

Explaining and Predicting Print Quality Variations of Colour Prints

I. INTRODUCTION TO THE FIELD AND THE STATE OF THE ART

TO stand the high competition in the market related to the papermaking and printing industries, companies are striving to get the best possible return from their equipment. Therefore, ensuring manufacturing of products of a desired constant quality that meets customer's specifications offers a significant advantage for the companies. To assure high constant quality of colour prints, that is the ultimate goal of both papermakers and printers, a producer must have a possibility to objectively measure and monitor the quality of the end-products. However, presently, acceptance or rejection of a colour reproduction is mainly based on ink density measurements on specially designed solid print colour bars or—most often—on subjective evaluation by a colour technician. Moreover, a colour technician's decision about the acceptance or rejection is based not only on the degree of colour match between the original and its colour reproduction, but also on the subjective technician's perception how well the reproduction meets the customer's standards.

It is now almost unanimously agreed that to further boost quality of colour prints, it is important to understand the interaction mechanisms between paper and a printing press governed by different settings of numerous parameters. There are many paper, printing press, and process parameters to be studied to explain the interaction. To our believe, we have to go even further in these interaction studies by exploiting information on ink, clothing of a particular paper machine as well as chemical additives used in the paper manufacturing process. Due to complicated interrelations between all these parameters, the interaction mechanisms can be only explained through the rigorous analysis of the huge amount of data comprehensively characterizing the issues that might have impact on the mechanisms.

It all substantiates that an advanced high resolution system for simultaneous on-line registration of paper and press parameters as well as colour images characterizing the printed result is needed to enable comprehensive analysis of the paper-printing press interaction and the print quality related problems. The collected data sets must then be augmented by additional information coming from paper mills, manufactures of ink, paper machine clothing, and chemical additives. During the last years our research group has developed novel optical methods and tools for on-line measuring of paper and print parameters from a running web [1], [2], [3]. Moreover, using advanced approaches to data analysis we have recently developed original techniques for colour print quality characterization and monitoring by measuring directly on halftone areas [4], [5], [6], [7], [8].

However, the usefulness of an instrumental print quality assessing system depends on how well the resulting system's decision correlates with human judgements. The perceived quality of a colour print is, however, a subjective sensation caused by different object attributes. Therefore, it is of vital importance to develop methods for print quality modelling capable to capture varying subjective impressions about print quality and integrate them into a unified concept that is easy to interpret. One of the most important steps in print-quality model building is constructing of the underlying stimuli configuration in the multi-attribute quality space from subjective judgements and predicting the configurations based on instrumental (objective) measurements on the prints.

There are unquestionable practical reasons for being interested in print quality modelling. Because of the large variety of paper quality grades, printing equipment, ink types, and control parameter settings used today, there is a great economical interest in being able to predict the influence of variations in the technical parameters of the equipment upon the resulting product quality. In the case of alternative equipment and materials, the resulting product quality becomes one of the major factors affecting the choice of the user. Print quality models can also be used to monitor the performance of existing systems and provide insight into which attributes of print quality are failing when the overall quality is insufficient. Moreover, rigorous analysis of the complex relations between different print quality attributes and various parameters characterizing papermaking and printing processes and materials involved in the processes may provide useful information for optimizing the processes.

II. INDUSTRIAL AND SCIENTIFIC RESEARCH PROBLEMS ADDRESSED

A. Industrial problems

- Uncertainty in both printing and papermaking industries about the main reasons causing too high quality variations of colour prints leading to insufficient overall print quality, customers' complains, and substantial economical losses.
- Lack of comprehensive knowledge of interaction between paper, printing press, ink, and other constituents of the printing process. This gap leads to difficulties in finding economically plausible means of adjusting technological parameters for optimizing the papermaking and printing processes.
- Lack of robust tools for print quality predictions based on various paper, ink, printing press and process parameters.
- Lack of tools capable of on-line measuring of several print quality attributes, which aggregated into a print quality measure provide print quality assessments well correlating with human evaluations.
- Lack of tools capable of explaining which technological process parameters are failing when the overall print quality is insufficient.

B. Scientific problems

- To identify measurable *print quality attributes* that can be estimated from on-line measurements of the printed result and to clarify relations between the print quality attributes and the parameters characterizing the paper, printing press, printing process, and ink. To identify the main parameters affecting the print quality attributes.
- To develop a method for integrating the print quality attributes into an overall quality measure capable of providing print quality assessments correlating well with evaluations obtained from humans.
- To develop a structure of a database containing on-line as well as off-line registered parameters. To devise tools for data-mining as well as continuous updating of the database.
- To develop a method for mapping values of parameters characterizing the paper, printing press, printing process, and ink into the space of the print quality attributes and the overall print quality score.
- To create an integrated decision support system capable of taking queries from and providing recommendations to a papermaker, printer, and ink supplier. Printing process optimization should be possible through the system suggestions of settings for the global process parameters depending on the incoming materials used in the printing process.

III. SCIENTIFIC APPROACH TO THE PROBLEM ADDRESSED

The main research areas addressed in this project are: print quality assessment, on-line measurements in paper production using modern optics, colour image analysis, optimization aiming to create an optimal data configuration in the multidimensional quality space, cluster analysis, fuzzy measures and fuzzy integration, feature extraction and selection, and discovering of mappings between different subspaces. Research will be focused according to the following main lines.

- i. Artificial neural network and image analysis based tools for measuring colour on printed halftone multicoloured bars in newspapers we have recently developed [4], [5], [6]. Based on these works research will proceed aiming to create intelligent computing based soft sensors for assessing print quality from colour camera measurements made directly on multi-coloured pictures.
- ii. The work presented in [1] has contributed to the creation of a platform for the development of future sensors and data acquisition systems for on-line quality monitoring of paper production. To be able to design special sensors and algorithms for the identification of specific quality related properties in the paper web, a multipurpose instrument for two-dimensional paper analysis will

been developed, in which different properties and parameters can be measured simultaneously using different sensors arranged with high geometrical precision.

- iii. Print quality attributes define a multidimensional quality space. A multidimensional quality space can also be derived based on quality comparisons (rankings) obtained from humans. The goal is to obtain quality spaces of these two types providing well correlating quality evaluations. To create the human quality comparisons based multidimensional quality space, to clarify the dimensions and to interpret neighbourhoods of the space, multidimensional scaling (MDS) and hierarchical cluster analysis techniques will be used. Relations between the dimensions and print quality attributes will be studied by employing the canonical correlation (linear and kernel) and cluster analysis, by learning a dissimilarity measure from data [9].
- iv. How we can ascertain that the model obtained from the MDS procedures does indeed provide an adequate characterization of the data at hand? Since, to estimate the model parameters we are going to use the mean squared error criterion, ANOVA will be employed for analyzing the goodness of fit between the model predictions and the experimental data used to build the model. ANOVA attributes the variance in the data being analyzed to a few likely sources and estimates the statistical evidence for those sources. To evaluate the model, the hypothesis that the model prediction errors can be attributed merely to noise will be tested.
- v. Linear as well as nonlinear techniques can be applied for aggregating multiple criteria into an overall evaluation score. Both types of techniques will be studied. The goal is to develop a technique for estimating aggregation parameters—a measure (additive or non additive—a fuzzy measure, for example), which enables obtaining overall evaluation scores closely correlating with similarity/dissimilarity rankings obtained from humans. Numerous studies of multi-criteria decision making have demonstrated that fuzzy integration is a worth considering approach to fusion of evidence from multiple interacting sources [6], [10], [11], [12]. The approach allows incorporating the subjective preference to the sources into a fusion procedure.
- vi. The next issue important for this project is analysis of relations and discovering mappings between different groups of variables including variable selection in the analysis process. To tackle the problem we are going to employ and combine the genetic search, kernel, and artificial neural networks based techniques. A special attention will be paid to model-free approaches discovering mappings through learning [13], [14], [15] and algorithms capable of exploiting both labelled and unlabelled data in the training process [16].
- vii. One of the essential goals of the work is to develop a system for data interpretation and decision support. By providing versatile characterization and interpretation of the complex process generating the data, it is expected the system to be able to support decisions of printers and papermakers striving to understand and optimize the manufacturing process. Data interpretation will also result into automatically provided recommendations that can be used in a pressroom to make the printing process more efficient. When developing the decision support system, a special attention will be paid to information fusion and decision-sharing interaction between the decision support system and the operator.

IV. PROJECT OBJECTIVES AND EXPECTED RESULTS

A. Project objectives

- *To obtain and utilize in industry new knowledge allowing to increase value of existing products.* The project should lead to a new level of understanding of interaction between paper, printing press, and ink.
- *To establish new competence for competitive future developments in Swedish industry.* The R&D personnel of the industries participating in the project and the university have deep knowledge in their corresponding areas. However, to further enhance the competitiveness of products coming from the industries, joint competence needs to be exploited. The project provides an opportunity to build up such new competence.
- *To strengthen the collaboration between researchers of the field and the papermaking and printing*

industries. An advanced hardware and software platform, enabling various inter-industry studies, will be created in the framework of the project. By no doubts, the competence gathered and the platform developed will assure long lasting collaboration and attract new partners.

- *To develop a test facility—hardware and software (a database and a decision support system)* installed in a printing shop—that can be used when searching for solutions to various production problems in papermaking and printing industries or investigating properties of new products.

B. Expected results

- A deep knowledge of paper, printing press, and ink interaction allowing to explore economically plausible means of adjusting technological parameters for optimizing the papermaking and printing processes. This will lead to higher quality of printed media and, therefore, less complains for several industries involved in the production process.
- Strengthened cooperation between partners from several industries involved in the printed media production process.
- A comprehensive database containing parameters obtained from online as well as off-line measurements characterizing paper, printing press, printing process, and ink. Data-mining tools and means for automatic database update.
- An integrated decision support system capable of taking queries from and providing recommendations to a papermaker, printer, and ink supplier.
- A tool for predicting the print quality score from a set of process parameters. Insight into which technological parameters are failing when the overall print quality is insufficient.
- Definition of soft, measurable print quality attributes, which when aggregated into a print quality measure provide print quality assessments correlating well with human judgements. The attributes will lend themselves to online measuring in a printing shop.

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