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Control of ink-water balance in offset lithography by machine learning

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Short abstract

This paper presents a concept for recording relevant press parameters and parameters influencing the ink-water balance. The sensor technology for recording additional process parameters is explained and the installation of a measuring traverse in a sheetfed offset press is shown. A measurement campaign with variation of various printing parameters was carried out. The set press parameters and the sensor data were digitally documented and then evaluated using sensor data fusion and a machine learning toolbox developed at Saarland University. The sensor data consists of temperature, humidity and gas sensor data, which were synchronized with the recorded press parameters. The target variable to be investigated is the setting of the dampening potentiometer. It was shown that the algorithm is able to relatively accurately reconstruct the setting of the dampening potentiometer.

Keywords: gas sensor, printing, AI, model, sensor fusion

1. Introduction and background

Offset lithography is a flat printing process in which the image and non-image areas lie in one plane. During printing a thin film of fountain solution (for simplicity water and fountain solution represent the same terms) is first applied to the printing plate, which is clamped onto the plate cylinder so that the ink can only adhere to the image areas (Kipphan, 2000). This is a special feature compared to the other conventional printing processes, but makes the printing process all the more complex and susceptible to faults. This is one of the reasons why Teschner (1995) describes offset lithography as "... the most problematic and technically complicated of all printing processes."

Figure 1 illustrates the operating principle of offset lithography. The printing plate is clamped around the plate cylinder, which is first wetted with fountain solution via the water rollers of the dampening unit. The printing plate is then inked in the image areas by means of inking rollers from the inking unit. The ink is then transferred to the substrate via the blanket cylinder, onto which an elastic blanket is clamped. The impression cylinder provides the required back pressure to transfer the ink on the printing substrate.

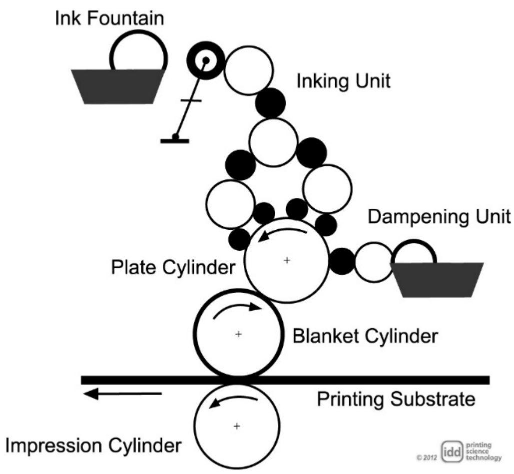


Figure 1: Operating principles of offset lithography

The ratio between ink and water is essential for high-quality printing. There is no process for automated control for the amount of water on the printing plate, yet. To this day it is still set and corrected manually several times during the printing process via the so-called dampening potentiometer, that controls the turning speed of the water rollers. Due to the noticeable decline in qualified printing personnel, the offset printing process must be further automated to regulate the ink-water balance. The approach is to control the ink-water balance based on sensor fusion and machine learning methods as suggested by Weber, et al. (2021).

The dampening potentiometer is set manually by the operator on the press at the control station for each printing unit individually. The value for the setting generally ranges between 0 and 100 percentage points. If the dampening potentiometer is set too low, scumming can occur, i.e., ink also reaches non-image areas on the printing plate. If the dampening potentiometer is set too high, the dampening solution may migrate into the ink duct; this is also known as emulsification, i.e. the ink exceeds its water absorption capacity (Knödl, et al., 2022).

In a first approach, machine learning is used to reconstruct the setting of the dampening potentiometer, that was controlled by an experienced operator and, thus, to mimic the operator`s know-how. A change in the dampening potentiometer set point leads to an increased or decreased supply of fountain solution. Fountain solution is mainly composed of osmosis water, additives, and isopropanol. Isopropanol can be detected in the gas phase by metal oxide semiconductor (MOS) gas sensors. In general, these gas sensors record the resistance of one or more gas sensitive layer which react to changes in the composition of the surrounding atmosphere. For this reason, among others, MOS sensors are used in the experiments presented here for the first time. In order to achieve a higher selectivity, a temperature-cycled operation (TCO) is implemented (Lee and Reedy, 1999). Here, the sensor layers are periodically heated to different temperatures resulting in a characteristic pattern for different gases (Wagner, 2014). Furthermore, TCO also improves the stability by desorbing or burning gas residues from the sensor layer at high temperature (Schütze and Sauerwald, 2020).

In some cases, glycerol is used as a substitute for isopropanol. The structural formula of glycerol is suitable for detection with semiconductor gas sensors. Due to the lower vapor pressure of glycerol results may differ. Fountain solutions without isopropanol are not part of these investigations.

The data evaluation is based on a tool for automated feature extraction and feature selection (Schneider, Helwig and Schütze, 2018). This tool is used in condition monitoring and related cases, but can also be used for novelty detection or to detect errors like sensor offset or drift. Basically, the Matlab-based toolbox offers individual feature extraction per sensor combined with sensor data fusion and rigorous validation of the obtained machine learning (ML) models (ML-Toolbox, 2023). The toolbox is modular and allows combining different algorithms for feature extraction, selection and classification or regression to select the best performing combination. It is also possible to add further algorithms in the form of modules, e.g., further extractors or selectors, but also transformers or regression algorithms.

2. Materials and methods

2.1 Sheet offset press, printing parameters and design of experiment

The experiments were carried out on a *Speedmaster XL 106* print press (Heidelberger Druckmaschinen AG, Germany) with 8 printing units, where only the last 4 printing units before the delivery were used. During the tests, the parameters printing speed, inking, printing form and the dampening potentiometer setting were systematically varied. Two different printing forms were used with high and low area coverage, inking was either −15 % or +15 % and printing speed was 12 000 sheets/h or 16 000 sheets/h. Half of the variations involved setting the machine to the scumming limit by carefully adjusting the dampening potentiometer. The other half consisted of increasing the dampening potentiometer setting by 5 percentage points starting from the scumming limit. From one variation to the next, only one of the above-mentioned parameters was changed at a time and a total of 24 variations were carried out, including 8 repetitions of variation. The individual variations were held for 4.5 minutes and 3.5 minutes at printing speeds of 12 000 sheets/h and 16 000 sheets/h, respectively, in order to be able to collect measured values in the stationary printing process. All experiments were performed in a closed environment at a temperature of 23 °C ± 0.5 °C and a relative humidity of 55 % ± 2.5 %.

2.1 Additional sensors

To record additional relevant process parameters, measuring traverses were developed in cooperation with Heidelberger Druckmaschinen AG, which were mounted on the delivery side in the 4 printing units. Gas, temperature and humidity sensors were mounted on the measuring traverses. Gas sensors *SGP40* (Sensirion, Schweiz), which contains four different gas sensing layers, and *ZMOD4450* (Renesas, Japan) as well as a combined temperature-humidity sensor *SHT35* (Sensirion, Schweiz) were integrated with the required control electronics in a 3D-printed housing with openings centered along the rollers. A suitable temperature cycle (TC) for detecting and quantifying isopropanol was identified in preliminary lab experiments, the TC parameters are given in Table 1.

Table 1: Temperature cycle parameters used for all gas sensors

Cycle segment	Duration in s	Temperature in °C
1	4	400
2	6	175
3	4	400
4	6	300

In addition, PT100 temperature sensors were mounted on each of the measuring traverses. Finally, an infrared thermometer was mounted on one measuring traverse to record the temperature on the oscillating roller above the fourth ink form roller. Another PT100 temperature sensor was magnetically attached to the side walls of the printing units on the operator side. Figure 2 shows the sensors mounted on the measuring traverse and Figure 3 shows the installation situation in the printing unit.

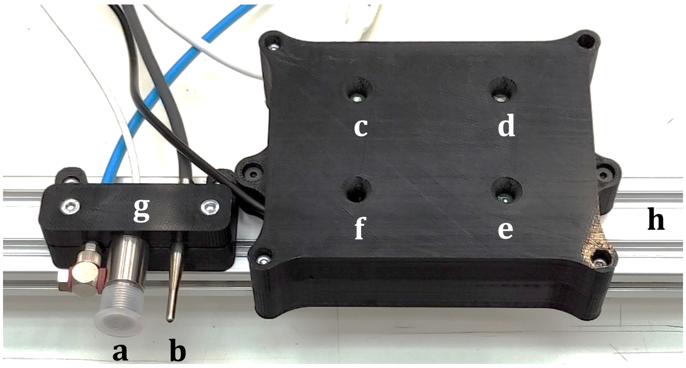


Figure 2: Mounted sensors on the measuring traverse (h); housing (f) with SGP40 (c), ZMOD4450 (d) and SHT35 (e); bracket (g) with PT100 (b) and infrared temperature sensor (a) with free blowing unit

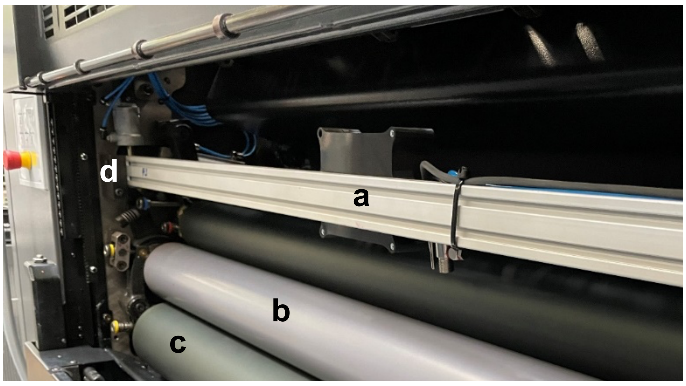
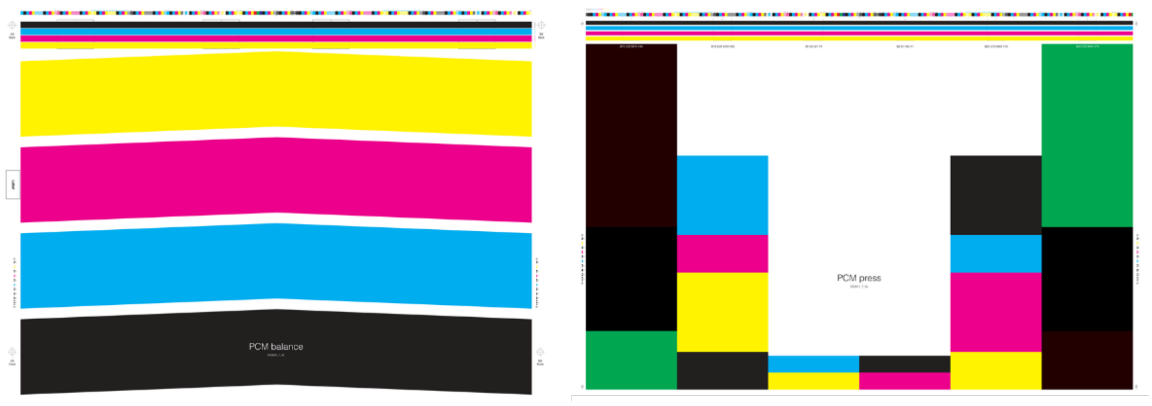


Figure 3: Measuring traverse (a) built into a printing unit with distributor roller (b), 4th ink form roller (c) and sidewall mounting (d)

2.2 Ink, fountain solution, substrate and printing plate

Four conventional offset printing inks, two black and two magenta, were obtained from two printing ink manufacturers. The fountain solution used had a content of 4.5 % isopropanol. A satin image printing paper with a grammage of 135 g/m^2 was selected as the substrate. The printing plates were *Saphira Thermal Plate PN 101* (Heidelberger Druckmaschinen AG, Germany). Figure 4 shows the two test printing plate images used in the experiments.



a) *b)*

Figure 4: Test printing forms (a) - high area coverage; (b) - low area coverage (Heidelberger Druckmaschinen AG)

2.3 Data preparation

After the implementation of the experiments with the different parameter variations, the collected sensor data as well as the machine data from the digital logbook were processed. For this purpose, the data were time-synchronized (all measurements were time-stamped) and sorted. Machine parameters that were not relevant were removed from the digital logbook and the sensor data was added. Finally, the data was structured in time so that a complete temperature cycle of the gas sensors with a duration of 20 s was specified as the smallest time increment and converted into the specific format for evaluation with the ML toolbox. All operations before inserting the data into the ML toolbox were performed with the program *Matlab* (The MathWorks, Inc., USA).

2.4 AI-generated model and training algorithm

For the generation of an ML-generated model, the ML toolbox explained in the introduction, is used which has a multi-stage structure. For feature extraction of the gas sensors, they are divided into segments of one second. For each segment, the mean and slope are calculated and were used as features. For humidity and temperature, the average over each 20-second cycle of the *SHT35* is included as a feature. The printing speed, inking, printing form, number of the printing unit are unchanged during each test and are also transferred to the model as a feature. Subsequently, a feature selection takes place in which the 20 features with the highest Pearson correlation coefficient in terms of amount are selected. These 20 selected features are correlated to the target variable by means of a partial least-squares regression. One observation is made per 20-second cycle that lies entirely within one experimental point of the experimental design. The leave-one-experiment-out methodology is used for validation. Each validation iteration 23 points of the experimental design are used to train the model and the remaining cycles of the last experimental parameter settings are used to validate the model. Choosing 20 for the number of features used gives the lowest validation error.

3. Results and discussion

3.1 Correlations between dampening potentiometer and varied parameters of the test plan

Multiple correlations can be identified in the data; here the Pearson correlation coefficient is evaluated unless noted otherwise. The correlation between the dampening potentiometer and the printing speed is 0.33. It should be noted here that the dampening potentiometer has a characteristic curve which is speed-dependent. This is used to control the amount of the fountain solution. The correlation coefficient between dampening potentiometer and inking is 0.27. For the printing form with the low area coverage, the dampening potentiometer was set slightly higher, with a correlation coefficient of 0.12. Since the temperature is lower on the second printing day on which the printing form with the low area coverage was used, a significant influence can be assumed. In addition, the setting of the dampening potentiometer increases the closer the printing unit is to the delivery, as can also be seen in Figure 5. The correlation coefficient for this is 0.57.

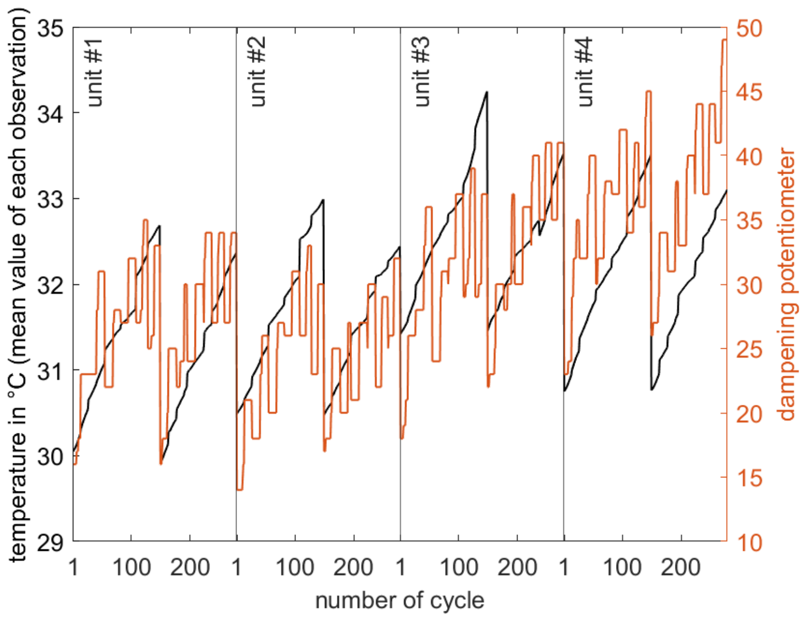


Figure 5: Number of cycles for printing unit vs. temperature and dampening potentiometer

3.2 Relationship between temperature and humidity to the dampening potentiometer

Figure 5 shows the strong influence between the setting of the dampening potentiometer and the temperature measured by the SHT35. On the abscissa axis, separated by the vertical lines within the graph, the four printing units are plotted. For each printing unit, one value per observation is plotted in chronological order. An observation period is 20 seconds each and lies entirely within the experimental period according to the experimental design and corresponds to a TC of the gas sensors. The values on the left ordinate axis (black) correspond to the average temperature, measured with the SHT35, during the respective observation period. The right ordinate axis (orange) shows the adjusted dampening potentiometer set point at the beginning of each observation period.

As the temperature rises, the set point of the dampening potentiometer is generally increased. The temperature jump at the approximate half of the cycles of each printing unit marks the beginning of the new test day and can be easily seen for each printing unit. For each printing unit, the first temperature values of the two test days shown here are very close together. Generally, the measured temperature increases during the course of the day while the press is running. Although the temperature tends to rise more on the first day of the trial than on the second day, the dampening potentiometer values are higher on the second day than on the first day of the trial, especially in printing units #3 and #4. Since the test plan is identical on both days, except for printing forms, the coverage seems to influence the selected set point. The most significant influencing factor on the selection of the dampening potentiometer set point is the temperature, as shown in Figure 5. As the temperature increases, the dampening potentiometer needs to be set higher. The printing press was not in use prior to the trials and warmed up during operation. Test points 13 through 24, corresponding to cycles 149 to 278, were performed on a subsequent day, so the machine cooled overnight.

The absolute humidity, calculated through the temperature and relative humidity, is closely correlated to the dampening potentiometer and whether the machine is currently printing. When the machine is switched off, the humidity always drops to approx. 12 g/m^3. Most of the drop in absolute humidity when the machine is switched off occurs within the first minute. When the machine is switched on, the humidity rises directly and levels off after about one minute. The value at which the absolute humidity settles depends on the dampening potentiometer set point. The higher this is, the higher the absolute humidity value. A representative time window is shown in Figure 6. The black graph corresponds to the absolute humidity, the red graph to the dampening potentiometer set point and the green graph is high while the machine is printing and otherwise low.

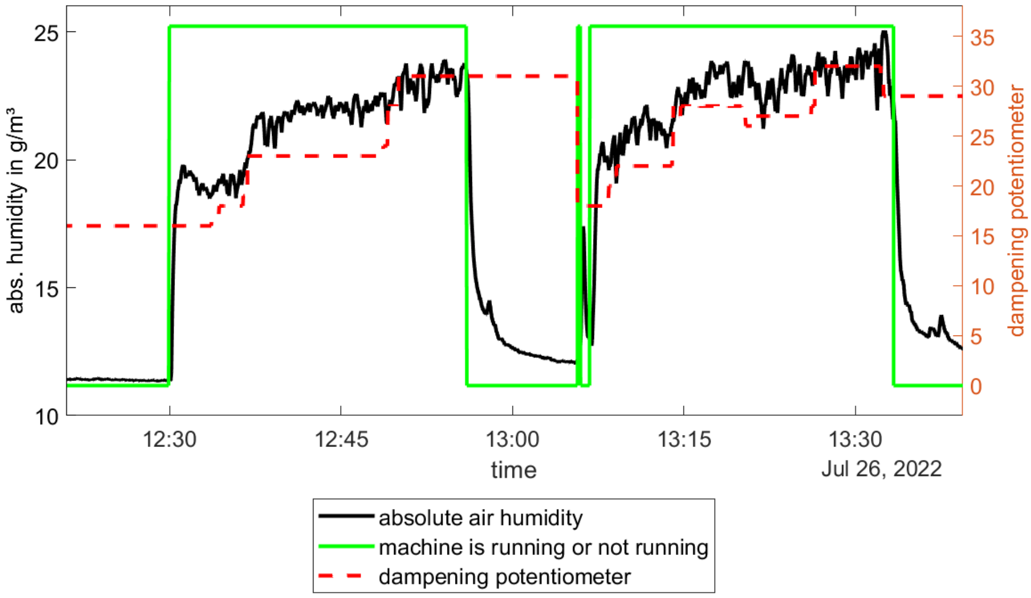


Figure 6: Representative example demonstrating the effect of the printing operation and dampening potentiometer set point on the absolute humidity

3.3 Machine learning model

In a first step, an ML model was built to predict the dampening potentiometer set point to demonstrate that the sensor data allow reproducing the experience of a printer. Later, a model should be trained allowing automatic adjustment of the dampening potentiometer based on the printing conditions and recorded sensor data.

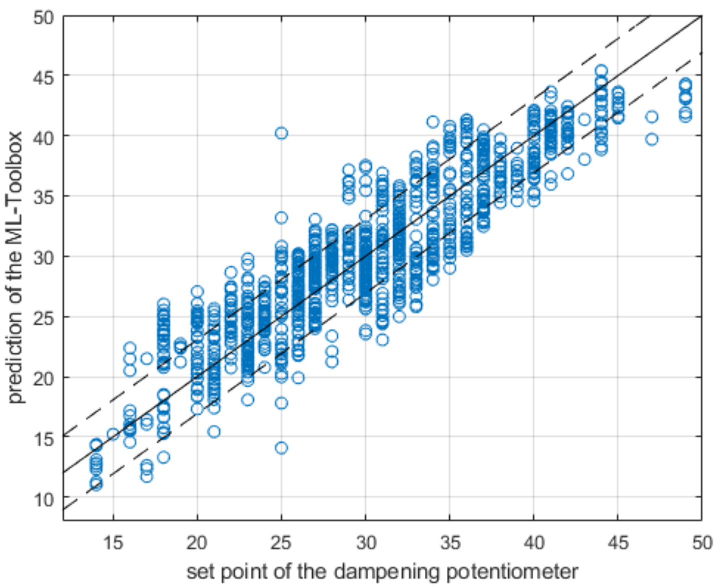


Figure 7: ML model showing dampening potentiometer set point vs. prediction of the ML toolbox

Figure 7 shows the result of one ML model. On the abscissa axis the actual dampening potentiometer set point is shown and on the ordinate axis the prediction by means of the ML toolbox. Optimally, it would run along the solid black line ($x = y$). The dotted lines indicate the root mean square error (RMSE) of the prediction corresponding to ± 3 % of the dampening potentiometer set point. The mean relative error is 8.8 %, determined from the range of the dampening potentiometer set point, i.e. the difference between the lowest and highest values of 14 % and 49 %, respectively. Overall, the model is basically able to reflect tendencies in the setting of the dampening potentiometer, but with an error to be noted. The largest deviations, e.g., the highest and lowest values for the dampening potentiometer set point at 25 %, are usually the first observation during a trial point of the experimental design. The number of outliers could decrease in a real production operation, since abrupt major changes of the settings as in the present experimental design occur less frequently.

Further analysis shows that the slope of the resistance during the high temperature phases of sensor layer 2 of SGP40 correlate strongly with the dampening potentiometer, similarly the average resistance in the low temperature phase at 175 °C. The greatest correlation with the dampening potentiometer set point, however, is observed for the temperature recorded by the SHT35, followed by the absolute humidity. Since certain characteristics correlate similarly strongly or weakly with the dampening potentiometer in each of the four printing units, a causal relationship can be assumed. The setting of the inking and the printing speed are included in the model as additional factors while the selected printing form is not considered in the model for the regression algorithm.

4. Conclusions and outlook

With these first tests, it could be shown that with the help of additional sensors, which record temperature, relative humidity and information about the gas atmosphere in the individual printing units, it is possible to reconstruct the set point of the dampening potentiometer relatively accurately. An evaluation with a similar test setup and design of experiments is currently taking place at another printing press manufacturer, which will provide further insights into the subject. In addition, a two-week measurement campaign is currently being planned at a printing company where, as described in this paper, the additional sensor technology will also be installed and production will then be monitored in 3-shift operation. In particular, the temperatures in the individual printing units can be tracked and analyzed more precisely. Since a printing house wants to sell its print products, it can be assumed that high-quality print products will be produced in this environment. A particular challenge later on will be to define a sensible threshold value above which the dampening potentiometer should be adjusted in order to be able to maintain the ink-water balance. In addition, scattering of the data was also observed, which was presumably caused by human influence (manual setting of the press parameters at the control station).

In general, it must also be said that due to the limited test time and the limited amount of paper substrate, more data must be collected through further tests. Since the tests took place in a controlled environment, real conditions are also being investigated with two-week measurement campaign.

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