Advanced Engineering Informatics 27 (2013) 93–107

Contents lists available at SciVerse ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

# Quality control engineering in automated ceramic tile production using a signal information content approach

Franjo Jovic [a], Alan Jovic [b,*], Darko Krmpotic [c]

[a] Department of Computer Engineering, Faculty of Electrical Engineering, University of Osijek, Kneza Trpimira 2B, HR-31000 Osijek, Croatia
[b] Department of Electronics, Microelectronics, Computer and Intelligent Systems, Faculty of Electrical Engineering and Computing, University of Zagreb, Unska 3, HR-10000 Zagreb, Croatia
[c] KIO Keramika Ceramic Tile Production Plant, Vladimira Nazora bb, HR-33515 Orahovica, Croatia

A R T I C L E   I N F O

*Article history:*
Received 8 March 2012
Received in revised form 25 September 2012
Accepted 21 November 2012
Available online 21 December 2012

*Keywords:*
Quality control
Automated batch production
Information measure
Qualitative coding
Monitoring signals
Crew monitoring

A B S T R A C T

The pressing process in the automated production of ceramic tiles is a complicated process that involves fully functional machinery and efficient coordination of the working crew. Quality control (QC) of the process relies on reasoning and acting on information coming from measured signals on the automated machinery. For QC, it is necessary to establish that these measurements are correct for the purpose of final product quality. In the process, tile batches are produced within a tolerable range of tile rejection. However, if the percentage of rejects rises above a certain threshold, e.g. 6%, the QC staff are responsible for finding the cause of the defect.

The aim of this work is the investigation of a short-term information measure, expanded tessellation entropy, which can aid the QC staff in discovering the causes of deviations in the quality of batch production of ceramic tiles. This unique signal measure is calculable from as few as four consecutive machinery signal measurements, it is sensitive to small changes in the signal, and its computation is fast. Its noise sensitivity is tested for a set of four standard analytical process signals, with the addition of 1% random noise, and is shown to be robust with appropriate setting. The information measure is applied to measured process-machinery signals, and the results are compared with the QC signal that measures the tile rejection rate. An interpretation procedure is proposed and applied that reveals which signals are significant for increased tile rejection. The procedure is based on comparing signals and QC sequences with similar information code patterns. The results show that the defects are mainly due to human error, and that they usually start with improper furnace handling or uncompensated tile humidity. The method is compared to Shannon entropy, approximate entropy, Pearson correlation, and control charts, and it is shown to be superior for detection of faults in a setting where there is not much historical data available for statistical analysis, and where the quality of the process (percentage of rejects) is continuously measured as a target signal. In employing the proposed procedure, all of the QC defects were explained. The interpretation procedure is not fully automated at this moment. However, it is shown to be applicable to monitoring automated press machines in a ceramic tile plant, and thus preventing future defects. It can be applied to other similar automated industrial processes.



## 1. Introduction

Technology is a synergy of simplicity, economy, and functionality of a particular device or machinery. The engineering problem is just in keeping the appropriate simplicity of the machinery in application such as to satisfy the economy and functionality of the machinery while producing an end-product at the required level of quality. Quality, in automated and robotized plants, is maintained by means of carefully chosen control indicators that monitor the aggregate behavior of a particular machine, often put into demanding production conditions. Quality control (QC) is a process that has to be employed in order to make sure that a certain level of quality in a consumer product or service is attainable. It may include whatever actions a business deems necessary to provide for the control and verification of certain characteristics of the product or service. The basic goal of QC is to ensure that the products, services, or processes provided meet specific requirements, and that they are dependable, satisfactory, and fiscally sound. The main reasons for product quality degradation are the unavoidable fallibility of the management and production crew, and inherent imperfections in machine tuning and behavior [1]. Thus, in an industrial production process, there exists the necessity

* Corresponding author. Tel.: +385 1 6129 548; fax: +385 1 6129 653.
*E-mail addresses:* franjo.jovic@etfos.hr (F. Jovic), alan.jovic@fer.hr (A. Jovic), dkrmpotic@kio.hr (D. Krmpotic).

1474-0346/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.aei.2012.11.007

to monitor the extent to which the products meet specifications. The misspecification of product quality can be measured as: (1) deviations from target specifications and (2) excessive variability around target specifications.

The quality-control engineering issue in this work is illustrated in the automated production of ceramic tiles at the ''Kio Keramika'' plant in Orahovica, Croatia, on tile pressing machines, of type Magnum 1203ES. These pressing machines are a part of an entire production chain consisting of slurry production, granulate production, pressing, decoration, and firing in a tunnel furnace. Several production machines are used for each part of this production chain, and altogether there are five presses in the process. Tile quality is controlled at the end of the production chain for each shift, while particular machining defects are controlled by the production crew at each production step. The press control indicators (a total of 30) that are centrally reported in each shift, and for each press, are: tile humidity, four pressing tool temperatures (of upper matrix, lower matrix, press frame and press oil), five thickness dimensions between the press frame signals, five thickness dimensions over the press frame signals, five skewness dimensions between the press frame signals, five skewness dimensions over the press frame signals, and five tile firmness indicators. In addition, seven furnace temperature indicators are reported.

Although this signaling seems to be satisfying enough, and despite the exclusion of each damaged tile from production by the worker at the press, because of pressing process complexity and its influence on further tile processing, there is a problem of increased rejection rate in the tiles' production. The rejection problem is increased by the fact that the tiles are classified into two commercial classes, while producing a lower tile quality class is not economically feasible. The alarm level for the management and QC staff starts when the tile rejection rate rises above 3–4% of the production bulk, and a rejection rate above 6% is considered unacceptable.

The basic problem of tile quality monitoring on the press is the fact that, in spite of all press signals being correct, there might be press-caused tile rejection or a decrease in ceramic tile quality. The press's working crew might not be responsible for the malfunction, or for tile misclassification, because there might be a combined effect of several factors that influence tile quality. Intervention on the press without knowing the exact cause of the defect is expensive because the machine should be stopped, while nonintervention, on the other hand, can cause even more damage. Increased rejection appears seldom, but it is nevertheless a major source of concern for the tile factory. Thus, any indication as to the cause of a defect ascribed to a given press is an important factor in decreasing further rejection. Production praxis has shown that the cause of the defect is the human factor in approximately 80% of cases. Failures resulting in increased tile rejection are thus usually caused by a lack of direct adaptability of the press worker to demanding production circumstances, and by their low motivation for learning new production skills in a highly automated production process.

The aim of this work is the investigation of a short-term information measure that can be used to discover the causes of deviations in quality in the batch production of ceramic tiles. Previous work on the information content of industrial signals suggests that such a measure might exists in the form of modified one-dimensional Carnap entropy [2]. However, the application of the measure and its interpretation have not been extensively studied thus far. Here, we introduce the leading pattern that has to be followed in order to find a defect's cause in the form of a QC output signal. This output signal measures the rejection rate of the tiles produced. The output signal is analyzed for its uniqueness, meaning that even the smallest variation in its content should be uniquely identified by the proposed information measure. The information measure calculated for other process signals is then compared to the QC output's information measure, and signals that mimic the QC output in the same time frame are reported as potential causes of malfunction.

The paper is organized as follows. Section 2 describes the engineering problem faced in this work: the actual setting of the pressing machine, working duties and procedures, and the issue of increased rejection. Section 3 provides an overview of the existing approaches in QC and gives a definition of system teleonomy that is used in order to properly define the proposed information measure. Section 4 introduces expanded tessellation entropy as an information measure capable of tracking short-term signal variability in automated production. Section 5 applies the information measure to relevant signals in the production process of ceramic tiles and proposes a suitable interpretation system for detecting possible defect sites in the production chain. Comparison with other methods is given in Section 6. A discussion of the results is presented in Section 7, with conclusions in Section 8.

## 2. Working cycle of the Magnum 1203ES pressing machine

The initial phase of the tile press is the feeding of the press silo with granulate. The quality of the granulate depends on the correctness of the work of the previous plant parts: the slurry atomizer and granulate silo. The press silo is automatically fed in each pressing cycle, and granulate humidity is controlled with a humidity gauge. Pressing-tool temperature is an important condition for automatic press work. Tool temperatures between 45 and 60 °C ensure that the tiles do not stick to the tools during pressing. There are three pressing tool parts: upper matrices, tool frame and lower matrices, each with specific functions for the tiles' processing.

The pressing cycle starts with the movement of the hydro motor's 'hand', which is mechanically coupled with the grate feeder. Two rods rifle excess granulate off the apertures on the tool frame and clean the tool frame of granulate at the moment of the feeder's return. The pressing force determines the number of pressing steps: two or three. The first pressing step is carried out with power pressure in the main cylinder and at lower speed because of the requirement to decrease granulate volume by blowing out all the air inside and among the granulate body. A pressure-preset second step is started when the required pressure is achieved with the first pressure step. The main cylinder stops pressing when the second preset pressure is achieved. The main cylinder then moves back to its upper position and, at the same time, the lower cylinder of the lower drive blasts off the lower matrices toward their upper position at the upper tool frame plane. When the main cylinder approaches the predefined point that is determined with the feeder height, it moves the feeder forward again and then, with its front bar, extrudes ceramic tiles from the tool to the transporter. The transporter removes such processed tiles toward a vertical drier. The main cylinder continues with the above process while, at the same time, the tiles are being removed from the tool frame. Overall press process control and monitoring in automated production is performed with a programmable logic controller. The technological press process of ceramic tiles is controlled and maintained by the press crew: presser, toolpusher, hydraulic worker, press department manager, and production manager. The working duties of the press crew relate to press process preparation, press production and press adjustment.

The pressing machine itself plays a major part in the overall process of the production of ceramic tiles. It is also the place where almost all of the malfunctions of the tiles start to occur. The workflow of the whole process is shown in Fig. 1.

After each step in the process, QC measures signals and determines the course of action. It is important to note that glazing,