# A System for Inspecting Colour Printing Quality

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The use of machine vision technology is being investigated at VTT for improving the colour quality and productivity of web offset printing. The visual inspection of colour quality is performed by a colour CCD camera which traverses the moving web under a stroboscopic light. The measuring locations and goal values for the colour register, the ink density and the grey balance are automatically determined from the PostScript™ description of the digital page. A set of criteria is used to find the most suitable spots for the measurements. In addition to providing data for on-line control, the page analysis estimates the zone wise ink consumption of the printing plates as a basis for presetting the ink feed. Target colorimetric CIE-values for grey balance and critical colours are determined from the image originals. The on-line measurement results and their deviations from the target values are displayed in an integrated manner. The paper gives test results of computation times, measurements of register error with and without test targets and the colour measuring capabilities of the system. The results show that machine vision can be used for on-line inspection of colour print quality. This makes it possible to upgrade older printing presses to produce a colour quality that is competitive with more modern presses.

## 1. INTRODUCTION

Readers and advertisers constantly demand more colour. The marketplace does not only demand more quantity, but also a better quality of colour. It is therefore essential to automatically control during printing the factors that affect the colour quality. These factors include the colour register, the ink densities, the grey balance and the critical colour rendition. At the same time, the economics of printing is in focus. The waste of printing materials during the make-ready of the press and during production disturbances causes considerable economic losses. Here, too, process control is the key technology.

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The creation and production of publications is becoming an integrated process with close electronic communication between the process stages[1]. This CIM methodology means that the colour determinations made in prepress should be propagated to the printing phase with as small deviations as possible. The process control will get its colour settings from the prepress. This allows for a new type of control of 4-colour images, where spotswith critical colours are checked.

Currently, feed-forward control of inking by presetting the zonal ink feed, using film or plate scanners, is widely accepted in the industry as a way to shorten the make-ready times. However, lithographic offset printing in colour is a complicated and unstable process. Therefore, feed-back control is required as a compliment to presetting. Off-line colour control with both handheld and scanning measuring instruments is currently the normal practice. [2] However, the big savings come when the quality is controlled on-line from the running web.

Commercial on-line feed-back control devices are available as separate solutions for the register error and the ink density. A list of products for automatic on-line register control is e.g. in [3]. The accuracy of the controllers may be as good as ± 0.02 mm. They use test targets, which are nowadays small in size, in some cases quite unnoticeable. However, the targets add complexity to the page makeup, where they must be inserted in the page. Therefore methods which do not use test targets should be developed.

The ALDEC product, now marketed by Honeywell, for the on-line ink density control with densitometers has been available for some years.[4] ALDEC uses for the measurements a testbar running across the web. As the bar has to be cut away, this solution does not suit newspapers. Instead, the ink densities should be determined by measuring the content of the printed page.

There are web video units to image the running web and to display the images on colour monitors. These devices make only very global measurements on the image data and, consequently, do not control the press automatically. There is also equipment on the market for finding serious quality errors, e.g. whether the plate is open or still tinting. That is to say that the equipment is able to distinguish pages which are almost completely black, grey or white.

To be economically feasible, the same inspection module should measure as many quality factors as possible. Separate modules may prove too costly in modern presses in which several webs and places need to be inspected. CCD cameras are a general measuring tool with the capacity to register most of the colour quality factors.[5] The selection of the locations to image is a problem, especially if no test targets are allowed. In our study, the suitable locations are determined by automatically analysing the digital page description obtained from prepress. The analysis also gives the goal values for the measurements.

The aim of the prototype, called ARGUS, described in this paper is to demonstrate how several colour quality factors may be measured on-line using a single camera-based station guided by an analysis of the page description received from prepress.

## 2. THE PROTOTYPE SYSTEM

The ARGUS prototype performs two things: 1) inspects the colour quality on-line and 2) offers presetting values for the ink screws by computing the zone wise colour consumption. Two aspects of the colour quality are inspected: the colour register and the zone wise inking (*Figure 1*). The inking is assessed by measuring the ink densities (= light absorption) and the grey balance (=3-colour grey) in every inking zone, if suitable measurement spots are found. In addition, spots with critical colours can be measured at the operator's request. Ink densities are measured in areas, where the process CMYK colours are totally pure or very little contaminated. The inking profile across the web can then be estimated from these measurements.

To compute the guiding information for the on-line quality inspection, the ARGUS system takes its input from the page design.

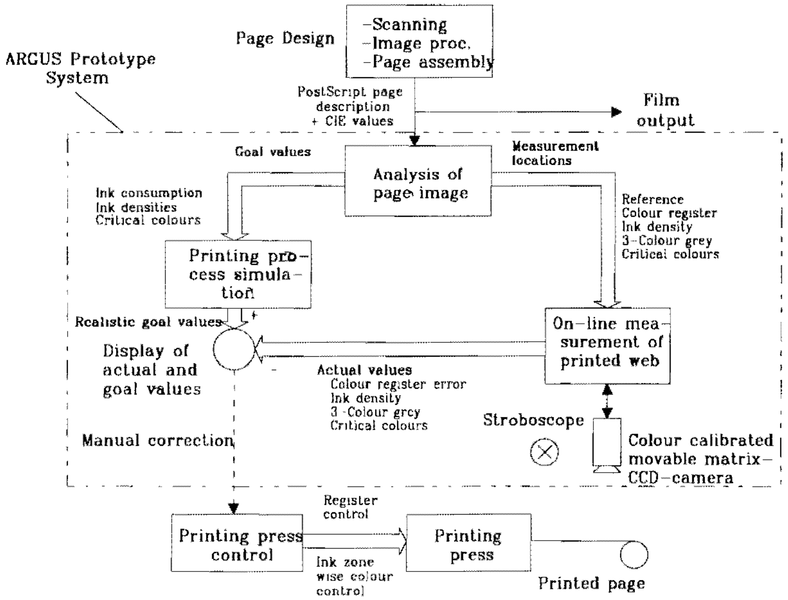



Figure 1. The ARGUS laboratory system.

The page analysis in ARGUS determines the measuring locations and goal values with a set of selection criteria. To handle 3-colour grey and critical colours more objective colour expressions are needed than the CMYK values. For this reason, the input colour images can be transformed into a CIE representation by using colour-calibrated input devices. The goal values of the critical colours have to be adjusted to the colour gamut of the printing process, otherwise the values are not realistic. This is done in the printing process simulator. The measured ink densities, 3-colour grey and critical colours are compared with goal values on the process display, where also the register error is displayed (*Figure 2*). The critical colour and grey balance values are displayed in the CIE-Lab space to allow for objective numerical comparisons.

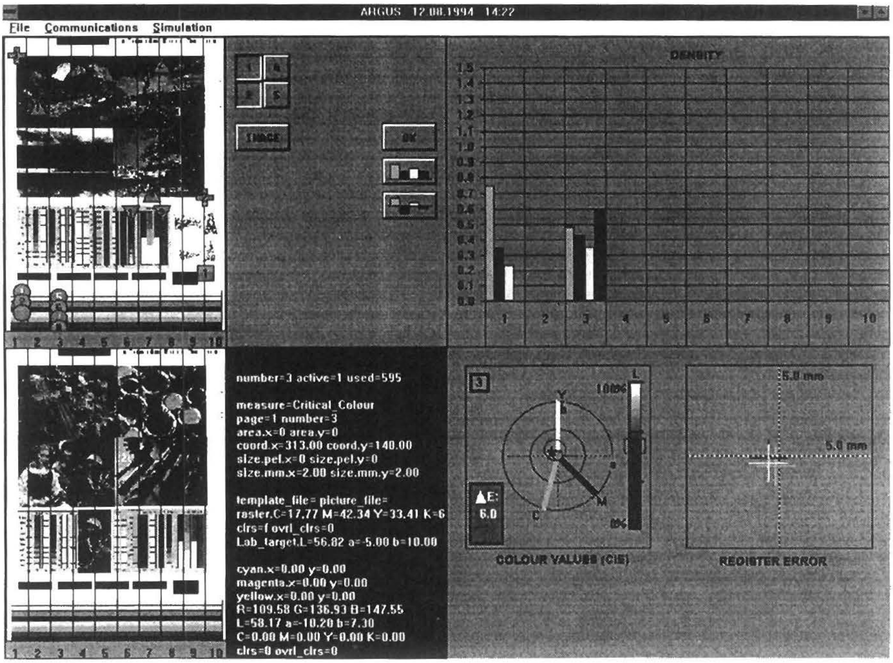



Figure 2. The ARGUS process display. The target critical colour value (marked as O on the CIE display) and the measured (*) values in measurement spot 3 (marked as Δ on the page image upper left) are displayed as well as the densities in the inking zones 1 and 3 (=O) and the register error in relation to black measured from register spot 1 (= □ ). The colour deviation is 6.0 $\Delta E_{Lab}$ in spot 3.

The running web is inspected by a movable matrix colour 3-chip CCD camera on the basis of the control data obtained in the page analysis (*Figure 3*). A stroboscope "freezes" the motion of the web. It is thus possible to grab an image from anywhere on the running web. The size of the imaged spot is 20 * 20 $mm^2$ and the imaging angle is $0^o$. The RGB-signals of the camera are linearly digitized with 8 bit per colour component. Colour calibration of the camera makes it possible to get reliable colour measurements. The measured values are passed to a display module, where they can be compared to goal values, if existent.

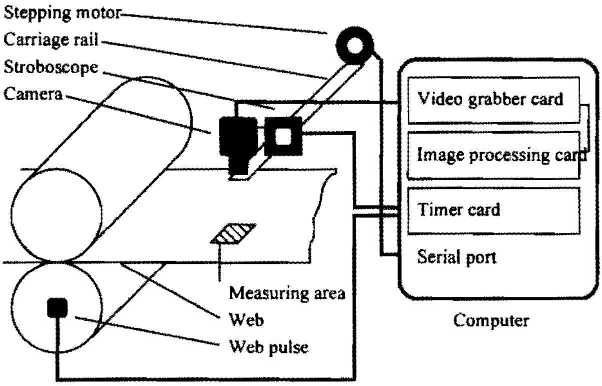



Figure 3. The set-up for on-line measuring . In the laboratory test bench, the web is simulated by a printed sheet attached to a rotating drum. This set-up is still far from a commercial on-line system.

## 3. ANALYSIS OF THE DIGITAL PAGE DESCRIPTION

The measuring points are comprised of location coordinates and goal values. The analysis is made with contone images acquired from ripping according to a set of criteria which describe the characteristics of each type of measuring point. The desired characteristics of the points can be set as adjustable parameters to meet the needs of the quality measuring device - in this case the inspecting camera - and the job to be printed. The advantages are increased flexibility and the possibility to use reliable and stable methods in the on-line measuring of the printed web.

The set of search criteria provide for four different measurements needed in quality control: the colour register, the colour ink density, the 3-colour grey (= the grey balance), the critical colours (e.g. skin colour). In addition, reference points are determined for technical reasons described below. The number of each type of measuring points is not limited. The adjustable characteristics of each type of measurement can be set as described below.

### Determination of the Reference Measuring Points

The exact position of the web on the roller varies typically by several millimetres. That is why reference points are needed. The reference points indicate the origin of the coordinate system and fix the inspecting camera on the coordinate system of the printed web. The requirements of the reference points are a high contrast (= a high dot percentage) and uniqueness. The adjustable characteristics are the size, the scale and the limits to the location.

Mask filters (corners , cross, dot) are used to create the energy map of every colour image. The general energy map is defined as the accumulation of all energy maps by different weights to different colour separations. Let $n_i(s)$ be the $i$:th energy map. The general energy map $N(s)$ is:

$$N(s) = \sum_{i=1}^{m} w_i n_i(s) \tag{1}$$

where $m$ refers to the number of the different printing colours. $w_i$ is the weight of the $i$:th colour. The analysis of the energy peaks in the general energy map $N(s)$ is straightforward. If there is only one peak, the mask filter is suitable and the peak position is the reference position. If there are more peaks than one, the highest peak must be $k$ times higher than the other peaks. Otherwise the mask filter is not suitable and the second filter is used, etc., until the reference position is found.

## Determination of the Measuring Points of the Colour Register

The measuring points of the colour register are of two subtypes: there are points at which the patterns printed with different process colours overlap and points at which they do not overlap (non-overlapping). The requirement for overlapping colour patterns is that they are equal in size and similar in shape, and have the same location. In both cases, the colour patterns must be unique and have a high contrast (= a high enough dot percentage) and high gradients both in the horizontal and in the vertical direction. Each measuring point is composed of at least two process colours, e.g. cyan/black. Thus, $m$-1 measuring points are needed at most ($m$ = number of colours). The size, the scale, the dot percentage interval, the percentages of the disturbing colours and the limits of the location can be adjusted.

The algorithms used in the determination are in *Appendix 1.*

An example is given in *Figure 4* of the determination of the register measuring points for a test tabloid page spread with 564 (H) * 789 (V) pixels (pixel size = 0.69 $mm^2$).


Figure 4.
Suitable locations for measuring the colour register of a test page spread The locations are automatically determined by analyzing the PostScript page description.[ | ] denotes non-overlapping colors and [ / ] overlapping colors. The process colors to be compared are indicated by letters.

## Determination of the Measuring Points of the Ink Density and the 3-colour Grey

The adjustable parameters of the measuring points of the ink density and the 3-colour grey are similar: the size, limits of the location ( e.g. the number of the inking zones), the required process colour, the dot percentage interval and the purity (= the presence of disturbing process colours). In addition, the colour intensity of the measuring point must be uniform.

We use the following measure for the uniformity,:

$$Er_k(s) = \sum_{t \in \Omega} \left| I_k(s+t) - M_k(s) \right| \tag{2}$$

Where $k$ refers to one of the process colours, $M_k(s)$ is the average intensity level of the template centred on the pixel $s$. The smaller $ER$ is, the smoother the template is for that colour.

To determine the measuring points of the 3-colour grey , the CIE values of the page representation are checked to find spots, where the neutral colours are expressed by all three MY process colours.

## Determination of the Measuring Points of the Critical Colours

The term *Critical colour* refers to a certain object-dependent colour such as the colour of the skin, sky and grass. The colour of a product in an advertisement may also be regarded as a critical colour. The characteristic features of such objects are very difficult to express in numerical values. They could rather be described verbally on the basis of their visual impression. The measuring point is therefore determined manually. So far only the allowed locations of the points can be adjusted by parameters.

## Estimation of the Ink Consumption

The estimate of the average ink consumption can be used in presetting the inking unit of the press. The computation is controlled by selecting the number of inking zones in use in the printing press. The ink consumption is approximated at the average intensity level in the inking zone of a certain colour separation. A more accurate estimate of the consumption is obtained by averaging the screened binary page version, which is equivalent with computing the proportion of the printed area to the white area. However, the differences between the two estimates are small. On a test page, we found the average difference in 8 inking zones to be only 0.1 percent units.

The estimation must, of course, take into account the dot gain. This is done in the printing simulation unit (*Figure 1*). In addition, a very accurate estimation must also take into account that the ink consumption per printed area is not constant in most presses. But since this is very difficult to compensate digitally, the effect is not included in ARGUS.

The time consumption for computing the measurement spots for the page spread in *Figure 4* is in *Table 1*. In addition to this, the conversion of the PostScript page description into pixel maps (72 dpi) takes about 1 minute in a software RIP. These times are quite plausible for production needs.

| The determined measuring | Seconds |
|---|---|
| Colour register | 42 |
| Ink density (10 inking zones) | 30 |
| 3-colour grey | 30 |
| Zonal ink consumption | 15 |

Table 1. The time required to determine the measuring points on the digital page in Figure I using Sun Spark II running at a clock rate of 40 MHz.

## 4. COLOUR MEASUREMENT

To handle four-colour images objectively, we have to characterize colorimetrically the components of the processing chain[6]. In the ARGUS system, the most important components to be characterized are the input devices in the prepress, i.e. the colour scanner and, occasionally, the electronic cameras, the printing process and the inspecting camera. Thus, the colours measured on-line by the inspecting camera can be compared with the colours of the original, taking into account the reduction in the colour gamut in the printing process. This comparison shows how to adjust the settings of the printing press to achieve as close a resemblance between the printed image and the original as possible.

The accuracy of our colour characterization determines how precisely the imaging devices measure colour. In the literature, two main methods are found for characterizing the colour response. The first is based on empirical mappings between device-dependent colour values (like RGB) and CIE-coordinates, whereas the other method uses model-based mappings. The empirical mappings either use multiple polynomial regression[7,8] or multidimensional interpolation[9]. The model-based mappings typically model the film by the Lambert-Beer law[10,11] and the print by the Neugebauer equations[12].

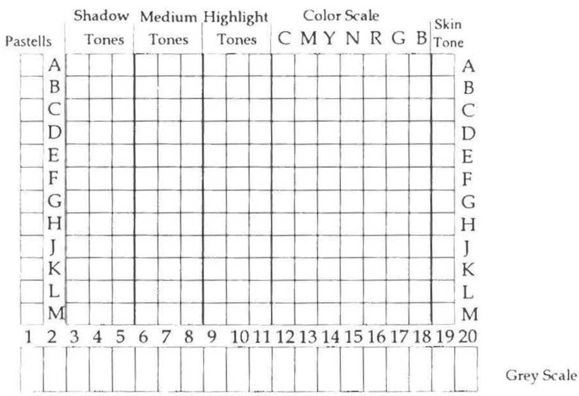
We chose to use polynomial regression for the characterizing the colour response, because our literature study showed that it is a competitive method in spite of its "black box" nature. We obtained an accuracy in $\Delta E_{Lab}$ for the two imaging devices of the study depicted in *Table 2* . In 95 % of the measurements with the inspecting camera station and the photographic medium, the error is under 4.3 $\Delta E_{Lab}$. For halftone newsprint (34 l/cm), 95 % of the measurements have an error under 11.3 $\Delta E_{Lab}$. The ISO standard for offset inks[13] defines the $\Delta E_{Lab}$ tolerances for cyan as ±3.0, for magenta ± 5 and for yellow ± 2.3. Overprints are the sum of these tolerances, i.e. for three colour prints ± 10.3 $\Delta E_{Lab}$ . Thus, the accuracy of the camera measurements are near to fit into the ISO tolerances, except for a small part of the colours represented in the Q60 target.

| Device | Medium | Average | Std.dev. | Max. error | Terms in fit |
|---|---|---|---|---|---|
| Flatbed Scanner | Photographic print | 1.81 | 1.53 | 10.48 | 14 |
| Inspecting camera station | Photographic print | 1.53 | 1.35 | 8.07 | 27 |
| Inspecting camera station | Halftone newsprint | 5.77 | 2.80 | 30.7 | 14 |

Table 2. The accuracy in $\Delta E_{Lab}$ of colour measuring with two CCD imaging devices. The colour estimation is calculated on all the 236 patches of the test Q60-C target by using multiple polynomial fitting of measured RGB into $XYZ_{50}$ with an optimal number of terms. The test patches are measured with the spectrophotometer Gretag SPM100 at $D_{50}$ and $2^{o}$. The RGB values are averaged over a 50 x 50 pixel area.

*Figure 5* shows more in detail, that the big measurement errors with the inspection station occur only in a few colour patches which are mostly dark and in the blue region. This reflects the well-known weaknesses in the sensitivity of the CCD sensor. The figures also show that the neutral 3-colour greys in column 15 are well fitted, except for the darkest patch. It is thus feasible to inspect the colours and grey balance with this equipment in all but the darkest regions.

Q60 test target



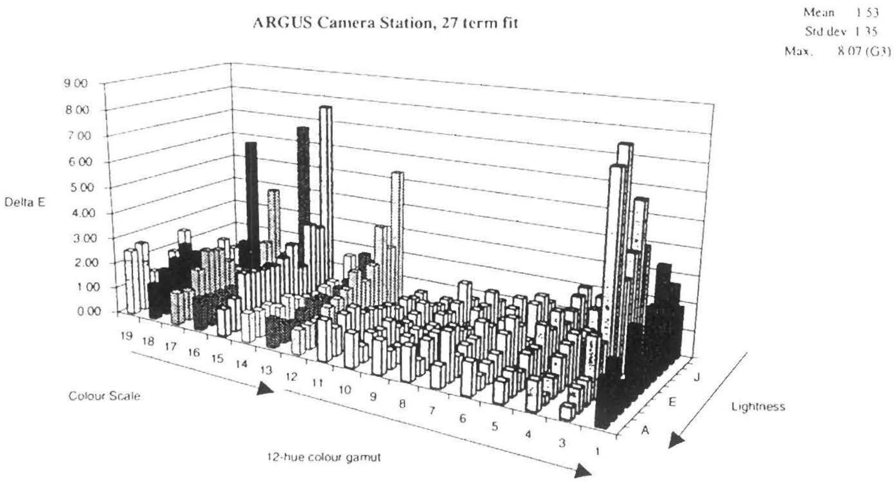




Figure 5. The errors in the colour estimation for the Q60-C patches (above) with the inspecting camera station and the photographic medium.

The *densities* $D_{ink}$ of the printing colours are measured from screened areas by using the formula:

$$D_{ink} = {}^{10}\log \frac{I_{paper}}{I_{ink}}, \qquad (3)$$

where the light intensities $I_{ink}$ and $I_{paper}$ are determined from the intensity histogram if the imaged area. It has to be noted, that the density decreases with the decreasing tonal value of the area as pointed out in [14]. Both our laboratory tests as well as the field tests showed that the density can be measured with this method with an accuracy of ± 0.05 *D*-units, which is good enough for density control. The same analysis also gives the dot size and thereby the dot gain.

## 5. THE ON-LINE MEASURING OF THE COLOUR REGISTER

The registration error between the printing colours were determined our camera-based ARGUS system both without and with test targets. For the case without test targets, measurements were made on 22 test prints with different registration errors. The measurements were taken both from CMY and CMYK areas. The calculation is based on cross-correlating the estimated CMYK separations and finding the maximum correlation. The disturbances created by the screening of the print are reduced by adding a frequency band filter. The measuring accuracy at the 5 measuring points are given in *Figure 6.* DRK is the corner of a dark 3-colour grey area (dot percentage 80), LIG is a similar lighter area (dot percentage 30), CAM is a greyish part of a 4-colour picture, COR is a corner of the 4-colour picture with just a little background. EYE is a woman's eye with great colour contrasts.

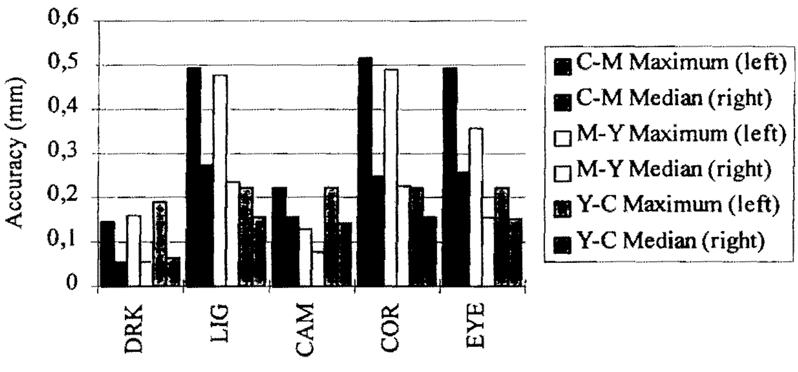



Figure 6. Measuring errors (error vector length ) for colour register determined from colour print without test targets. The accuracy is determined as the difference to *known* value of the register error in the test prints. The ARGUS laboratory system has been used for collecting data from 22 test prints with different register errors. Smaller values than 0.05 mm are not relevant, because of the inaccuracy in the manual register error determination in the test prints.

The figure shows that the median values for all test points are under 0.3 mm and the maximum error is under 0.52 mm. The low accuracy is mainly due to the difficulties to estimate the CMYK signals form the RGB camera signals. Even if the accuracy is much too low for normal register control, it is enough as an alarm of rough register error. On the other hand, the good results in the DRK point show that production accuracy can be achieved, if suitable measurement points can be found in the prepress analysis.

The accuracy is significantly improved by using test marks. In a field test at a Finnish printing plant, the ARGUS system managed to measure the colour register from test marks with a +/-0.05 mm accuracy, which is enough for on-line register control.

## 6. CONCLUSIONS AND DISCUSSION

The ARGUS prototype was built to demonstrate, how colour print quality can be inspected by machine vision under the guidance of prepress information. The inspection points for colour register, zone wise ink density and zone wise 3-colour grey can in ARGUS automatically be determined from the digital page description on the basis of a set of selection criteria. Points for critical colours are marked manually. The system can be modified to take the guiding information from the page proof instead from the page design.

The measurement of the colour register without test targets could display only rough register errors, mainly because of colour separation inaccuracy. However, a successful choice of measurement point was found to improve the accuracy near to what is needed in newspaper production. In a shorter practical perspective, our study shows that the use of test targets is still well motivated in register control. In the long term, more precise criteria for the choice of measurement locations as well as a better utilization of prepress information should allow for register measurements without test targets. One interesting enhancement is to use cameras with special filters for CMY instead of RGB. This should give a better discrimination between the measured print colours than currently.

Colour calibration of the prepress input devices and the inspecting camera enables ARGUS to compare the colours of the scanned image original with the printed colours with an average accuracy, which is sufficient for on-line control. However, some colours, especially in the dark and blue regions, have too large measuring errors to allow colour comparison in the current set-up. In a practical system, these colours could be left outside the colour control. Other solutions would be to quantize the colour signal with more than 8 bit and thus increase the measurement accuracy. The use of CCD-sensors based on the new virtual phase method will give a manifold accuracy in the blue region and therefore raise the overall accuracy.

The colour densities of the halftone print are measured accurately enough as well as the dot sizes.

## 7. ACKNOWLEDGEMENTS

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**APPENDIX 1**

## METHODS USED IN THE DETERMINATION OF POINTS FOR MEASURING COLOUR REGISTER

The registration templates must be located on colour edges. There are several classical edge detection operators for the detection of the edge of the colour image. We adopted the following operator for our application,:

$$E(i,j) = \sum_{k=1}^{m} w_k * (|I_k(i,j+1) - I_k(i,j-1)| + |I_k(i+1,j) - I_k(i-1,j)|) \qquad \text{(A1.1)}$$

where m again refers to the number of process colours. $I_k$ refers to one of the colour separations. $w_i$ refers to the weight parameters of different process colours. In practice, the yellow colour is assigned a lower weight compared with the other colours.

Before the edge detection, an edge preserving smoothing algorithm is used to smooth every colour separation image.

The printing shift can occur on the printing web in both the horizontal and the vertical direction. Therefore the edges in these directions are not suitable for the identification of the registration template. The edge pixels with such a gradient direction must be set to 0. In our program, we set the following parameter to measure the gradient directions.

$$\frac{|I_k(i,j+1) - I_k(i,j-1)|}{|I_k(i+1,j) - I_k(i-1,j)|} \tag{A1.2}$$

If this parameter with one edge pixel is > 4 or < 1/4, we set the edge pixel to 0.

After the edge detection, the produced edge map is binarized and thinned by a method, which shrinks the binary image simultaneously in four directions. Such a method ensures that the error of the final edge allocation is within ±1/2 pixel. After finding the suitable edges, the colour intensity criteria depicted below are applied to the page areas, where the edges are strong enough.

The measuring template must be one of the following three types (*X1*,*X2*,...*X7*) denote threshold parameters for the dot percentages of the CMYK image, M is window size):

a) two or more non-overlapping details printed in different CMYK colours. The same details must not exist in the neighbourhood. The rasterizing of the detail must be over X1 % and the other disturbing colours below X2 %.
b) one detail printed with two overlapping CMYK colours and the detail can be seen in both colour components. The rasterizing of the details must be between X3 % and X4 %. The other disturbing colours are below X5 %.
c) one detail printed with all colours and the detail can be seen in all colour components. The detail must fit into a window of $M$ x $M$ pixels.. The rasterizing of the details must be less than X6 % for all CMYK colours. The neigbourhood of the detail must be less than X7 % for all CMYK colours.