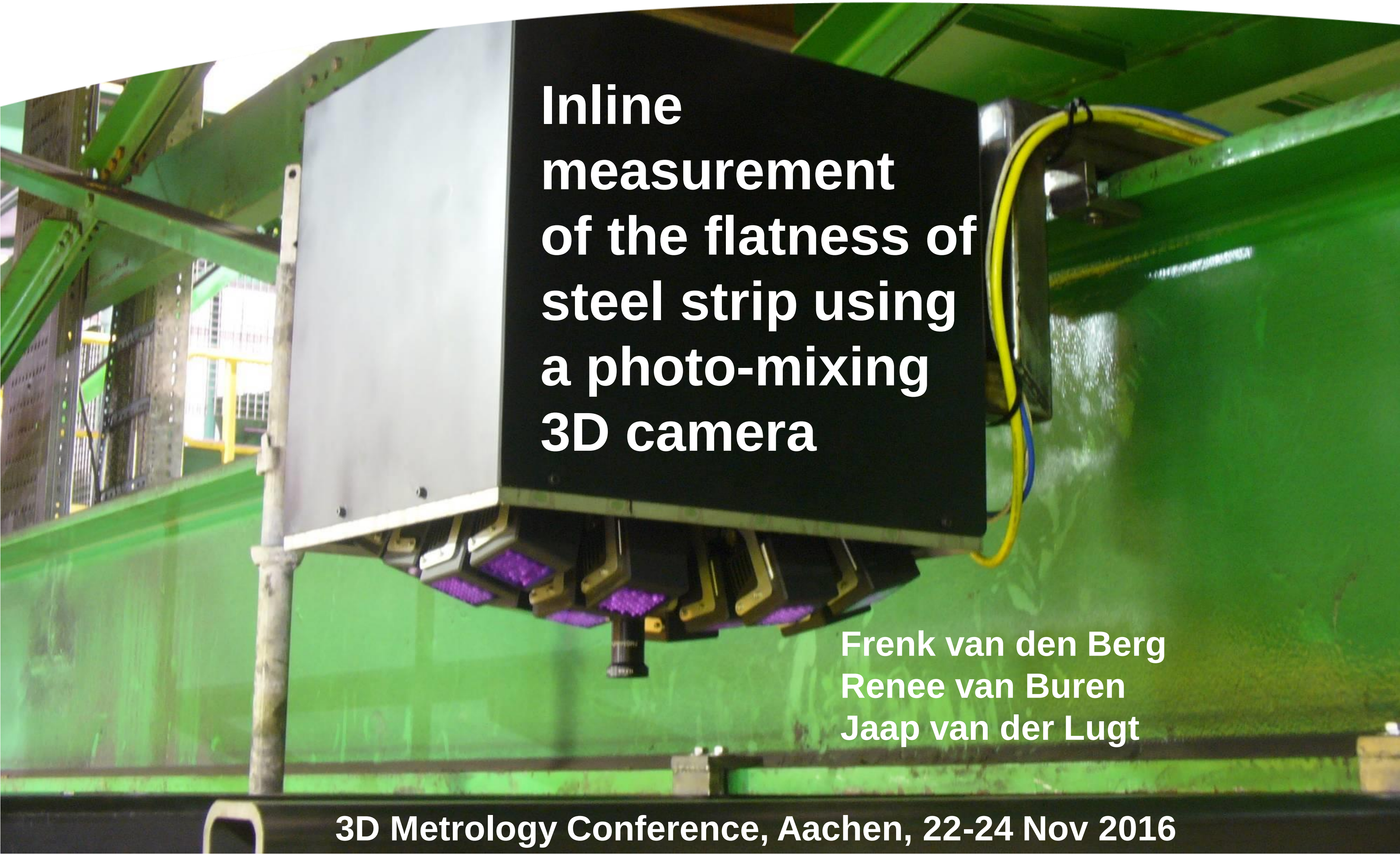
TATA STEEL

TATA

Inline measurement of the flatness of steel strip using a photo-mixing 3D camera

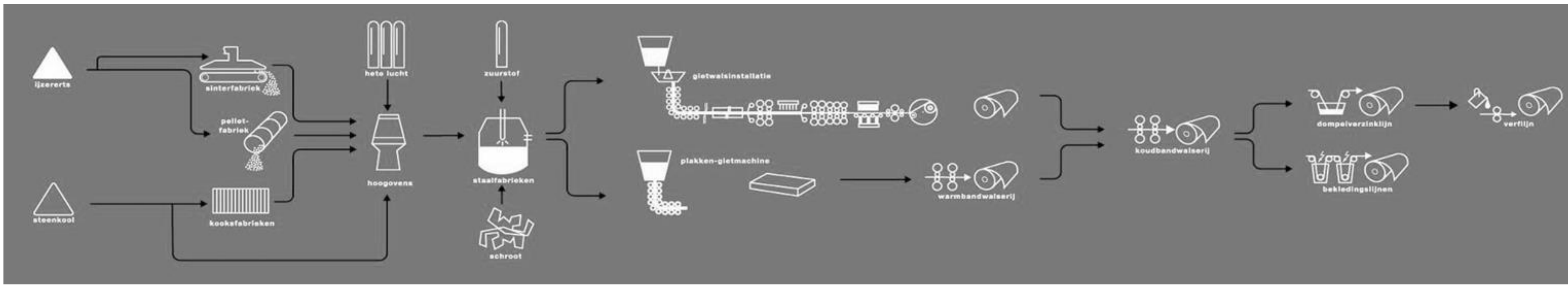


Frenk van den Berg
Renee van Buren
Jaap van der Lugt

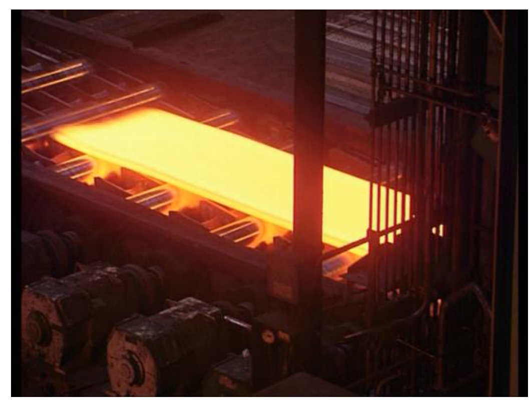
3D Metrology Conference, Aachen, 22-24 Nov 2016

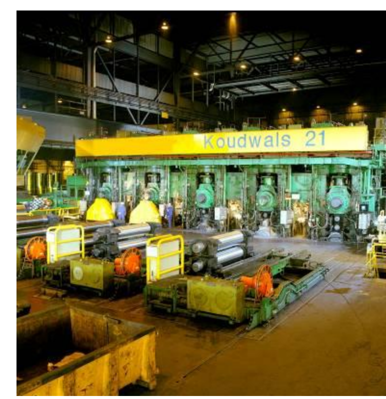
Introducing Tata Steel in IJmuiden, NL

Tata Steel in IJmuiden produces high-quality, hot- & cold-rolled and coated steel strip



Raw Materials – Raw Iron – Steelmaking – Casting – Rolling – Coating





Agenda

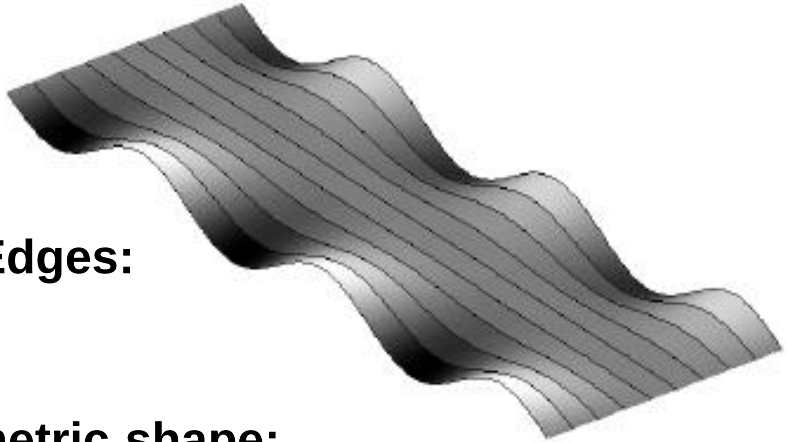
Strip shape: FLAT versus NON-FLAT

FLAT

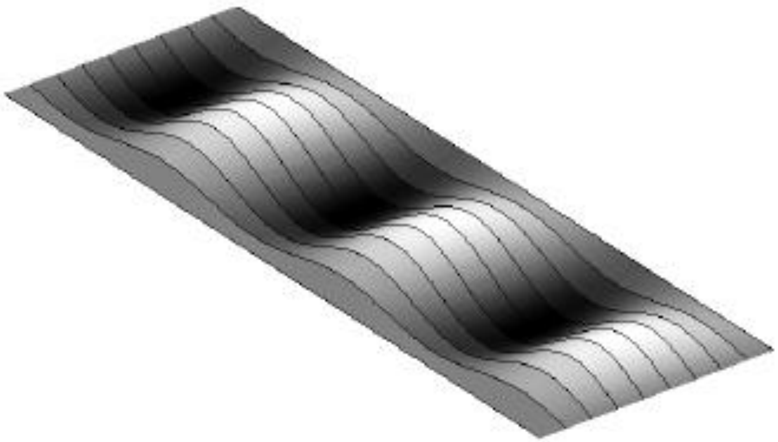
NON - FLAT

Strip shape: Classification of shape defects

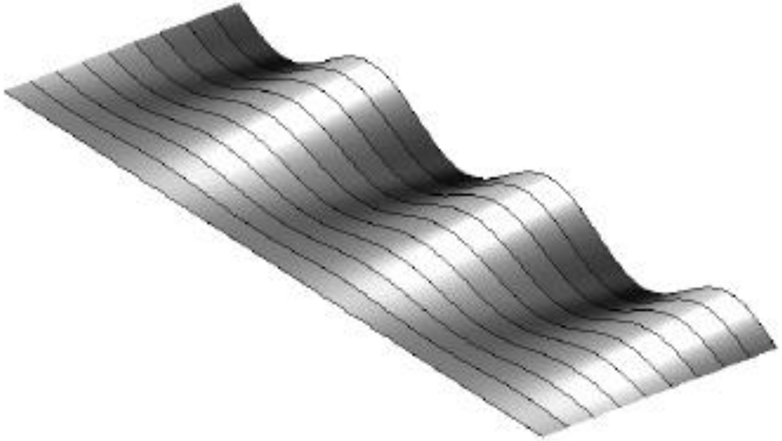
Wavy Edges:



Centre Buckles:



Asymmetric shape:



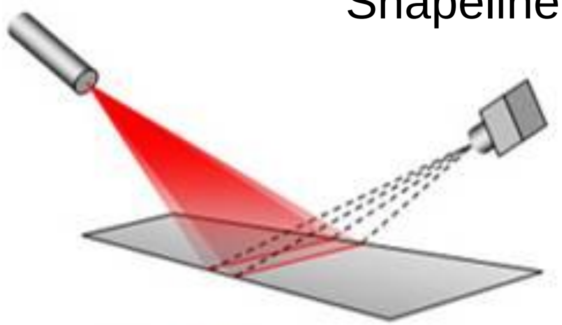
Figures from Julio Molleda,* Rubén Usamentiaga, and Daniel F. García, Sensors (Basel). 2013 Aug; 13(8): 10245–10272

Shape measurement systems – commonly used technologies

All industrial shape measurement systems are based on optical triangulation techniques

Laser Triangulation

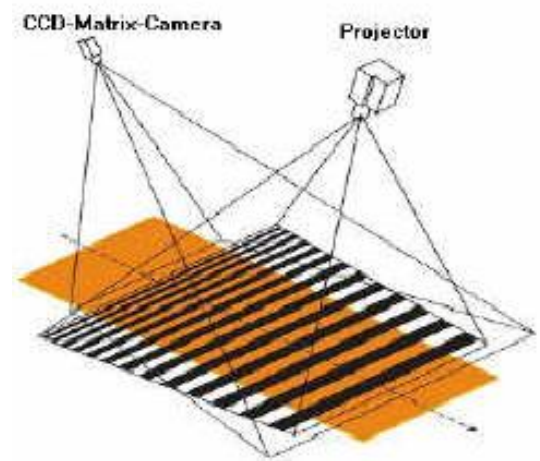
- Systems from e.g. Lase, Sick, Shapeline



Two laser lines are projected and viewed by the camera

Fringe projection

- Systems from e.g. BFI -> IMS



Issues:

- Space budget: Present systems need relatively large space
- Safety issues: Use of lasers is a concern for operators
- Price – Systems are expensive: > 200.000 EU

Shape measurement systems – Development opportunity

Development opportunity for shape measurement system, with features:

2D field of view

- 2D area view over area of ~2 x 2 m is required to suppress false shape-defect hits due to strip vibrations and hopping ghost defects introduced into strip due to (high-speed) strip motion.

Safe and Compact

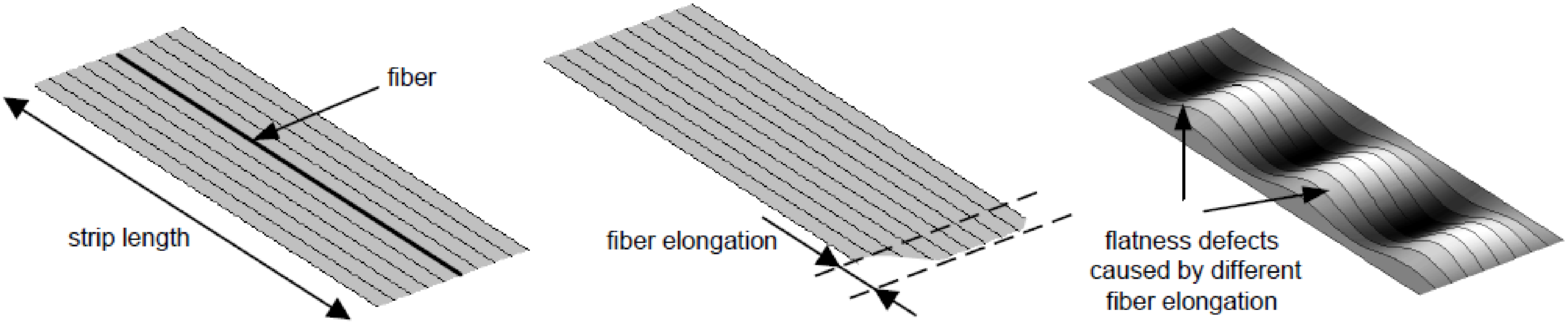
- Avoid use of laser;
- Integration of (light) source and camera into a single monolithic device

Medium accuracy and Low price

- Medium accuracy is sufficient to detect the coarser type of flatness deviations, which may cause temporary stops in production.
(tiny deviations do not cause problems in manufacturing and can be corrected)
- A low price favours the roll out at different locations
- Challenge: hardware price of < 10% of commercial systems.

Shape measurement on metal strip: the concept of I-units

Length fibres, and the effect of their elongation (*):



To express severity of shape defect, the dimension-less **I-unit** is used:

$$I_i = \frac{\Delta L_i}{L_{\text{shortestfibre}}} * 10^5 \quad \text{with:} \quad \Delta L_i = L_{\text{fibre i}} - L_{\text{shortestfibre}}$$

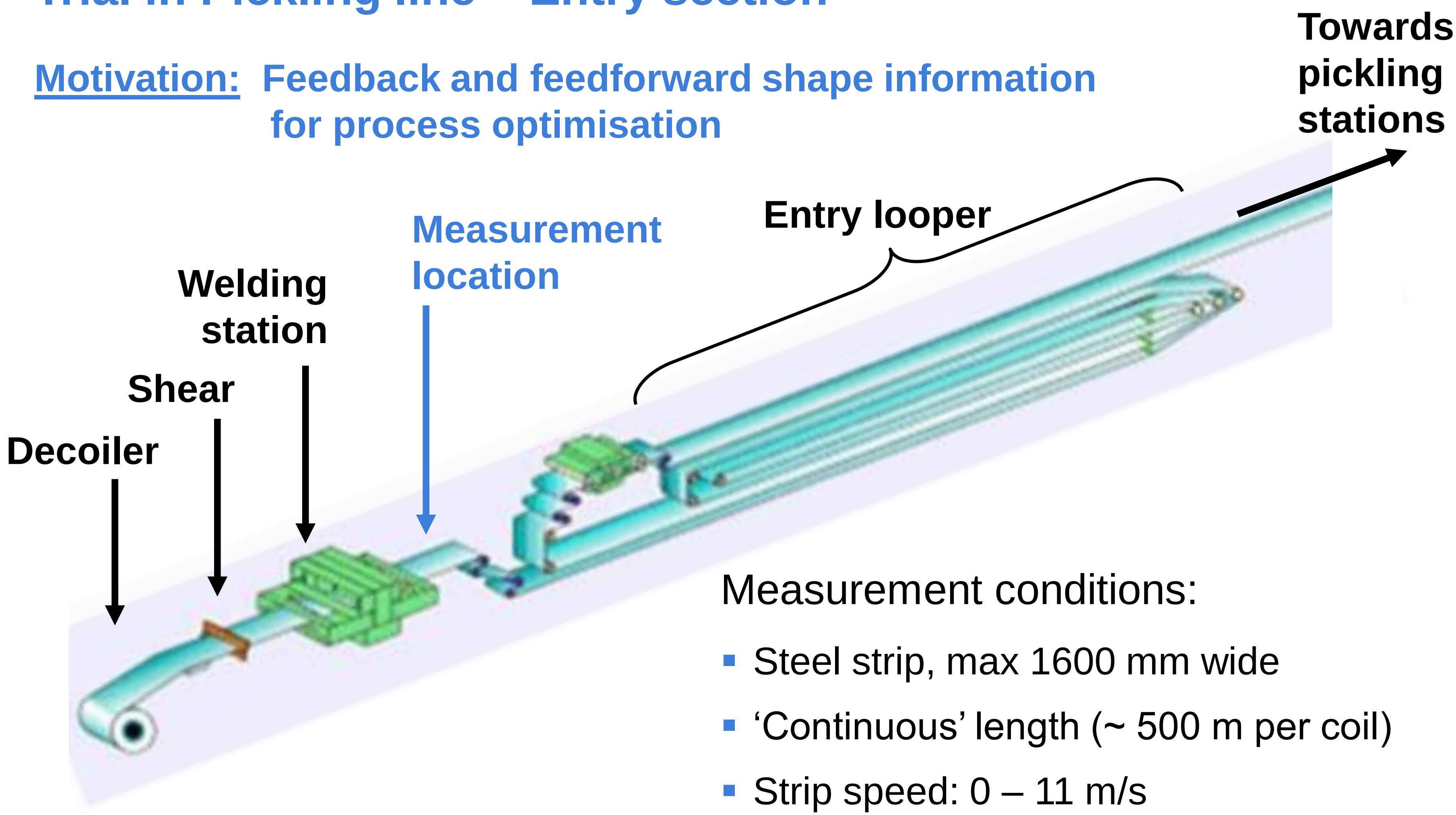
(*) Figures from Julio Molleda,* Rubén Usamentiaga, and Daniel F. García, Sensors (Basel). 2013 Aug; 13(8): 10245–10272

Agenda

1	Background: Flatness measurements in steel industry
2	**Phase I: Proof of principle with 3D camera system**
3	Phase II: Realisation of industrial prototype
4	Results, Problems encountered, Solutions
5	Conclusions & Outlook

Trial in Pickling line – Entry section

Motivation: Feedback and feedforward shape information for process optimisation

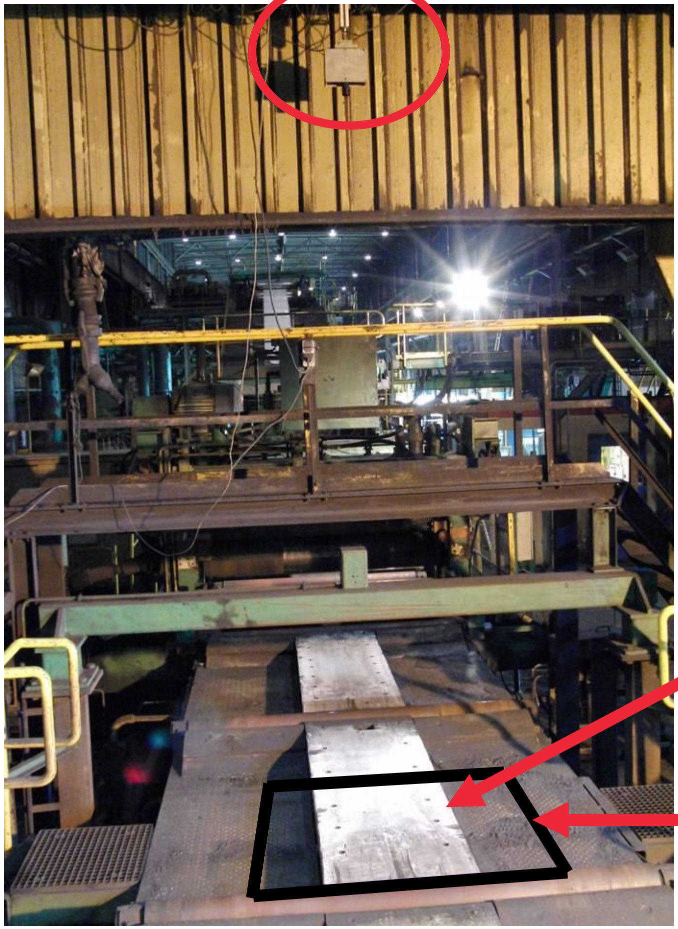


Measurement conditions:

- Steel strip, max 1600 mm wide
- 'Continuous' length (~ 500 m per coil)
- Strip speed: 0 – 11 m/s
- Atmosphere: dust, acidulous air
- Operating temperature ~ 20-40 ° C.

Phase 1 – Proof of principle

Standard PMD 3D camera ,
positioned 3.5 m above line



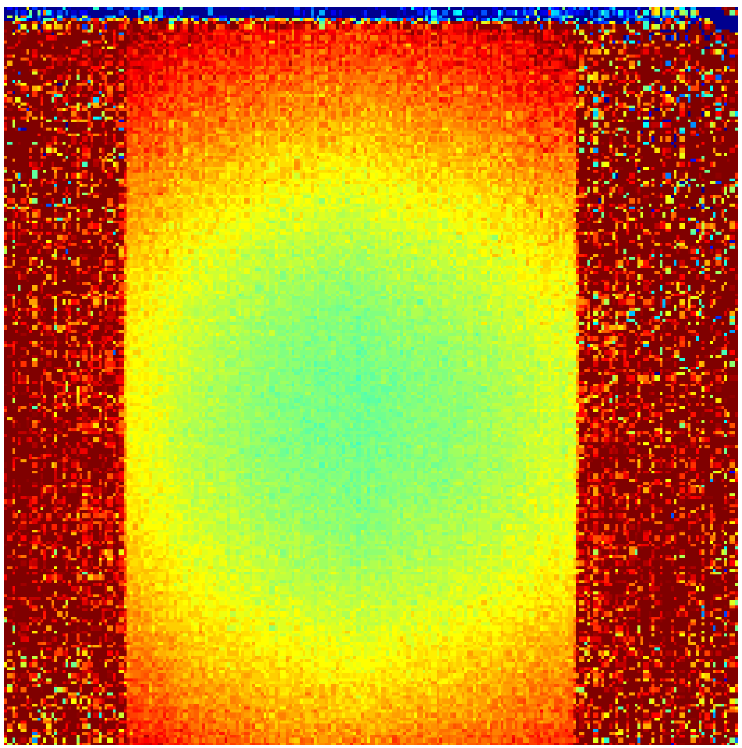
Via USB-extender to DAQ PC

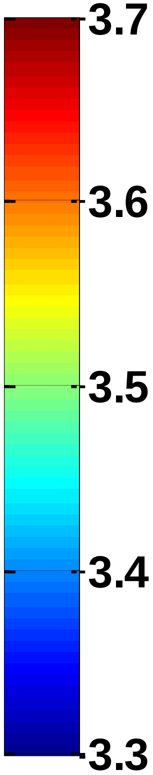
Support table

Black Square = Measurement Area 2 x 2 metres

Phase 1 – Proof of principle – Calibration with flat plate

**Distance Image
(direct from camera)**

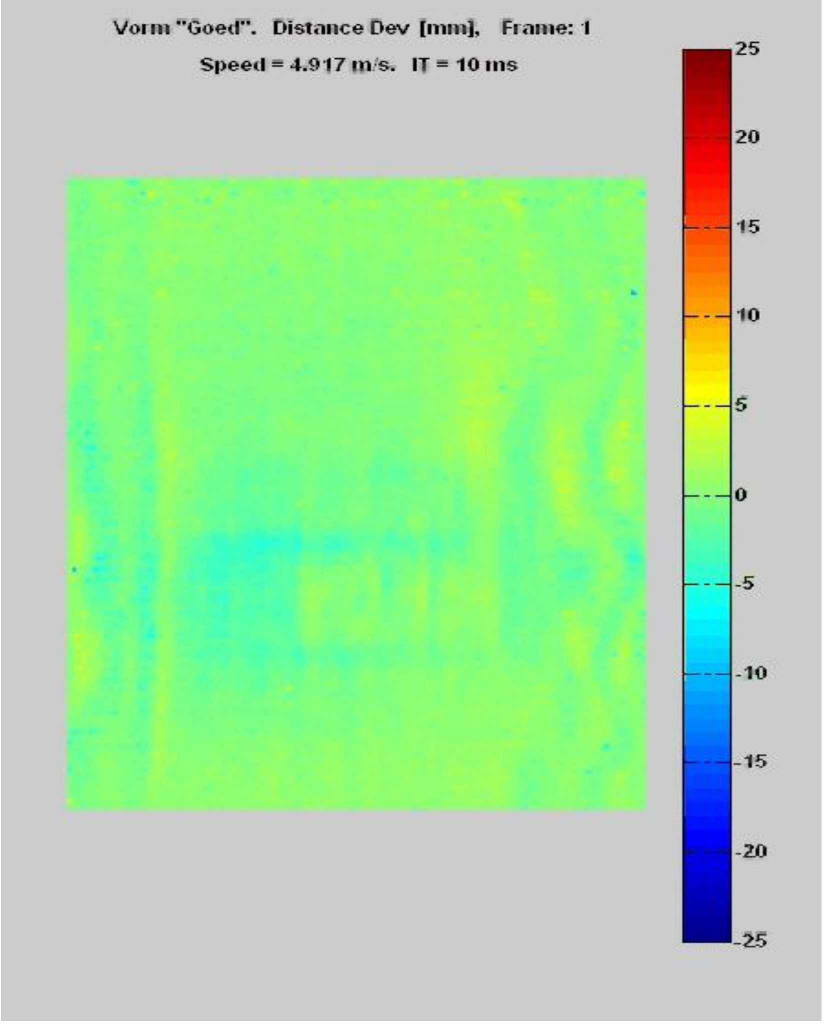




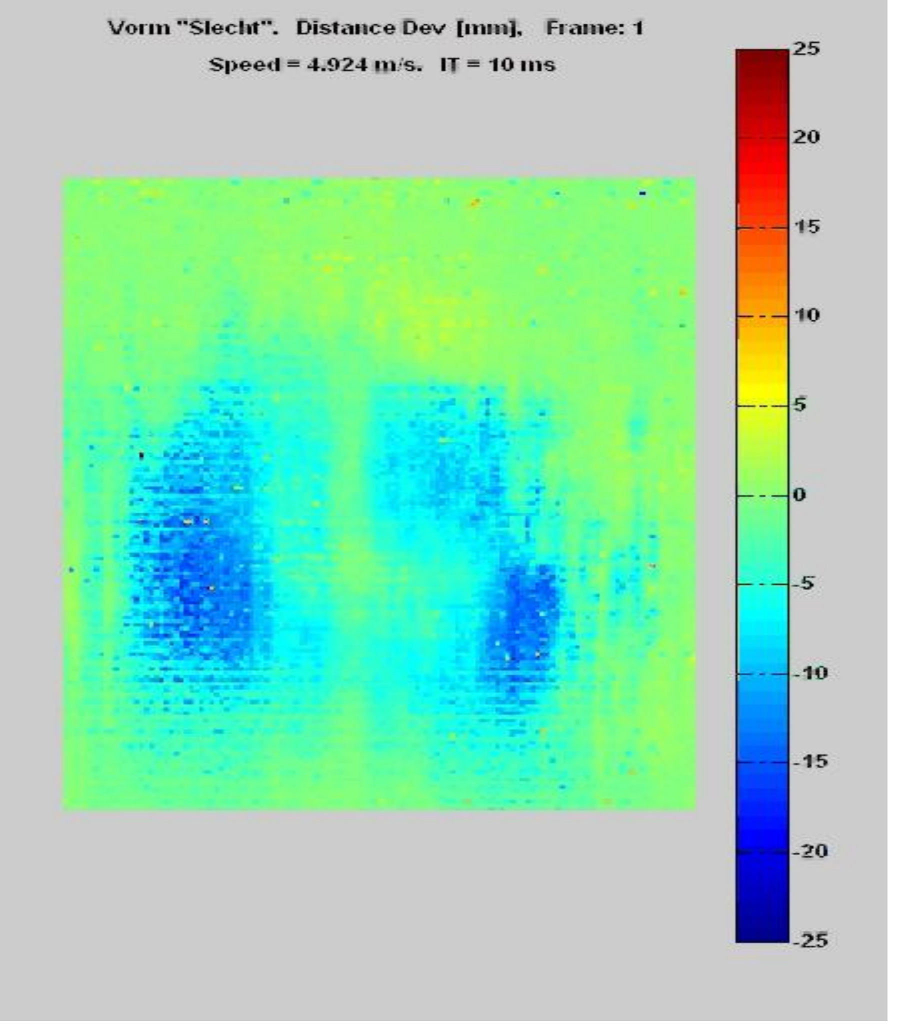
**Distance Image
after cropping &
correction for perspective**

Phase 1 – Proof of principle – Results: FLAT vs NON-FLAT

FLAT strip

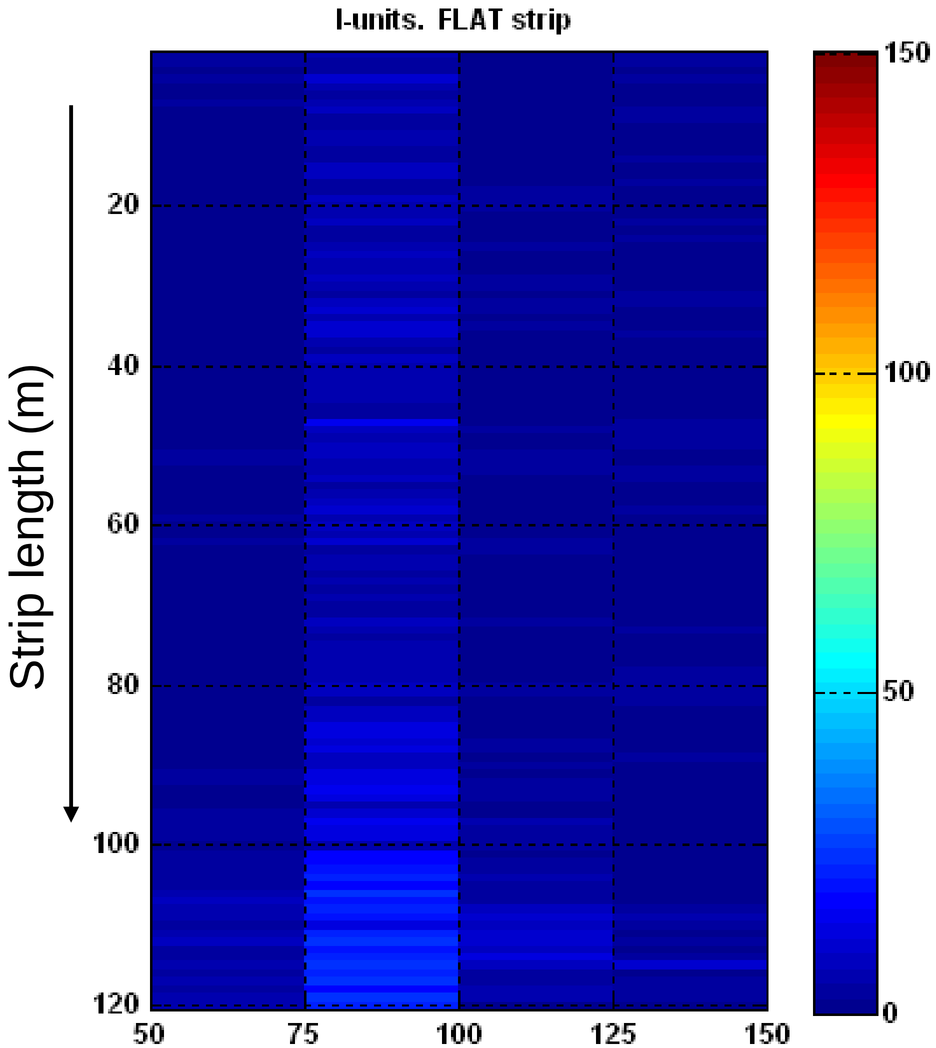


NON-FLAT strip

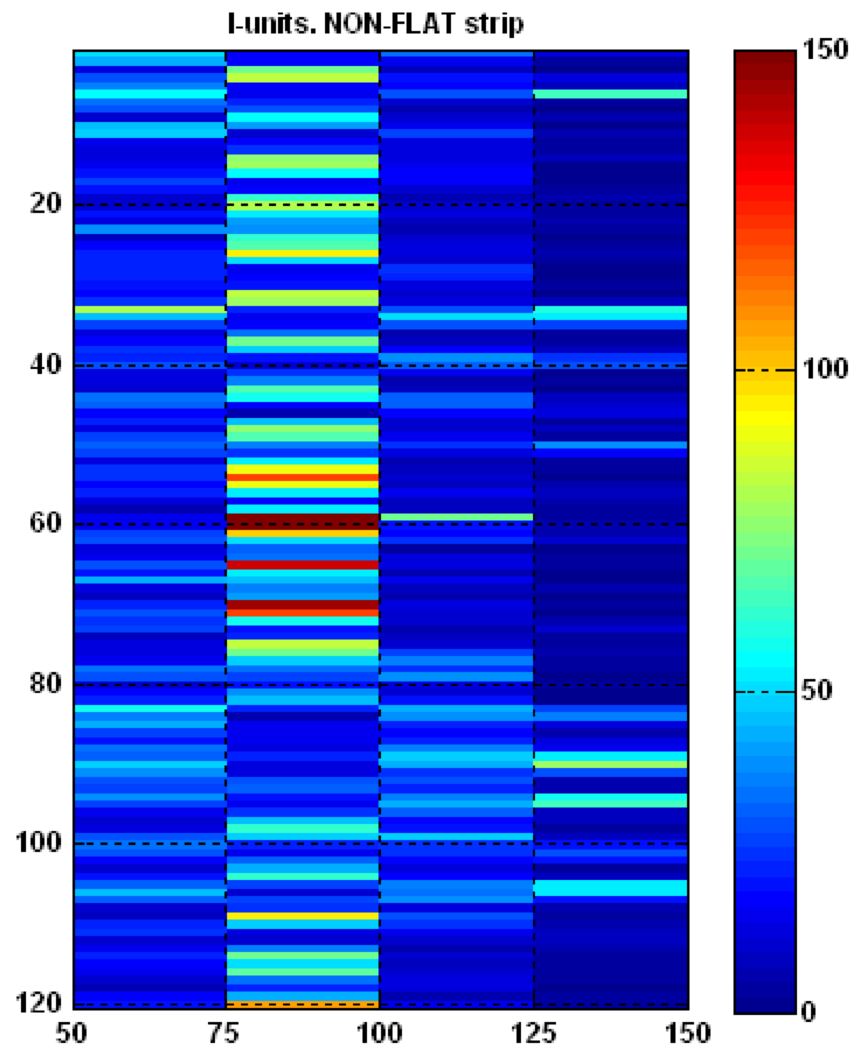


Phase 1 – Proof of principle – Results: FLAT vs NON-FLAT

FLAT STRIP: ~120 m



NON-FLAT STRIP: ~120 m



Phase 1 – Proof of principle – Lessons Learned

Principle of operation is proven

- Height images can be recorded and converted to I-units
- Real-time acquisition and data processing

Full area coverage is problematic

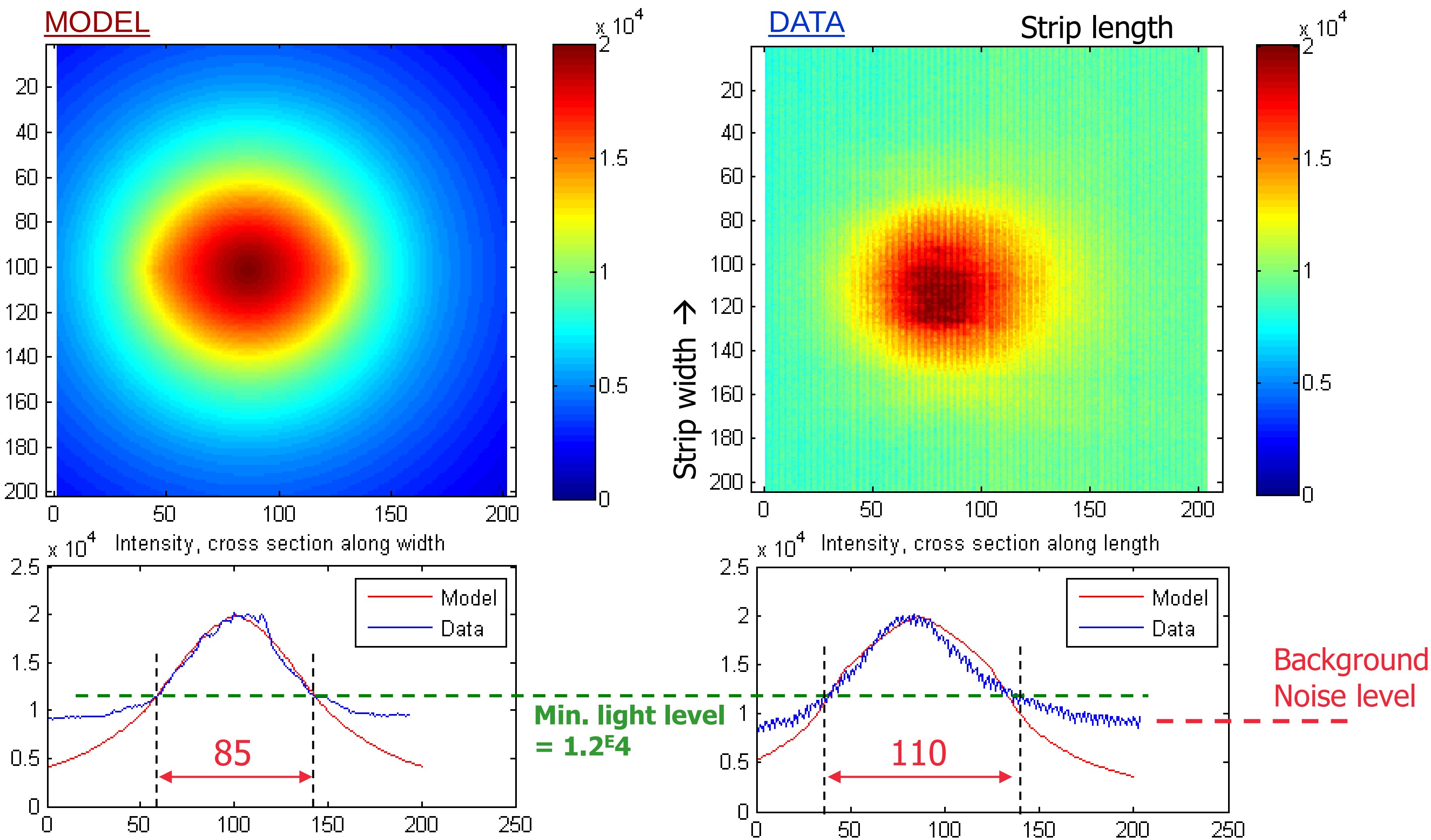
- Not sufficient light coverage of the area-of-interest by the standard LED illumination
- Recommendation: more uniform illumination required (see next sheet)

Operation at full line speed is problematic

- At line speeds > 2.5 m/s, system has problems to cope with the line speed, due to movement “blur” (integration time ~ 4 * 10 ms → 100 mm lateral shift)
- Recommendation: stronger illumination required (*see next sheet*)

Simulation of reflected light intensity, as received by camera

Situation: 2 spotlights, under angle (-5°, +5°), system under angle (2.4°)



Data in width shifted over 10 pixels (camera misalignment)

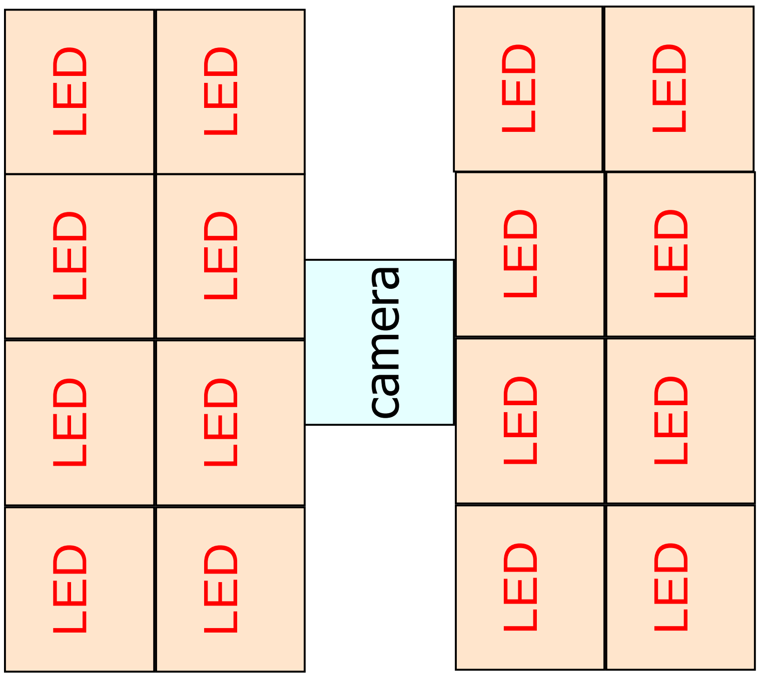
Agenda

1. Background:
Flatness measurements in steel industry
2. Phase I: Proof of principle with 3D camera system
3. **Phase II: Realisation of industrial prototype**
4. Results, Problems encountered, Solutions
5. Conclusions & Outlook

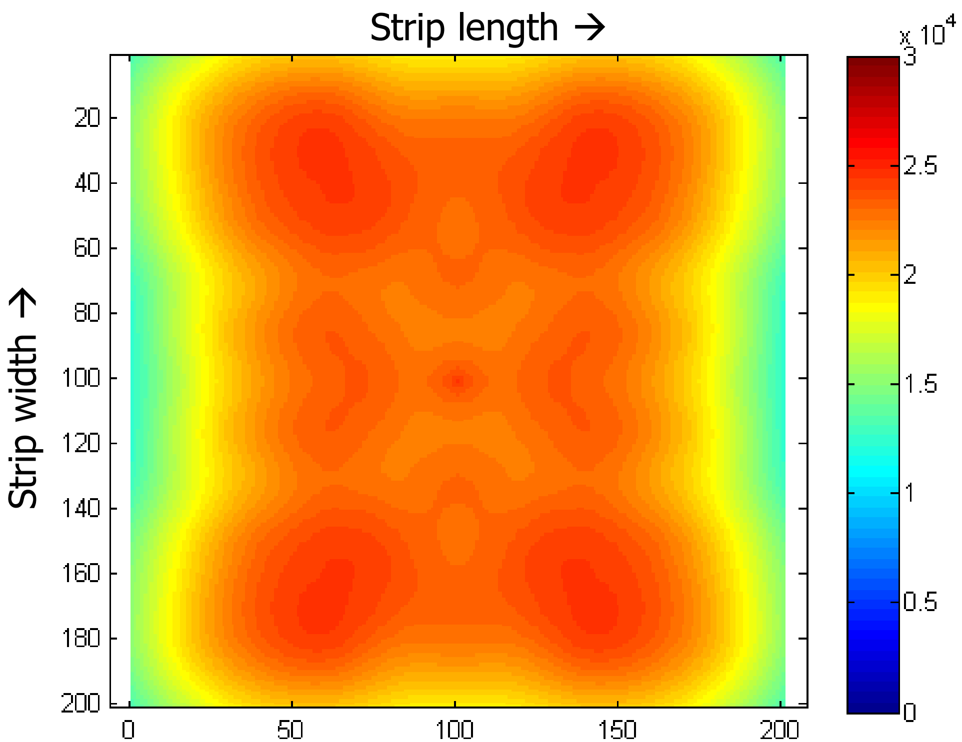
Phase 2 – Realisation of industrial prototype

Customized LED Light illumination to increase intensity and uniformity:

Illumination by 16 LEDs:
(under different angles)



Predicted illumination pattern:
(as observed by camera)

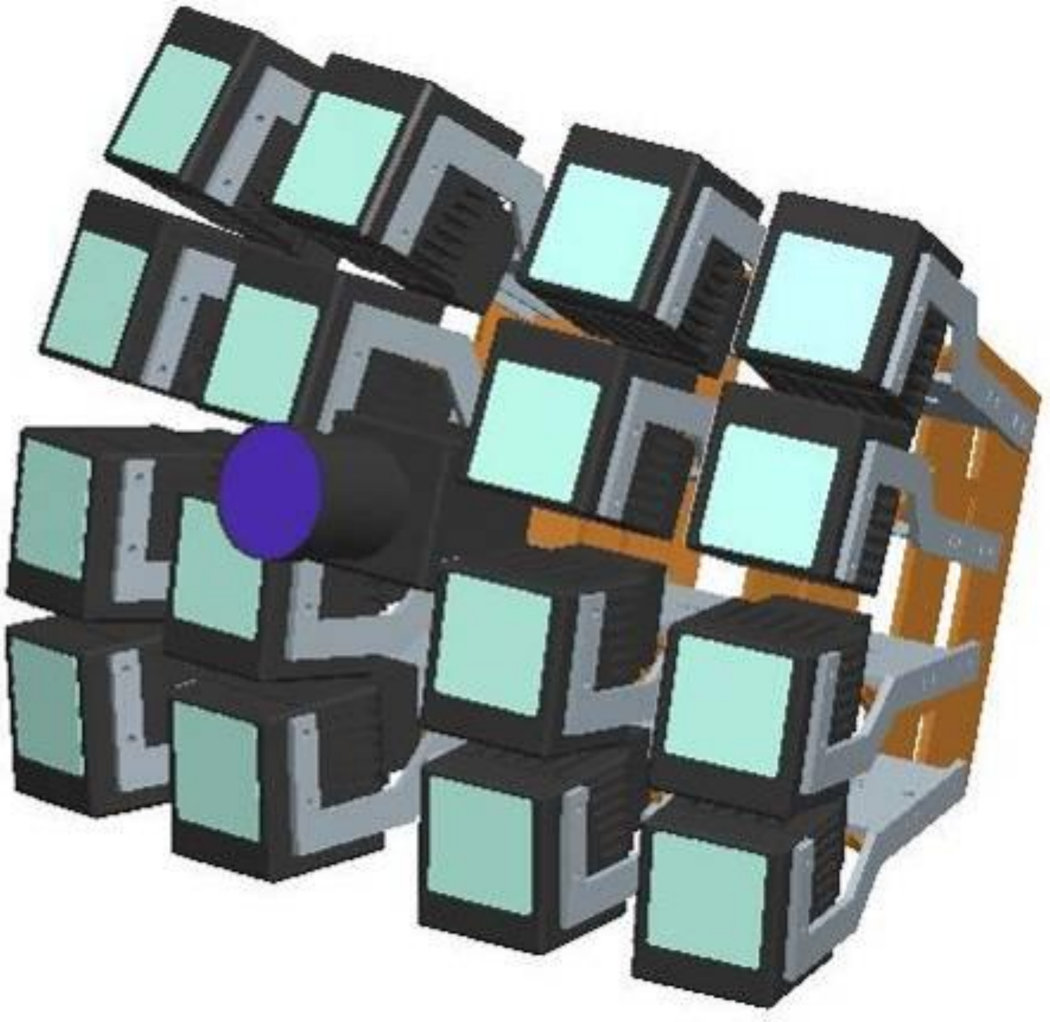


Conclusion:

- **Suited for viewing area of 200 x 150 cm**
- **Overall intensity smooth, uniform and strong enough**

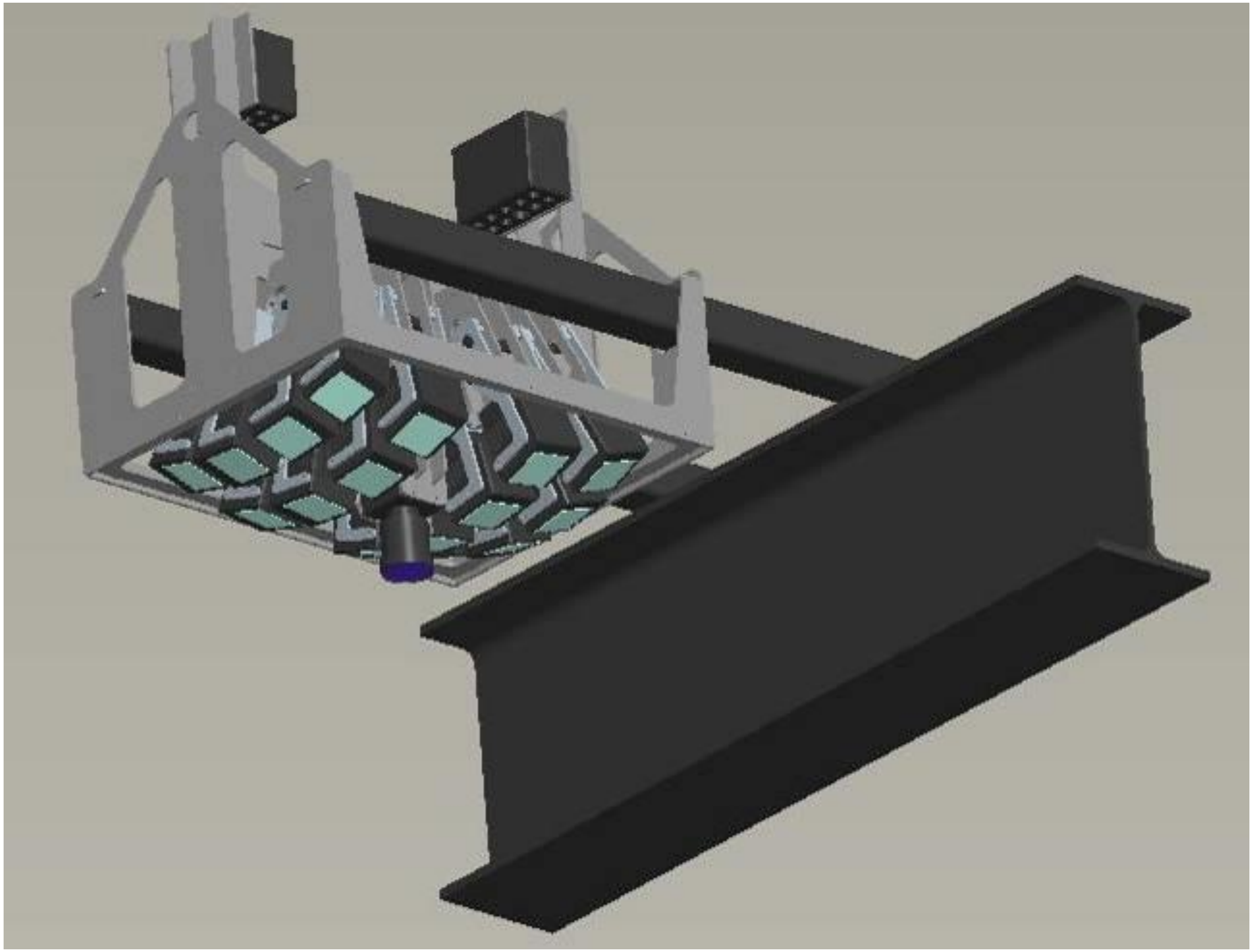
Phase 2 – Realisation of industrial prototype

Customized LED Light illumination to increase intensity and uniformity:



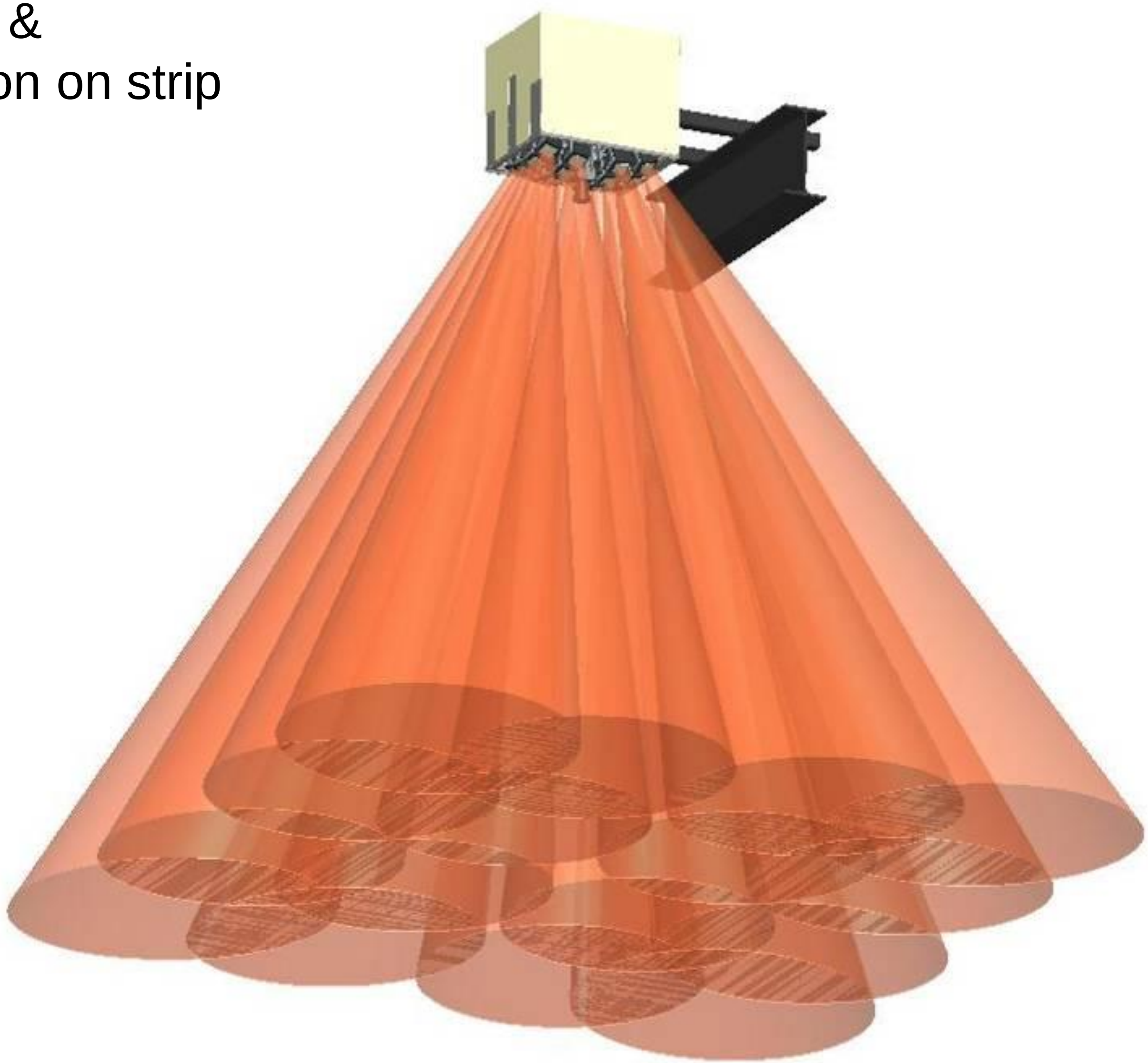
Phase 2 – Realisation of industrial prototype

Fixation in rig and suspension above production line:

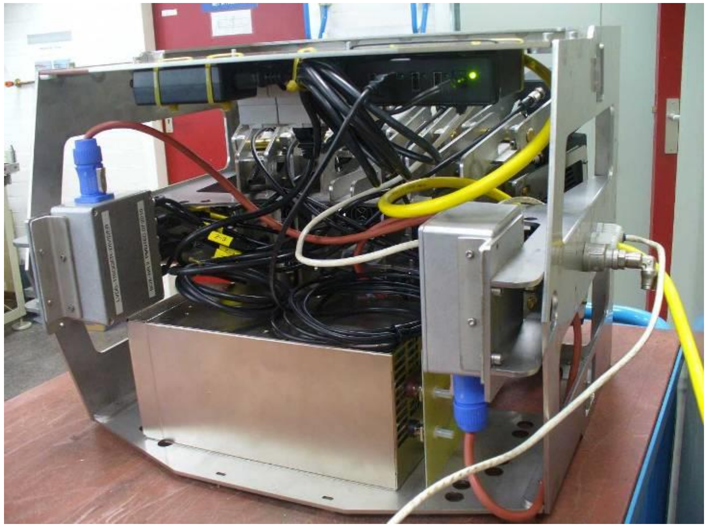


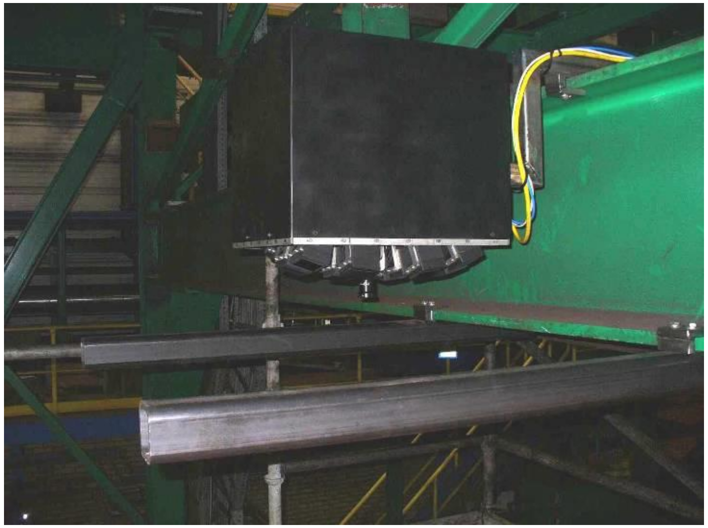
Phase 2 – Realisation of industrial prototype

Protection housing &
Light cone projection on strip



Phase 2 – Realisation of industrial prototype → Installation

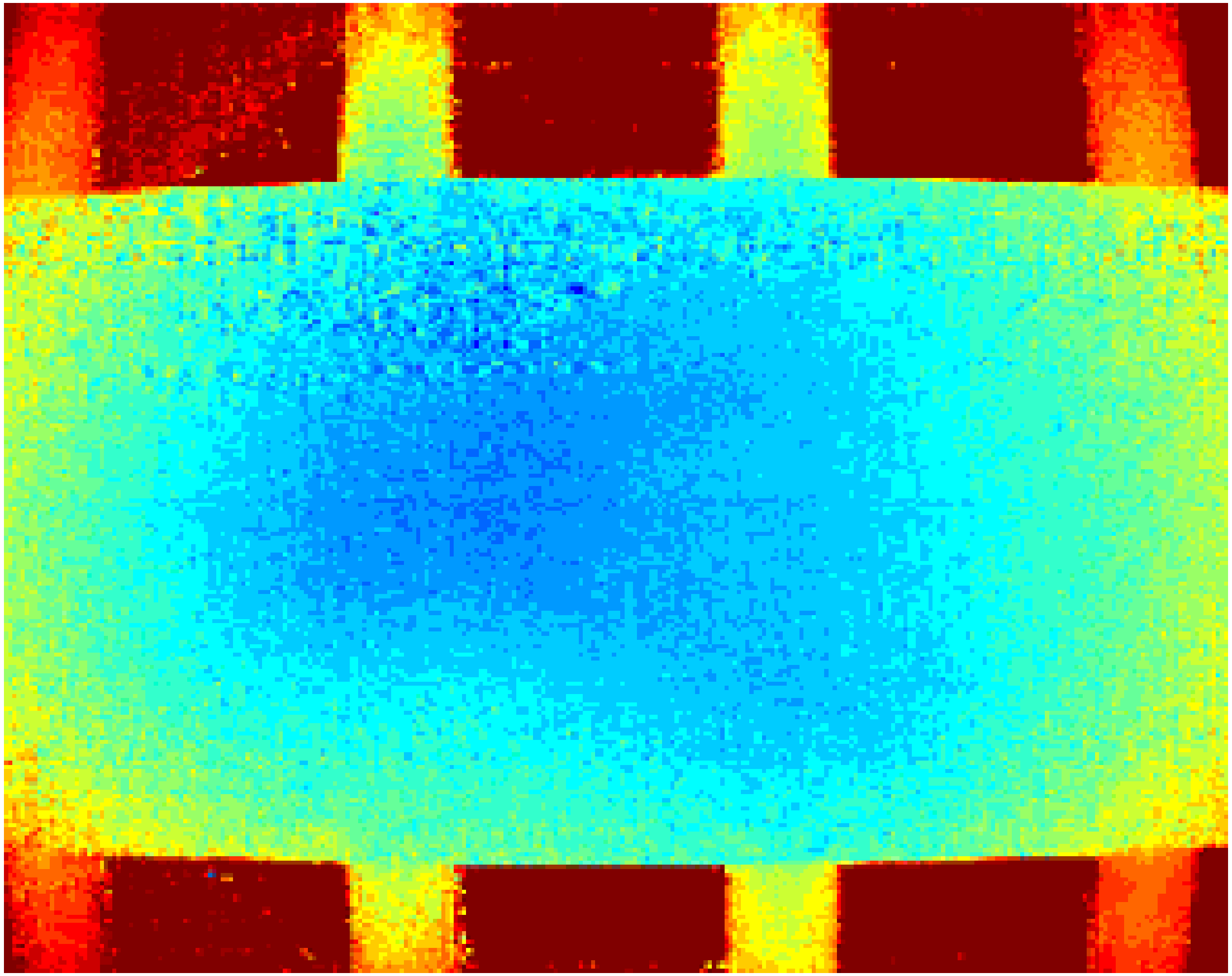




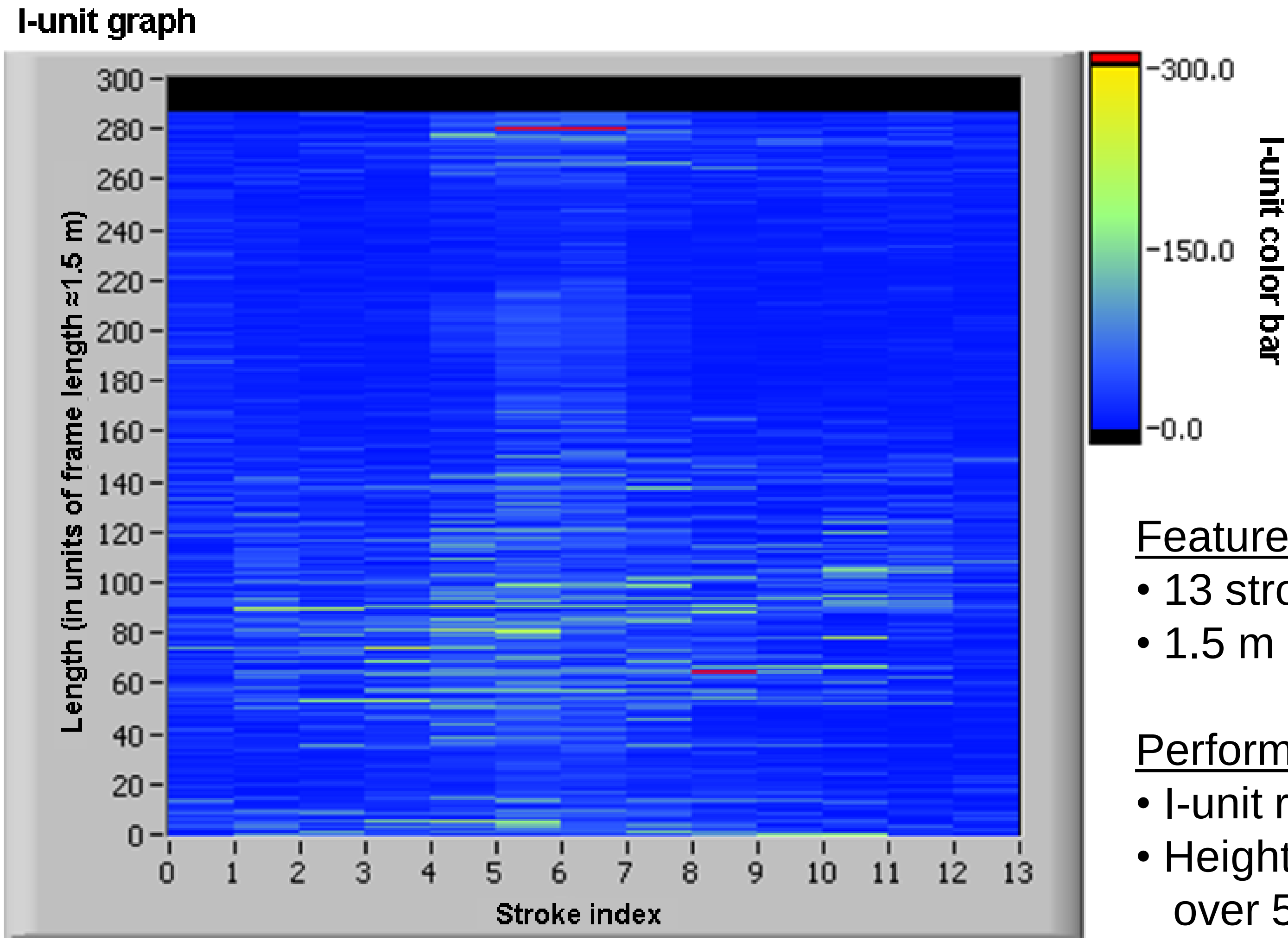
Agenda

1	Background: Flatness measurements in steel industry
2	Phase I: Proof of principle with 3D camera system
3	Phase II: Realisation of industrial prototype
4	**Results, Problems encountered, Solutions**
5	Conclusions & Outlook

Height map (single frame)



I-unit map (1 entire coil)



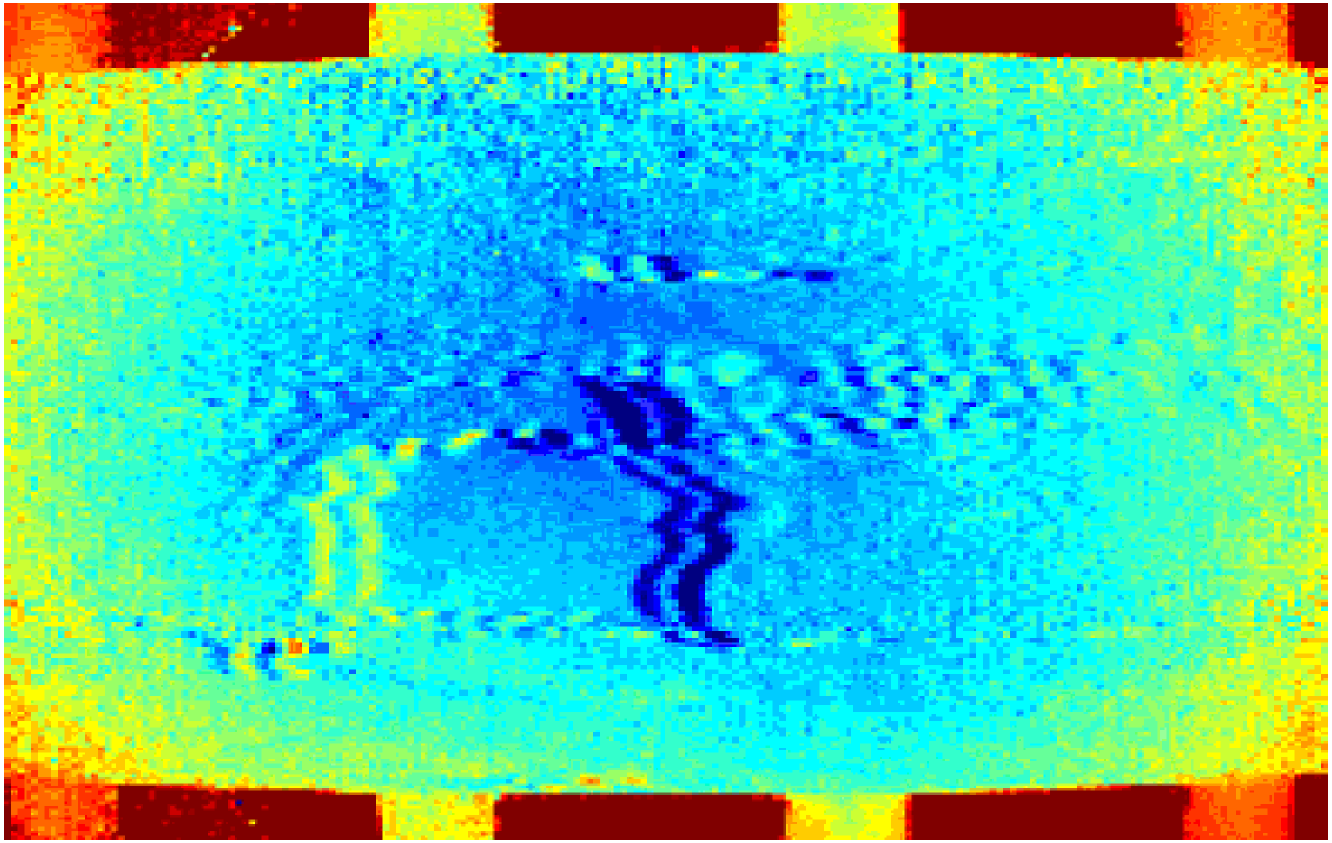
Features:

- 13 strokes over width;
- 1.5 m in length direction.

Performance:

- I-unit resolution: ~ 3 I-units
- Height resolution: ~ 1 mm over 50 x 50 mm voxels

Difficulties due to abrupt changes in reflectivity

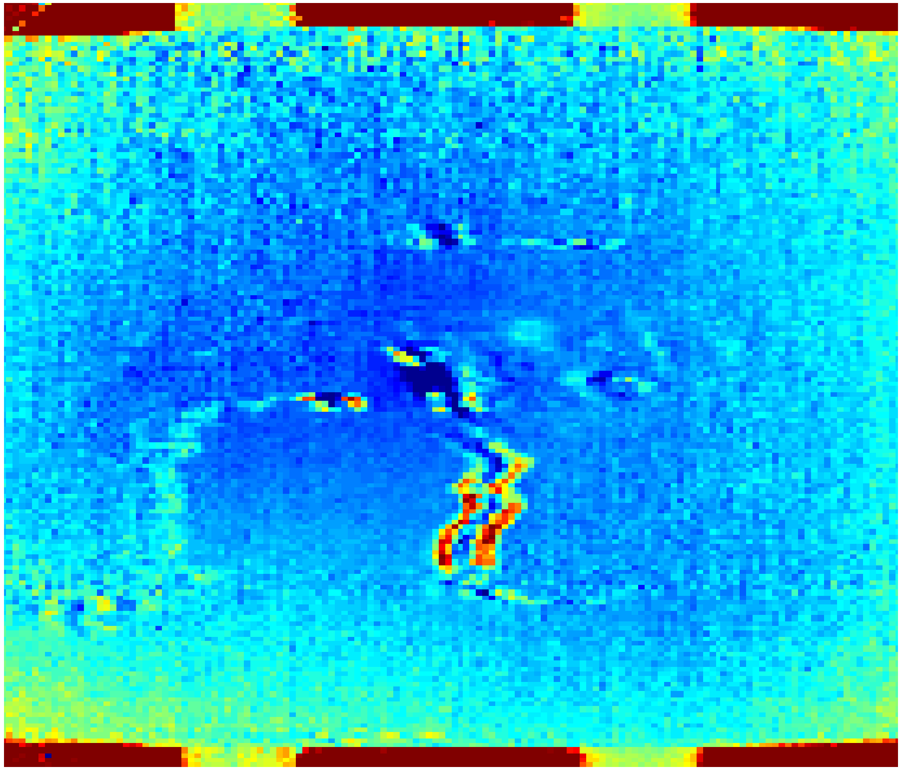


Processing raw data to detect these reflectivity transitions

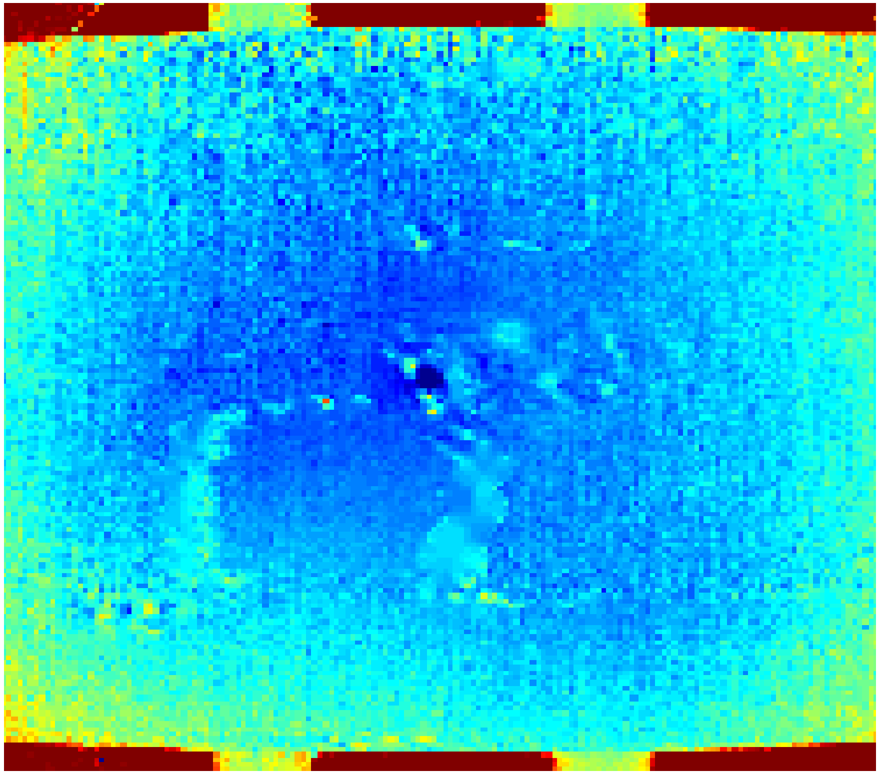
→Identification of “bad pixels” due to these reflectivity changes:
- → Bad pixel if difference between $(A+B)_1$, $(A+B)_2$, $(A+B)_3$, $(A+B)_4$ is above a given threshold

→Omit these bad pixels and re-process data

Before correction for bad pixels:



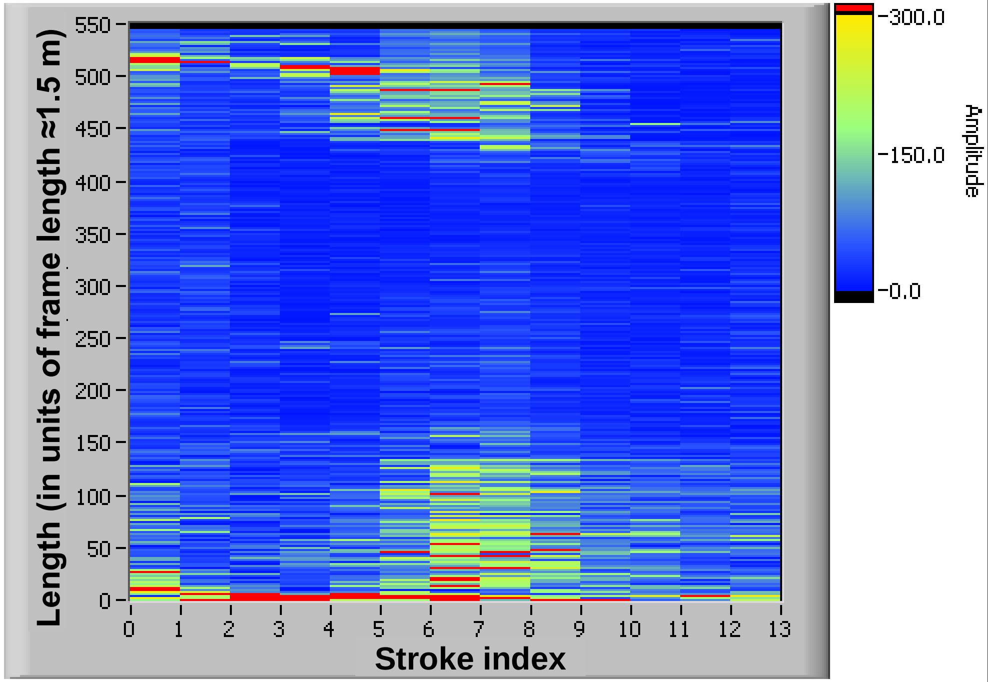
After correction for bad pixels:



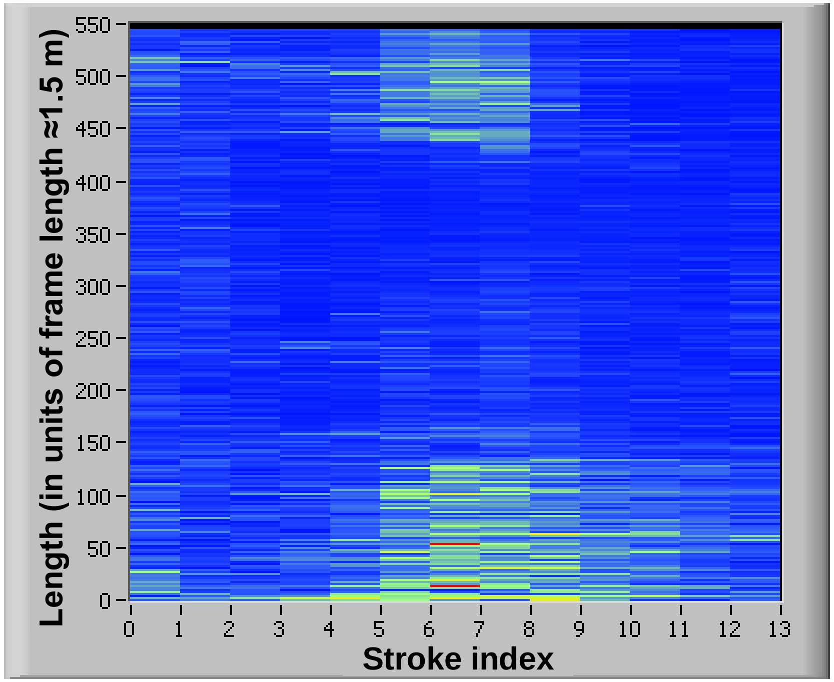
Processing raw data to detect these reflectivity transitions

→Effect on I-unit diagram:

Before correction for bad pixels:



After correction for bad pixels:



Agenda

1	Background: Flatness measurements in steel industry
2	Phase I: Proof of principle with 3D camera system
3	Phase II: Realisation of industrial prototype
4	Results, Problems encountered, Solutions
5	**Conclusions & Outlook**

Conclusions

3-D camera technology proven for industrial flatness measurement

- Safe, cheap, large stand-off, compact
- 2D height map with medium resolution (~ 5 mm per pixel; ~1 mm per voxel)
- Robustness of components: 3+ Yrs of stable operation in pickling line
- Real-time acquisition and data processing;
- Data compactification and visualisation in I-unit graphs
- Additional Software developed to reduce false hit rate caused by stains
- Software gives a “bad pixel count” as indicator for the quality of the deduced I-unit values

Outlook

Opportunities for further 3-D camera technology developments

- Alternative principle, being less sensitive to fast changes in the scenery (thus less sensitive to stains); e.g. true Time-Of-Flight
- Decrease integration time → reduce “motion blur”
- Increase distance resolution → opens up applications that require higher accuracy
- Use of blue light → to measure on hot surfaces
- Increase pixel size → to detect smaller topological defects

Questions ?

Back up slides

Phase 2 – Realisation of industrial prototype → Data Acquisition