Automatic quality control for industrial printing

Results

Project Information

MONOTONE

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Exploitable results

Addition of organic dyes to suspensions in ceramic tile production to increase contrast

Addition of organic dyes to suspensions in ceramic tile production is essential in the quality control of the process. Any suspension or ink applied on a tile will obtain a higher contrast and combined with optical inspection this gives the possibility to control the results immediately after application instead of after the firing. This efficiently reduces the loss during production. The dyes do not harm the suspension properties and can be added without any changes in the existing production.

Design of multigoal real-time schedulers using genetic algorithms

Production scheduling is a difficult task because of the great number of possible schedules. Genetic algorithms are a young technique that solves efficiently optimisation problems with a lot of possible solutions. The genetic algorithms could be an efficient technique to production schedule. Other genetic algorithms qualities are:
-No need to know all the production line details
-Effective with problems with a big number of restrictions.
-Can solve multi objective problems.

Development and application of an on-line measurement system for the quantity of applied glaze on each tile

In ceramic industry each machine for ink, glaze or engobe application requires that the quantity of applied glaze is fixed in a very precise and narrow range.

The increasing need of flexibility imposes, as a consequence, the requirement for an improvement of the on-line control techniques. In ceramic tile industry normally the quantity (weight) of applied glaze is manually measured every 1 hour in order to verify the quality of the implemented production. Therefore the possibility of measuring on-line this parameter on a high percentage of the production seems to be of great relevance for control purposes. The result of this part of research is devoted to determine an on-line measurement method for glaze weight measurement. The measurement of the quantity of applied glaze is being approached by an on-line weight control station. This solution seem to be the most simple, in particular given the difficulties in determining the quantity of glaze by optical properties. At the moment the whole measurement chain has been completely designed, defining the different stations to be installed on the line. Therefore it has been decided that a first prototype will be realised in the second half of the project.

Design and implementation of a scheduler adapted to Tile Sector

Currently, and after a deep study of work schemes at the industries of the tile sector, we have notice that it does not exist a good specific planning tool, neither before or later, about tasks to do in all the

context of production. This entails the diminution of the production capacity, as well as the obtaining of benefits. For this reason, QIS has decided to design and implement a scheduler that will adapt its funcionality to the necessities presented by the tiles sector manufacturers.This Scheduler , endowed with models of the tiles production process, will act in a multiobjective environment and will interact with the plants events in realtime.

Algorithms for defect detection

Defect detection in stochastic textures via Parzen window (Mean Shift) method:
A non-parametric, unsupervised method. Colour pixel clustering performed to produce stack of binary images. Stack describes spatial colour distribution of given image. Parzen window test performed at each pixel to measure density and distribution regularity. Coherence map results indicating uniformity of texture in acquired image. Morphological and thresholding techniques applied to extract possible defects. Threshold established during training phase of algorithm. Good results indicating vibration lines, smudges and misprints. Method is difficult to extend to random textures with structural elements and computationally unsuitable for real-time application at this time.

Defect detection and localisation in pseudo-random textures via texem models:
Novel texture analysis model developed: texem model. Assuming each image is constructed from a set of sub-image patches of various sizes, possibly overlapping, then images of the same product contain similar base textural elements: texems. Given an initial training set of defect free images, a set of various sized image patches are extracted. Similar patches are grouped in a multidimensional feature space and clusters extracted via a Gaussian mixture model utilising an Expectation and Maximisation algorithm. Given a new image, extract a small patch at each pixel position and compare it to the set of learnt texems. A multi-scale approach is utilised to reduce computation costs. Candidate defective regions from different scales are combined to generate a final localised defect map. Method achieved good results but is computationally unsuitable for real-time application at this time.

Defect detection and localisation in pseudo-random textures via colour texem models:
Texem model extended to model colour images, initially via separate image eigenchannels. Given an initial set of defect free images, a reference eigenspace is derived such that decomposed images preserve major colour features. Grey level texem analysis is then applied independently to each decomposed eigenchannel. Defect candidates from each channel are combined to form final defect map. However, interaction between image channels ignored, e.g. vectorisation leads to causal effect that is not necessarily present within original image data. Therefore texem model extended to 3D. Improved performance

noted, particularly when defects chromatic in nature. Method achieved good results but is computationally unsuitable for real-time application at this time.

Defect Detection via Frequency Space Analysis:
Generic defect detection technique for textured tiles via frequency space was investigated. A defect free image is split into patches and for each patch a Fourier transform calculated and a feature vector extracted. Statistical methods are applied to determine if a given patch differs significantly from its corresponding model patch. Initial results showed promise, however, method not applicable to pseudo-random textures and not viable for real-time implementation. Specific case of vibration lines then investigated. Training set of ideal tiles processed in frequency domain and best representative model profile extracted. Given new tile, profile extracted and compared to model via Chi squared similarity metric. Low order similarity statistics derived during model creation used to create threshold to determine if new profile significantly different. Initial results were promising and the algorithm runs in real-time. Colour mapping stage implemented to decrease suppression of subtle tonal variations. However, few data sets exist for testing and validation due to infrequent nature of defect.

Defect detection and localisation for pseudo-random tiles via affined templates (Jigsaw):
Method reconstructs texture space from multiple tile images, similar to solving a jigsaw puzzle. Correlation used to ?stitch? new pieces into texture space via hierarchical sub-sampled pyramid of images. Initial 2D position estimators via exhaustive search, histogram-based hash table indexing and Fourier-based phase correlation examined. For each level thereafter a 5D affined transform is derived with previous transform as basis for current search. Final model pyramid rendered via vector directional stack smoothing to provide resilience to noisy inputs. Newly acquired images located within model as in training, once located dynamic local window differencing, segmentation and a novelty metric derived. User-defined threshold applied to determine if region defective. Algorithm detected and localised defects and end users can tune algorithm sensitivity. Method performs in real-time and is equally applicable to fixed pattern tiles.

Tone analysis and Luminance correction

Tone analysis for plain tiles with uniform colour:
Consistency of tonality is usually more stringent than textured cases as less information is present to ?mask? variations. Proposed method inspects spatial uniformity in separate opponent colour channels: black/white, red/green, blue/yellow. A linear transformation is utilised to decrease computation costs. Initial set of ideal tonality tiles are acquired and tonality distributions of the set established as the reference model. Each channel is split into small, non-overlapping patches and the

patches ordered according to relative intensity to form a distribution profile. The distribution range is constrained via a spatial uniformity test. Given a new tile, the tonality profile distributions are extracted and compared to the respective reference model profiles. A tonality difference is derived via a weighted sum of the Mean Squared Error of the relative profiles. Good results in both synthetic tests and from images acquired during trials with the SI prototypes were reported. An online version was implemented in real-time on the latest SI prototype.

Tone analysis for pseudo-random textured tiles via colour histograms:
Colour histograms provide a simple, low-level representation of texture space, invariant to translation, rotation and spatial distribution of pixels. They offer good candidates for colour shade discrimination irrespective of textured pattern present. A set of ideal images is required to construct a concept of acceptable tonality. Multiple colour spaces investigated including Lab (high computation cost due to non-linear mapping) and RGB (computationally fast and results suggest sufficient for representation). Histograms are stored via a binary tree distribution to minimise storage requirements and increase distribution comparison performance. Distributions compared using Normalised Cross Correlation (NCC) and Chi squared statistical methods. NCC method selected due to its bounded output values (-1,1). A bounded output range aids the selection and application of defect detection thresholds. Results illustrated the ability to detect missing print defects in addition to tonal defects. An online version was implemented in real-time on the latest SI prototype.

Tone analysis for pseudo-random textured tiles via eigenspace features:
Multi-dimensional histogram based approach for colour tonality defects on textured tiles combining local and global colour distributions to characterise tonality. A voting scheme to extract a reference tile from the initial defect free sample set was employed. Vector directional processing method applied to compute Local Common Vector amongst pixels in RGB space, eliminates noise and perceptually smooth acquired images. For each pixel a 9D feature vector was computed and Principal Component Analysis (PCA) performed on the resultant 9D feature space. The first few eigenvectors displaying the largest eigenvalues were selected to form the reference eigenspace. Colour features then projected into reference space and a multi-dimension histogram created. New tiles processed in a similar manner and projected into the reference space. Histogram distribution comparison performed utilising NCC as in the previously outlined histogram based technique. Method produced better results than the original colour histogram approach but computationally unsuitable for real-time application at this time.

Spatial and Temporal Luminance Correction via Histogram Specification:
Radial camera used for image acquisition in the UoB laboratory. Image acquisition is non-linear by nature, spatial and temporal variations in illumination occur: cosine-4th fall off, vignetting effects, non-uniform illumination of the target etc. Acquired image is transformed into Luv space to separate the luminance and chromatic channels. The luminance channel is then split into patches and a single patch selected as a reference, the remaining patches are corrected in relation to the reference. Method can correct spatial luminance variations with minor negative effects and may be detrimental to the task of defect detection if applied to remove temporal variations. Method is applicable to radial cameras only; line-scan cameras require an alternate method as each column of pixels are derived from a single CCD element. Therefore a column based luminance profile is generated utilising a plain,

matt white tile to give a balanced response in RGB. Given a plain tile the colour can be assumed to be constant, any variations observed are due to external influence. Colour channels are modelled independently and a median based profile is generated for robustness to noise. Resulting profiles are then converted into normalised corrective forms and applied as a scalar correction factor to acquired image colour channels.
An online version was implemented in real-time on the latest SI prototype and forms one of the initial processing steps prior to higher level processing.

On line automatic camera setting-up and configuration

SIL developed a new method for automatic camera setting-up and configuration, ensuring the best image quality achievable.

During the Monotone trials, it was noted that considerable time was spent on setting up the camera configuration parameters when the machine was move to a new location. Repeated calculations of these parameters often manifest into a laborious task. What is more, some of these parameters, such as the alignment of the camera, were assessed visually. This often results in images with geometrical error. In order to overcome this problem, in addition to the image acquisition software, SIL developed, coded and implemented software, which automatically calculates the following parameters:
- Camera alignment
- Line speed and resolution
- Focusing
- White balancing

Real time factory tests showed that the method works effectively. As a result, SIL has decided to implement it on SIL□s mainstream commercial products. This automatic camera setting-up program method can be adapted to any on-line image acquisition.

On-Line inspection system to detect print defect of ceramic tiles

An innovative modular image acquisition system has been developed for installation at any location on the glazing line.

When equipped with processing algorithms developed by University of Bristol and OFAI, this system will be capable of detecting print defects generated by various print machines, including:
- silk-screen printing
- rotary screen
- rotary photogravure
- ink jet

The main capability of this inspection machine is to detect print defects and tonality deviation before the firing state, so that defective tiles can be removed and recycled to save energy and raw material

costs. Additionally, the system can be integrated with other sensors on-line to form a process control loop to automatically adjust line settings to maintain tile print quality.

- The key features of the machine can be summarized as the following:
- High quality of colour images of tiles before firing
- Large inspection range
- Physically small, compact and versatile
- Two inspection heads to inspect each side of the print machine
- Robust and environmentally protected (IP66)
- SCADA

The prototype was delivered and installed in factory for testing before the required deadline. It fully met the specification defined by the user and the project. Currently there is no other product available on the market offering similar capabilities. Existing products on the market can only be installed after flatbed machines, and do not have the sophisticated algorithms required inspecting multiple layers of print.

Flexible software framework for modularising a multi-ink printing process with strategies for prediction, diagnosis, set points and batch-adaptivity.

The developed system provides a flexible software framework for modularising a halftone printing process, possibly consisting of more than one printing stages, as is the case, e.g., in industrial tile printing. It has the following characteristics:

- Setup and training is done in an initialisation step prior to production
- The prediction algorithm is based on efficient Machine Learning techniques and is capable of approximating the final colour appearance based on arbitrary input parameters to each of the stages
- The prediction phase can also be run backwards (meta-induction) to derive the best set of adjustments (set points) for achieving a desired output
- Slight environmental changes can be incorporated into the predictions without the need for re-training
- For adapting to significant environmental changes the system includes a novel batch- adaptivity strategy for re-training the internal models
- All colour computations can - if needed - be based on a novel theoretical halftone model that was found to represent a good approximation of the Yule-Nielsen effect (i.e. the hue shift often occurring in intermediate printed halftones)
- Finally, the framework contains diagnostic algorithms that can be used to optimise the sequence of ink applications and halftone patterns to achieve a desired tile appearance.

Diagnostic System for green tiles structural integrity by I.R. Thermography and Non contact ultrasonics

The developed system is based on the combined use of temperature measurement by non-contact IR techniques for the detection of temperature gradients due to internal delaminations and non-contact ultrasonic sensors for the detection of cracks or other possible structural defects. Thermal images and ultrasonic signals are processed to give a complete judge and the result is classified by neural networks, in order to automatically have information about the integrity status of the tile (damaged or not). This information could be used for the regulation of the press parameters and for quality control. The system could be applied the pressing process or after the drier, before the tiles enter the glazing line. The developed methodologies can be utilised also in other production technologies, as in the quality control for composite materials.

Process variables and their correlation

Experiments performed during Monotone project have lead to a better understanding and quantification of the intercorrelation among some variables of the glazing and printing process and their influence on final shade and quality, In particular, influence between glaze and ink density, viscosity, applied weight and tile temperature on final shade have been investigated.The obtained results will be used for a better control strategy of the ceramic process, with the purpose of increasing percentage of first quality and reduce the amount of scraps.

Colour Prediction Model for Ceramic Tiles

Colour Prediction Models allow us to estimate the colour of a printed dithered design as a function of the some physical characteristics of the printed dots which form part of that design. The analysis of the applicability of Colour Prediction Models (CPMs) to the ceramic tile industry is relevant because CPMs could relate printing problems at dot level (microscopic level), i. e., shape of dots, area of occupation, ink density distribution, with colour variation at macroscopic level. They could be used as a control system of the printing quality. In fact, as it has already been proved elsewhere, printing systems are the source of almost the half of the defects that appear on the tile surface.

Definition of a methodology for knowing the chromatic differentials thresholds of the persons, specifically of the tiles classifiers.

One of the classic problems of the tile industry is the difficulty to know when there is variation in the measured colour (more or less complex calculation of the values tristimulus), and there is not in the perceived colour (response of the visual system).

A methodology for knowing the chromatic differentials thresholds of the persons, specifically of the tiles classifiers has been defined. During this process a dissertation has been made.

Utilisation of organic dyes for the control of quality prior to the tile vitrification in order to detect printing defects

Addition of organic dyes to Inkjet Inks in ceramic tile production is essential in the quality control of the process. Any ink applied on a tile will obtain a higher contrast and combined with optical inspection this gives the possibility to control the results immediately after application instead of after the firing. This efficiently reduces the loss during production.

The dyes do not harm the suspension properties and can be added without any changes in the existing production.

Ferro has brought licenses rights for the use of organic colorants in its inks, and is researching their improvement, with the purpose of obtaining an intensity of point before the kiln, which makes it possible the identification, and analysis of problems of application in the Inkjet technology.

Integration of Sensors and Actuators into an industrial network for the glazing line

This result includes the ceramic line design at the basic level of automation (i.e. selection of suitable sensors, integration of this sensors on a low level network and selection of suitable actuators). The applications of this result are all ceramic lines that fulfil the specifications (appropriate tile dimensions + belt velocity to allow the sensors to stabilize the measures when the tile goes under the sensor) In the project this result has been implemented at an end user factory (Keros Ceramica).

The main benefits for this result are the automation of the ceramic line that allows maintaining the process under control with its associated benefits (lower material waste, lower energy consumption, higher repeatability of the products that allows to reduce the batch size). This is, the automation of the line is an investment that will be translated in a lower cost of production that permits to recover the investment. It also permits to store historical data on the production line operation for future applications (to know weakness and strengths of the process. It will allow designing products in agreement with these characteristics).

Tone quality fuzzy-based control of tiles production lines

Achieving steady tone is the main goal of the Project. Currently there exists an important amount of know-how (expert knowledge) about the actions to be taken so as to correct tone deviations in the line. Formalizing this knowledge and building up a fuzzy-rules based system emulating the experts control is important both for control and training purposes. The developed system performs this task.

Model Based control for tile glazing lines

Achieving a steady state at the glazing lines is one of the main problems at the tiles production industry. Temperature, density and viscosity of the glaze greatly influence the quality of the tile. Keeping them at optimal values is, therefore, of prime importance. The developed control of the glazing lines is based on the use of models taking into account the nonlinearities and parameter variations typical of these systems. The control aims at keeping the relevant process variables within prescribed interval, in spite of the uncertainty. Uncertainty is treated within the intervalar arithmetic framework.
The system either modifies on-line the appropriate manipulable variables or warns the operator, providing a hint.

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