EVIDENTIAL VALUE FROM INK-JET PRINTERS

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ABSTRACT: The widespread use of ink-jet printers has made it necessary for document examiners to find a method of linking a questioned document to an individual ink-jet printer. The identification and characterisation of defects produced by ink-jet cartridges provides a means of achieving this.

This study was primarily to investigate the physical nature of defects in inkjet printers and show how printer outputs and printers can be linked. Thus it was hoped to establish whether or not ink-jet printers can be linked to their print-outs through their physical appearance on the paper and if so to estimate the evidential value of any defects or other physical features. By identifying such features it was hoped that a protocol for the examination of this type of printer could be developed.

Defects can be easily introduced into printouts by blocking the electrical defects that control a particular print-head. The behaviour of the defects thus produced is different for different types of ink-jet print cartridges. By studying the behaviour of such defects it is possible to devise a strategy for the examination to distinguish between different printers. Not all nozzles get blocked with the same frequency so if a particularly rare nozzle gets blocked then the evidential value in linking that particular printer to the printout will increase.

KEY WORDS: Ink-jet printers; Document examination; Printing defects; Office machinery.

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INTRODUCTION

In recent years there has been a gradual move away from manual multi-element fixed type bar typewriters and single element electric typewriters containing golf balls and print wheels, towards computer based word processors for the production of "typewritten" documents. This has brought about an increase in the occurrence of computer printouts which are produced using a variety of types of printers. These include laser printers, inkjet printers and dot-matrix printers. As a result, document examiners are likely to encounter such documents with more frequency, making it necessary to have a means by which they can identify a particular printer as the one used for production of a particular document.

The term “word processor” actually refers to the computer program used by the keyboard operator to prepare a computer file of the document which is to be printed. The appearance of the printed characters which finally appear on the paper may be influenced by the type of printer used but to a large extent is governed by the word processing software which produced it.

With typewriters it is possible to relate a document to a specific machine by examining and comparing any individual characteristics produced by the machine i.e. damaged letter blocks, striking out of alignment etc. This is not the case when attempting to separate computer printed documents which are not produced mechanically. Printers are compatible with many different computers which possess a range of fonts, sizes of text and spacing associated with word processing packages making the overall appearance of the document and its typeface of little use when seeking to link a particular printer to a questioned document. However the physical characteristics of the print itself is determined by the printer and may be used to link a document to a printer, particularly if consistent faults can be identified.

In inkjet printers the only moving part in the print-head is the ink itself. The printer uses a grid of tiny nozzles to which specially formulated ink flows from a reservoir. The computer sends an electrical signal to the print-head to determine which nozzles fire for any particular letter. When the ink from the inkjet printer hits the paper it spreads into the fibres and gives the print a slightly ragged appearance. This appearance will depend to some extent on the paper used. In general it is difficult to identify a particular machine or differentiate between work of several machines.

This study concentrates on the outputs from two printers – the Hewlett-Packard Deskjet 500 and the Lexmark 1000. These are both single colour printers, but the principles outlined here can also be applied to most colour ink-jet printers.

INK-JET PRINTERS

Basic Operation

Hewlett-Packard invented the first non-impact printer in 1979 and commercially introduced the ThinkJet in 1984 [4]. Since then, the ink-jet printer has become the most dominant output device used with the personal computer as it has several advantages over other printing approaches, including low printing cost, reduced printing noise, lighter weight and less expensive printing apparatus. The difference in cost is especially significant for colour printing. However, the print quality of inkjet printers is generally not as good as that of other approaches, which can provide higher resolution. The technology of ink-jet printing is advancing considerably and many manufacturers are adding new features constantly to meet the demand for high quality resolution and for improved colour graphics [5, 9].

Ink delivery

There are two systems in which ink is delivered to the paper. Early types of inkjet printers [8] used a continuous-stream method that generated a steady, constant stream of charged ink droplets which could be deflected towards or away from the printing surface by means of an electrical field. Due to their complicated structure this method is only employed now by some uni-colour inkjet manufacturers and for special applications such as printing on packaging. Second is the drop-on-demand method that only supplies ink droplets to the paper when they are instructed by the computer to form a printed image. This is the most popular method of delivery for the ink-jet print-head in the commercial market. This method is described in more detail below.

Drop-on demand print mechanism

Today most ink-jet printers use one of two principal drop-on demand methods to propel ink. Thermal inkjet printers use heat to generate a bubble that creates an actuating force, and piezoelectric printers use electrically driven actuators to pump ink from a chamber. In development at the moment is an electromagnetic printer which uses a tiny ball to squirt ink from a nozzle. The work described in this paper was performed using thermal ink-jet printers, so the mechanism for this is described in more detail below.

Thermal printers

A thermal ink-jet print-head consists of series of tiny holes or nozzles in a small metal plate. Behind each plate is an electrical resistor which is connected by flexible circuitry to a number of electrodes on the outside of a cartridge. These in turn connect with other electrical contacts within the printer and through which the print-head is controlled. The other major component of this cartridge is the ink reservoir which contains a special ink with a high thermal expansion coefficient. A diagram of a thermal ink-jet nozzle is shown in Figure 1.

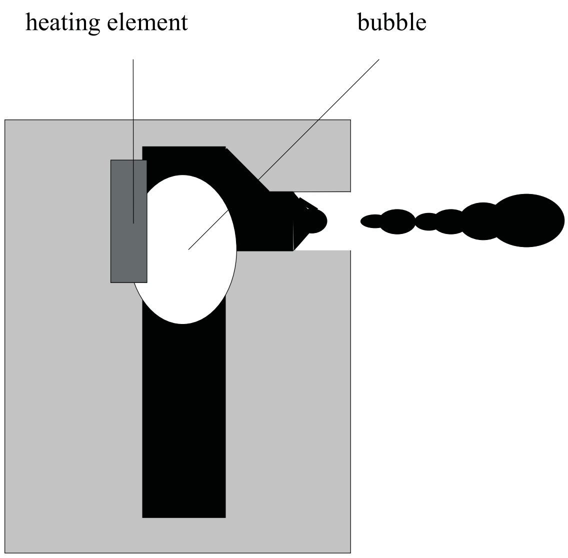

Fig. 1. Thermal ink-jet nozzle.

In operation a voltage pulse is passed through the resistor which causes it to heat up rapidly. The large heat flow generated is transmitted to the ink through heat conduction and consequently produces a vapour bubble. The temperature at which the bubble forms is called the "superheat limit", which depends on the chemical composition of the ink and ambient temperature. A typical value is about 300°C at atmospheric pressure for the ink used in many commercial inkjet print-heads [2]. The heating resistors can produce several thousand heat rises per second. As the bubble grows, momentum is transferred to the surrounding fluid and ink is ejected at velocities of typically 10 metres per second. After completion of ink ejection, the cavities are refilled from the ink reservoir by capillary force. Figure 2 shows a diagram of the stages of operation a typical thermal print-head.

The ejected ink droplet usually has a comet shape with a long tail [6, 10]. The head and tail can separate during travel, the head becoming a separate drop and the tail forming two or more satellite drops. The result of these satellite drops severely effects the printing quality of the print-head causing the appearance of ink spatter.

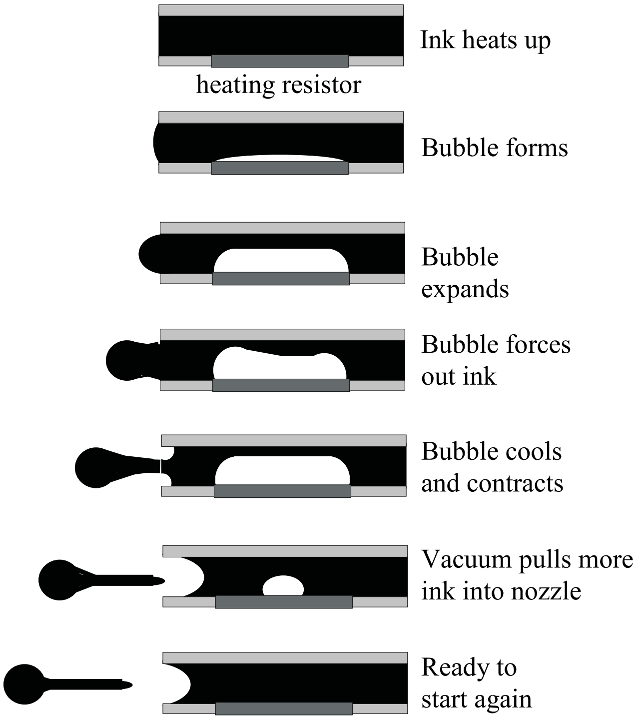

Fig. 2. Stages in the operation of an ink-jet nozzle.

Inks

When ink is ejected from the cartridge upon the surface of the paper it evaporates and penetrates to make a permanent mark. The inks used in the past were made up of a carrier (water or oil) and pigment combination [8]. To prevent the ink from spreading and thereby reducing the image quality, special clay coated papers were used to absorb the carriers. Manufacturers have recently developed new inks which eliminate the need for coated papers [4]. This has been done in two ways:

– By using fluid inks that dry rapidly by evaporation. Problems have arisen with this method as evaporation of some of the ink components takes place in the cartridge causing a hard plug or clogging of the nozzles.
– By using special formulated inks which are "solids" at room temperatures and become fluids when heated beyond their low melting points. These solid plastic inks are liquefied by a heater inside the printer and are then stored as a liquid inside the cartridge ready to be sprayed

from the nozzle. Once the ink is ejected the ink cools quickly and solidifies on the paper surface. The advantage of this method lies in the fact that no volatile carriers are used to dilute the inks so that evaporation in the nozzle aperture is not a problem [8].

Types of defect and their causes

As with other types of printer, the principles that can be used to link a given printout to a particular printer are essentially the identification of defects and an assessment of their significance. It should be remembered that the print-heads used for many ink-jet printers are associated with the ink reservoir and are therefore replaced regularly. Consequently some of the defects described below will disappear when the print-head is changed.

In ink-jet printers the characters are composed of dots such that the density is generally above 300 dots per linear inch and therefore the individual dots are very difficult to detect. These printers may develop faults, but it can be very difficult to detect them due to the fine dot structure. Since the print-head moves horizontally, the defect can often be seen under a microscope as a horizontal white line running through the characters. The causes of some of the more common faults are listed below:

– With thermal ink-jet printers, the resistors are subjected to large pressure changes in the nozzle cavity. As the bubble collapses, it creates a microjet of fluid which impacts the surface of the resistors at high pressure. This pressure can be up to 13 atmospheres and induces cracks and craters. Once damaged it can initiate a chain of events that can cause the resistor to break open and fail [3, 11]. There are also thermal stresses exerted on the print-head due to the large temperature changes that occur over micro-seconds while firing. Once a resistor has failed, the nozzle will no longer print and a permanent defect will be seen in the printout.
– Sometimes at high temperatures, the dye in the ink wall break down into insoluble fragments that stick to the resistor surface. This build up of fragments of degraded dye reduces the heat transfer to the ink and in severe cases the ink cartridge will no longer fire [1]. This effect is known as Kogation. Again, this will give rise to a permanent defect.
– At low temperatures, the thickening of the dye-carrying agent can cause the nozzles to clog [7]. This can also happen when a nozzle has been idle for some time as viscous plugs can form due to evaporation. This type of defect is likely to be cleared when the head is cleaned and is not therefore of much use to the document examiner.
– Occasionally, nozzles will misfire due to the continued heating of a neighbouring nozzle causing the ink to reach its superheat limit. This defect is intermittent.

– A nozzle can appear to be blocked when the connection to the printer is severed, either by an electrical fault (in which case it is likely to persist) or by dirt on the electrical contact (which may or may not persist).

Hewlett-Packard are currently using a thermal inkjet system similar to the one described above in their Deskjet range. As the print-head is attached to their ink cartridges, the print-head is changed every time the cartridge runs out of ink. HP print-heads therefore, are not subjected to thermal stresses for a prolonged time. Some manufacturers also use Hewlett-Packard thermal print cartridges in their machines e.g. Brother while Lexmark and Canon use their own thermal inkjet delivery system for most of their more common printers. While the designs differ in the arrangement and number of the nozzles, position of the electrical contacts etc. the basic components of the cartridges remain the same.

Piezoelectric systems do not heat the ink and so there are no thermal stresses exerted on the print-head. This should eliminate the need for periodic print-head replacement, so the print-head will last the life of the printer. Epson are currently using a system similar to this in their Stylus range under the trade name MicroPiezo™. MicroPiezo™ uses tiny crystal pumps to control each ink droplet with absolute precision. The manufacturers claim the technology produces more spherical dots and less satellite droplets (or spatter) than the thermal systems. It also can achieve higher resolution (up to 1440 dots per inch compared to 1200 dpi) as the print-head does not have to wait while the ink cools before it can be re-fired, thus it can operate at higher frequencies.

Ink-jet print cartridges

There are an increasing number of manufacturers of inkjet printers trying to exploit this rapidly growing segment of computer printers. In this investigation, We chose to look at two machine/cartridge combinations in detail to study the behaviour of faults within these machines. We also looked at other machine/cartridge combinations from four of the leading manufacturers namely Hewlett-Packard, Lexmark, Canon and Epson. in less detail. Of the remaining manufacturers, most use the Hewlett-Packard print cartridge and as this is the critical part of the printer the results described below will be equally applicable to these systems.

Each cartridge was viewed under a microscope to get a detailed look at the components. A graticule was used to measure the dimensions of the cartridge and the print-head. The print-head plate can be easily removed using a mounted needle to inspect the electrical components inside he cartridge.

The printers studied

The printers used for the experiments were the Hewlett-Packard Deskjet 500, fitted with a 51626A cartridge and the Lexmark 1000 fitted with a 13620HC cartridge, both being thermal drop-on demand ink-jet systems. They were operated using the appropriate printer driver installed in Microsoft Windows NT. The print-head on the Hewlett Packard cartridge consisted of 54 nozzles arranged in a rectangle with a maximum print height of 4.1 mm (see Figure 3).The two columns of nozzles are out of phase i.e. the left-hand side nozzles are positioned in-between those of the right. This means that microseconds after the right hand side has fired; the left side will fire ink to fill in the gaps to leave a completed line of text. (The actual length of the nozzle array is 4.5 mm, but tests show that on this cartridge the corner nozzles do not fire when printing text).

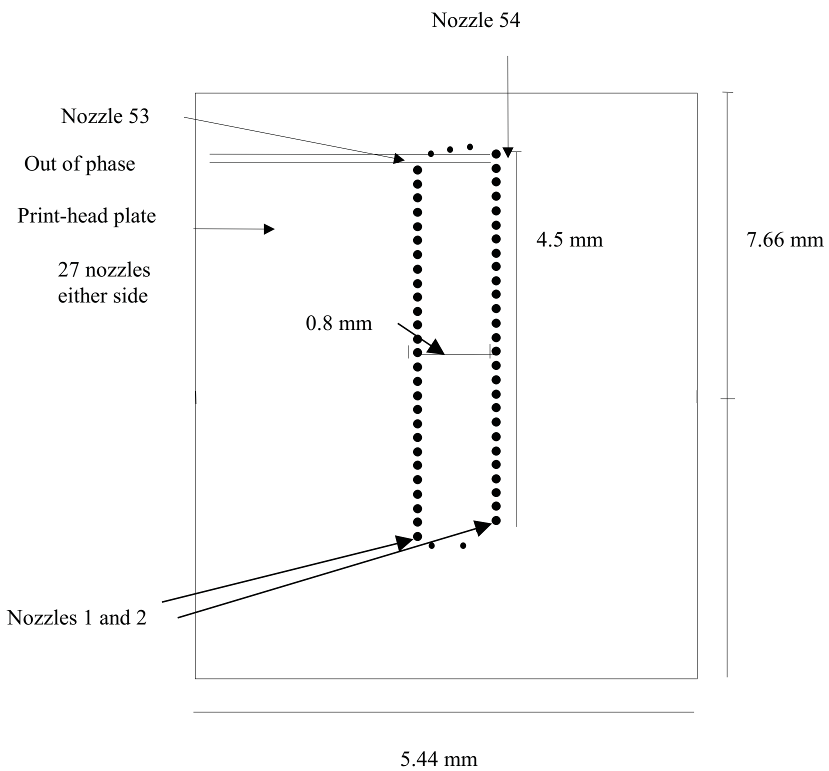

Fig. 3. Hewlett Packard print-head 51626A.

The Lexmark cartridge had 60 nozzles and a print-head size of 4.7 mm but is similar in other respects.

To study how the different operating conditions affect the distance between defects printed on different scans of the print-head it is important to know that the HP Deskjet 500 software prints individual lines of text i.e. it will try to print one line of text in one scan. If this is not possible then it will print the remaining part of the characters on its next scan and will print no other line of text. It also prints moving in both directions, but a forward print is not necessarily followed by a print scan in the opposite direction. The forward/backward pattern is a function of the software driver.

The Lexmark printer only prints in one direction and prints using all available nozzles, irrespective of the text it is printing. In applying the findings of this paper it is important to realise that the direction of print and the number of nozzles used is determined by the software but the physical size of the print-head and number of nozzles is a property of the print-head.

DEFECT EXPERIMENTS

A number of experiments were designed for each of the cartridges, to answer the following questions:

1. Do all blocked electrical contact pads create a defect?
2. Is a defect consistent throughout the text?
3. How is the same defect affected by different fonts?
4. How is the same defect affected by different sizes of font?
5. How is the same defect affected by different line spacing?
6. Does a cartridge, which produces a defect in one printer, produce the same defect if it is changed to another printer of the same, make and model?

It is known that defects occur in ink-jet printers, but there is a perception that these defects are rare and too variable to be useful. Defects occur in cartridges over time due to mechanical and thermal stresses. For these experiments, a known defect was introduced into a printer and then to study its behaviour under different conditions. Both the Hewlett Packard cartridge and the Lexmark cartridge have a series of electrical pads or contacts on the outer surface that engage with contacts in the machines themselves. By blocking the electrical contact pads it was found that a single line defect was produced on most occasions. To enable us to link the electrical pad with the nozzle that it controls each pad was numbered and then blocked in turn using a small piece of insulating tape. The cartridge was then loaded into the appropriate printer and asked to print out the mission of the Forensic Science Service in 12 point font in Microsoft Word®, which is "The Mission of the Forensic Science Service is maximise the benefit of forensic science to the criminal justice system by being the leading provider."

The printouts were then viewed under a microscope to check for the presence or absence of a defect. After each individual pad had been taped, neighbouring pads were taped together to see if this affected the number of defects they produce. The electrical circuitry inside the cartridge was also examined and the circuit traced.

In this way we were able to determine which pad controlled which nozzle. In the Hewlett Packard cartridge examined the relationship of pad to nozzle was fairly straightforward. The exceptions are the contact pad numbers 23, 25, 26, 29, 30, and 56 (see Figure 4). Pad numbers 29 and 30 do not create defects and appear to have no function in this particular print-head (the components of this print-head are used in other related printers and no doubt this accounts for their presence here). The other four pads, 23, 25, 26, and 56, produce more line defects than one. When pad number 23 is blocked it produces a number of line defects that affect the bottom half of the print. If number 56 is blocked, again the bottom half is affected. When both 23 and 56 are blocked, the whole of the bottom half of the print is missing. The same happens for pads 25 and 26 but they affect the top half of the print (see Figure 4). From these results, it seems that they "control" the other heating resistors on their side of the nozzle array. Thus if one of these pads becomes defective it will create a very obvious defect in the printing produced by the machine. Despite this, we have come across this particular defect in casework.

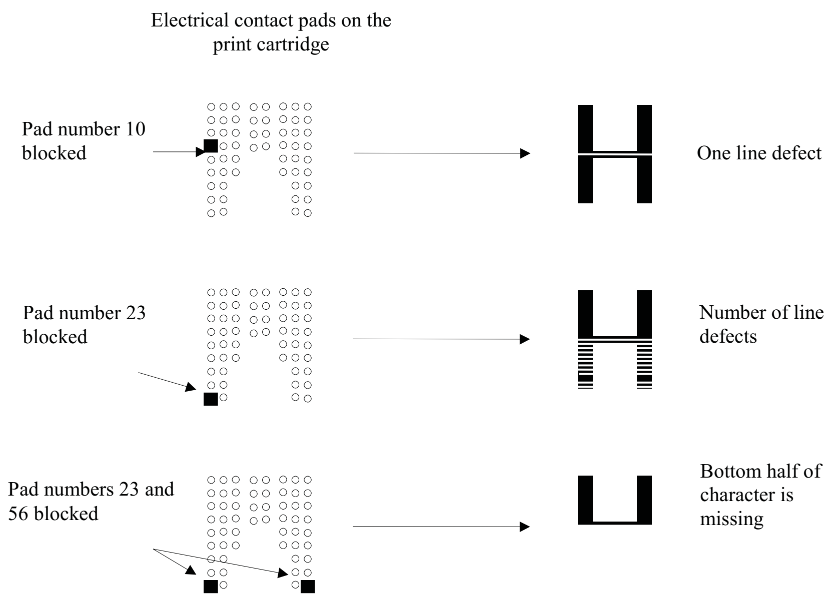

Fig. 4. Generation of line defects.

RESULTS

Measurement of defects

Once a defect had been introduced into the page of ink-jet printed material it was examined with a binocular microscope to identify any defects that had been introduced into printing.

Attempts were made to measure the distance from the top of the letter "H" as this letter uses most of the nozzles to print the character. A micrometer graticule was used to measure the distance from the top of the printed character to the top of the defect. This distance was recorded and used to compare to other samples. The defect can also be measured by counting the droplets of ink above it. The appearance of the letter under the microscope allows the individual dots that make up the letter to be counted. This is less accurate than the graticule method, as two dots can easily become fused together if a nozzle is firing incorrectly i.e. not firing perpendicular to the paper.

The most practical way of determining whether defects were consistent was found to be measurement of the distances between defects on different lines. This allowed a pattern of defects to emerge although, as will be seen later, this pattern does not necessarily repeat from line to line and may require several lines to be inspected before the pattern emerges (the distance to be measured can be seen in the illustration below, Figure 5).

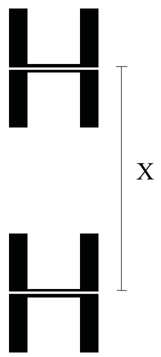

Fig. 5. Measurement of inter-line defect spacing.

Consistency tests

A single pad was taped (which pad does not matter, but we chose pad 10) to see if the defect it produced occurred in the same position in each line of text and also if it appears in the same position each time the document is printed. For these experiments, the first page of this introduction in Microsoft Word® was printed. A microscope was used to observe the positions of the defect down the page. This experiment was run throughout the period of study to see if the defects are consistent over time. It was found that, providing exactly the same conditions were used each time, then the defect did not vary and occurred in exactly the same place in each line of text.

Different fonts

The above experiment was repeated but this time the font of the document was changed to see if this affected the positioning and distance between defects. The point size for each font used was 12 point. The fonts used in these experiments were Arial, Book Antiqua, Bookman Old Style, Century Gothic, Century Schoolbook, Courier New, Footlight MT Light, and Times New Roman.

The results of these experiments for a number of different cartridges are shown in Table I.

TABLE I. DISTANCES BETWEEN THE SAME DEFECT OF DIFFERENT 12 POINT FONTS FOR FOUR DIFFERENT CARTRIDGES

Typescript	Size of H (mm)	Distance between defects [mm]			
		51626A	51629A	51645A	13620HC
Arial	3.1	5.1/5.0	5.1/5.0	14.4/14.3	4.7
Book Antiqua	3	5.1	5.1	14.4	4.7
Bookman Old Style	2.9	5.1/5.0	5.1/5.0	14.4/14.3	4.7
Century Gothic	3.1	5.4/5.3	5.4/5.3	14.7/14.6	4.7
Century Schoolbook	3	5.1	5.1	14.4	4.7
Courier New	2.5	4.5/4.4	4.5/4.4	13.6/13.5	4.7
Footlight MT Light	2.8	4.4	4.4	13.5	4.7
Times New Roman	2.9	5.1/5.0	5.1/5.0	14.4/14.3	4.7

Arial,
Book Antiqua,
Bookman Old Style,
Century Gothic,
Century Schoolbook,
Courier New,
Footlight MT Light,
Times New Roman

Fig. 6. Example of type fonts used.

For the Hewlett Packard cartridge under study, 51626A, when the font of the document was changed then the spacing between the same defect in different lines changed. This is because this cartridge prints a line at a time therefore the defect distance is dependent on the size of the font and the size of the line spacing between.

In addition to this, in some of the fonts the distance between two consecutive lines of the same defect changed while in others the distance remained the same. This is because different typescripts of the same point size differ in their heights. If a typescript is created by an even number of nozzles then the distance between defects will be constant throughout the document. However if the document is created from an odd number of nozzles then the distance will vary in alternate lines. Thus if the distance between a defect in line 1 and 2 is 5.1 mm, the distance between a defect in line 2 and 3 may be 5 mm, but the defect between lines 3 and 4 will again be 5.1 mm. This pattern will continue down the page. Table I shows the differences between the different fonts in length between two lines of text produced from the same defect.

Because the Hewlett Packard printer prints one line at a time and prints travelling in both directions the distance between the same defect on different lines will be nearly the same each time. A different size of character and therefore a different size of line spacing will create a different distance between the same defect. However the software controlling the print-head is designed to use slightly different nozzles on the way forward than on the way back thus giving rise to the differences observed.

The Lexmark printer (cartridge 13620C), on the other hand, prints using the complete array of nozzles irrespective of the text being produced. Therefore if spaces between lines coincide with a pass of the print-head then the corresponding nozzles will not produce an image. Hence the distance between a defect in different lines will be constant and will be the size of the print-head (in this case 4.7 mm) no matter which font is used.

Using different point size (character height)

Again the consistency experiment is repeated but this time the point size was changed to see if this affected the positioning and distance between defects. The sizes used in these experiments were 10 point, 12, 12.5, 13, 13.5, 14, 16, 18, and 20 point using Times New Roman typescript (see Figure 6).

10 point,
12 point,
12.5 point,
13 point,
13.5 point,
14 point,
16 point,
18 point,
20 point

Fig. 7. Examples of different point sizes.

The Hewlett Packard cartridge is only capable of producing print which is 4.1 mm high, which corresponds to 12.5 point in Times New Roman. Therefore when point sizes of less that 12.5 are used the pattern described above in the study of font is again seen. In a point size requiring an odd number of nozzles a permanent defect has an alternating pattern while in one requiring an even number the pattern is repeated every line. However, if the printer is asked to print out text which is larger than the print-head size, then the printer has to complete the character in more than one scan and so the defect may or may not occur more than once. With this cartridge, for point sizes greater than 12.5, the print-head will need to scan across the page twice to complete the character. If the defect was in a nozzle close in position to nozzle 1, then the defect is more likely to be repeated in the same character. If the defect is repeated, it represents the maximum size that the print cartridge can print. (for this cartridge this distance was 4.1 mm). The pattern of firing thus becomes complicated and the exact appearance of the text on the paper will depend on the position of the nozzle which is not firing and the point size used. In addition, the alternate pattern described above may be superimposed onto the existing pattern. Figure 8 shows the pattern of firing for one such situation. For 12 point size characters, the number of dots in a straight line are the same but the nozzles that ejected those dots change for alternate lines of text. The first line of text is printed by nozzles 4–47, the second line by nozzles 5–48, the third line is printed like the first and the fourth like the second and so on. This is the reason why the distance between defects changes for every alternate line.

For 12.5 point font size characters, all the lines are printed by the same nozzles. The nozzles that fire are 5–49, thus there is an extra dot of ink for the change of 12 to 12.5 point size. For this point size all the distances between defects will be the same.

For 13 point font size characters, nozzles 4–49 plus nozzles 4 and 5 from the second scan print the first line of text. Nozzles 5–50 plus nozzles 4 and 5 from the second scan print the second line of text. If here nozzle 5 were blocked then the line defect would be repeated twice in both lines of text.

For 14 point font size characters, nozzles 4–49 plus nozzles 4–8 from the second scan print the first line of text. Nozzles 5–50 plus nozzles 5–9 from the second scan print the second line of text.

These different firing patterns produced by the nozzles creates the differing distance between defects but by careful study a regular pattern should emerge if the defect is consistent.

It is interesting to note that if nozzle 4 is showing a defect then some lines of typing in 12 point will not contain the visible defect while in 13 point the defect will occur twice in the same line.

- Using Times New Roman
- 12 point uses nozzles 4-47 and 5-48 alternately
- 12.5 point uses 5-49 all the time
- 13 point uses 4-49 and 5-50 alternately and nozzles 4 & 5 of the return scan

Fig. 8. Firing pattern for Times New Roman in different point size.

Using different line spacing

Again the consistency experiment is repeated but this time the line spacing of the document is changed to see if this affects the positioning and distance between defects. The spacing used were single, 1.5 lines, and double again using the Times New Roman typescript in 12 point. The effect of this in the Hewlett Packard machine was simply to make the distance between the defects in each line greater while in the Lexmark machine the distance between the defects remained at 4.7 mm, the size of the print-head. However, in some circumstances the defect in this type of printer may appear to vanish for parts of the text down the page because it conicides with a line spacing. By measuring differences in the spacing of defects down the page the regular pattern should be apparent and the size of the print-head can be determined.

Changing cartridges between machines

A print cartridge known to have a defect was used to print a document in a number of different machines. The experiments were conducted to see if the defect remained in the same place from one machine to the next. The machines used were the Deskjet 500, 510 and 510C which all use the same cartridge. The resulting printouts were viewed under a binocular microscope with a graticule so the defect positions could be compared. It was found that the defect behaved in the same way whichever machine was used.

Print direction

Some machines can print in both directions while some can only print in one direction. Further the pattern of printing is not always left to right then right to left. Sometimes the print-head will travel several times in one direction then several times in the other, depending on what it has to print. From viewing the printouts underneath a microscope, the direction of print can be found by looking at the ink spatter. This predominately occurs on the side of the printed character towards the end that the print-head is travelling. This can be seen in Figure 9. Thus if the bulk of the spatter is on the right of the character then the print-head was travelling from left to right (it occurs on the leading edge). The reason for this can be easily understood by referring back to Figures 1 & 2. The comet-like tail of the ejected drop is ejected slightly after the main drop and therefore reaches the paper slightly further along the paper than the main drop, resulting in the spatter. The amount of spatter will vary from machine to machine.

By looking at these spatter patterns one can see when the direction of the print-head changes direction of print and consequently this provides a method of determining the size of the print-head nozzle array. This is a feature which cannot vary and is therefore very useful in distinguishing between printers using different cartridges or different manufacture.

Occasionally ink droplets from the tail can travel through the main droplet and reach the paper in advance of the main dot, creating spatter on both sides of the character. However, this is uncommon.

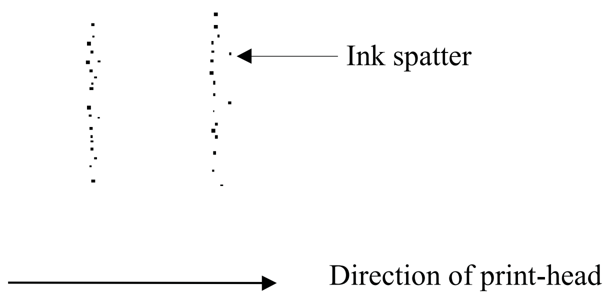

Fig. 9. Diagram showing ink spatter.

Sample printouts

Printout samples were collected from as many machines as possible to try to identify how common defects occur in printouts and which of the nozzles were prone to become defective.

Of the 53 printouts, 14 had defects (approximately 1 in 4) of some description. The manufacturer's reliability goal is for the cartridge to run out of ink before a nozzle becomes blocked. Of those with defects 71.4% of the defects were around the centre of the print-head, but this may not be significant due to the small sample size. Some other defects were detected apart from line defects in two printouts. These were e print quality defects which resulted in unevenness of print. This is probably caused by slightly varying drop volumes due to imperfections in the manufacturing process of the nozzles.

One inkjet cartridge containing a defect was changed to another printer model that also uses the same type of cartridge. The resulting printouts had the same defect but the defect was in a slightly different place for each machine. This could be due to the printers being different models. However, the distance between the defects remained the same from the two printers.

DISCUSSION

While the appearance of a document printed using an ink-jet printer is largely determined from the way the printer interacts with the controlling software the above experiments show that there are some features which are properties of the printer itself. Using these features the document examiner can develop a protocol for the comparison of print-outs and thus determine whether two documents share a common origin. The following steps are one such protocol:

– direction of print-head motion: by looking carefully at the spatter pattern on single colour printed text one can determine how the print-head is moving. If it is printing one line of text at a time before beginning another then this can be distinguished from a printer that has software which prints without regard to lines of text.

– maximum size of print-head: additionally, by examining the transitions from one print pass to another the size of the print-head can be measured. In line-at-a-time printers this will be particularly evident in areas of the print which contain diagrams or print with a point size larger than the print-head, usually around 13 point. In other printers the print-head can easily be determined when it changes direction in the middle of the line of text.

– repeating pattern of line defects: defects in a print-head can arise through a number of reasons. Whatever the cause, most result in a fine white line running through the print. Consistent defects occur in about 25% of inkjet printers. The problem for the document examiner is distinguishing between defects that are consistent from those which are not. This is done by looking for regular patterns that repeat in the lines of text. In some printers, that do not follow the lines of text, this is relatively easy and is simply a matter of identifying the positions of the defect and measuring the repeating distance between them. In others the position of the white line may vary depending on the point size, font, line spacing etc. Here the document examiner must look for a pattern that repeats within a particular section of the text. This pattern can be quite complicated, especially if the point size used is generally larger than the size of the print-head.

– position of line defect with respect to the top of "H": by measuring the height of the block capital letter "H" and determining the position of the line defect with respect to the top of the "H" in a number of lines it may be possible to determine which nozzle is actually defective. If the definition of the dots is clear enough and the print quality is not too high then it may be possible to count the number of nozzles in operation and the exact origin of any defect.

Limited studies of the type described above have been carried out using a number of other printers from different manufacturers and with colour printers and the general examination principles seem to apply to them also. The machines studied were: Hewlett Packard 51629A, 51645A, 51641A, 51625A; Lexmark 13620HC, 13619HC, 13400HC, 12A1970.

Some Canon and Epson printers were also studied but no detailed measurements were taken from these machines.

CONCLUSION

From the observations made it can be seen that there are a number of ways in which the products of an inkjet printer and the printer that produced them can be associated with a greater degree of certainty than has hitherto been reported. However, these methods are likely to be much more reliable in showing that different printers are involved and, whatever the situation, the techniques still need to be used with caution.

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