CAMERA-BASED ANALYSIS OF ROTARY KILNS

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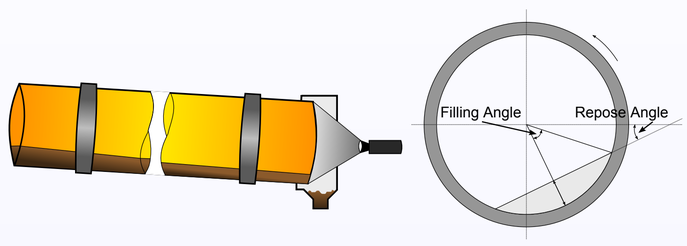
ICVSS 2011
Sicily ~ 11-16 July
International Computer Vision Summer School

Abstract

Rotary kilns are industrially used in processes with high energy consumption such as cement production or metal recycling. Our goal is to optimize the process control by utilizing new camera-based features out of the inside of the kilns. Here, a method to detect the repose and the filling angle of the solid bed is presented. At first, the inner kiln wall is spatially transformed to a rectangle. The segmentation is accomplished with a level set based algorithm by using intensity, motion and shape information. Both angles can be extracted directly.

Background

A rotary kiln is a cylindrical vessel slightly inclined to the horizontal. Raw material is brought into the upper end of the kiln. Mixed by the kiln's rotating movement the solids gradually move towards the lower end.



Reducing energy consumption, improving the product quality and lowering pollutant emission are important goals for the operation of rotary kiln plants. Our research field comprises the optimization of the process control with an appropriate image processing system that extracts meaningful information of the process state. Geometric characteristics of the solid bed such as filling angle and repose angle allow for conclusions on the bed material properties. [1,2]

References

[1] Waibel P., et al., Segmentation of the solid bed in infrared image sequences of rotary kilns, in *ICINCO*, 2010

[2] Matthes, J., et al., A new infrared camera-based technology for the optimization of the Waelz process for zinc recycling, in *Miner. Eng.*, 2011

[3] Brox T., et al., High accuracy optical flow estimation based on a theory for warping, in *ECCV*, 2004

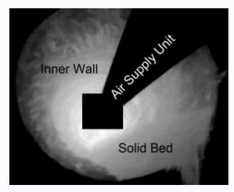
[4] Chan T., and Zhu W., Level set based shape prior segmentation, in *CVPR*, 2005

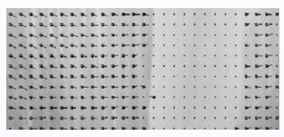
Image Acquisition

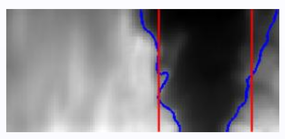
- Infrared camera with spectral filter at $3.9 \pm 0.1\,\mu m$ (for maximum transmission in burning gas atmosphere)
- Image resolution is 384×288 at image depth of 16 bit
- Image sequences were captured at a rotary kiln for metal-recycling (kiln length $43\,m$, inner diameter $3.6\,m$, $1.2\,rpm$, residence time of the material inside the kiln 4-6 h)
- Camera position is at the top-left of the rotary axis at the lower end of the kiln

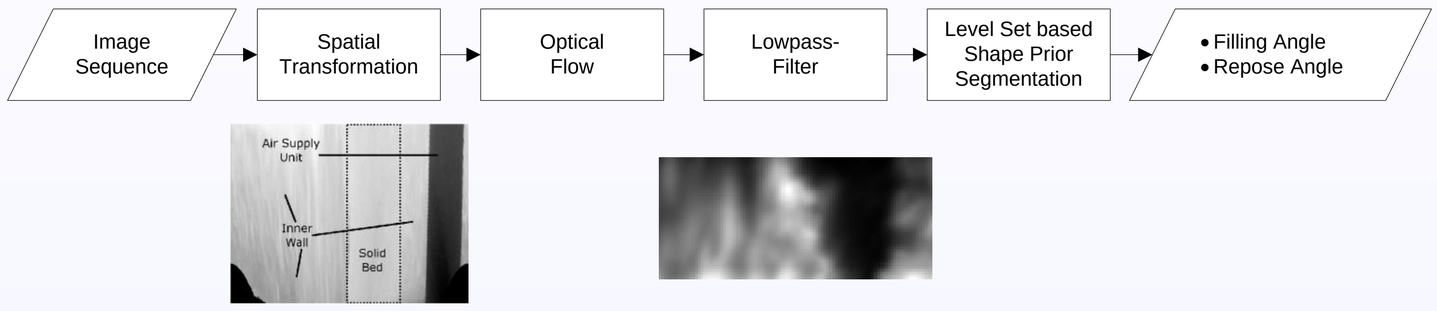
Image Segmentation and Feature Extraction

Reliable discrimination of solid bed and inner kiln wall is required for parameter extraction. Due to similar intensity values, in particular in the upper right part of the solid bed, different dynamic properties of solid bed and inner kiln wall are employed. Shape information is integrated to raise robustness of segmentation.









1. Spatial transformation of inner kiln wall to a rectangle; reducing to ROI
2. Determination of motion between two succeeding transformed images via optical flow algorithm [3] (kiln wall rotation corresponds to a constant movement to the right; solid bed randomly moves to the left)
3. Lowpass filtering of motion in horizontal direction
4. Level set based segmentation based on motion and intensity with shape prior information (rectangle with variable *x-position* and *width*) [4]
5. Extraction of filling angle and repose angle. Both angles can directly be deduced from the adapted shape prior's *x-position* respectively *width*. (optional reverse spatial transformation of segmentation result in original image)

Conclusion and Future Works

The extraction of solid bed characteristics, filling and repose angle, out of infrared images of the inner kiln is shown. Determination of other features e.g. temperature distributions or output rate is possible. Future works comprise:

- Image-based detection of cakings in kiln
- Analysis of relations between extracted parameters and process values (e.g. product quality)
- Implementation of image processing system in process control
- Examination of applicability at other rotary kiln applications (e.g. cement production, waste incineration)