Measuring and Using Paper and Print Parameters for an Enhanced Monitoring and Control of Paper Production and Printing Processes

Project Plan

Introduction to the Field

The newsprint as well as printing markets have become very competitive. Companies are striving to get the best possible return from their equipment. Therefore, ensuring production of paper or printed products of a desired constant quality that meets customer's specifications offers a significant advantage for the papermakers and printers. Process control plays a key role in the effort of obtaining products of a desired constant quality.

Control of paper machines and wood chip refiners is a challenging problem due to the following main reasons. Firstly, the disturbances coming with the feed, such as bulk density, chip size distribution, moisture content, and fibre quality are difficult to measure on-line. Secondly, refiners and paper machines are multivariable non-linear systems. Thirdly, the relationships between the final paper quality and the operating conditions of a paper machine are rather complex.

Monitoring and controlling a paper machine to keep it stable have reached a high level of acceptance and success. Today such control systems are a necessity for industrial newsprint production. These systems are based on monitoring physical parameters, and the data from the sensors are generally smoothed over a specific time by taking out running mean values. The vision for the next big step in the paper-making control strategy is to develop systems that can be operated on-line in the paper machine and with an ability to appreciate the print quality that can be reached after an ideal printing process on the very paper just being produced in the paper machine. This is a big challenge to the paper industry, which needs a commitment to long-term technical goals and a willingness to incorporate new scientific and technical results from the frontiers of different disciplines.

Each printing press possesses unique characteristics. The sources of variability include operating conditions, press age, plate and cylinder wear, and printing loads. A particular press may produce a significantly different quality print than another press with the same settings of the adjustable variables. Therefore, it is generally difficult to develop a general-purpose control system for running a press. However, using modern information processing technologies, such as learning systems, it is possible to develop specific process or machine oriented control systems.

A modern printing press registers numerous process parameters. However, none of them is related to paper properties. It is clear that printing quality depends, to great extent, upon the quality of paper. Recent developments in paper making and printing technologies made it clear that on-line measuring and use of primary paper parameters for an enhanced control of a paper machine and a printing press is an important step for further boosting the quality of paper and printed products. The interrelated use of paper parameters for controlling papermaking and printing processes requires of high speed on-line measuring of the parameters on a micro scale. Such measuring is a challenging problem.

The primary results obtained by our group in the fields of paper physics and printing quality control substantiate the usefulness of parameters directly characterising the quality of products [10,11,16] The approach taken to tackle the problem of on-line measuring seems also to be very promising [17]. Now we are ready to develop methods and tools for creating soft sensors that could provide the desired parameters to be used for an enhanced control of paper machines and printing presses. Exploiting these parameters and the results achieved in the field of learning systems we are going to develop robust no-linear models of a printing process. Based on the models developed and the parameters measured adaptive control systems will be created for on-line/off-line printing and papermaking process control.

Project Description

Since we advocate an idea of an integrated use of knowledge from both papermaking and printing processes for obtaining high quality products, problems related to both papermaking and printing industries will be solved in the project. The research carried out in the project will be focussed along the following main lines.

a) Simultaneous on-line measuring of parameters, characterising paper (paper structure, homogeneity, shrinkage of paper profile) and printing quality (colour vector components measured in arbitrary areas of a halftone multicoloured picture), including further development of methods and instruments necessary.
b) Analysis of relation between these two types of parameters, characterising paper and printing quality.
c) Unsupervised selection of variables important to the problem. Numerous parameters, including those we are going to measure on-line, are available from a printing press or a paper machine. Usually only a limited number of them prove to be useful for a problem at hand.

d) Detecting and quantifying residual ink in de-inked pulp by colour image analysis. A significant part of newsprint is produced using recycled pulps. Thus, the quality of the recycled pulps used directly affects the quality of printed products.
e) Non-linear artificial neural networks based modelling of a printing process. Parameters characterising both paper and printing quality will be used for creating the models.
f) On-line printing press control based on the developed models and "*Malcolm*" measurements. *Malcolm* is an image processing and artificial neural networks based instrument, developed by our group, capable of measuring an ink level of four primary colours directly on halftone multi coloured pictures.

Summary of the Group's Earlier Research Results Relative to the Project

1.1 On-line measurements using modern optics in paper production

One important quality parameter of the paper is its homogeneity, i.e. having as low variations as possible over the paper sheet in terms of different paper properties. Therefore, the need to monitor the distribution of different substances in the paper on-line have become important. In newsprint the main constituent is wood fibers, carrying cellulose, hemicellulose and lignin. Measuring the distribution of these constituents in the paper could, for example, be used as an indicator of the homogeneity of the final paper product. However, the print quality is governed by how well the smallest print entity, the individual halftone dot is reproduced on the paper. Therefore, the properties of the newsprint at precisely that spot on the paper where the dot is to be printed govern the result. Consequently, a high geometrical-resolution of the sensors of the monitoring system is required for measuring such variations in the paper.

A robust sensor with high geometrical-resolution has been developed and tested for on-line measurements in paper production. The sensor is designed for measuring the fluorescence response from lignin in paper. A fast system for monitoring and recording the signal from the new sensor has also been designed and built [18]. With this system a whole tambour, about 60 km of web length, can be sampled along a line with a physical distance between adjacent samples of 25 μm at a web speed of 30 m/s. Thus the behaviour of the paper machine can be studied at different length scales, from sub-millimetre variations to behaviours taking place at the scale of many kilometres of produced paper. The sensor system has been evaluated and tested on-line at newsprint mills. From these measurements it could be concluded that the system can be adapted to the industrial environment and give valuable results related to the variations in the process.

The high geometrical resolution of the fluorescence sensor has opened up the possibility of measuring small variations in the paper structure [18]. Another example worth to mention is the possibility to measure imprints made in the paper by the forming fabric [20]. This property has been used to develop a fast and robust method for measuring the paper shrinkage [21].

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 has been developed. The instrument is an adaptive test bench in which different properties and parameters can be measured simultaneously using different sensors arranged with high geometrical precision. Such a test bench is a key tool in the study of different paper properties and in the development of new optical sensors.

The work presented in [17-26] 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. The many on-line experiments and implementations made at Swedish newsprint mills have demonstrated that the use of high resolution optical sensors and high-capacity data acquisition systems can provide new input for our understanding of the dynamics of the manufacturing process.

1.2 Neural Networks Based Colour Analysis

A neural network based method and a system for colour measurements on printed halftone multicoloured pictures and halftone multicoloured bars in newspapers have been developed [2,3,7,11]. The measured values, called a colour vector, are used by the operator controlling the printing process to make appropriate ink feed adjustments to compensate for colour deviations of the picture being measured from the desired print. The 18 months experience of the use of the system in the printing shop witnesses its usefulness through the improved quality of multicoloured pictures, the reduced consumption of inks and, therefore less severe problems of smearing and printing through.

Hierarchical modular neural networks for colour classification in graphic arts, capable of distinguishing among very similar colour classes have been developed [4,5,9]. The networks perform analysis in a rough to fine fashion and are able to achieve a high average classification speed and a low classification error. The structure of the networks is automatically established during the training process. Experimental investigations show the capability of the network to distinguish among very similar colour classes that can occur in multicoloured printed pictures. The classification accuracy obtained is sufficient for the network to be used for inspecting the quality of multicoloured prints.

1.3 Monitoring the De-Inking Process through Neural Network Based Colour Image Analysis

An approach to determining colours of specks in an image of pulp being recycled has been developed [10,13]. The task is solved through colour classification by an artificial neural network. The network is trained using fuzzy possibilistic target values. The number of colour classes found in the images is determined through the self-organising process in the two-dimensional self-organising map. The experiments performed have shown that the colour classification results correspond well with the human perception of colours of the specks (KK-project 1998/0720).

1.4 Neural Process Control

During a period of time a printing press operator learns to quantitatively relate the observable variables to the adjustments of the ink keys necessary to perform to restore print quality. In the approach proposed, the observable variables are measured on multi-coloured halftone areas by a committee of neural networks. The obtained measurements are then further used by a neural network based printing press control unit for generating control signals to compensate for colour deviation in offset newspaper printing. In this application, we adopted the indirect adaptive control strategy [16] (KK-project 270/00).

1.5 Learning Algorithms that Use both Labelled and Unlabelled Data

Learning is traditionally categorised as being supervised or unsupervised. Supervised learning uses labelled data. Data labelling may be, however, very expensive, time consuming, or even impossible sometimes.

Therefore, it is important to device learning algorithms that can exploit both labelled and unlabelled data when learning decision making or mapping problems. Our research in this area has shown that substantial gain in classification performance may be achieved from the use of both labelled and unlabelled data in the training process [6,12].

1.6 Committees of Neural Networks

Neural networks are unstable to perturbations in a learning set. Hence, the use of small training sets may cause generalisation problems. As we know, in most of practical applications of intelligent systems, training sets are rather limited. One way to cope with the problem of sensitivity to a learning set is to build a committee of neural networks by bootstrapping, boosting or half&half bagging the original learning data set when training members of the committee. Several new methods for fusing separate neural networks into a committee have been proposed and investigated [8,14]. The work of addressing the feature selection problem in a context of neural network committees is going on. To our knowledge, almost no research has been carried out in this area.

1.7 Feature Selection with Neural Networks

The reduced risk of data-overfitting and the reduced cost of future data acquisition are the main advantages of using small feature sets of only relevant features when solving classification problems. Therefore, robust feature selection procedures are of great value.

We have recently proposed a neural network based feature selection technique for classification based on a single neural network as well as neural network committees. A network is trained with an augmented cross-entropy error function. The augmented error function forces the neural network to keep low derivatives of the transfer functions of neurons when learning a classification task. Such an approach reduces output sensitivity to the input changes. The feature selection is based on the reaction of the cross-validation data set classification error due to the removal of the individual features [15].

Description of the Scientific Approach to the Problem

Our research will be focused according to the following main lines.

1. The need to control the production process has grown in the paper industry during the last decades, due to the technological development and the continuing increase in quality demands. In a modern paper machine measurements are made in a quite coarse grid. However, the recent development of sensors and fast, high-capacity computers opens up new possibilities for the development of high-capacity monitoring systems for the paper industry. Optical systems seem to be the most promising measuring technique in this area. An optically based sensor offers the possibility of a high geometrical resolution, e.g. the focusing of a laser beam is in theory only limited by the wavelength used. For newsprint however, the detection limit is often set by the light-scattering property of the paper. Within the framework of this project we are going to develop optical sensors which will possess the possibility of performing fast measurements with high geometrical resolution without any physical contact with the sample measured.

2. Extending the supervision of a paper machine into the area of on-line estimation of print quality potential requires an increased knowledge of the underlying processes involved in paper manufacturing and the processes governing the print quality. Consequently, an improved understanding of the interaction between the photons, the paper structure and the ink is important. The underlying causes of light scattering in the paper structure can be related to interfaces between substances with different refractive indices and different absorption coefficients. In the paper structure this can also be related to the size distribution of, e.g. fibers, fillers, fines, porosity, etc. In addition to that, different calendering techniques which affects the roughness of the paper surface also influence the optical properties of the paper. Therefore, a homogeneous distribution of substances and properties in the paper structure is of central importance to achieve a high quality print. Consequently, this requires that the monitoring system should be able to record variations in the homogeneity of such substances at a resolution similar to that of a halftone dot. We are going to develop methods for interrelated analysis of parameters characterising papermaking and printing processes.
3. To extract a diagnostic value from the recorded data measured by the high-resolution sensors, the sensor must be integrated with fast signal-processing hardware. A trend in this area is the so-called "intelligent" sensors, where computational power, often a digital signal processor (DSP), is integrated with the sensor unit. One advantage is that a number of truly parallel computations and algorithms can be run at high speed simultaneously. This also means that the processing power of the system is distributed to where it is most needed. Consequently, with the introduction of high-geometrical-resolution sensors the demands on data processing as well as the necessity to distribute the required computational power increase. As a result of the project, adaptive hardware of a high computational power will be developed for measuring parameters relevant to robust characterisation of papermaking and printing processes.
4. One of the goals in both engineering and everyday life activities is the efficient combination and use of all available and relevant information. Information relevant to our problem, as well as many other engineering problems, can arise in various forms, including: numerical observations from automated sensors and expert opinions from purely human-based sources. This information is typically uncertain. Besides classical probabilistic randomness, there are various types of uncertainty, such as imprecision in the Dempster sense and fuzziness. The methodologies utilised in accomplishing the above goal have been given a variety of names including “data fusion”, “information fusion”, “combination of evidence”, “sensor fusion”, and “synthesis of observations”. In a general sense data fusion refers to a broad range of problems which require the combination of quite diverse types of information, provided by a variety of sensors, in order to make decisions and initiate actions. A sometimes bewildering variety of techniques are being applied to data fusion problems, such as statistical decision theory, fuzzy logic, Dempster-Shafer theory, Bayesian nets, neural nets, rule-based approaches, genetic algorithms, random set theory, conditional event algebra, and so on. To use the various types of uncertainty in the most effective manner we are going to: a) develop reasoning models capable of dealing with various types of uncertainty; b) design fully-automated and operator-assisted computationally feasible algorithms.
5. In many practical applications, we can measure or calculate (extract) a large number of variables, while only some of the variables could prove useful for a specific task. Some variables can even deteriorate performance of a mapping system or can be very expensive to measure. Variable selection is usually limited to supervised approaches concerning data classification. In this project, we are going to focus on unsupervised variable selection for learning mapping problems.
6. So far, modelling of a printing press has been limited to rather simple empirical equations relating ink density to the adjustments of ink keys controlling the ink flow. These equations have been developed using conventional regression analysis and have very limited modelling capabilities. We are going to develop and investigate non-linear neural network based printing press models, capable of taking into account numerous parameters characterising the printing quality, the printing press status, and the paper properties.
7. A very few attempts have been made to implement an on-line control of a printing press. As a rule, ink density serves as an observable variable in these applications. The developed instrument “Malcolm” gives us a unique possibility to measure the ink level directly on halftone multi-coloured pictures and to use the measured values as observable variables in on-line control of a printing press. We are going to investigate different neural modelling based control configurations, paying a special attention to the approximate *NARMA* models based control and *PID* neural networks.