PRODUCTIVITY ENHANCEMENT BY CAMERA BASED INSPECTION OF THE VISIBILITY OF DEFECTS IN INK-JET PRINTED CERAMICS

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ABSTRACT

A novel inspection technology uses the optical scanning of ink-jet decorated ceramic biscuits prior to firing and perception-based image processing algorithms both for the early detection of typical ink-jet nozzle defects and for the prediction of the visibility of these defects on the finished, fired tiles.

1. SOME MIS-FIRING NOZZLES ARE THE NORM, NOT THE EXCEPTION

The rapidly rising market of ink-jet decorated ceramic surfaces is pushed by the many unquestioned advantages of this technology: batch size flexibility, rapid changing of décor, rather small foot-print of the equipment, "digital" data flow etc. Ink-jet decoration nevertheless also introduces a new category of production problems which are directly linked to the underlying technology of the extremely miniaturized and delicate droplet ejection nozzles of the printing heads.

With a typical deposition of 100 million droplets per square meter, ejected at frequencies up to 12000 drops/sec by some 4000 printing nozzles, it is not surprising that a few nozzles always misbehave, despite the very high MTBF (mean-time-between-failure) of the single ejector.

"Bad" nozzles may permanently block droplet ejection because of contaminations, clogged ink, trapped air etc. Bad nozzles also may refuse to shut, producing a continuous line of ejected ink drops. Nozzle defects can be detected via built-in electronic nozzle sensors or just by visual monitoring of the digitally decorated biscuit. The rather faint colour contrast of the not yet fired inks however makes visual detection a challenge.

The usual reaction on the detection of a mis-ejecting nozzle is to halt the production line and to start an automatic nozzle rinsing and cleaning cycle. Such a production stop takes about 10 minutes and results into a significant loss of productivity of the digital decoration line.

Quite a number of these typical nozzle defects however are barely visible to the human eye in the final, fired and fully coloured décor. Stopping the tile decoration on every nozzle defect is therefore an unjustified loss in productivity.

We discuss a solution to this problem which is based on advanced imaging and machine-learning technologies. We have already commercially introduced a somewhat similar system to support the heliogravure printers of decorated wood-based panels for the flooring and the furniture industry [2]. We expand and modify this technology now to the automatic, camera-based inspection of the ink-jet decoration of ceramic tiles.

2. AUTOMATIC DETECTION OF INK-JET PRINTING DEFECTS PRIOR TO FIRING

In order to reliably detect and grade ink-jet printer defects we should be able to scan the decorated biscuits immediately after the printer (and of course well before firing). This will allow for removing badly printed décors as early as possible and significantly reduce the costs of bad tile scrapping. As Peris-Fajarnés *et al*. have discussed in [2], the vast majority of ceramic tile production defects are linked to the decoration process, and this situation has not really changed with digital printing. These researchers have concentrated on *global* colour defects and have proposed a mathematical prediction model for computing the final colours of the fired tile given the spectrally measured colours immediately after the ink-jet printer.

We are focusing in our contribution on *local* defects which are specific for ink-jet printers:

- longitudinal stripy patterns due to non-closing or not-opening nozzles
- "noisy" nozzles with a random functioning
- banding defects, i.e. larger stripes of different intensities

We want to provide a tool for the early detection of "misbehaving" printer nozzles AND a grading tool for measuring the later visibility of these defects on the final fired tiles.

The colour appearance of the non-fired biscuits is of course very different from the final tile as shown in Fig. 1: a decorated biscuit scanned immediately after the digital printing shows very faint colours noticeable as a rather small number of different colours at high values of L in the HSL histogram. Only after the firing do we observe the fully deployed colour gamut.

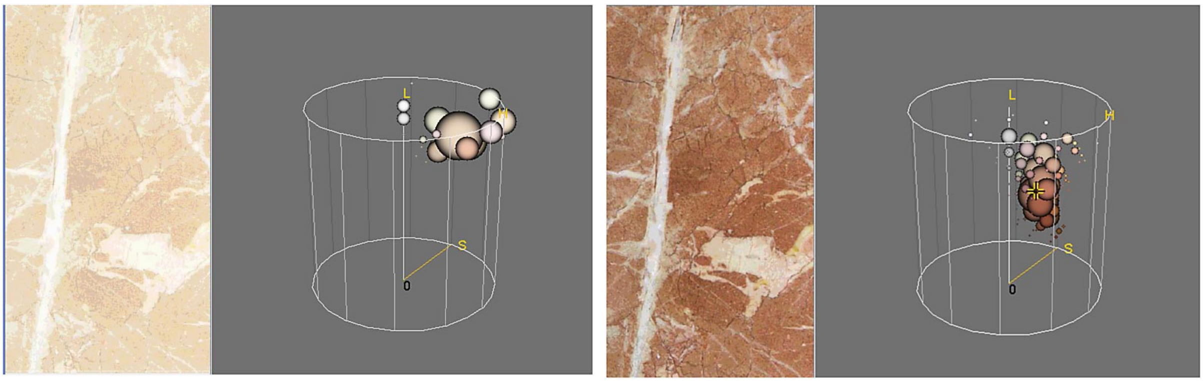


Fig. 1 left: HSL colour histogram of digitally printed biscuit before firing: faint colours right: HSL colour histogram of fired tile; fully developed colours

We have therefore to solve two quite different problems:

a) to assure a robust automatic visual detection of nozzle defects immediately after the printing using imaging and real-time image processing, operating on the very faintly coloured biscuits, i.e. on images with a sparsely populated colour histogram

b) to predict in advance the later visibility of a nozzle defect on the fired tiles and to automatically decide on the ejection immediately after printing.

We expect that quite a number of the nozzle defects will sufficiently hide within the décor pattern and as such do not have to be ejected nor the printer to be stopped for servicing. Our aim is to increase the productivity of a digital tile decorator by preventing unnecessary production stops.

3. CAMERA-BASED DETECTION OF NOZZLE DEFECTS

Our goal is to detect nozzle defects immediately after printing, i.e. before firing. We detect the very specific nozzle defects based on their line-type geometry within the décor texture, be it an artistic (synthetic) décor or a décor which mimics natural surfaces. This direct defect detection approach greatly simplifies the inspection task for the user, as no correlation or matching with the décor graphic RIP files is required.

The non-fired tiles are scanned with high-resolution cameras using specific multiple-wavelength LED illuminators. The acquired multi-channel images are numerically transformed into the approximate décor appearance after firing by using a prediction model and small sample machine-learning concepts. This "prediction image" enhances the difference between the correct décor and singular nozzle-defects. It allows for a robust discrimination between good tile décor and local nozzle defect via a quite sophisticated multi-stage texture analysis (Fig. 2).

In a final step the inspection system computes the "visibility" of a nozzle defect, i.e. the appearance of the linear graphical pattern of a nozzle defect within the tile décor when observed by the human eye from a typical viewing distance (patents pending).

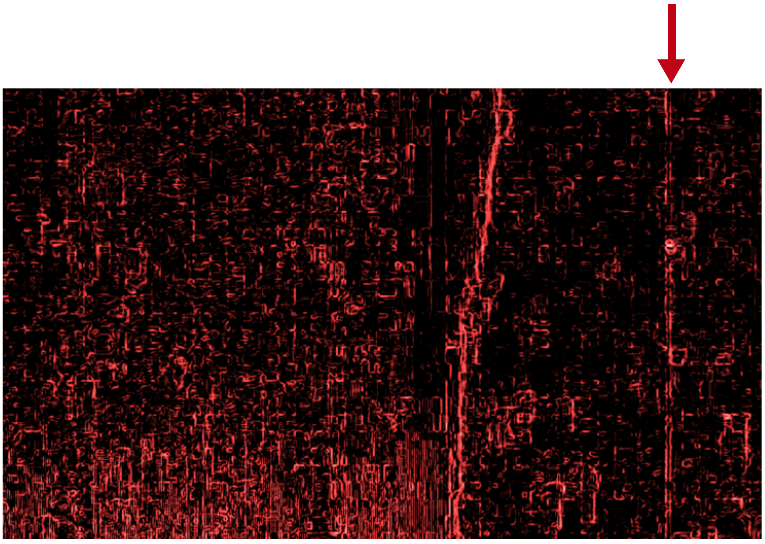
A numerical "Visibility Grade" measure is displayed to the operator. Only those nozzle defects which exceed the user selectable visibility threshold generate an alarm and a subsequent printer stop for an automatic nozzle head cleaning cycle.

Nozzle defects below visibility the threshold are counted and stored in the quality management system of the optical inspection; they are signalled as a potential weak nozzle requiring a more focused ongoing observation.

For those rare décors which may comprise linear graphic elements running exactly in the direction of tile transportation, we use the digital graphic file to define beforehand narrow inspection corridors, where the texture-based defect detection algorithms are tuned to measure the correct definition of the line-type graphics produced by the CMYK nozzle heads.

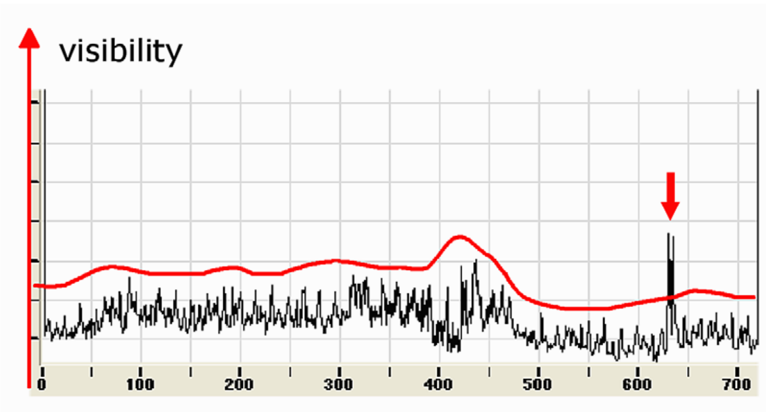
Step 1:

Prediction of colour contrast after firing



Step 2:

Texture-based detection of nozzle defects



Step 3:

Grading of the visibility of nozzle defects

Fig. 2 Detection and Visibility grading of nozzle defects on the scanned non-fired biscuit

4. HIGH DECORATION PRODUCTIVITY DESPITE A DEMANDING JET TECHNOLOGY

We acknowledge the effort of ink-jet printer head manufacturers to increase the reliability of correct nozzle operation, of drop formation and ejection. At the same time, however, we see a trend towards higher dot densities, smaller nozzles, higher droplet ejection frequencies and a larger range of inks having quite different physical properties. The increased number and the increased frequencies of ejected droplets per sqm of decoration will at least partially reduce the achieved higher printing-head reliability.

The specific nozzle defects of ink-jet printers will therefore not disappear or become irrelevant, but we see them as a characteristic behaviour of this technology the decorator has to live with. Leaving an ink-jet printer operating without a 100% real-time inspection of the drop ejection process will just become too risky and too costly. Today's periodic manual inspection will become much too unreliable and costly.

That's why we foresee camera-based inspection integrated into the ink-jet printer a must for producing good quality at high productivity.

Looking at unavoidable ink-jet defects with a productivity-minded eye means that we can tolerate nozzle defects if they are below a given visibility threshold. Such a tempered quality philosophy significantly reduces the number of printer stops for cleaning/rinsing cycles and increases the productivity accordingly.

Ejecting tiles with a too visible printing defect immediately after decoration and well before firing will also save a substantial amount of raw materials and kiln energy compared to the traditional inspection after the kiln (see similar arguments in [1]).

Scanning the non-fired decorated biscuits and displaying the (numerically) predicted final décor on a calibrated colour monitor will provide the shift operator with an advanced prediction of the system's productivity and of the stability of the decoration equipment.

Continuous inspection also generates the data for discovering weak points linked to the ink-jet decoration process, i.e. all that data the quality department is eager to obtain for improving the decoration process.

REFERENCES

[1] Peris-Fajarnés *et al*. Evaluation of color prediction models in the decoration of ceramic tiles. Journal of the Ceramic Society of Japan 116 [1], pp. 146 – 152, 2008

[2] Baumer Inspection GmbH Technical Information on the "ColourBrain® DecoProof" system, www.baumerinspection.com