On-line Vision System for Ink-jet Printed Media

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Abstract

Vision and Recovery for Nozzle Failures

The implications for inkjet technology to be modified to print colour images on a wide range of new surfaces has quickly been recognised. This is particularly apparent for wide format designs. Using specialist inks, short run designs can be inkjet printed onto everything from floor coverings, to walls, to textiles, to ceramics.

Speed and reliability are two important factors that can be developed to improve production printer results. Nozzle blocking can be a serious problem when using exotic inks and media. Imperfect prints mean wasted time, materials and energy. This problem has been particularly seen in the textile industry where attempts to inkjet print textile with specialist inks have proven problematic.

Research at Leeds addresses these problems with emphasis being on the development of a vision and control system that enables detection and rectification of faults. Using two CCD arrays at either side of each colour print head and an appropriately tuned illumination source, live images can be processed to detect blocked nozzles. Results can be reported to a control system for online rectification. Colour line scan technology is still expensive in comparison to the technology used in desktop scanners. Work is being undertaken to create hybrid-scanning devices that use low cost linear arrays that potentially allow each head to have its own independent detection system.

Introduction

One of the most obvious wide format non paper inkjet printable media is textile. There are a number textile printers available on the market and the majority print at speeds between 1.8-15 m^2/hour and cost under $150,000, however more expensive machines have been developed[1]; for example the Artistry from Dupont is commercially available but costs nearer to half a million dollars and can achieve speeds of up to 40 m^2/hour on a low resolution setting.[2] Currently textile printing machines and other specialist inkjet printers share the common problem that they are trying to print complex inks that are very prone to causing print head nozzles to block. Blocked nozzles cause colour variations and visual imperfections in the printed textile. A process to monitor the substrate as it prints would make it possible to detect when a nozzle had failed. Depending on the severity of the fault, the controller could implement a cleaning cycle in an attempt to unblock the particular nozzle, use additional heads to rectify the faults in real time or ignore it until it gets worse. This will eliminate the need for slow, labour intensive manual checking of the printed fabrics.

Drop on Demand (DOD) Technology

A typical DOD head could have between 48 and 256 nozzles[3] and print drop volumes, depending on the application, between 30 to 5000 picolitres.[4] Ejected drops hit to the surface of textile at frequencies of between 6 to 15 kHz and create the colour dots between 50 to 300 microns in diameter.

Experimental work has shown that in the majority of contemporary printers, lines of dots are printed side by side on each pass with about 200-600 μm intervals. The number of lines printed coincides with the number of nozzles on the head (Figure1). Like other inkjet printers, current textile printers utilize various numbers of colour inks, for example the Encad has 4 and Fabri-Jet XII has 12 colours, to get the large gamut of colour shades. Virtually every digital printed image includes several layers of colour inks (CMYK+), which within several passes (2, 4, 8 or 12) will be produced.

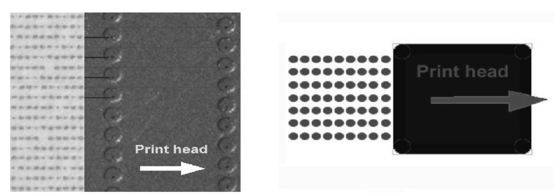

Figure 1. Drop on demand printing

Inkjet Image Build-Up

The inkjet printer works on an x, y architecture, building up the image by traversing the head across the substrate forming a stream of dots across the width of the substrate (x) and then stepping the substrate forward ready for the next traverse of the head (y).[4] These repeated traverse and steps form the 2D array of drops that constitute the image. The location of the CMYK+ drops is calculated by the RIP software. When a digital image is being sent to the printer, RIP software algorithms converts each pixel of the original image from an intermediate tone directly into a matrix of binary dots, based on a pixel-by-pixel comparison of the original image with an array of thresholds,[5,6] (figure

2). By splitting the matrix up for different passes of the head a resultant train of pulses is sent directly to the nozzles (synchronised to encoder).

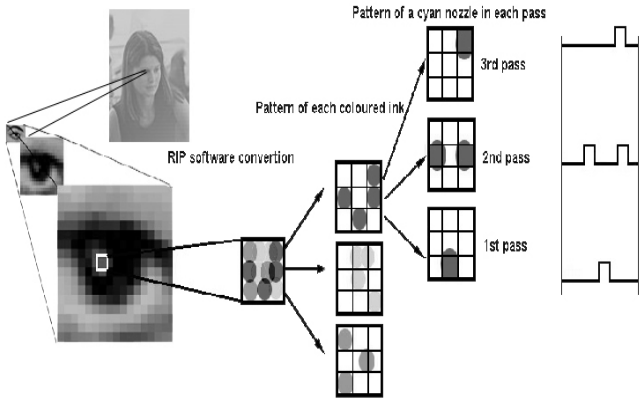

Figure 2. RIP software changes the digital image in to binary signals

The BIP Reference Image

Each nozzle has a two dimensional array of binary codes: BIP (Binary Image Pattern). These represent when and when not to print a drop for the whole of the image, as shown in figure 3. By monitoring the signals, which are sent to the print head, the BIP for every nozzle can be recorded as a reference pattern. *This BIP reference pattern is used to cross reference with what the vision system detects (see later).*

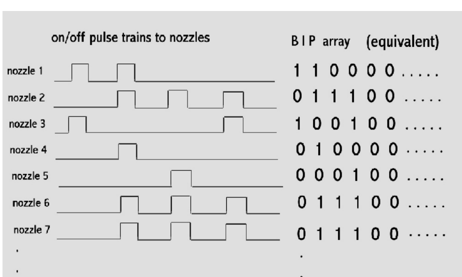

Figure 3. BIP (Binary Image Pattern), which will be sent to the nozzles

Synchronising the Substrate Co-Ordination with the Drop Firing

It is usual in an x, y architecture that the printer has two encoders, responsible for identifying head position relative to substrate during printing. These are the **carriage movement encoder** that is checking the ‘x’ location of print head and **step-advance encoder** that monitors the feed of the substrate through the printer.[4] It can be assumed that the substrate is split in to series of cells in a two-dimensional array described by the x and y values of the encoders. Each cell can be located using the encoders. The accuracy of the nozzles’ locations will be the accuracy of the encoders.

Machine Vision System

‘Before’ and ‘After’ Scanners

Charge coupled device (CCD) based technology[7] is successfully being used in digital stills cameras and digital video cameras to capture high quality colour images. Line scan and area scan digital video cameras are being used in industrial imaging applications to monitor production and perform quality control activities in a number of areas. These applications come at a relatively high cost (typically over £10,000 and over) however CCD technology is available at a much lower cost when used in consumer scanning products.

Research work at Leeds uses these low cost linear CCD arrays in the development of an on-line vision system for detecting printing imperfections. The concept is based on using 600 dpi monochrome arrays and selected wavelength of illumination to identify the ink on the substrate .

Illustrated in figures 4 and 5, the system is based on utilizing two arrays at the sides of each print head and illuminating with the relevant complementary light to that of the ink being printed. Printed images can be checked continuously during the printing process.

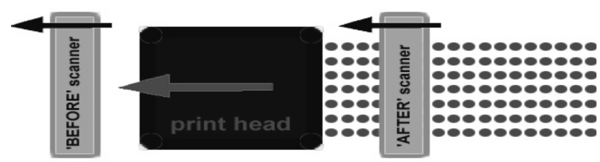

Figure 4. Mono-colour print head with before and after scanners

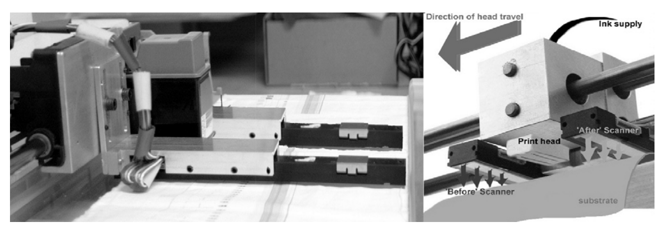

Figure 5. Duel array vision system (test rig left, concept right)

During carriage movement the scanners capture the ‘*before’* and *‘after’* printed images. The substrate is illuminated in a particular colour to detect specific colour inks. Changes in grey level values between *‘before’* and *‘after’* show where drops have been printed.

It is illustrated in figure 6 how the linear arrays can be positioned to the sides of, for example, a Spectra head to monitor a full set of 256 nozzles. The size of the Spectra head is of ideal length to match with the 130mm array.

Figure 6. The linear array and Spectra head

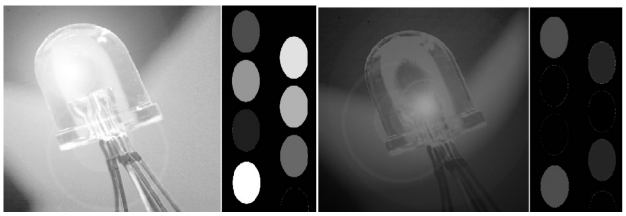

Figure 7. Effect of white and red illumination on colour palette

Detection Process

Illumination

To detect the particular of colour ink it is useful to just look at a single colour channel (i.e. that of the colour being printed and therefore that being detected). This enables other coloured drops on the substrate to be ignored which is crucial if a monochrome CCD device is to be used. The volume of data to read is very high in this application and it is important to reduce the information at source to a minimum: scanning in a single channel (compared to say 3 channel RGB) is very adventageous both in speed and cost.

It is known that a surface illuminated by a particular band width of light will only reflect that particular colour.[8] This is demonstrated in figure 7, where the effect of illuminating an RGBW and CMY samples with a red LED is shown. In the RGB pallete the red and white reflect the red light, however the green and blue (colours containing no red) do not. In the CMY sample the cyan (being the complement to red) does not reflect and the yellow and magenta show some reflection as they both contain some red.

To ensure that the single channel detection idea would work in practice a series of controlled experiments were undertaken. Experimental work was carried out using the discussed colour linear scanner and a calibrated light source (e.g. LED) to detect printed images in accordance with RGB colour representation and traditional colour theory.[8] This is illustrated in Figure 8, where a primary colour light (red) is used to illuminate the colour dots on pre-treated cotton. There was no light reflected from the colour's complement (cyan). Similar results are found when using blue and green sources with their corresponding compliments.

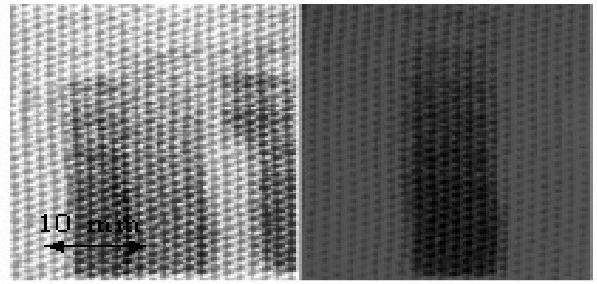

Figure 8. CMY printed substrate with white (left) and red (right) illumination

Digitally Controlled Illumination

In order to conveniently illuminate the sample in the required colour it is necessary to have a system that can be digitally controlled. A high-speed digital illumination device has been developed that can combine red, green and blue LED light sources. As it is illustrated in figure 9, each colour is pulsed at high speed with differing on/off times in order to effectively mix differing ratios of the three colours (RGB) together. The resulting combination of digital light pulses will be exposed to the CCD sensor with the resultant effect being of illuminating in a specifically controlled colour. This colour can be tuned digitally to detect specific colour inks.

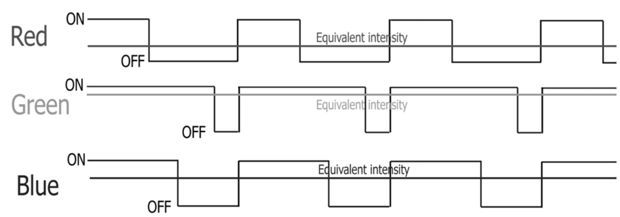

Figure 9. Digitally pulsing RGB sources allows the intensity to be varied

Test Rig and Control System

A number of test rigs have been developed. A computer controlled scanning table can be used to move the arrays across the substrate at a pre-programmed speed. A print head, situated between the heads, can eject drops in response to the encoder. Illumination is provided by high intensity LEDs.

A sophisticated control system is necessary to control the very large volumes of data being transferred around the system. A high performance Pentium 4 with a series of high-speed interface cards and frame grabbers is used. The control software is being developed in Visual C++ and is responsible for synchronizing the system, controlling the position of the print head, sending image information to the head as well as operating, reading and processing the information from the heads.

Detection and Image Processing

Summarised Process

The outputs of the two linear arrays are digitised, subtracted from one another, and then compared with the BIP reference file (discussed earlier). As discussed, every nozzle will have a BIP array dictating what is to be printed and when for the duration of the print. This provides the data to cross reference with the subtracted on-line scanner data. After processing the data into a suitable format, the condition of nozzles is determined. Possible errors due to any blockages can be estimated. If the number of blocked nozzles implies an imperfect print, the head can be taken out of service, a cleaning cycle can be initiated or another print head takes the responsibility to finish printing process.

Specifics of Process

The data needs to be organized in to an effective format and location for the developed Visual C++ processing algorithms to run. Some considerations are outlined here:

- For every nozzle, depending on the type of substrate and the resolution of printing, 3 to 5 sensors are needed to sense each drop. For example, a current high specification linear array might have 3200 pixels and run with a clock frequency of 6MHz outputting data serially at twice this speed (12MHz). Effectivly this means that the linescan rate is going to be 3.75kHz (12MHz/3200pixels). This is a lower frequnecy to that which the heads eject drops and indicates that less than one sample per drop would be taken. It is anticipated that 3-5 samples will be reqired for reliable detection of the dots. This means that a 3 x 3 or 5 x 5 matrix samples the drop. However with scanner technolgy becoming faster and faster this is not expected to be a problem as it is anticipated that scanners of the required specification will be available in the near future. For the purposes of testing the vision system it is possible to run the head at a lower speed.
- After scanning, the analogue outputs from scanners are digitised using 8-bit A/D converter and are grabbed and stored in to the host computer.
- Depending on the width of the print head and the width of scanners there will be a delay between receiving *'before'* and *'after'* information. The data for the *'before'* scanner should be saved in a buffer and used at the appropriate time.
- Each set of 3 or 5 lines that make up a column of *'after'* dots are stored together as a new frame and they will be subtracted from appropriate frame in the *'before'* image.

Processing the Subtracted Image Into a Binary Value

By segmentation the subtracted image[9-11] to find the number of pixel values in the 5 x 5 matrix that have had the considerable pixel values (more than zero). If sufficient number of cells had the values more than zero, it means the existence of dot. Then for reducing the memory space of 5 x 5 matrix with 8-bit pixel values it converts to binary image.

Results

The results shown here demonstrate the functionality of the scanner. Figure 10 provides photographic images of a substrate printed first with cyan drops then with yellow drops. The overlapping areas are of most importance as these are most difficult to detect due to the second colour masking by the undercoat.

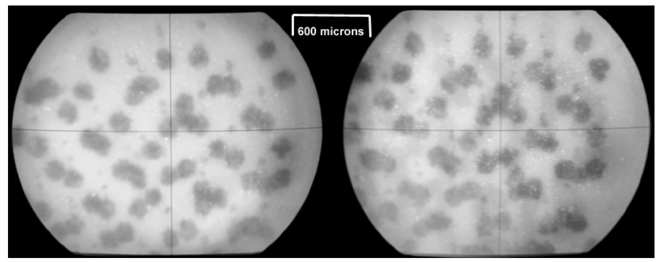

Figure 10. Cyan drops (left), Cyan drops over printed with yellow drops (right)

To gain a measure of the ability of the vision system experiments are undertaken to determine the ability of the system. These experiments include detecting different size of drops, detecting new drops on same colour, detecting new drops on a background of other colour drops and tests on different types of substrate. Refinement of the vision system is a sophisticated process and requires a number of evolutions before it is full functioning for every case. Results for 200-micron diameter drops and above are very successful, however array resolution is a draw back for smaller drops. Likely improvements in array densities will not prevent this from being a draw back for long.

The images shown in Figure 11, 12 and 13 show how the images from the arrays compare with the photographic images.

Figure 11 is the reference stage where no colour is printed between scanning by the *'before'* and *'after'* arrays. Illumination is red to detect the cyan. Due to some slight accuracy errors in the system it is noticeable that there is some noise on the subtracted image, rather than a completely black image, that would be expected from the subtraction of two identical images. However, after processing and converting each drop location to a binary value, it can be seen that the final image is completely black signifying that there were no new cyan drops applied.

Figure 12 is exactly the same experiment but this time magenta drops are printed between *'before'* and *'after'* scanning. Again the illumination is red and therefore the magenta should be reflected meaning magenta drops do not appear in the final image. The result of the subtraction shows that there is some noise due to grey level changes caused by the magenta. These disappear in the processed image and again a completely black image demonstrates that no cyan drops were added between scanners.

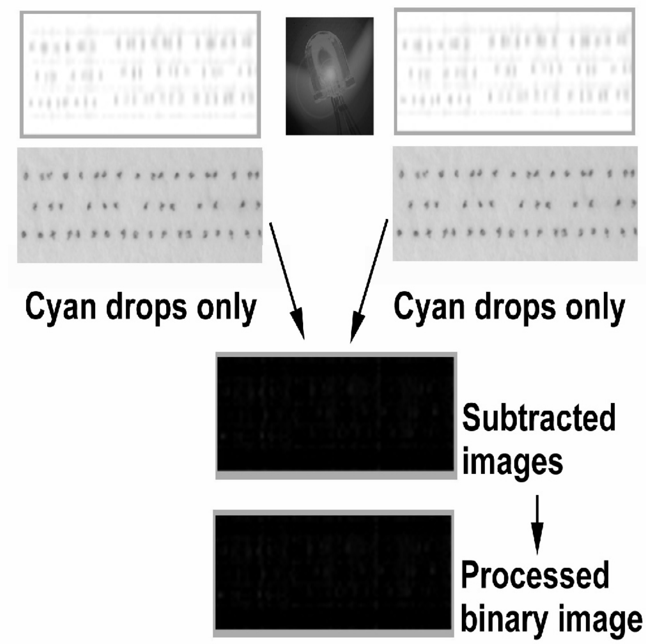

Figure 11. The 'before' and 'after' arrays scan the preprinted cyan drops under RED illumination with no colour applied between them. The images are then subtracted and then each drop is processed and thresholded to create a BIP file.

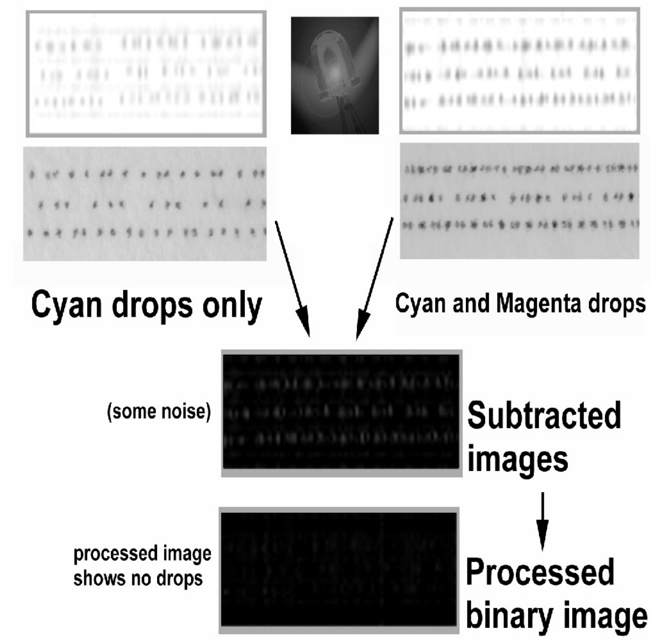

Figure 12. The 'before' and 'after' arrays scan the preprinted cyan drops, but with a coat of magenta printed between the scanners- under red illumination. The images are then subtracted and then each drop is processed and thresholded to create a BIP file.

The third test shown in figure 13 was to illuminate the *'before'* and *'after'* images with green light. This time the cyan drops are only seen very lightly but the magenta is very noticeable on the *'after'* scanner. Subtraction leaves light areas where each of the magenta drops was printed. These transform themselves into white binary values after the final stage of processing. Each binary value can be compared to a drop in the photographic image showing the system is working correctly.

Discovering if Drops Are Missing

As discussed at the beginning of the paper an image is sent as reference BIP signals to the nozzles (this is the array of what should have been printed). A second set of data is available from the comparitive BIPs generated from the scanned prints (what was actually printed). The final stage is a comaprison of these two sets of BIP files to check the performance of every individual nozzle. Thus detectinhg the blocked nozzles. By using some 'Bitwise' functions in Visual C++, the results can show the places where unprinted area start.

After each series of checks the history of each nozzle can be checked statistically and where a nozzle is deemed to be failing too frequently the head will be either taken out of service for cleaning cycle or the other print head takes the responsibility of that and the printing process will continue.

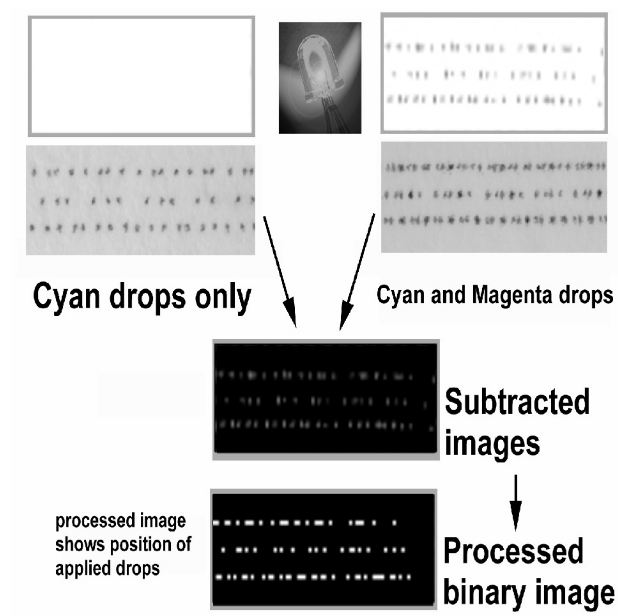

Figure 13. The 'before' and 'after' arrays scan the preprinted cyan drops, but with a coat of magenta printed between the scanners- under green illumination. The images are then subtracted and then each drop is processed and thresholded to create a BIP file.

The Future

Further development and refinement of the image processing software to evolve and optimize the system.

Integration of the vision system with the recovery system on a prototyping printer is outlined in a paper.[12] The aim is to produce a real time system that is able to detect the faults and trigger a recovery system.

It is envisaged that each print head will have its own vision system, controller and positioning system to make it an independently functioning unit that can monitor itself, report to a host controller and reposition itself in response to the printer requirements.

Another stage will be the development of a colour calibration system operating using the tri-colour LED system.

Conclusion

Protyping of the vision system has been sucesssful to a large extent with results for a working vision system looking promising. Current restrictions to array density mean that the system is less reliable at detecting drops below 150 microns im diameter. These restrictions will be overcome with theanticipated improvements in array technology. There is also work to be done to increase processing and scanning speeds to competitve rates. The next phase of develpoment rig, currently under construction, encompasses improved phyical tollerances, increased size and integration with a recovery design.

Acknowledgement

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