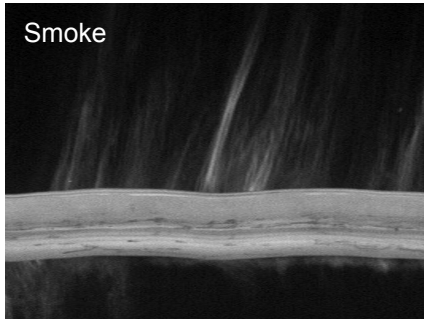
Examples of variability – defects

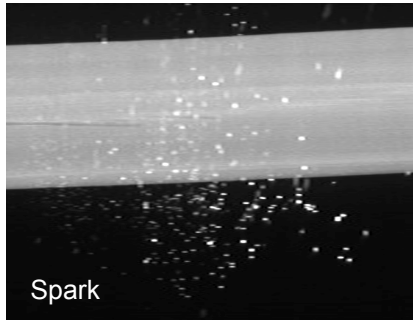
Various types/shapes of defects (indications of equipment failure or potential finished product failure)

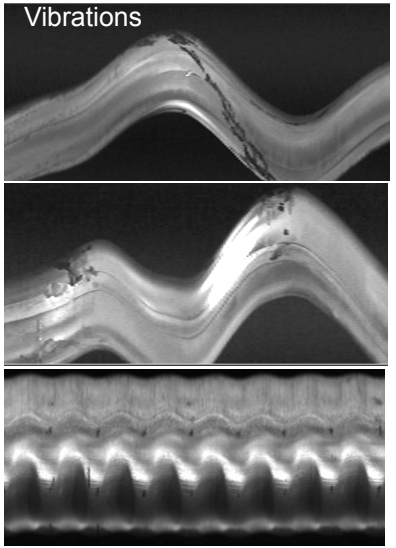


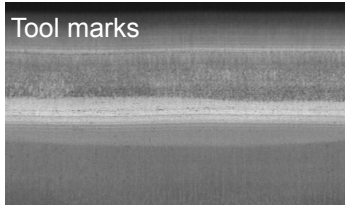
Example of variability – noise

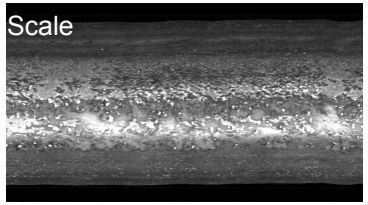


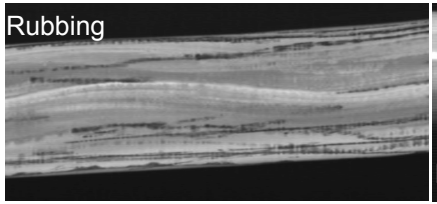


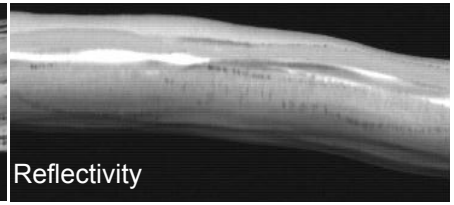












Constraints

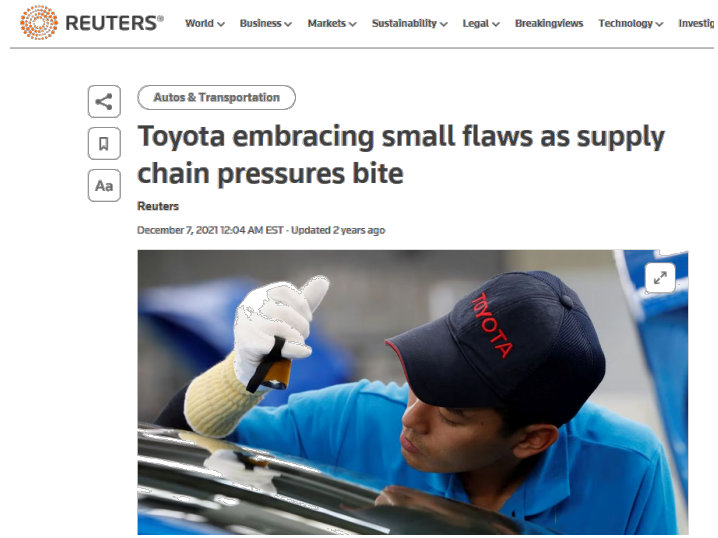
- **Available components –** not as critical for visible light applications nowadays with the advances in electronics and materials
- **Clock ticks –** to meet the throughput or cycle time
- **Space, in particular fitting into existing equipment**
  - Obvious – space used during normal production
  - Latent – space used during special case (e.g., maintenance or repair)
- **Work style –** style of operation, maintenance, management, etc. due to regional differences and limitations

Additional consideration

- **Technical feasible ≠ applicable**
- **How much would the industry pay for?**

  Limited pocket depth with an attitude –

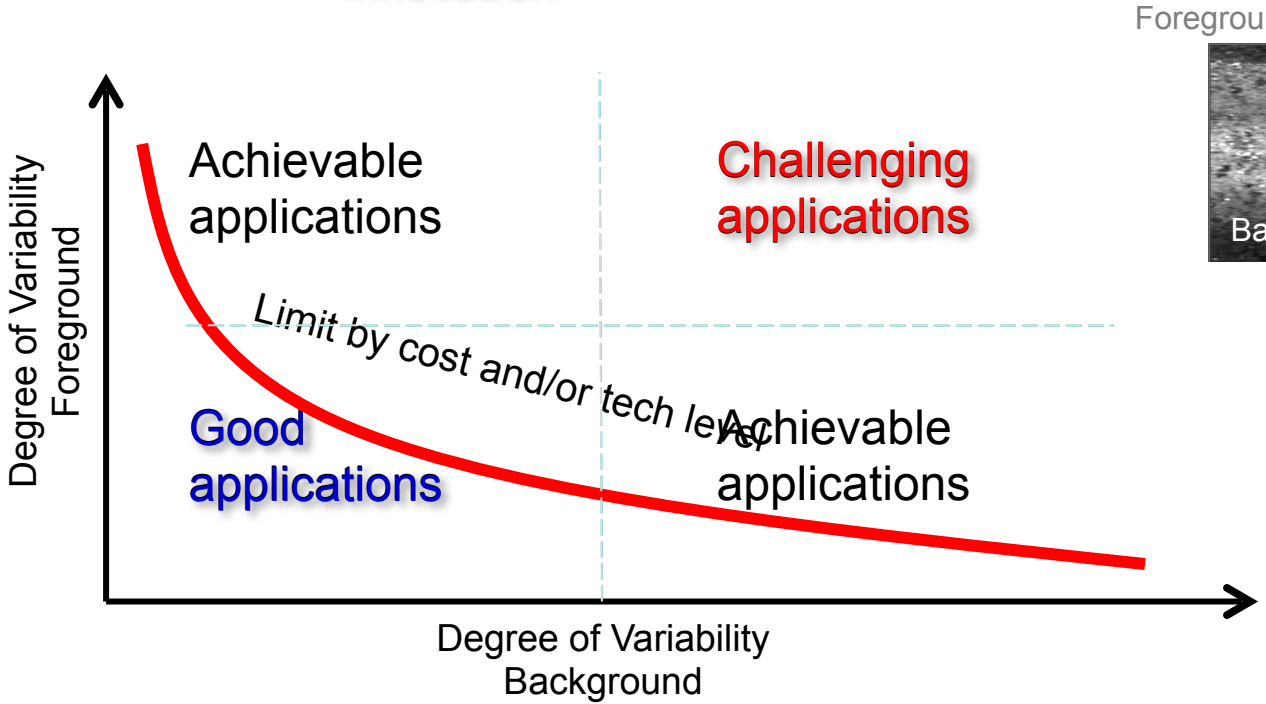
  - Quality focused : quality a must
  - Quality oriented : quality of high priority
  - Quality sensitive : quality for profitability
- **Circumstances change!**
  - Repair cost lower than reject
  - Market demand

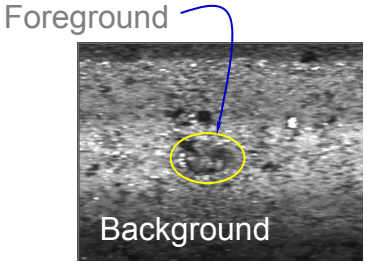


"TOKYO, Dec 7 (Reuters) - Toyota Motor Corp on Tuesday said it is happy to use scratched or blemished parts from suppliers as the world's biggest car producer tries to trim costs amid a production-curbing global chip shortage and rising material costs."

Variability, trade-off & innovation

Moving the lines by innovation





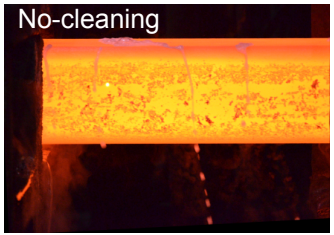
Coping with variability

A few thoughts:

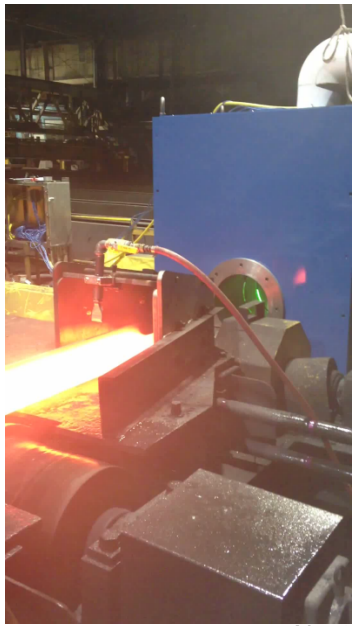
- **Physical means –** preventing variability by changing conditions
- **Engineering knowledge –** detecting in variability by way of engineering oriented image abstraction
- **High dimension discerning –** enhancing precise and stable decision boundaries using large quantity of samples for training

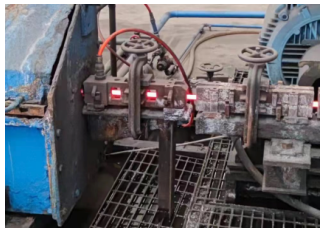
Physical noise reduction

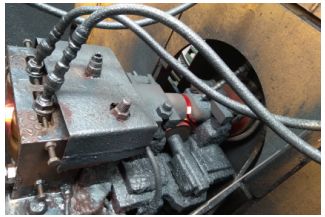
Change the conditions – high pressure water and/or air stripping, effective, but at a cost



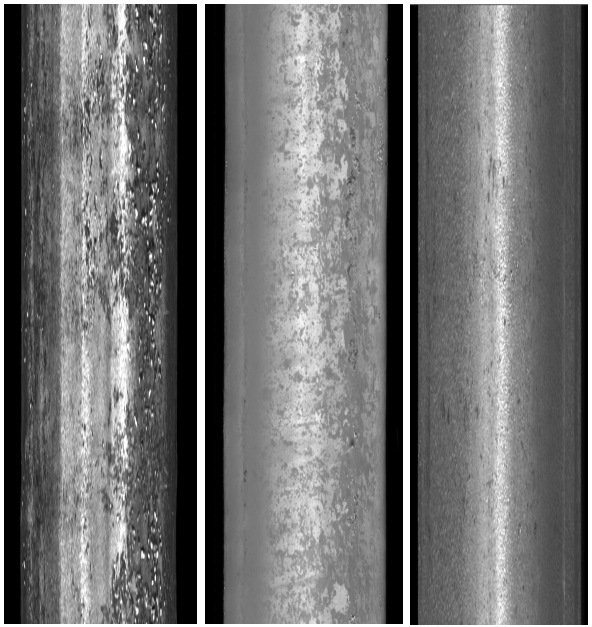
Water stripping



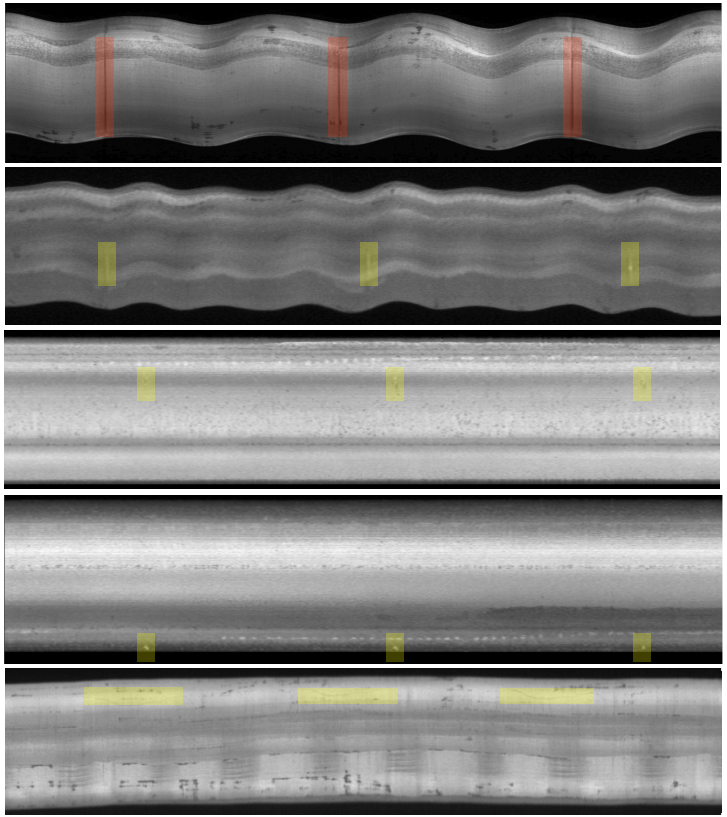




Air stripping

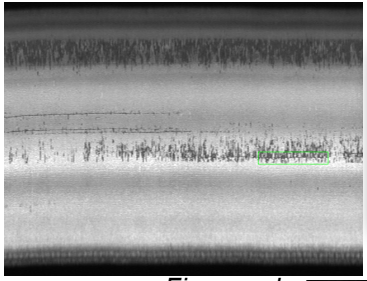


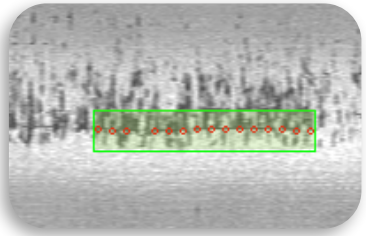
Detecting in variability



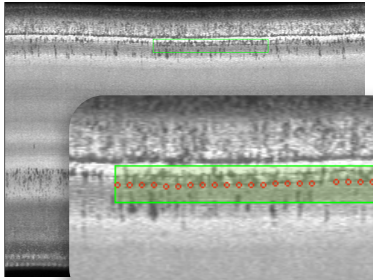
Same marks from two views

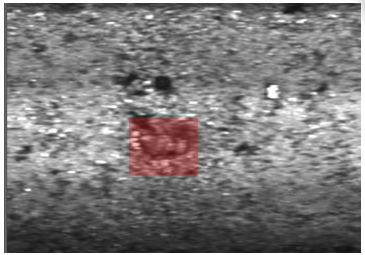
Detection of different roll marks
Pitch: from 75~20,000mm
Length: up to 14,000m





Fine cracks



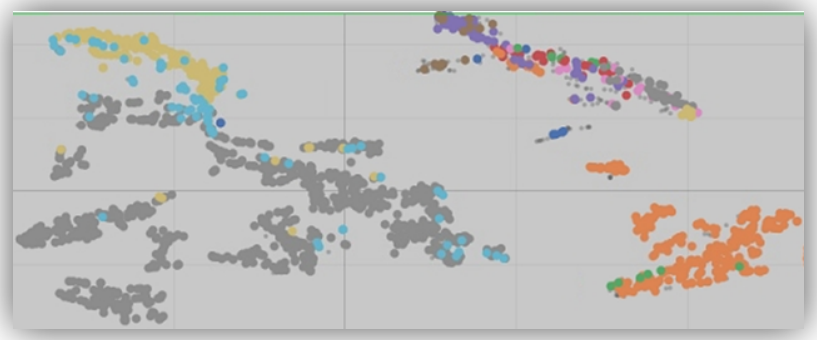


Scab

Discerning capability

- **High #samples + good sample variety + consistent labeling**
  → better defined, or "learned", decision boundaries in the data universe for precise and stable detection and classification.

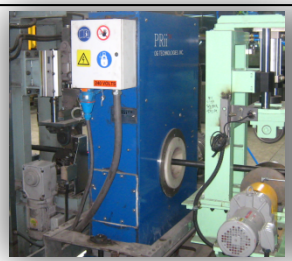
- **Unsupervised labeling**
  - The unsupervised clustering can greatly reduce the need of human work and promote consistency in labeling.
  - Example of clustering 50K image samples:
    - Accomplished ~85% satisfactory results;
    - Reduced the need of human intervention to less than 5% of the image samples.



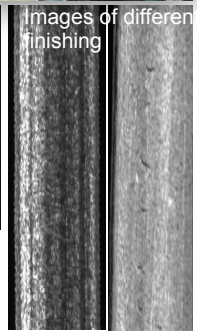
Summary

- **Think beyond imaging**
  - Not only engineering imaging, but also engineering for imaging to work.
- **Alignment**
  - Definition of surface defect could be difficult, but critical.
  - Not only a process of detection/classification, but also a process of "learning" from and being adaptive to the users and/or market
- **Make it work** vs. **prevent it from failing**
  - Prevent it from failing for new batch, different production equipment / line, various operating / maintenance / management styles, environmental changes, etc.
  - Cautious on extrapolation.

More Challenges

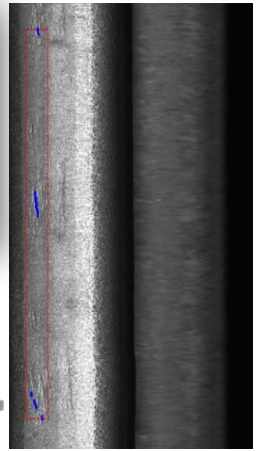


Metal bars of different surface finish (digital photo)



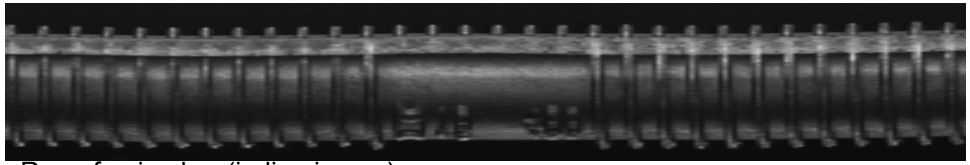
Images of different finishing

Rails of different geometry (digital photo)



Rail (in-line image)

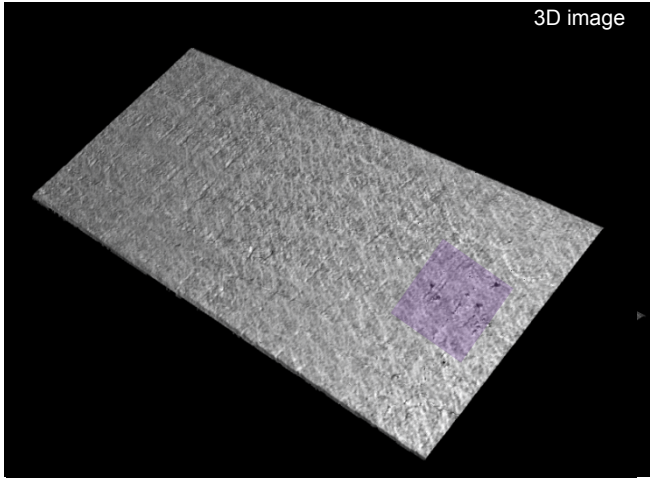
Hot state internal surface inspection

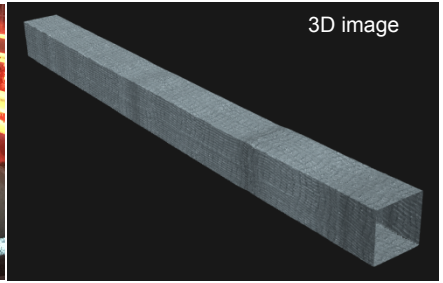


Re-enforcing bar (in-line image)

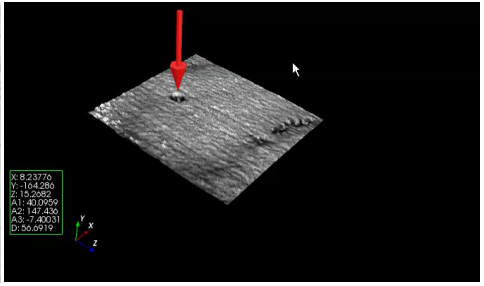
3D applications

- More intuitive than 2D images
- Higher dimension data → more features to overcome noise
- An application: continuous casting
  - Extremely harsh environment
  - Super noisy surfaces with irregularity





Digital photo of pinholes



Detection of a pinhole

The End

Special acknowledgement to our R&D partners at **Georgia Tech**, **University of Michigan**, and other institutes

Case report based on the focus of **OG Technologies, Inc.**

- A group of engineers with expertise in optics, imaging devices, algorithm/software development, controls, mechanisms, and system integration
- Focusing on imaging and imaging data applications requiring specialties in inline measurement/inspection and process control for automotive parts, diamond pad conditioners, forging and metal long products
- Over 80 customers located in 14 countries across Americas, Asia and Europe