

105

1 RELATED PATENT DOCUMENTS

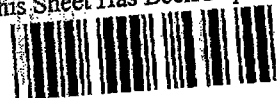
2
3 Three closely related documents are other, coowned
4 U. S. utility-patent applications filed in the United
5 States Patent and Trademark Office substantially contemporaneously with this document -- and also hereby incorporated by reference in its entirety into this document.
6
7 One is in the names of Ronald A. Askeland et al., and
8 identified as Hewlett Packard Company docket number PD-
9 1093053-1, and entitled "INKING FOR COLOR-INKJET PRINTERS,
10 USING NONINTEGRAL DROPS, MEDIA-DEPENDENT INKING, OR MORE
11 THAN 2 DROPS/PIXEL" -- and subsequently assigned utility-
12 patent application serial 08/____,____, and issued as
13 U. S. Patent 5,____,____ on _____, 199____.
14
15 Another such document is in the names of Gregory D. Raskin
16 et al., and identified as Hewlett Packard Company docket
17 number PD-189492, and entitled "DIRECTION-INDEPENDENT
18 ENCODER READING; POSITION LEADING & DELAY, & UNCERTAINTY
19 TO IMPROVE BIDIRECTIONAL PRINTING" -- and subsequently assigned utility-patent application serial 08/____,____, and
20 issued as U. S. Patent 5,____,____ on _____, 199____.
21
22 A third related document is in the names of Broder
23 et al., and identified as Hewlett Packard Company docket
24 PD-1092153-1, and entitled "COMBINED CENTRAL AND LATERAL
25 HOLD-DOWN PLATES, AND END-OF-PAGE ADVANCE-DISTANCE DECREASE, IN LIQUID-INK PRINTERS" -- and subsequently assigned utility-patent application serial 08/____,____, and
26 issued as U. S. Patent 5,____,____ on _____, 199____.
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28
29
30

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32 BACKGROUND

33
34 1. FIELD OF THE INVENTION

35
36 This invention relates generally to machines and
37 procedures for printing text or graphics on printing media
38 such as paper, transparency stock, or other glossy media;

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1 and more particularly to a scanning thermal-inkjet machine
2 and method that construct text or images from individual
3 ink spots created on a printing medium, in a two-dimen-
4 sional pixel array. The invention employs print-mode
5 techniques to optimize image quality (primarily on trans-
6 parent and glossy media) vs. operating time, and also to
7 minimize image distortion (primarily on paper) imposed by
8 an ink-drying heater.

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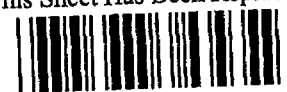
11 2. PRIOR ART

13 To achieve vivid colors in inkjet printing with
14 aqueous inks, and to substantially fill the white space
15 between addressable pixel locations, ample quantities of
16 ink must be deposited. Doing so, however, requires subse-
17 quent removal of the water base -- by evaporation (and,
18 for some printing media, absorption) -- and this drying
19 step can be unduly time consuming.

20 In addition, if a large amount of ink is put down all
21 at substantially the same time, within each section of an
22 image, related adverse bulk-colorant effects arise: so-
23 called "bleed" of one color into another (particularly
24 noticeable at color boundaries that should be sharp),
25 "blocking" or offset of colorant in one printed image onto
26 the back of an adjacent sheet with consequent sticking of
27 the two sheets together (or of one sheet to pieces of the
28 apparatus or to slipcovers used to protect the imaged
29 sheet), and "cockle" or puckering of the printing medium.
30 Various techniques are known for use together to moderate
31 these adverse drying-time effects and bulk- or gross-
32 colorant effects.

34 (a) Prior heat-application techniques -- Among these
35 techniques is heating the inked medium to accelerate
36 evaporation of the water base or carrier. Heating, howev-
37 er, has limitations of its own; and in turn creates other

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1 difficulties due to heat-induced deformation of the print-
2 ing medium.

3 Glossy stock warps severely in response to heat, and
4 transparencies too can tolerate somewhat less heating than
5 ordinary paper. Accordingly, heating has provided only
6 limited improvement of drying characteristics for these
7 plastic media.

8 As to paper, the application of heat and ink causes
9 diimensional changes that affect the quality of the image
10 or graphic. Specifically, it has been found preferable to
11 precondition the paper by application of heat before
12 contact of the ink; if preheating is not provided, so-
13 called "end-of-page handoff" quality defects occur -- this
14 defect takes the form of a straight image-discontinuity
15 band formed across the bottom of each page when the page
16 bottom is released.

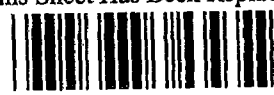
17 Preheating, however, causes loss of moisture content
18 and resultant shrinking of the paper fibers. To maintain
19 the paper dimensions under these circumstances the paper
20 is held in tension by a system of pinchwheels used in con-
21 junction with paper-advance drivewheels.

22 Unfortunately these provisions have their maximum
23 effect, in preventing image-quality defects, only while
24 the paper is constrained by the wheels. As soon as the
25 bottom of the page has been printed and the paper leaves
26 the constraint of the wheels, the paper contracts.

27 This happens very quickly, and as it does the paper
28 and the dots of ink on it move in at the edges and up in
29 the center. The quality defect caused by this sudden
30 releasing of stress can be identified as an "end-of-page
31 paper-shrink defect"; it appears as a thin arched gap of
32 reduced color density.

33 Prior efforts to eliminate this arched gap have
34 included avoiding the page-long accumulation of stress by
35 cyclically lifting or releasing the constraining force of
36 the pinchwheels. This works to decrease the paper-shrink
37 defect by allowing the internal stress to be released or
38 equalized incrementally -- rather than cumulatively.

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1 Unfortunately, however, this cyclical-release tech-
2 nique sacrifices control over paper position at each of
3 the release points along the way. This loss of paper-
4 position control can create numerous misalignment regions
5 that are a greater problem than the paper-shrink defect.

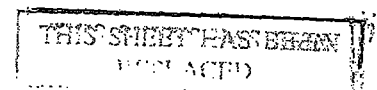
6
7 (b) Prior print-mode techniques -- Another useful
8 technique is laying down in each pass of the pen only a
9 fraction of the total ink required in each section of the
10 image -- so that any areas left white in each pass are
11 filled in by one or more later passes. This tends to
12 control bleed, blocking and cockle by reducing the amount
13 of liquid that is all on the page at any given time, and
14 also may facilitate shortening of drying time.

15 The specific partial-inking pattern employed in each
16 pass, and the way in which these different patterns add up
17 to a single fully inked image, is known as a "print mode".
18 Heretofore three-pass print modes have been used success-
19 fully to reduce bulk-colorant problems on paper -- but
20 less successfully on glossy and transparency stock, which
21 are much less absorbent and so rely to a greater extent
22 upon evaporation.

23 Attempts have also been made to use print modes for
24 hiding the paper-shrink error discussed in subsection (a)
25 above. Heretofore such efforts have had relatively little
26 effectiveness, or have caused still other problems.

27 For example, some print modes such as square or rect-
28 angular checkerboard-like patterns tend to create objec-
29 tionable moire effects when frequencies, harmonics etc.
30 generated within the patterns are close to the frequencies
31 or harmonics of interacting subsystems. Such interfering
32 frequencies may arise in dithering subsystems sometimes
33 used to help control the paper advance or the pen speed.

34 Checkerboard print-mode patterns also are subject to
35 objectionable so-called "banding" -- horizontal stripes
36 across the finished image. These arise because between
37 each swath the paper advances by substantially the full





1 height of a swath, in effect another type of cumulative-
2 error display.

3 Print-mode patterns that are instead made up of
4 either mostly all horizontal or mostly all vertical ele-
5 ments can still produce similar interference effects, but
6 only along that direction of the pattern (the direction
7 along which most of the pattern elements are aligned) --
8 and also tend to exaggerate other print-quality defects in
9 the directional lateral to the pattern. Such problems
10 have defeated earlier efforts to find print-mode solutions
11 to the end-of-page paper-shrink problem.

12

13 (c) End-of-image print-medium advance errors --

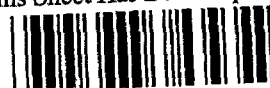
14 Another problem, related to the end-of-page defect intro-
15 duced above, arises when printing near the beginning or
16 end of a sheet of printing medium -- but arises in a
17 somewhat simpler or more mechanical fashion. As suggested
18 earlier, in representative modern printing machines de-
19 signed for fine resolution and high image quality, the
20 printing medium is generally held taut in the print zone,
21 between two sets of rollers or the like.

22 This arrangement promotes very high precision and
23 accuracy of printing-medium advance, and thus of printing-
24 medium positioning relative to the pen. Near both longi-
25 tudinal ends of each sheet or page of printing medium,
26 however, necessarily the medium is held only by one set of
27 rollers etc.

28 This arrangement leads to relatively less precise
29 positioning of the printing medium in those two regions.
30 This situation may be troublesome in particular when
31 printing near the bottom end of a sheet, as there the
32 sheet is held only by a tensioning roller -- which for
33 other reasons is advantageously made rather small in
34 diameter, but such sizing may be adverse to best
35 precision.

36 One current development (not prior art with respect
37 to the present invention) importantly mitigates that
38 relative diminution of precision by taking smaller steps

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1 in the printing-medium advance, particularly near the
2 bottom or end of each page. That system and its benefits
3 are described in the Broder et al. document mentioned
4 earlier; although that system represents a major contribu-
5 tion to attainment of good print quality near the bottom
6 of the page, nevertheless precision is not improved to the
7 level enjoyed in regions where the medium is held taut.

8
9 (d) Known technology of print modes: general intro-
10 duction -- One particularly simple way to divide up a
11 desired amount of ink into more than one pen pass is the
12 checkerboard pattern mentioned above: every other pixel
13 location is printed on one pass, and then the blanks are
14 filled in on the next pass.

15 To avoid the banding problem (and sometimes minimize
16 the moire patterns) discussed above, a print mode may be
17 constructed so that the paper advances between each ini-
18 tial-swath scan of the pen and the corresponding fill-
19 swath scan or scans. In fact this can be done in such a
20 way that each pen scan functions in part as an initial-
21 swath scan (for one portion of the printing medium) and in
22 part as a fill-swath scan.

23 Once again this technique tends to distribute rather
24 than accumulate print-mechanism error that is impossible
25 or expensive to reduce. The result is to minimize the
26 conspicuousness of -- or, in simpler terms, to hide --
27 the error at minimal cost.

28 For instance a two-pass print mode may start a page
29 by printing with only some of the nozzles in an array of
30 only half of the pen's nozzles, all positioned at one end
31 of the pen -- as an example, selected ones of the nozzles
32 consecutively numbered one through fifty, on a hundred-
33 nozzle pen. This first pass may be in a checkerboard
34 pattern -- thus actually using, e. g., for example, exclu-
35 sively odd-numbered nozzles 1, 3, . . . in the first row,
36 and then only even-numbered nozzles 12, 14, . . . in the
37 second row, next selecting only odd-numbered nozzles 21,

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1 23, . . . again in the third row, etc. -- and thus print-
2 ing in half of the pixel locations in the swath area.

3 The paper then advances by a distance equal to the
4 length of the half-array of nozzles (in other words, the
5 height of fifty nozzles), and the pen would print in both
6 ends of its nozzle array -- but again only printing a
7 fifty-percent checkerboard pattern. Now, however, while
8 the forward end of the pen (selected ones of nozzles one
9 through fifty) as before prints on fresh paper, the rear-
10 ward end (selected ones of nozzles numbered fifty-one
11 through one hundred) fills in the area already printed.

12 This behavior is then repeated all down the page
13 until the last swath -- which is a fill-in swath only,
14 again using selected nozzles of those numbered fifty-one
15 through one hundred.

16
17 (e) Space- and sweep-rotated print-mode masks -- The
18 pattern used in printing each nozzle section is known as
19 the "print-mode mask". The term "print mode" is more
20 general, usually encompassing a description of a mask, the
21 number of passes required to reach full density and the
22 number of drops per pixel defining "full density".

23 In the two-pass example above, the second half of the
24 pen (certain ones of nozzles numbered fifty-one through
25 one hundred) filled in the blank spaces left by the first
26 half. For each pass, this may be symbolized using a
27 letter "x" for each pixel that is printed and a letter "o"
28 for each pixel that is not, as follows.

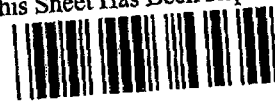
29
30 pattern 1: pattern 2:
31 nozzles 1 through 50 nozzles 51 through 100

33	xoxoxoxoxo	oxoxoxoxox
34	oxoxoxoxox	xoxoxoxoxo
35	xoxoxoxoxo	oxoxoxoxox
36	oxoxoxoxox	xoxoxoxoxo
37	xoxoxoxoxo	oxoxoxoxox

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1 In each of these diagrams, the xs appear in diagonal
2 lines -- which are angled, if the vertical and horizontal
3 spacings are the same, at forty-five degrees (to both the
4 columns and rows). These lines of xs represent pixels
5 that are printed (if the desired image calls for anything
6 to be printed in each of those pixels respectively), and
7 the os represent diagonal lines of pixels that are not
8 printed.

9 To conserve space in this document, the diagrams
10 above represent only eight pixel rows, out of fifty creat-
11 ed by each half of the hundred-nozzle pen that is under
12 discussion. The nozzles are laid out along the pen in
13 substantially only one vertical row, one hundred nozzles
14 long -- although as a practical mechanical matter they are
15 staggered laterally to permit very close spacing along the
16 vertical axis. Therefore to obtain the checkerboard (or
17 other) patterns described in this document the various
18 nozzles are fired selectively and rapidly many times, in
19 careful synchronism with scanning of the pen across the
20 printing medium -- taking into account not only the scan-
21 ning motion across the page but also the nozzle staggering
22 across the pen.

23 In the "pattern 1" diagram, one line of xs begins in
24 the upper left-hand corner, and at pixel positions offset
25 by two pixels along both top and left-hand edges of the
26 pattern. In the "pattern 2" diagram, however, it is
27 instead a line of os that begins in the corner, whereas
28 lines of xs begin at positions offset from the corner by
29 just one pixel along the top and left-hand edges -- and so
30 fitting between the lines of xs put down by "pattern 1".

31 Hence these diagrams show that pixel positions left
32 unprinted by the first ("pattern 1") pass are filled in by
33 the second. In other words, looking all the way across
34 any row -- and taking into account all the xs formed by
35 both "pattern 1" and "pattern 2" in the aggregate -- all
36 positions in the row are filled.

37 One way to achieve this pattern is to always keep
38 nozzles one through fifty in "pattern 1", and always keep

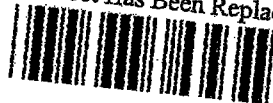
1 nozzles fifty-one through one hundred in "pattern 2".
 2 This is known as "space rotated" masking; using this
 3 method to print down the page would progressively produce
 4 these patterns -- illustrated here too using an abbreviat-
 5 ed vertical nozzle-array representation of just eight
 6 nozzles rather than one hundred:

	<u>pass 1</u>	<u>pass 2</u>	<u>pass 3</u>	<u>pass 4</u>	<u>pass 5</u>
10	----				
11					
12					
13					
14	xoxo	oxox			
15	oxox	xoxo			
16	xoxo	oxox			
17	oxox	xoxo			
18		xoxo	oxox		
19		oxox	xoxo		
20		xoxo	oxox		
21		oxox	xoxo		
22			xoxo	oxox	
23			oxox	xoxo	
24			xoxo	oxox	
25			oxox	xoxo	
26				xoxo	oxox
27				oxox	xoxo
28				xoxo	oxox
29				oxox	xoxo
30					
31					
32					
33					----

<- first printed row

<- fifth printed row

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35 In this mode, the pen uses the same pattern all down the
 36 page, but the mask is different in different portions of
 37 the pen: "pattern 1" for nozzles one through fifty (rep-
 38 resented in the abbreviated drawing by the lower four

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1 positions in each eight-nozzle group); vs. "pattern 2" for
2 nozzles number fifty-one through one hundred (represented
3 by the upper four positions in each group).

4 The availability of this method of masking for vari-
5 ous printing devices depends in part on the basic mechan-
6 ical and firmware architecture of each device. In partic-
7 ular, it depends upon whether the basic operating system
8 provides for efficient addressing of different mask pat-
9 terns to different segments of the overall nozzle array.

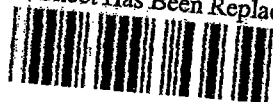
10 Another way to use the same print mode is to apply
11 one mask pattern to the entire pen, but to change that
12 mask pattern from pass to pass. This is so-called "sweep
13 rotated" masking -- still using the same abbreviated
14 representation for purposes of illustration:

15
16 pass 1 pass 2 pass 3 pass 4 pass 5
17
18 -----
19 | |
20 | |
21 | |
22 xoxo xoxo
23
24 xoxo xoxo
25 xoxo xoxo
26 xoxo xoxo
27 xoxo xoxo
28 xoxo xoxo
29 xoxo xoxo
30 xoxo xoxo
31 xoxo xoxo
32 xoxo xoxo
33 xoxo xoxo
34 xoxo xoxo
35 xoxo xoxo
36 xoxo xoxo
37 xoxo xoxo
38 | |

<- first printed row

<- fifth printed row

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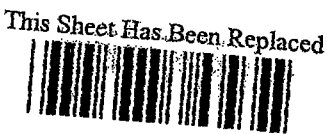
1
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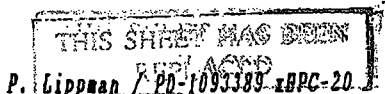
In both these diagrams -- as in the basic "pattern 1" and "pattern 2" diagrams discussed just before, it can be seen by reading all the way across any row that after both passes at each row all positions in that row are filled -- but by comparing the space- and sweep-rotation diagrams it will now be appreciated that the order in which some of the positions are filled in sweep rotation is opposite to that in which they are filled in space rotation. For example, in the fifth printed row the left-hand column is printed in the second pass (and the adjacent column left blank for printing later) in space rotation -- but is printed in the third pass (after the adjacent column) in sweep rotation.

This can be shown more compactly by a different notation that allows comparison of space and sweep rotation side by side. In this notation, "0" represents nozzle groups that are not fired at all -- at the top and bottom scans of the page -- while "1" and "2" represent not individual pixel rows but rather half-swaths, in "pattern 1" and "pattern 2" as defined above.

<u>Space rotation</u>	<u>Sweep rotation</u>
0	0
1 2	1 2
1 2	2 1
1 2	1 2
1 2	2 1
1 2	1 2
0	0



Now in these abbreviated forms it is easier to see that within the printed image every half-swath receives one "1" and one "2" -- but not always in the same order. Thus in



1 the second half-swath the "1" goes down first in space
2 rotation, but second in sweep rotation.

3
4 (f) Autorotating print-mode masks -- Operating
5 parameters can be selected in such a way that, in effect,
6 rotation occurs even though the pen pattern is consistent
7 over the whole pen array and is never changed between
8 passes. Figuratively speaking this can be regarded as
9 "automatic" rotation or simply "autorotation".

10 To understand what produces this condition, it is
11 necessary first to take note of what constitutes a basic
12 cell or unit of the print-mode mask, and then to note its
13 height h_c in pixels. It is also necessary to note the
14 number of pixels (or the length measured in number of
15 nozzles) by which the paper moves m_p in each of its ad-
16 vances. For example, in the simple cases diagrammed
17 above, since each mask repeats every two rows, $h_c = 2$; and
18 the paper advances by fifty nozzles at a time, so $m_p = 50$
19 (or as in the abbreviated-notation diagram the paper
20 advances four diagrammed nozzles at a time, so $m_p = 4$).

21 The next step is to determine whether the ratio m_p/h_c
22 of these two parameters is integral. If so, as in this
23 case, since $m_p/h_c = 50/2 = 25$ actually (or $4/2 = 2$ as
24 illustrated), the mask will not autorotate.

25 If however, in the two-pass example the paper advanc-
26 es by three diagrammed pixel rows instead of four -- but
27 the basic cell remains two pixels tall -- then for this
28 case as diagrammed the ratio $m_p/h_c = 3/2$ is nonintegral
29 and at each pass the mask will "automatically" fill in the
30 blank spaces left by the previous pass:

31
32 pass 1 pass 2 pass 3 pass 4 pass 5
33
34 xoxo
35 oxox
36 xoxo
37 oxox xoxo
38 xoxo oxox

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1	oxox	xoxo	
2		oxox	xoxo
3		xoxo	oxox
4		oxox	xoxo
5			oxox xoxo
6			xoxo oxox
7			oxox xoxo
8			oxox
9			xoxo
10			oxox

(This diagrammatic example symbolizes a real case of, for instance, three passes, a total of ninety-six nozzles used in the pen, thirty-two nozzles used in each of three sections of the pen, thirty-two-nozzle printing-medium advance -- and a basic-pattern cell three pixels tall. In algebraic notation, $m_p/h_c = 32/3$, a nonintegral ratio. This three-pass mode is discussed in the next section.)

The print mode produced in this way is essentially a space-rotation mode (though in a sense that condition is not specifically called for). For example, if the pen is a six-row pen as diagrammed above, the first three rows are in "pattern 1" and the second three are in "pattern 2":

26	xoxo	
27	oxox	pattern 1
28	xoxo	
29	oxox	
30	xoxo	pattern 2
31	oxox	

For an autorotating case, either "pattern 1" or "pattern 2" may be used all down the pen. Thus the paper advance turns one simple pattern into a space-rotated mask "automatically". In the shorthand notation introduced above, the pen provides the following periodic behavior as the paper advances.

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```

1      autorotation
2
3      0
4      1 2
5      1 2
6      1 2
7      1 2
8      0
9

```



11 (g) Three-pass modes -- Heretofore, one highly fa-
12 vored print mode has specified a one-third-density-per-
13 pass pattern that constructs dots in a diagonal pattern --

```

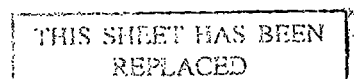
14
15      xoo
16      oxo
17      oox
18

```

19 -- rather than the one-half-density-per pass checkerboard
20 modes discussed above. The diagonals, however, remain at
21 forty-five degrees as in the checkerboard mode.

22 This pattern has been considered advantageous because
23 it worked well with software dithering algorithms and had
24 minimal tendency to create moire patterns when printing
25 partial-density-shaded and gradient area fills. The use
26 of forty-five-degree diagonals was considered particularly
27 beneficial for its tendency to distribute error-hiding
28 capability equally between vertical and horizontal axes of
29 the pixel array to be constructed on the printing medium.

30 Generally a printing apparatus is characterized --
31 through its basic hardware and firmware design architec-
32 ture -- by a general maximum-size print mask or mode
33 pattern that can be formed with the apparatus in one pen
34 pass; any mask pattern to be used with a printing appara-
35 tus must fit within its maximum pattern. For example, in
36 a particular one printing device (of the Hewlett Packard
37 Company) which produces high-quality images, that maximum
38 mask or pattern size is eight rows tall and four columns





1 wide -- and will readily accommodate, among other possi-
2 bilities, a mask that is three rows tall ($h_c = 3$) and
3 three columns wide.

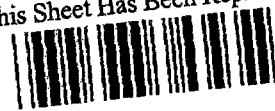
4 Just such a mask produces the one-third-density
5 diagonal three-pass pattern introduced at the beginning of
6 this section. If that mask is used in conjunction with a
7 unit paper advance of thirty-two nozzles -- for a print-
8 ing-medium advance movement $m_p = 32$ -- then the previously
9 introduced ratio $m_p/h_c = 32/3$, which is not integral.

10 This combination of conditions accordingly provides
11 autorotation of the three-row mask pattern shown above (as
12 noted parenthetically in the preceding section). No mask
13 rotation sequence is required; and a mask specification
14 for the three passes accordingly might read "111" to
15 indicate that the first column of the pattern should be
16 used in common to begin each sweep -- that is, printing
17 the pixel in column number one of the top row of the swath
18 (assuming that there is any image information to print
19 there). Equally well a mask specification might read
20 "222" or "000", as indeed the pattern may begin with
21 printing in any of the three columns of the basic cell.

22 If instead the number of dot rows were an integral
23 multiple of the pattern height, then as previously ex-
24 plained the printer would have to be instructed to use a
25 rotation sequence telling it how to build the pattern in
26 each succession of sweeps. For example, using the same
27 three-row pattern but thirty-three-nozzle advance -- which
28 is to say, a printing-medium-advance movement of thirty-
29 three dot rows -- the ratio $m_p/h_c = 33/3$ is integral, and
30 a rotation sequence must be specified.

31 Such a sequence might be "012". The numbers are the
32 swath or pass numbers in which the respective columns of
33 the base pattern will start a page. The printer will form
34 so-called "swath number zero" (the first swath) using the
35 first column of the pattern as the first column at top of
36 the page, swath one (the second swath) using the second
37 column as the first column at top of the page, and swath
38 two (the third swath) using the third column, as follows.

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1 thirty-three rows fully filled, another thirty-three two-
2 thirds filled, and thirty-three more one-third filled.

3
4 (h) Print-quality defects on transparency and glossy
5 stock -- As mentioned earlier, known techniques have not
6 been entirely successful in eliminating bulk-colorant
7 problems on transparent and other glossy media. Dividing
8 the total desired amount of ink into three passes has been
9 considered the limit for application of print-mode tech-
10 niques in attempts to solve this problem.

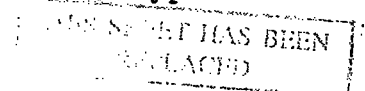
11 As noted earlier, evaporation from these media --
12 because they are relatively much less absorbent -- is
13 necessarily more important than from plain paper. Some
14 evaporation can be obtained straightforwardly by convec-
15 tion (stimulated by an air-circulating fan), but inducing
16 evaporation by applying radiative heat takes on greater
17 importance with plastic media.

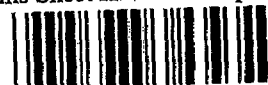
18 Heat, however, is most straightforwardly applied from
19 below (the opposite direction from that of ink applica-
20 tion). These media present more thermal mass and there-
21 fore an effectively longer thermal path than does plain
22 paper.

23 Accordingly with these media a much greater fraction
24 of applied heat radiation ends up absorbed in the printing
25 medium as compared with the ink carrier; this adverse
26 energy distribution is compounded by the previously men-
27 tioned dimensional hypersensitivity of these media to
28 heat. Generally speaking, as can be seen from the forego-
29 ing discussion, the application of heat is more problemat-
30 ic for glossy and transparent stock than for plain paper.

31 Heretofore the lower liquid absorption, higher heat
32 absorption, and higher dimensional sensitivity to heating,
33 of these media has defied efforts to obtain adequate
34 liquid removal. Accordingly the prior art has left con-
35 siderable room for refinement in this area.

36
37 (i) Black-ink detail -- Printing-machine users often
38 prefer to present lettering and certain other types of





1 finely detailed image elements in black, and the eye is
2 capable of discerning black-inked elements (and defects in
3 them) quite sensitively -- as compared with elements and
4 defects marked in other colors. It would therefore be
5 desirable to use finer position control for black inking
6 than for other colors, even within the same image.

7 Such a strategy, however, is difficult to implement.
8 Generally speaking, the fineness of position control, or
9 to put it another way the pitch of the pixel array, is
10 commonly set by the frequency of a waveform derived by
11 electrooptically reading, while the pen scans, a special
12 scale extended across the printing medium.

13 Within a printing machine of reasonable cost it is
14 preferable to employ multiplexing techniques for control
15 of the pens. In other words, a single set of signal lines
16 -- and control signals time-sharing or otherwise coexist-
17 ing in those lines -- is used to operate all of the pens.

18 Providing finer position control for printing of
19 black in direct conjunction with other colors would re-
20 quire somehow establishing a separate such waveform for
21 black. That waveform would have to be provided simulta-
22 neously with the position-establishing waveform for the
23 other colors -- but at a different, higher frequency.

24 It would also require arranging for the signals of
25 different frequencies to share the same basic position-
26 signal transmitting system. These special provisions, to
27 accommodate established multiplexing arrangements, would
28 be awkward or at least costly. In engineering jargon,
29 electrically it would be hard to "talk" to a color pen
30 (for instance, a cyan pen) and a black pen at the same
31 time.

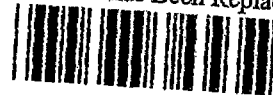
32 An alternative would be to print black in a separate
33 sweep, between sweeps for the chromatic-color pens. This
34 alternative would pay a heavy price in reduced throughput
35 and accordingly would be very undesirable.

36
37 (j) Conclusion -- End-of-page print-quality defects
38 on paper, as well as bulk-colorant problems on glossy and

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1 transparent media, heretofore have continued to impede
2 achievement of uniformly excellent inkjet printing -- at
3 high throughput -- on all industrially important printing
4 media. Awkwardness of overprinting fine detail in black
5 is another adverse limitation of the prior art. Thus
6 important aspects of the technology used in the field of
7 the invention remain amenable to useful refinement.

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10 SUMMARY OF THE DISCLOSURE

11
12 The present invention introduces such refinement. In
13 its preferred embodiments, the present invention has
14 several aspects or facets that can be used independently,
15 although they are preferably employed together to optimize
16 their benefits.

17 In preferred embodiments of a first facet or aspect
18 of its aspects, the invention is a method of printing
19 desired images on a printing medium by construction from
20 individual marks formed in pixel arrays. The marks are
21 formed by a scanning print head that operates in conjunc-
22 tion with a printing-medium advance mechanism.

23 The method includes the step of scanning the head
24 repeatedly along a pen-scanning axis that is substantially
25 orthogonal to a printing-medium-advance axis. The method
26 also includes the step of, during each scan of the head
27 along the pen-scanning axis, forming marks in a pattern
28 that approximates at least portions of a large number of
29 generally parallel, separated lines that are relatively
30 steeply angled relative to the pen-scanning axis and
31 relatively shallowly angled relative to the printing-
32 medium-advance axis.

33 This first facet or aspect of the invention also
34 includes the steps of (1) during one or more earlier scans
35 with respect to each segment of an image, leaving
36 unprinted regions between the angled lines; and (2) during
37 one or more later scans with respect to each segment,
38 filling in the unprinted regions.

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1 A second aspect of the invention differs from the
2 first in that it expressly includes -- instead of the two
3 steps recited in the preceding paragraph:

- 4
- 5 - forming the marks with a liquid-based colorant; and
 - 6
 - 7 - substantially concurrently with the mark-forming
 - 8 step, heating the medium to accelerate drying of the
 - 9 liquid-based colorant -- this heating step having a
 - 10 tendency to create an end-of-page paper-shrink defect
 - 11 that accentuates positional error components parallel
 - 12 to the printing-medium-advance axis.
 - 13

14 The relatively steeply angled lines have a tendency to
15 minimize the positional error components parallel to the
16 printing-medium-advance axis.

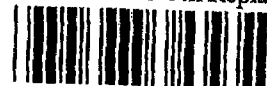
17

18 The foregoing may constitute descriptions or defini-
19 tions of each of these two different facets of the inven-
20 tion in its broadest or more general form. Even in these
21 general forms, however, it can be seen that these aspects
22 of the invention significantly mitigate the difficulties
23 left unresolved by the prior art.

24 In particular, the use of patterns with lines gener-
25 ally close in orientation to the paper-advance direction
26 tends to minimize the conspicuousness of positional errors
27 along that direction. This minimization of such errors in
28 turn permits use of heat to accelerate drying of the print
29 medium -- and thereby facilitates operation at high
30 throughput, but with minimal apparent degradation of image
31 quality.

32 Although the features or characteristics expressly
33 included in these two different aspects of the invention
34 are subject to practice independently of each other,
35 nevertheless as mentioned above they are preferably prac-
36 ticed together to maximize and optimize the benefits of
37 the invention. In addition, they are preferably practiced

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1 in conjunction with certain other features or characteris-
2 tics that further enhance enjoyment of overall benefits.

3 For example, it is preferred that the mark-forming
4 step include placing marks only at selected pixel loca-
5 tions where marks are desired for construction of a par-
6 ticular such desired image. By virtue of this provision,
7 the angled lines are incomplete where marks are not de-
8 sired for construction of such particular desired image.
9 Similarly it is preferred that the filling-in step include
10 placing marks only at other selected pixel locations where
11 marks are desired for construction of a desired image.

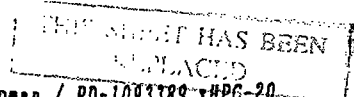
12 It is also preferred that the mark-forming step
13 include forming the angled lines at substantially a steep-
14 est angle possible within design architecture of the
15 scanning print head and printing-medium-advance mechanism.
16 Stated more generally, it is preferred that the mark-
17 forming step include forming the angled lines at substan-
18 tially a steepest angle possible that:

- 19
- 20 - is within design architecture of the scanning print
21 head and print-medium-advance mechanism;
 - 22
 - 23 - also provides at least approximately an equal number
24 of marks per print-head scan, for desired images in
25 which all pixel locations are to be marked;
 - 26
 - 27 - does not contribute significantly to other types of
28 error.
- 29

30 Such other error types include, for example, interference
31 with dithering patterns; and diagonal lines that are so
32 vertical as to introduce significant print-quality aberrations
33 relative to the print-head scanning axis.

34

35 Preferably the mark-forming step includes forming the
36 angled lines at a slope much greater than 1:1 relative to
37 the pen-scanning axis. Even more highly preferable is
38 forming the angled lines at a slope of at least 2:1 rela-





1 tive to that axis. As will be seen, the specific pattern
2 that is now most highly preferred provides a slope in the
3 range of at least approximately 2.5:1 to 3:1 -- or very
4 roughly 3:1 -- relative to the pen-scanning axis.

5 In this now-most-highly-preferred embodiment of the
6 invention, the mark-forming step includes forming the
7 angled lines in a basic pattern cell that is three pixels
8 wide and eight pixels tall. Within this embodiment,
9 advantageously during one of the scans the cell is printed
10 with:

- 11
- 12 - a mark in one column of the cell for each of three
- 13 rows in direct succession;
- 14
- 15 - a mark in another column of the cell for each of
- 16 three other rows in direct succession; and
- 17
- 18 - a mark in still another column of the cell for each
- 19 of two other rows in direct succession.
- 20

21 The same embodiment can be implemented in another way that
22 is particularly advantageous in printing on glossy or
23 transparent media. Here the total number of pen scans
24 with respect to each segment of the image is multiple,
25 i. e., a relatively high number, in any event greater than
26 about four; and the mark-forming step comprises, during
27 each of selected pairs of said multiple scans, printing
28 the cell with:

- 29
- 30 - two marks in one column of the cell for each of three
- 31 rows in direct succession,
- 32
- 33 - two marks in another column of the cell for each of
- 34 three other rows in direct succession, and
- 35
- 36 - two marks in still another column of the cell for
- 37 each of two other rows in direct succession.
- 38

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1 This manner of practicing the invention provides superior
2 drying properties; if in addition the printing medium is
3 advanced relative to the marking head between each pair of
4 successive scans, of the multiple scans, then positional
5 error along the direction of the medium-advance direction
6 is relieved numerous times per swath, yielding very high
7 image quality.

8 At least four and preferably more scans are needed to
9 obtain the benefits of this manner of practicing the in-
10 vention. The number of scans now regarded as most highly
11 preferred is six.

12

13 In a third basic aspect or facet, the invention is an
14 apparatus for printing desired images on a printing medium
15 by construction from individual marks formed in pixel
16 arrays. The apparatus includes some means for supporting
17 such a printing medium; for purposes of generality and
18 breadth in expressing the invention these means will be
19 called simply the "supporting means".

20 The apparatus further includes a print head mounted
21 for motion along a direction across the medium; and some
22 means for scanning the head across the medium. Once again
23 for breadth and generality these will be designated the
24 "scanning means".

25 Also included are some means for providing relative
26 motion of the printing medium with respect to the print
27 head (the "relative-motion-providing means") along a
28 direction of movement that is substantially orthogonal to
29 the print head motion. The apparatus of this third facet
30 of the invention also includes some means for heating the
31 medium ("heating means"); and some means for forming marks
32 in a particular pattern ("mark-forming means").

33 More specifically that pattern is one which was
34 introduced in regard to the first two aspects of the
35 invention. It is a pattern that approximates at least
36 portions of a large number of generally parallel, separat-
37 ed lines that are relatively steeply angled relative to
38 the print-head motion and relatively shallowly angled

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1 relative to the direction of relative movement of the
2 printing medium with respect to the print head.

3 As to the apparatus of the third facet of the inven-
4 tion, the mark-forming means form this pattern while the
5 relative-motion-providing means are not operating, In
6 other words, while the pen forms a particular swath of
7 dots or ink spots constituting a partially inked pixel
8 array having the lines just described, there is no rela-
9 tive motion -- along the orthogonal direction -- of the
10 printing medium with respect to the pen.

11

12 In preferred embodiments of a fourth of its aspects,
13 the invention is a method of printing desired images on a
14 low-liquid-absorption printing medium, by construction
15 from individual marks formed in pixel column-and-row
16 arrays by a scanning multiple-nozzle pen that operates in
17 conjunction with a printing-medium advance mechanism. The
18 method includes the step scanning the pen repeatedly along
19 a pen-scanning axis across the medium, to place marks on
20 the medium within a swath of pixel rows that is exposed to
21 the multiple nozzles of the pen; in this system each
22 nozzle corresponds to one pixel row.

23 The method also includes the step of periodically
24 advancing the printing medium relative to the pen, along a
25 printing-medium-advance axis that is substantially orthog-
26 onal to the pen-scanning axis, to bring a fresh portion of
27 the medium within the swath that is exposed to the pen.
28 The method further includes the step of, in each scanning
29 of the head across the medium, firing at most one-third of
30 the nozzles in each pixel-position column and thereby
31 depositing, over the total number of scans at each pixel
32 row, at least two drops of ink in each pixel position that
33 is inked.

34 This method is thus in effect a double-density or
35 200% form of a six-pass printing mode, which has been
36 found to effectuate a particularly advantageous balance
37 between high quality and throughput. Indeed for optimum

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1 benefit this method is preferably practiced in conjunction
2 with six printing-medium advances per full swath height.
3

4 As to preferred embodiments of a fifth of its as-
5 pects, the invention is similarly a method of printing
6 desired images on a low-liquid-absorption printing medium,
7 by construction from individual marks formed in pixel
8 column-and-row arrays by a scanning multiple-nozzle pen
9 that operates in conjunction with a printing-medium ad-
10 vance mechanism. This method too includes the step of
11 scanning the pen repeatedly along a pen-scanning axis
12 across the medium, to place marks on the medium within a
13 swath of pixel rows that is exposed to the multiple noz-
14 zles of the pen, each nozzle corresponding to one pixel
15 row; and periodically advancing the printing medium rela-
16 tive to the pen, along a printing-medium-advance axis that
17 is substantially orthogonal to the pen-scanning axis, to
18 bring a fresh portion of the medium within the swath that
19 is exposed to the pen.

20 This method differs from that of the fourth aspect or
21 facet of the invention, however, in that it includes the
22 step of -- in each scanning of the head across the medium
23 -- firing at most one-sixth of the nozzles in each pixel-
24 position column. This method is thus more straightfor-
25 wardly recognized as a six-pass printing mode, and like
26 the fourth is preferably practiced with a one-sixth-swath
27 advance distance.
28

29 A sixth aspect or facet of the invention is, in its
30 preferred embodiments, a method of printing a desired
31 image, which has two ends, on a printing medium by con-
32 struction from individual marks formed in pixel column-
33 and-row arrays by a scanning multiple-nozzle pen that
34 operates in conjunction with a printing-medium advance
35 mechanism. The printing medium is held taut beneath the
36 pen between two sets of rollers except while printing near
37 top and bottom edges of the printing medium, when it is

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1 constrained from only one direction by one of said sets of
2 rollers.

3 This method includes the step of scanning the pen
4 repeatedly along a pen-scanning axis across the medium, to
5 place marks on the medium within a swath of pixel rows
6 that is exposed to the multiple nozzles of the pen. Here
7 as before, each nozzle corresponds to one pixel row.

8 In addition the method includes the step of -- when
9 the pen is not substantially at either end of the desired
10 image, and while the medium is held taut between two sets
11 of rollers -- periodically advancing the printing medium
12 relative to the pen, along a printing-medium-advance axis
13 that is substantially orthogonal to the pen-scanning axis.
14 Each such step operates to bring a fresh portion of the
15 medium within the swath that is exposed to the pen, where-
16 by the pen moves stepwise from one end of the image to the
17 other.

18 The method also includes a further step that is
19 performed when the pen is substantially at either end of
20 the desired image, and at least until completion of full
21 inking for the swath of pixel rows that is exposed to the
22 nozzles of the pen. This step is holding the printing
23 medium substantially stationary relative to the pen while
24 performing a plurality of said scanning steps.

25 This step is performed at least if the medium is
26 constrained from only one direction by one set of rollers.
27 Preferably this step is performed only while the medium is
28 constrained by one set of rollers, since its performance
29 is less robust with respect to tolerance of nozzle fail-
30 ures; however, this step need not be strictly limited to
31 performance under these conditions, as stationary-medium
32 operation can also be performed in a generally
33 satisfactory fashion at the end of the image even if the
34 paper is still taut.

35 The method of this sixth facet of the invention is
36 particularly beneficial in suppressing print-quality
37 defects that arise from print-medium positioning errors
38 due to mechanical tolerances. The method has this benefi-

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1 cial effect because -- while the stationary-medium opera-
2 tion is being used -- in fact no print-medium positioning
3 takes place, and accordingly no error in positioning can
4 occur.

5 Although this method even as thus broadly couched
6 serves an excellent purpose, nevertheless preferably it is
7 performed with certain additional features or characteris-
8 tics. During the holding-stationary step, the scanning
9 steps preferably include employing a sequence of print
10 masks in rotation to progressively provide full inking for
11 the swath of pixel rows that is exposed to the nozzles of
12 the pen; and preferably that sequence of masks is such as
13 to compensate for absence of printing-medium advance.

14 Also it is preferred that the mask-sequence-employing
15 step comprise changing nozzle printing patterns between
16 substantially every pair of scans of the pen.

17
18
19 All of the foregoing operational principles and
20 advantages of the present invention will be more fully
21 appreciated upon consideration of the following detailed
22 description, with reference to the appended drawings, of
23 which:

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25
26 BRIEF DESCRIPTION OF THE DRAWINGS

27
28 Fig. 1 is a block-diagrammatic representation of a
29 hardware system according to the invention; and

30 Figs. 2a through 2d are diagrammatic print-mask
31 representations of inking patterns used in, respectively:
32 (a) special top-of-page sweep mask rotation to enable sup-
33 pression of printing-medium advance in that region, (b)
34 midpage space rotation with one-third advance, (c) bottom-
35 of-page handoff space rotation with one-sixth advance, and
36 (d) special bottom-of-page sweep rotation to enable sup-
37 pression of advance in that region.

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1 DETAILED DESCRIPTION
2 OF THE PREFERRED EMBODIMENTS

3
4 1. STEEPER DIAGONAL

5
6 The print mask of the present invention forms diago-
7 nal lines that are skewed more toward the printing-medium
8 advance direction than those of prior-art masks. This is
9 beneficial because in this direction there tends to be
10 more error due to paper advancement and paper shrinkage.

11 In at least some commercial printers the above-men-
12 tioned largest permissible pattern, within the basic
13 architectural constraint of the printing apparatus that is
14 in use, is rectangular and vertically oriented -- in other
15 words, longer in the direction of the printing-medium
16 advance. In this case, preferably the diagonals formed
17 by the invention approximate the longest diagonal line
18 possible within that vertically oriented largest permissi-
19 ble pattern.

20 Within the previously mentioned eight-by-four pattern
21 constraint of one Hewlett Packard printer, a particularly
22 desirable print mode creates the following eight-by-three
23 pattern cell or "base pattern".

24
25 xoo
26 xoo
27 xoo
28 oxo base pattern
29 oxo or cell
30 oxo
31 oox
32 oox

33
34 012 <- column number within the base pattern

35
36 The resulting pattern still appears as diagonal lines
37 when printed on the page, but now they are angled at
38 roughly seventy degrees from the pen-scan axis -- or, as

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1 it may be called, the "horizontal". The pattern alignment
2 is now more vertical than horizontal, and this more effec-
3 tively maks dot dislocation due to error in printing-
4 medium shrinkage or advance.

5 The diagram above shows that within the eight-row
6 cell or base pattern there are three rows of the repeating
7 subpattern "xoo" and three of the subpattern "oxo", but
8 only two of the bottom subpattern "oox". This asymmetry
9 is without substantive consequence, or may possibly aid
10 slightly in suppressing undesirable moire patterns and the
11 like due to excessively regular cell structure.

12 The slope of the diagonal is probably best defined as
13 the angle from any point (for example, the first dot)
14 along the repeating unit to the same point on the next
15 diagonally adjacent repeating unit. Using this defini-
16 tion, the slope is the ratio of eight vertical units to
17 three horizontal units, or 8:3, corresponding to an angle
18 of about $69\frac{1}{2}$ degrees. Other reasonable candidate methods
19 of defining the slope generally will yield comparable
20 values between roughly 68 and $71\frac{1}{2}$ degrees.

21 In any event it will be understood that the apparent
22 slope of the diagonals created by this mask is roughly
23 (within ten percent) 2.67 -- which is much greater than
24 the 1:1 value provided by the checkerboard or three-by-
25 three cells of the prior art. The angle of the diagonals
26 relative to the pen-scan axis or "horizontal" is approxi-
27 mately (within three percent) seventy degrees.

28 While the invention in this preferable form accord-
29 ingly is very beneficial, a great advance over the perfor-
30 mance of the prior art in hiding paper-shrinkage and
31 paper-advance errors can be enjoyed even with considerably
32 less-emphatic vertical orientation. Any slope over about
33 2:1 (or angle over about sixty degrees), for instance,
34 produces much better error-hiding properties than the 1:1
35 forty-five-degree diagonals of the prior art.

36 If the above-illustrated eight-dot-row pattern is
37 used with a printing-medium advance of thirty-two nozzles,
38 then the determining ratio m_p/h_c is $32/8$, which is inte-

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1 gral -- so the mode is not autorotating. Therefore the
 2 order in which the columns create the print patterns must
 3 be specified. The order normally is not critical. One
 4 acceptable sequence is shown in the following example.

5

6 pass 1 pass 2 pass 3

7

8 012 120 201 <- internal rotation
 9 sequences

10	xoo	oox	oxo
11	xoo	oox	oxo
12	xoo	oox	oxo
13	oxo	xoo	oox
14	oxo	xoo	oox
15	oxo	xoo	oox
16	oox	oxo	xoo

17 oox oxo xoo <- last row in first cell

18 oox xoo oxo oox xoo oox <- starting next 8-row cell

19 oox xoo oxo oox xoo oox

20 oox xoo oxo oox xoo oox

21 oox oox xoo xoo oox oox

22 . . .

23

24 These patterns correspond to a rotation sequence of
 25 "012". The phrase "rotation sequence" actually is used in
 26 two different senses, but as will be seen 012 is the
 27 rotation sequence for at least part of the above diagrams
 28 in both senses.

29 One definition of "rotation sequence" is entirely
 30 internal to the cell -- that is to say, the rotation
 31 sequence is the order in which pixel rows are printed
 32 within the cell or basic pattern. Thus "sequence 012"
 33 means that -- as shown above for the first pass:

34

35 - 0 is the number of the column in which the first
 36 group of rows (rows 1 through 3) within the cell is
 37 printed;

38

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- 1 - 1 is the column (the second column) in which the
2 second group (rows 4 through 6) is printed; and
3
4 - 2 is the number of the column (the third) in which
5 the third group of rows (rows 7 and 8) is printed.
6

7 (As will be noted, in keeping with customary computer-
8 science practice the rows are numbered starting with
9 zero.) Correspondingly for the second pass, as marked in
10 the tabulation above, the (internal) rotation sequence is
11 120; and for the third pass the sequence is 201.

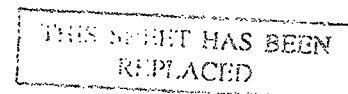
12 The other sense in which the phrase "rotation se-
13 quence" is used is partly external to the base pattern.
14 Here the rotation sequence identifies a series of swath or
15 path numbers in which the consecutive columns of the base
16 pattern are used in starting positions, so defining the
17 swath pattern: thus in the tabulated case, swath number:
18

- 19 - 0 (the first pass) is assigned to begin with the
20 first column of the base pattern;
21
22 - 1 (the second swath) takes the second column of the
23 base pattern for its beginning column; and
24
25 - 2 (the third) uses the third column of the base
26 pattern as the first column of the swath.
27

28 Now if the printer is stopped halfway down a page, a
29 pattern generally like the following abbreviated diagram
30 can be seen (not starting at the left-hand edge of the
31 image) -- except that the eight-nozzle cell shown above
32 repeats four times within each swath, rather than occur-
33 ring only once as suggested by the diagram. Due to this
34 repetition the height of each band of fill, measured in
35 number of nozzles, is thirty-two dot rows rather than
36 eight as diagrammed.

37

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```

1      xxxxxxxxxxxxxx
2      xxxxxxxxxxxxxx
3      xxxxxxxxxxxxxx
4      xxxxxxxxxxxxxx
5      xxxxxxxxxxxxxx      completely filled
6      xxxxxxxxxxxxxx
7      xxxxxxxxxxxxxx
8      xxxxxxxxxxxxxx
9      oxxoxoxoxoxoxo
10     oxxoxoxoxoxoxo
11     oxxoxoxoxoxoxo
12     xoxxoxxoxxoxx
13     xoxxoxxoxxoxx      two-thirds filled
14     xoxxoxxoxxoxx
15     xxoxxoxxoxxox
16     xxoxxoxxoxxox
17     oxooxooxooxoo
18     oxooxooxooxoo
19     oxooxooxooxoo
20     ooxooxooxooxo
21     ooxooxooxooxo      one-third filled
22     ooxooxooxooxo
23     xooxooxooxoox
24     xooxooxooxoox
25

```

26 Another potentially useful cell might be an eight-by-
 27 four pattern -- the maximum permitted within the system
 28 architecture mentioned earlier. Such a cell contains
 29 thirty-two pixels, which cannot be divided up equally
 30 among three passes.

31 Equal division among the number of passes selected is
 32 desirable to avoid other types of artifacts. This princi-
 33 ple might suggest that an eight-by-four pattern would work
 34 moderately well with four passes; but for best throughput
 35 on plain paper four passes is less desirable because it
 36 would be slower.

37 Also the slope in that case would be definitely 8:4 =
 38 2 (an angle of about sixty degrees). That slope would be

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1 a distinct improvement over the prior art -- but has not
2 been tested, and possibly would be noticeably less effective
3 than 8:3 in hiding vertically oriented errors. For
4 these various reasons an eight-by-four cell is now regarded
5 as at least no more advantageous -- and possibly less
6 advantageous -- than an eight-by-three.

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2. SIX PASSES FOR PLASTIC MEDIA

11 As mentioned earlier, in the prior art three print
12 passes were considered ideal. The present invention,
13 however, recognizes that the number of passes used by a
14 system represents a tradeoff between throughput and quality
15 (particularly distribution of paper-advance error over
16 a large number of passes so as to hide that error).

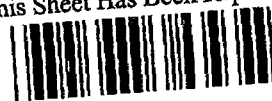
17 Thus in principle, if only quality were needed, each
18 swath could be printed using a thousand pen passes, with
19 one ink spot deposited in each pass; this print mode might
20 produce virtually flawless images but also might require
21 an hour per page. Typical draft-mode printing does the
22 opposite -- laying down an entire swath in just one pass.

23 The present invention further recognizes that in
24 balancing throughput and quality, it is desirable to take
25 into account the properties of different media. In other
26 words, the ideal compromise may call for a different
27 number of passes with some media than with other media.

28 In accordance with the present invention, for use on
29 transparent and glossy media, six passes has been found
30 highly preferable to three. A higher number of passes is
31 more optimal for glossies and transparencies than for
32 paper because -- as explained in the "PRIOR ART" section
33 of this document -- in practice the other parameters
34 (quantity of heat, and effectiveness of convection and
35 absorption) used to mitigate bulk-colorant problems cannot
36 be set as high for these media as for paper.

37 To put it another way, the present invention proceeds
38 from the recognition or discovery that the drying charac-

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1 teristics of these media shift the optimum tradeoff point
2 toward a greater number of printing passes.

3 Different numbers of ink drops of the various prima-
4 ries are desirable for these two different media types
5 respectively. In this regard the ink application consid-
6 ered ideal is quite complicated -- encompassing use of
7 fractional average numbers of drops for certain colorants.
8 These best-known modes of practice of the invention are
9 set forth in considerable detail in the Askeland et al.
10 document identified above.

11 In addition to using six passes and employing the
12 inking arrangements set forth in that document, it is also
13 highly preferable to incorporate the maximum-diagonal
14 aspects of the invention described in the preceding sec-
15 tion. The basic three-pass eight-row cells are in essence
16 repeated, making two passes over every pixel location
17 rather than one -- to provide double density.

18 In addition it is highly preferred to halve the
19 advance distance. Thus whereas the three-pass embodiment
20 of the invention is now believed to operate ideally with
21 advance by thirty-two pixel rows (about $32/24 = 1.33$ mm)
22 at each step, the six-pass embodiment operates instead
23 with advance by sixteen rows ($16/24 = 0.67$ mm) per step.

24 The resulting masking patterns may appear as shown.

25	pass 1	pass 2	pass 3	pass 4	pass 5	pass 6
26	xoo	oox	oxo	xoo	oox	oxo
27	xoo	oox	oxo	xoo	oox	oxo
28	xoo	oox	oxo	xoo	oox	oxo
29	oxo	xoo	oox	oxo	xoo	oox
30	oxo	xoo	oox	oxo	xoo	oox
31	oxo	xoo	oox	oxo	xoo	oox
32	oox	oxo	xoo	oox	oxo	xoo
33	oox	oxo	xoo	oox	oxo	xoo
34	012	120	201	012	120	201
35	(rotation sequence)					

1 If as before the printer is halted partway down a page the
2 developing pattern can be seen from the following repre-
3 sentative rows. Capital letters represent double inking:
4

5 XXXXXXXXXXXXXXXX
6 XXXXXXXXXXXXXXXX
7 XXXXXXXXXXXXXXXX
8 XXXXXXXXXXXXXXXX 200% filled,
9 XXXXXXXXXXXXXXXX after passes 1 through 6
10 XXXXXXXXXXXXXXXX
11 XXXXXXXXXXXXXXXX
12 XXXXXXXXXXXXXXXX

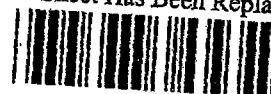
13 xXXxXXxXXxXXxXX
14 xXXxXXxXXxXXxXX
15 xXXxXXxXXxXXxXX
16 XxXXxXXxXXxXXxX 167% filled,
17 XxXXxXXxXXxXXxX after passes 2 through 6
18 XxXXxXXxXXxXXxX
19 XXxXXxXXxXXxXXx
20 XXxXXxXXxXXxXXx

21 xXxxXxxXxxXxxXx
22 xXxxXxxXxxXxxXx
23 xXxxXxxXxxXxxXx
24 xxXxxXxxXxxXxxX 133% filled,
25 xxXxxXxxXxxXxxX after passes 3 through 6
26 xxXxxXxxXxxXxxX
27 XxxXxxXxxXxxXxx
28 XxxXxxXxxXxxXxx

29 xxxxxxxxxxxxxxxx
30 xxxxxxxxxxxxxxxx
31 xxxxxxxxxxxxxxxx
32 xxxxxxxxxxxxxxxx 100% filled,
33 xxxxxxxxxxxxxxxx after passes 4 through 6
34 xxxxxxxxxxxxxxxx
35 xxxxxxxxxxxxxxxx
36 xxxxxxxxxxxxxxxx

37 oxxoxxxoxxxoxxx
38 oxxoxxxoxxxoxxx

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1	0XX0XX0XX0XX0XX	
2	X0XX0XX0XX0XX0X	67% filled,
3	X0XX0XX0XX0XX0X	after passes 5 and 6
4	X0XX0XX0XX0XX0X	
5	XX0XX0XX0XX0XX0	
6	<u>XX0XX0XX0XX0XX0</u>	
7	0X00X00X00X00X0	
8	0X00X00X00X00X0	
9	0X00X00X00X00X0	
10	00X00X00X00X00X	33% filled,
11	00X00X00X00X00X	after pass 6 only
12	00X00X00X00X00X	
13	X00X00X00X00X00	
14	X00X00X00X00X00	

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16 The inking arrangements outlined above provide
 17 double-drop-per-pixel coverage of all pixel positions.
 18 For primary colors (in preferred embodiments those are
 19 cyan, magenta and yellow), this is a now-preferred treat-
 20 ment for images on transparency or glossy stock as well as
 21 on paper.

22 In accordance with the aforementioned Askeland docu-
 23 ment, however, it may be preferable to ink certain pixel
 24 positions more than two times, for example three times, in
 25 a single image -- or through use of spatial averaging ar-
 26 rangements to provide a mean deposition of fractional
 27 drops. More-than-double fractional inking has been found
 28 particularly useful for secondary colors (red, green and
 29 blue in preferred embodiments) on transparency and glossy
 30 stock -- and can be achieved by, for instance, "stripping"
 31 selected data bits from the pattern.

32 Preferably such data stripping is introduced starting
 33 in the fourth pass (pass 4 in the tabulation above). As
 34 an example, suppose that a particular pixel is to receive
 35 2.5 dots, on the average, of red ink.

36 In other words, in half of the passes that pixel is
 37 to receive one yellow and one magenta (symbolized "YM")
 38 and in the other half of the passes it is to receive one

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1 yellow and two of magenta (YMM), instead of the simplest-
2 case four dots (YMYM). To implement this plan, that pixel
3 would receive the first "YM" in the first three passes;
4 and in the remaining passes that pixel would be given a
5 single-bit-stripped treatment to add one more dot of
6 magenta and so yield YMM.

7 Secondaries ordinarily in each position receive two
8 drops (one of each of two different colors), so by this
9 treatment secondaries if not data-stripped would receive
10 four. Colors produced in this way are very rich, but such
11 excess colorant deposition produces blocking etc. as
12 described earlier; an extra alternating firmware switch or
13 so-called "filter" can be put into operation to suppress
14 or strip the alternate drops.

15 The result can be tailored to produce either two or
16 four drops at selected pixels -- and thus three, or two
17 and a half, etc. per position on the average. Further
18 detail appears in the Askeland document.

19 If in addition to inking each swath in six passes the
20 printing medium is advanced relative to the pen after each
21 pass -- in other words, if the medium is advanced six
22 times per swath -- then besides improved drying the inven-
23 tion also relieves medium-advance-direction positioning
24 error each one-sixth swath.

25 That is, advance errors are smaller since the step
26 size is only half as large (0.67 mm rather than 1.33 mm);
27 and the advance errors are averaged over six advances
28 rather than only three. In addition to these benefits,
29 six-pass modes as outlined above facilitate use of frac-
30 tional-dot techniques to optimize hue and chroma for each
31 color and printing medium.

32 An overall result of a six-pass method is to balance
33 the need for high quality and high throughput. Although
34 taking more passes (eight, twelve, etc.) would accomplish
35 the same or better quality goals, throughput would be
36 significantly degraded. Conversely, as mentioned earlier
37 four, or preferably more than four, passes will produce
38 some improvement in quality and are considered within the

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1 scope of claim of the appended claims but the quality
2 provided by six passes is believed to be significantly
3 better.
4
5

6 3. DOUBLE-FREQUENCY BLACK ON RETRACE 7

8 It has been found that finer control of black inking
9 at high throughput can be provided with reasonable economy
10 through use of a higher-frequency positioning waveform for
11 black -- and actual printing of black -- only during each
12 return sweep of the pen. The return pass of the pen is
13 known as the "retrace".

14 An additional interpolation stage can be put into
15 operation -- and the resulting signal transmitted on the
16 pen signal bus -- straightforwardly on retrace. As no
17 other precise-pen-position signals are in use then, there
18 is no interference with control signals for other colors.

19 Preferably the position waveform for black on retrace
20 is at twice the frequency used for other colors on the
21 forward sweep. The result is twice as many pixel posi-
22 tions -- with corresponding ability to represent finer
23 detail -- and the pen discharge signals can be correspond-
24 ingly adjusted to make the resulting ink spots smaller.

25 Whereas a pixel spacing of about twelve per millime-
26 ter (three hundred dots per inch) is appropriate for the
27 color-ink spots, the double-frequency black-ink position-
28 ing signal produces a spacing of about twenty-four dots
29 per millimeter (six hundred per inch). In printing of
30 text alone, in black and without any color printing, the
31 higher frequency and the finer pixel spacing are pref-
32 erably used in both directions rather than only on re-
33 trace.

34 While this system of printing black on retrace, when
35 it is part of a color image, resolves the difficult prob-
36 lem of multiplexing different pens that are operating at
37 different frequencies, other factors too militate in favor
38 of this method. One such factor is that positional preci-



sion in bidirectional operation is in fact adequate for such operation; this high precision is obtained through use of a related invention disclosed in the previously mentioned document of Raskin et al.

Another factor is that this system very significantly enhances throughput, as the time required to print black on retrace is considerably less than the time required to print black in a separate forward sweep plus the time required for two nonprinting return slews. This advantage is particularly notable in comparison with the major alternative of printing black in a separate forward sweep, between color passes.

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4. SUMMARY OF PRINT MODES

In its most highly preferred practice, the invention makes use of several different, complicated combinations of operating parameters and characteristics to accommodate various operating requirements. These combinations are summarized below.

		thru-		di-	scan	re-		den-	max.freq.		
		put		rec-	speed	trace	heat	si-	kHz	split	
<u>mode</u>	<u>passes</u>	<u>pg/min</u>	<u>RET</u>	<u>tions</u>	<u>cm/sec</u>	<u>cm/sec</u>	<u>W</u>	<u>ton.</u>	<u>CMY</u>	<u>K</u>	<u>text</u>
FAST:											
text	1	6	no	bi	67.6	67.6	73	yes	8		OK
graph-											
ics	1	1.4	no	uni	33.8	88.9	73	yes	4		
NORMAL:											
text	1	6	no	bi	67.6	67.6	73	yes	8		no
graph-											
ics	3	0.56	no	uni	50.8	88.9	73	yes	2	2	

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1	HIGH-QUALITY:										
2	text	1	4	yes	bi	33.8	33.8	73	yes	8	no
3											
4	graph-										
5	ics	3	0.45	yes	bi	50.8	50.8	73	yes	2	4
6											
7											
8											
9	TRANSPARENCY:										
10		6	0.33	no	uni	50.8	88.9	63	no	2	2
11											
12	GLOSSY:										
13		6	0.33	no	uni	50.8	88.9	27	no	2	2
14											

- color forward;

- black on retrace

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15 In this tabulation, the column heading "RET" repre-
16 sents "resolution-enhanced technology" -- the system
17 described above in which black is printed at a pixel
18 spacing of twenty-four pixels per millimeter along the
19 pen-scan axis, rather than the standard twelve. In the
20 preferred system described here, the pixel spacing along
21 the printing-medium-advance axis remains twelve whether
22 RET is in use or not.

23 The column heading "densitom." refers to a subsystem
24 by which the firmware preevaluates on a swath-by-swath
25 basis the optical density of image areas not yet reached
26 in actual printing -- but to be printed soon. If the
27 optical density (and therefore quantity of ink) will
28 shortly be high, then the printing is decelerated gradual-
29 ly to accommodate the anticipated higher drying demands
30 while at the same time avoiding abrupt speed-change-gener-
31 ated image discontinuities. In fast and normal modes the
32 turn-on threshold is much higher and the slowdown is much
33 smaller than those used for high-quality mode.

34 The column headings "CMY" and "K" refer to ink color:
35 CMY represents the chromatics cyan, magenta and yellow
36 respectively; and K represents black. The machine prefer-
37 ably switches to three-pass "graphics" printing automati-
38 cally in normal or high-quality mode whenever (a) the

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1 swath contains color or (b) black text or graphics cross
2 the swath boundary. The sole distinction between single-
3 pass "text" printing as between the fast and normal modes
4 appears in the right-hand column: only in the fast mode
5 is text split.

6 As drying of transparencies and glossy media must
7 rely more heavily upon convection, a drying fan is operat-
8 ed in those modes. Transparency stock can accept consid-
9 erable warping; therefore in transparency mode the heater
10 power is almost as high as for the paper modes tabulated
11 above. Glossy stock, however, being hypersensitive to
12 warp, is best heated only slightly as indicated.

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15 5. HARDWARE FOR IMPLEMENTING THE INVENTION

17 Fig. 1 illustrates the general preferred layout of a
18 programmed-microprocessor-based printing machine according
19 to the invention. An input stage 41, which may include
20 manual controls, provides information defining the desired
21 image. The output 42 of this stage may proceed to a dis-
22 play 43 if desired to facilitate esthetic or other such
23 choices; and, in the case of color printing systems, to a
24 color-compensation stage 44 to correct for known differ-
25 ences between characteristics of the display 43 and/or in-
26 put 41 system vs. the printing system 47-61-31-32-33.

27 An output 45 from the compensator 44 proceeds next to
28 a rendition stage 46 that determines how to implement the
29 desired image at the level of individual pixel-position
30 printing decisions -- for each color, if applicable. The
31 resulting output 47 is directed to a circuit 61 that deter-
32 mines when to direct a firing signal 77 to each pen 31.

33 The pens discharge ink 32 to form images on paper or
34 some other printing medium 33. Meanwhile typically a
35 medium-advance module 78 provides relative movement 79 of
36 the medium 33 in relation to the pens 31.

37 In developing its firing-signal determination, the
38 firing circuit 61 must take into account the position of

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1 the pen carriage 62, pen mount 75 and pen 31. Such ac-
2 counting is enabled by operation of an electrooptical
3 sensor 64 that rides on the carriage 62 and reads a code-
4 strip 10.

5 A timing module 72 is positioned in the line between
6 the sensor 64 and firing circuit 61. The timing module 72
7 provides for various special positioning functions, in-
8 cluding encoder-signal inversion or equivalent, during
9 scanning in one of two directions.

10 It also provides for backing off by one pulse and
11 then delay in pen firing, also during scanning in one of
12 two directions. Most particularly for purposes of the
13 present invention the timing module 72 switches into use
14 the interpolated, double-frequency positioning signal
15 mentioned above, for use only in printing black on re-
16 trace, when colors are being printed in the alternating
17 forward sweeps. (As noted earlier, this signal is also
18 used in printing black bidirectionally, when colors are
19 not being printed; but in this case the use of the inter-
20 polated signal is not switched by the timing module.)

21 Operation of this timing module 72 thus is not de-
22 sired at all times, but rather only synchronously with the
23 directional reversals of the carriage 62. Specifically,
24 the timing module 72 is to be inserted during operation in
25 one direction only, and replaced by a straight-through
26 bypass connection 73 during operation in the other direc-
27 tion -- in other words, operated asymmetrically -- and
28 this is the reason the timing module 72 is labelled in
29 Fig. 1 "asymmetrical".

30 This synchronous insertion and removal is symbolized
31 in Fig. 1 by a switch 67 which selects between the conven-
32 tional connection 73 and a timing-module connection 71.
33 This switch 67 is shown as controlled by a signal 66 that
34 is in turn derived from backward motion 63_b of the pen
35 carriage 62.

36 Thus the switch 67 is operated to select the timing-
37 module connection 71 during such backward motion 63_b, and
38 to select the bypass or conventional route 73 during

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1 forward motion 63_p. This representation is merely symbol-
2 ic for tutorial purposes; people skilled in the art will
3 understand that the switch 67 may not exist as a discrete
4 physical element, and/or may instead be controlled from
5 the forward motion 63_p and/or -- as will much more common-
6 ly be the case -- can be controlled by some upstream
7 timing signal which also controls in common the pen-car-
8 riage motion 63_p, 63_p. Further the synchronous switch 67
9 need not be at the input side of the timing module 72 but
10 instead at the output side -- where in Fig. 1 a common
11 converging signal line 74 is shown as leading to the
12 firing circuit 61 -- or may in effect be at both sides.

13 Use of a system as illustrated in Fig. 1, at least as
14 most naturally interpreted, will result in the encoder-
15 signal inversion, the pulse "backing off" step and the
16 firing delay step all being performed during pen motion in
17 the same, common ("backward") direction. This limitation
18 while preferred is not required for successful practice of
19 the invention.

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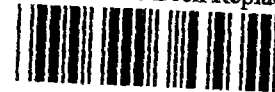


21
22 6. TOP/BOTTOM-OF-PAGE MASK ROTATION ONLY
23

24 At the bottom of each sheet of print medium, a rela-
25 tively tall region, that may be called the bottom-of-page
26 "handoff" zone, is defined by the distance between sets of
27 rollers that hold the medium taut. As noted earlier --
28 and as explained in greater detail in the above-mentioned
29 Broder et al. document -- preferably for printing on paper
30 in this region the printing-medium advance height is low-
31 ered to half (Fig. 2c) its normal midpage value (Fig. 2b).

32 For example, in a preferred embodiment each pen has
33 ninety-six nozzles and so makes a ninety-six-pixel swath;
34 the normal advance distance (except for plastic media, per
35 this invention) is one third of this height, or thirty-two
36 pixels -- 1.33 mm, for a preferred pixel spacing of 1/24
37 mm (Fig. 2b). When the medium cannot be tensioned, as set

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1 forth by Broder et al. the advance preferably is halved to
2 sixteen pixels or about 0.7 mm (Fig. 2c).

3 In shallower end zones consisting of the single top
4 (Fig. 2a) and bottom (Fig. 2d) swaths on each sheet of me-
5 dium, however, according to the present invention the ad-
6 vance height is reduced to zero -- i. e., eliminated
7 entirely. This is done when the pen (or set of pens) is
8 at either end of the data, but most preferably only if
9 that occurs while the medium is untensioned -- either in
10 the "handoff" zone or an analogous one at the top.

11 This operating mode is particularly important when
12 the pen is actually printing along the top or bottom edge
13 of the sheet. Ordinarily good performance is not obtained
14 with the pen skimming partly on and partly off the edge,
15 but space rotation would demand starting or ending in just
16 that condition, to provide three or six passes in a frac-
17 tional-swath zone along the edge. Under these circum-
18 stances, since space rotation can no longer be made to
19 occur, in effect, as a consequence of print-medium ad-
20 vance, it is provided through sweep rotation -- changing
21 the inking pattern between pen scans.

22 On each page the mask is first sweep-rotated on the
23 pen by firmware, for the first two sweeps, while the pen
24 is stationary (Fig. 2a); then the mask is fixed on the pen
25 and paper advance begins (Fig. 2b), producing space rota-
26 tion -- that is, the mask does not change relative to the
27 pen -- and most of the page is printed in this normal
28 three-pass mode. In the handoff zone, but not yet at the
29 end of data, the system makes a transition to one-sixth
30 advance, and only half (forty-eight) of the nozzles print,
31 but the mask is still space rotated (Fig. 2c). When final
32 data are reached, advance again halts and the remaining
33 two passes are flushed out -- with firmware sweep-rotating
34 the mask (Fig. 2d).

35
36 The above disclosure is intended as merely exemplary,
37 and not to limit the scope of the invention -- which is to
38 be determined by reference to the appended claims.

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WHAT IS CLAIMED IS:

1 1. A method of printing desired images on a low-liquid-
2 absorption printing medium, by construction from individu-
3 al marks formed in pixel column-and-row arrays by a scan-
4 ning multiple-nozzle pen that operates in conjunction with
5 a printing-medium advance mechanism; said method compris-
6 ing the steps of:

7 scanning the pen repeatedly along a pen-scanning axis
8 across the medium, to place marks on the medium within a
9 swath of pixel rows that is exposed to the multiple noz-
10 zles of the pen, each nozzle corresponding to one pixel
11 row;

12 periodically advancing the printing medium relative
13 to the pen, along a printing-medium-advance axis that is
14 substantially orthogonal to the pen-scanning axis, to
15 bring a fresh portion of the medium within the swath that
16 is exposed to the pen; and

17 in each scanning of the head across the medium,
18 firing at most one-third of the nozzles in each pixel-
19 position column and thereby depositing, over the total
20 number of scans at each pixel row, at least two drops of
21 ink in each pixel position that is inked.

1 2. The method of claim 1, wherein:

2 for portions of a desired image in which a mark is
3 desired in every pixel position, the firing step comprises
4 firing substantially one-third of the nozzles in substan-
5 tially every pixel-position column.

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1 3. The method of claim 2, wherein:

2 the medium-advancing step comprises advancing the
3 medium between substantially every pair of scans of the
4 pen.



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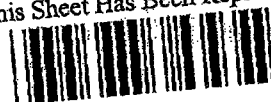
104

1 4. The method of claim 2, wherein:
2 the medium-advancing step comprises advancing the
3 medium by a number of pixel rows equal to substantially
4 one-sixth of the number of operating nozzles of the pen,
5 between substantially every pair of scans of the pen.

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1 5. The method of claim 1, wherein:
2 the medium-advancing step comprises advancing the
3 medium by a number of pixel rows equal to an integral
4 multiple of one-sixth of the number of operating nozzles
5 of the pen, between substantially every pair of scans of
6 the pen.

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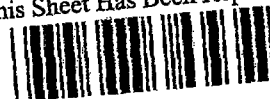
1 6. A method of printing desired images on a low-liquid-
2 absorption printing medium, by construction from individu-
3 al marks formed in pixel column-and-row arrays by a scan-
4 ning multiple-nozzle pen that operates in conjunction with
5 a printing-medium advance mechanism; said method compris-
6 ing the steps of:
7 scanning the pen repeatedly along a pen-scanning axis
8 across the medium, to place marks on the medium within a
9 swath of pixel rows that is exposed to the multiple noz-
10 zles of the pen, each nozzle corresponding to one pixel
11 row;
12 periodically advancing the printing medium relative
13 to the pen, along a printing-medium-advance axis that is
14 substantially orthogonal to the pen-scanning axis, to
15 bring a fresh portion of the medium within the swath that
16 is exposed to the pen; and
17 in each scanning of the head across the medium,
18 firing at most one-sixth of the nozzles in each pixel-
19 position column.

1 7. The method of claim 6, wherein:
2 for portions of a desired image in which a mark is
3 desired in every pixel position, the firing step comprises
4 firing substantially one-sixth of the nozzles in substan-
5 tially every pixel-position column.

1 8. The method of claim 7, wherein:
2 the medium-advancing step comprises advancing the
3 medium between substantially every pair of scans of the
4 pen.



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6_{or}

1 9. The method of claim 7, wherein:
2 the medium-advancing step comprises advancing the
3 medium by a number of pixel rows equal to substantially
4 one-sixth of the number of operating nozzles of the pen,
5 between substantially every pair of scans of the pen.

1
2
3
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5

1 10. The method of claim 6, wherein:
2 the medium-advancing step comprises advancing the
3 medium by a number of pixel rows equal to an integral
4 multiple of one-sixth of the number of operating nozzles
5 of the pen, between substantially every pair of scans of
6 the pen.

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1 ||. A method of printing a desired image, which has two
2 ends, on a printing medium by construction from individual
3 marks formed in pixel column-and-row arrays by a scanning
4 multiple-nozzle pen that operates in conjunction with a
5 printing-medium advance mechanism; said printing medium
6 being held taut beneath the pen between two sets of roll-
7 ers except while printing near top and bottom edges of the
8 printing medium, when it is constrained from only one
9 direction by one of said sets of rollers; said method com-
10 prising the steps of:

11 scanning the pen repeatedly along a pen-scanning axis
12 across the medium, to place marks on the medium within a
13 swath of pixel rows that is exposed to the multiple noz-
14 zles of the pen, each nozzle corresponding to one pixel
15 row;

16 when the pen is not substantially at either end of
17 the desired image, and while the medium is held taut
18 between two sets of rollers, periodically advancing the
19 printing medium relative to the pen, along a printing-
20 medium-advance axis that is substantially orthogonal to
21 the pen-scanning axis, to bring a fresh portion of the
22 medium within the swath that is exposed to the pen; where-
23 by the pen moves stepwise from one end of the image to the
24 other; and

25 when the pen is substantially at either end of the
26 desired image, at least if the medium is constrained from
27 only one direction by one set of rollers and at least
28 until completion of full inking for the swath of pixel
29 rows that is exposed to the nozzles of the pen: holding
30 the printing medium substantially stationary relative to
31 the pen while performing a plurality of said scanning
32 steps.

33

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1 12. The method of claim 11, wherein:
2 during the holding-stationary step, said scanning
3 steps comprise employing a sequence of print masks in
4 rotation to progressively provide full inking for the
5 swath of pixel rows that is exposed to the nozzles of the
6 pen; and
7 said sequence of masks is such as to compensate for
8 absence of printing-medium advance.

1 13. The method of claim 12, wherein:
2 the mask-sequence-employing step comprises changing
3 nozzle printing patterns between substantially every pair
4 of scans of the pen.

1 14. The method of claim 13, wherein:
2 each said scanning step comprises firing at most one-
3 third of the nozzles in each pixel-position column and
4 thereby depositing, over the total number of scans at each
5 pixel row, at least two drops of ink in each pixel posi-
6 tion that is inked.

1 15. The method of claim 13, wherein:
2 each said scanning step comprises firing at most one-
3 sixth of the nozzles in each pixel-position column.

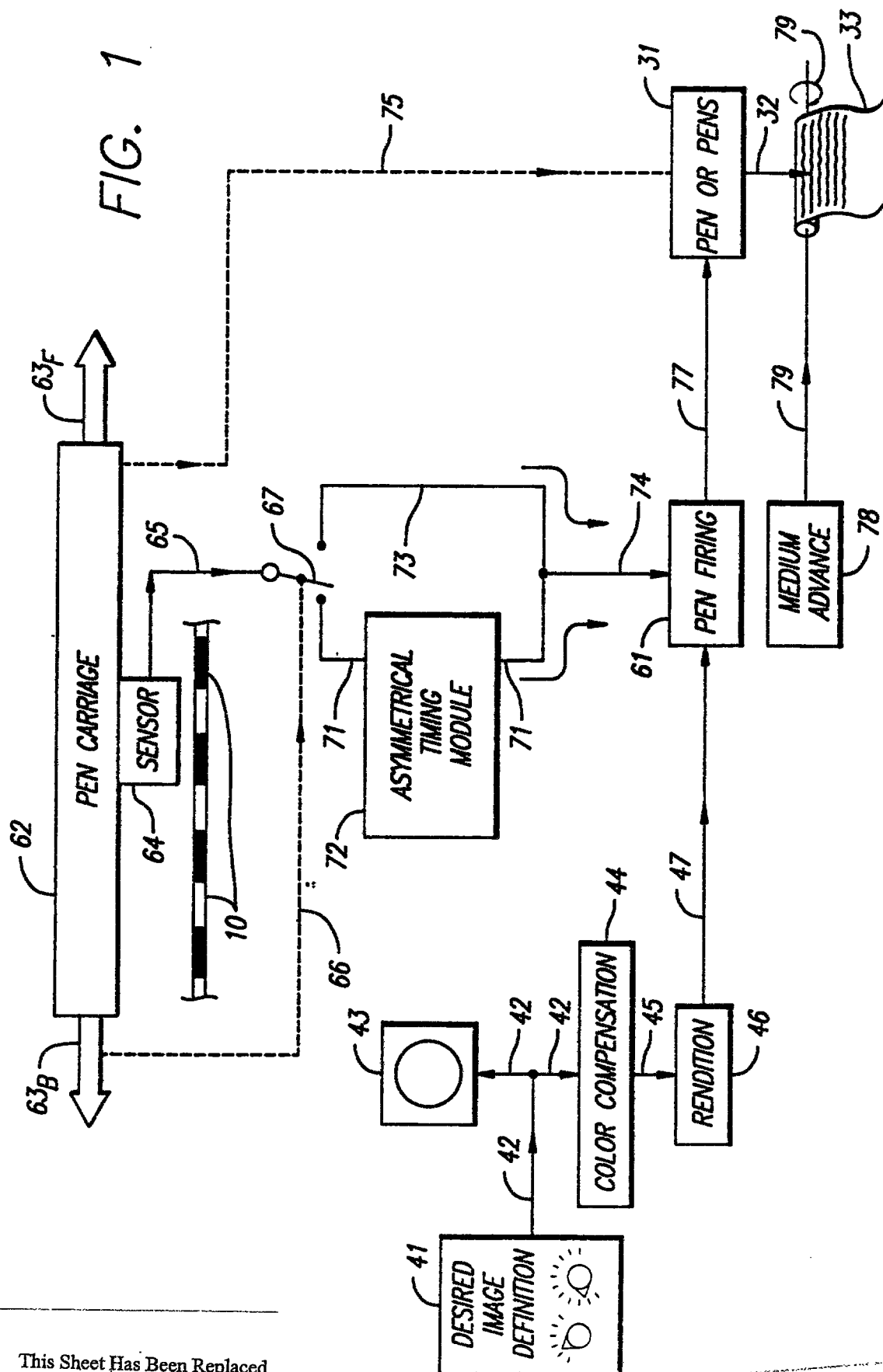
1 16. The method of claim 11, wherein:
2 the periodically-advancing step comprises advancing
3 the printing medium between substantially every pair of
4 scans of the pen.

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FIG. 1

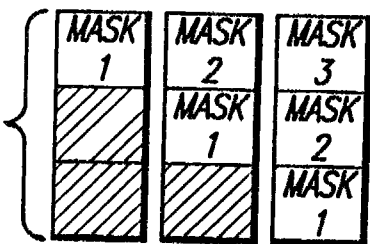


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96 NOZZLES
TOTAL



START OF DATA ON PAGE
32-ROW ADVANCE BEGINS

32-ROW ADVANCE CONTINUES

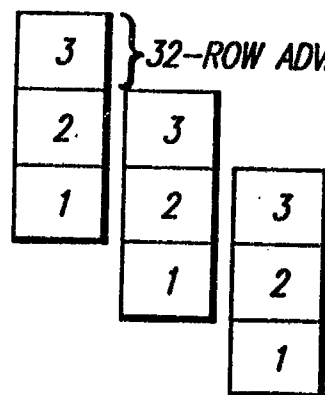
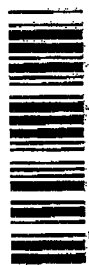


FIG. 2a

- SWEEP ROTATION
- NO ADVANCE

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FINAL DATA REACHED

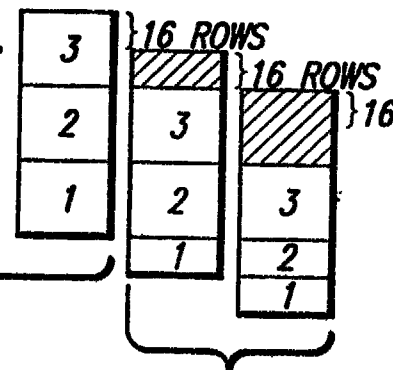


FIG. 2b

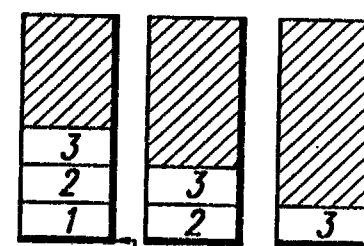
- 3-PASS NORMAL MODE
- 32-NOZZLE ADVANCE
- 96 NOZZLES PRINTING
- SPACE ROTATION

/// = NOZZLES
DISABLED

FIG. 2c

- HANDOFF ZONE
- TRANSITION TO
16-NOZZLE ADVANCE
- 48 NOZZLES PRINTING
- SPACE ROTATION

SWEEP
ROTATION



FINAL DATA ROW
ON PAGE

FIG. 2d

- NO ADVANCE

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1 INKJET PRINTING: MASK-ROTATION-ONLY AT PAGE EXTREMES;
2 MULTIPASS MODES FOR QUALITY & THROUGHPUT ON PLASTIC MEDIA
3
4

5 ABSTRACT OF THE DISCLOSURE
6

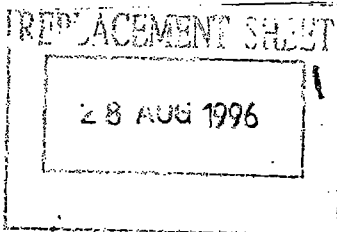
7 Images are printed using marks formed in pixel arrays
8 by a scanning print head. For transparent and glossy
9 media, with poor absorbance, drying is enhanced by a
10 multipass (preferably six-pass) print mode in which the
11 total number of ink drops or spot is allocated among
12 correspondingly multiple masks, though some may be dupli-
13 cates. To further hasten drying, heat is applied --
14 through the medium, from the opposite side as that on
15 which ink is deposited -- but the amount of heat is
16 strictly moderated, particularly for nontransparent glossy
17 media, to accommodate the hypersensitivity of these media
18 to heat-induced warping. Heating for glossy media is
19 preferably restricted to about one-third the power used
20 for drying plain paper. Convective drying too is promot-
21 ed, by operating a fan over the printed image. Certain
22 special techniques well-suited for plain-paper printing
23 have been found undesirable for use with plastic media;
24 these techniques include so-called "resolution-enhanced
25 technology", bidirectional printing (particularly of
26 black), and optical-density controlled printing speed. At
27 top and bottom of each page or sheet of printing medium,
28 where it is undesirable to operate with the pen partly off
29 the edge of the sheet, and where also the printing medium
30 is constrained from only one direction rather than being
31 held taut beneath the pen, the print mask is rotated while
32 the printing medium is held stationary -- thereby entirely
33 avoiding reliance upon accuracy of print-medium advance.

(Fig. 2)

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Substitute sheet - 27 August 1996

- 1 -

INKJET PRINTING:-MASK-ROTATION-ONLY AT PAGE EXTREMES;
MULTIPASS MODES FOR QUALITY & THROUGHPUT ON PLASTIC MEDIA

RELATED PATENT DOCUMENTS

Three closely related documents are other, coowned U. S. utility-patent applications filed in the United States Patent and Trademark Office substantially contemporaneously with this document -- and also hereby incorporated by reference in its entirety into this document.

One is in the names of Ronald A. Askeland et al., and identified as Hewlett Packard Company docket number PD-1093053-1, and entitled "INKING FOR COLOR-INKJET PRINTERS, USING NONINTEGRAL DROPS, MEDIA-DEPENDENT INKING, OR MORE THAN 2 DROPS/PIXEL" -- and subsequently assigned utility-patent application serial 08/_____, and issued as U. S. Patent 5,_____, on _____, 199__.

Another such document is in the names of Gregory D. Raskin et al., and identified as Hewlett Packard Company docket number PD-189492, and entitled "DIRECTION-INDEPENDENT ENCODER READING; POSITION LEADING & DELAY, & UNCERTAINTY TO IMPROVE BIDIRECTIONAL PRINTING" -- and subsequently assigned utility-patent application serial 08/_____, and issued as U. S. Patent 5,_____, on _____, 199__.

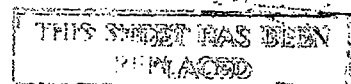
A third related document is in the names of Broder et al., and identified as Hewlett Packard Company docket PD-1092153-1, and entitled "COMBINED CENTRAL AND LATERAL HOLD-DOWN PLATES, AND END-OF-PAGE ADVANCE-DISTANCE DECREASE, IN LIQUID-INK PRINTERS" -- and subsequently assigned utility-patent application serial 08/_____, and issued as U. S. Patent 5,_____, on _____, 199__.

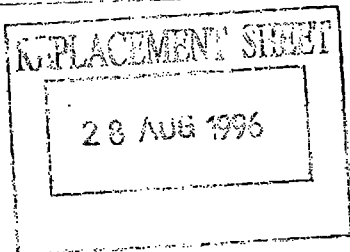
BACKGROUND

1. FIELD OF THE INVENTION

This invention relates generally to machines and procedures for printing text or graphics on printing media such as paper, transparency stock, or other glossy media;

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Substitute sheet - 27 August 1996

-2-

and more particularly to a scanning thermal-inkjet machine and method that construct text or images from individual ink spots created on a printing medium, in a two-dimensional pixel array. The invention employs print-mode techniques to optimize image quality (primarily on transparent and glossy media) vs. operating time, and also to minimize image distortion (primarily on paper) imposed by an ink-drying heater.

2. PRIOR ART

To achieve vivid colors in inkjet printing with aqueous inks, and to substantially fill the white space between addressable pixel locations, ample quantities of ink must be deposited. Doing so, however, requires subsequent removal of the water base -- by evaporation (and, for some printing media, absorption) -- and this drying step can be unduly time consuming.

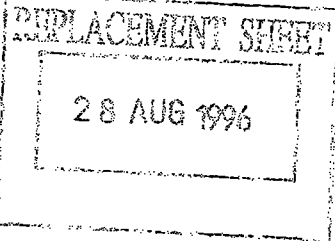
In addition, if a large amount of ink is put down all at substantially the same time, within each section of an image, related adverse bulk-colorant effects arise: so-called "bleed" of one color into another (particularly noticeable at color boundaries that should be sharp), "blocking" or offset of colorant in one printed image onto the back of an adjacent sheet with consequent sticking of the two sheets together (or of one sheet to pieces of the apparatus or to slipcovers used to protect the imaged sheet), and "cockle" or puckering of the printing medium. Various techniques are known for use together to moderate these adverse drying-time effects and bulk- or gross-colorant effects.

(a) Prior heat-application techniques -- Among these techniques is heating the inked medium to accelerate evaporation of the water base or carrier. Heating, however, has limitations of its own; and in turn creates other

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Substitute sheet - 27 August 1996

-3-

difficulties due to heat-induced deformation of the printing medium.

Glossy stock warps severely in response to heat, and transparencies too can tolerate somewhat less heating than ordinary paper. Accordingly, heating has provided only limited improvement of drying characteristics for these plastic media.

As to paper, the application of heat and ink causes dimensional changes that affect the quality of the image or graphic. Specifically, it has been found preferable to precondition the paper by application of heat before contact of the ink; if preheating is not provided, so-called "end-of-page handoff" quality defects occur -- this defect takes the form of a straight image-discontinuity band formed across the bottom of each page when the page bottom is released.

Preheating, however, causes loss of moisture content and resultant shrinking of the paper fibers. To maintain the paper dimensions under these circumstances the paper is held in tension by a system of pinchwheels used in conjunction with paper-advance drivewheels.

Unfortunately these provisions have their maximum effect, in preventing image-quality defects, only while the paper is constrained by the wheels. As soon as the bottom of the page has been printed and the paper leaves the constraint of the wheels, the paper contracts.

This happens very quickly, and as it does the paper and the dots of ink on it move in at the edges and up in the center. The quality defect caused by this sudden releasing of stress can be identified as an "end-of-page paper-shrink defect"; it appears as a thin arched gap of reduced color density.

Prior efforts to eliminate this arched gap have included avoiding the page-long accumulation of stress by cyclically lifting or releasing the constraining force of the pinchwheels. This works to decrease the paper-shrink defect by allowing the internal stress to be released or equalized incrementally -- rather than cumulatively.

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28 AUG 1996

Substitute sheet - 27 August 1996

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- 4 -

Unfortunately, however, this cyclical-release technique sacrifices control over paper position at each of the release points along the way. This loss of paper-position control can create numerous misalignment regions that are a greater problem than the paper-shrink defect.

(b) Prior print-mode techniques -- Another useful technique is laying down in each pass of the pen only a fraction of the total ink required in each section of the image -- so that any areas left white in each pass are filled in by one or more later passes. This tends to control bleed, blocking and cockle by reducing the amount of liquid that is all on the page at any given time, and also may facilitate shortening of drying time.

The specific partial-inking pattern employed in each pass, and the way in which these different patterns add up to a single fully inked image, is known as a "print mode". Heretofore three-pass print modes have been used successfully to reduce bulk-colorant problems on paper -- but less successfully on glossy and transparency stock, which are much less absorbent and so rely to a greater extent upon evaporation.

Attempts have also been made to use print modes for hiding the paper-shrink error discussed in subsection (a) above. Heretofore such efforts have had relatively little effectiveness, or have caused still other problems.

For example, some print modes such as square or rectangular checkerboard-like patterns tend to create objectionable moire effects when frequencies, harmonics etc. generated within the patterns are close to the frequencies or harmonics of interacting subsystems. Such interfering frequencies may arise in dithering subsystems sometimes used to help control the paper advance or the pen speed.

Checkerboard print-mode patterns also are subject to objectionable so-called "banding" -- horizontal stripes across the finished image. These arise because between each swath the paper advances by substantially the full

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28 AUG 1996

Substitute sheet - 27 August 1996

- 5 -

height of a swath, in effect another type of cumulative-error display.

Print-mode patterns that are instead made up of either mostly all horizontal or mostly all vertical elements can still produce similar interference effects, but only along that direction of the pattern (the direction along which most of the pattern elements are aligned) -- and also tend to exaggerate other print-quality defects in the directional lateral to the pattern. Such problems have defeated earlier efforts to find print-mode solutions to the end-of-page paper-shrink problem.

(c) End-of-image print-medium advance errors --

Another problem, related to the end-of-page defect introduced above, arises when printing near the beginning or end of a sheet of printing medium -- but arises in a somewhat simpler or more mechanical fashion. As suggested earlier, in representative modern printing machines designed for fine resolution and high image quality, the printing medium is generally held taut in the print zone, between two sets of rollers or the like.

This arrangement promotes very high precision and accuracy of printing-medium advance, and thus of printing-medium positioning relative to the pen. Near both longitudinal ends of each sheet or page of printing medium, however, necessarily the medium is held only by one set of rollers etc.

This arrangement leads to relatively less precise positioning of the printing medium in those two regions. This situation may be troublesome in particular when printing near the bottom end of a sheet, as there the sheet is held only by a tensioning roller -- which for other reasons is advantageously made rather small in diameter, but such sizing may be adverse to best precision.

One current development (not prior art with respect to the present invention) importantly mitigates that relative diminution of precision by taking smaller steps

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28 AUG 1996

Substitute sheet - 27 August 1996

- 6 -

in the ~~printing-medium~~ advance, particularly near the bottom or end of each page. That system and its benefits are described in the Broder et al. document mentioned earlier; although that system represents a major contribution to attainment of good print quality near the bottom of the page, nevertheless precision is not improved to the level enjoyed in regions where the medium is held taut.

(d) Known technology of print modes: general introduction -- One particularly simple way to divide up a desired amount of ink into more than one pen pass is the checkerboard pattern mentioned above: every other pixel location is printed on one pass, and then the blanks are filled in on the next pass.

To avoid the banding problem (and sometimes minimize the moire patterns) discussed above, a print mode may be constructed so that the paper advances between each initial-swath scan of the pen and the corresponding fill-swath scan or scans. In fact this can be done in such a way that each pen scan functions in part as an initial-swath scan (for one portion of the printing medium) and in part as a fill-swath scan.

Once again this technique tends to distribute rather than accumulate print-mechanism error that is impossible or expensive to reduce. The result is to minimize the conspicuousness of -- or, in simpler terms, to hide -- the error at minimal cost.

For instance a two-pass print mode may start a page by printing with only some of the nozzles in an array of only half of the pen's nozzles, all positioned at one end of the pen -- as an example, selected ones of the nozzles consecutively numbered one through fifty, on a hundred-nozzle pen. This first pass may be in a checkerboard pattern -- thus actually using, e.g., for example, exclusively odd-numbered nozzles 1, 3, . . . in the first row, and then only even-numbered nozzles 12, 14, . . . in the second row, next selecting only odd-numbered nozzles 21,

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28 AUG 1996

Substitute sheet - 27 August 1996

-7-

23, . . . again in the third row, etc. -- and thus printing in half of the pixel locations in the swath area.

The paper then advances by a distance equal to the length of the half-array of nozzles (in other words, the height of fifty nozzles), and the pen would print in both ends of its nozzle array -- but again only printing a fifty-percent checkerboard pattern. Now, however, while the forward end of the pen (selected ones of nozzles one through fifty) as before prints on fresh paper, the rearward end (selected ones of nozzles numbered fifty-one through one hundred) fills in the area already printed.

This behavior is then repeated all down the page until the last swath -- which is a fill-in swath only, again using selected nozzles of those numbered fifty-one through one hundred.

(e) Space- and sweep-rotated print-mode masks -- The pattern used in printing each nozzle section is known as the "print-mode mask". The term "print mode" is more general, usually encompassing a description of a mask, the number of passes required to reach full density and the number of drops per pixel defining "full density".

In the two-pass example above, the second half of the pen (certain ones of nozzles numbered fifty-one through one hundred) filled in the blank spaces left by the first half. For each pass, this may be symbolized using a letter "x" for each pixel that is printed and a letter "o" for each pixel that is not, as follows.

pattern 1:nozzles 1 through 50

```

xoxoxoxoxo
oxoxoxoxox
xoxoxoxoxo
oxoxoxoxox
xoxoxoxoxo

```

pattern 2:nozzles 51 through 100

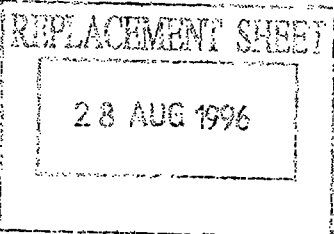
```

oxoxoxoxox
xoxoxoxoxo
oxoxoxoxox
xoxoxoxoxo
oxoxoxoxox

```

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Substitute sheet - 27 August 1996

- 8 -

In each of these diagrams, the xs appear in diagonal lines -- which are angled, if the vertical and horizontal spacings are the same, at forty-five degrees (to both the columns and rows). These lines of xs represent pixels that are printed (if the desired image calls for anything to be printed in each of those pixels respectively), and the qs represent diagonal lines of pixels that are not printed.

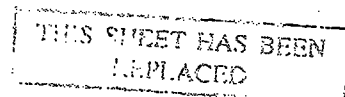
To conserve space in this document, the diagrams above represent only eight pixel rows, out of fifty created by each half of the hundred-nozzle pen that is under discussion. The nozzles are laid out along the pen in substantially only one vertical row, one hundred nozzles long -- although as a practical mechanical matter they are staggered laterally to permit very close spacing along the vertical axis. Therefore to obtain the checkerboard (or other) patterns described in this document the various nozzles are fired selectively and rapidly many times, in careful synchronism with scanning of the pen across the printing medium -- taking into account not only the scanning motion across the page but also the nozzle staggering across the pen.

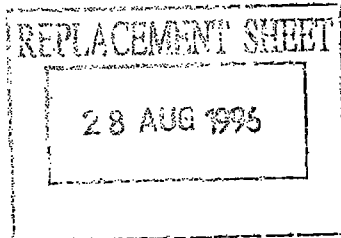
In the "pattern 1" diagram, one line of xs begins in the upper left-hand corner, and at pixel positions offset by two pixels along both top and left-hand edges of the pattern. In the "pattern 2" diagram, however, it is instead a line of qs that begins in the corner, whereas lines of xs begin at positions offset from the corner by just one pixel along the top and left-hand edges -- and so fitting between the lines of xs put down by "pattern 1".

Hence these diagrams show that pixel positions left unprinted by the first ("pattern 1") pass are filled in by the second. In other words, looking all the way across any row -- and taking into account all the xs formed by both "pattern 1" and "pattern 2" in the aggregate -- all positions in the row are filled.

One way to achieve this pattern is to always keep nozzles one through fifty in "pattern 1", and always keep

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Substitute sheet - 27 August 1996

- 9 -

nozzles fifty-one through one hundred in "pattern 2". This is known as "space rotated" masking; using this method to print down the page would progressively produce these patterns -- illustrated here too using an abbreviated vertical nozzle-array representation of just eight nozzles rather than one hundred:

pass 1 pass 2 pass 3 pass 4 pass 5

: :
: :
: :
: :

xoxo oxox
oxox xoxo
xoxo oxox
oxox xoxo

<- first printed row

 xoxo oxox
 oxox xoxo
 xoxo oxox
 oxox xoxo

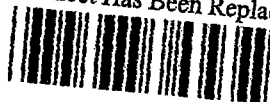
<- fifth printed row

 xoxo oxox
 oxox xoxo
 xoxo oxox
 oxox xoxo

 xoxo oxox
 oxox xoxo
 xoxo oxox
 oxox xoxo

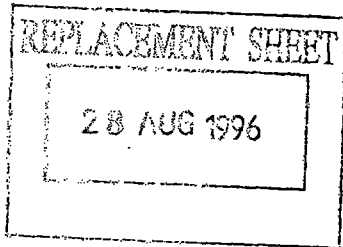
: :
: :
: :
: :

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In this mode, the pen uses the same pattern all down the page, but the mask is different in different portions of the pen: "pattern 1" for nozzles one through fifty (represented in the abbreviated drawing by the lower four

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Substitute sheet - 27 August 1996

- 10 -

positions in each eight-nozzle group); vs. "pattern 2" for nozzles number fifty-one through one hundred (represented by the upper four positions in each group).

The availability of this method of masking for various printing devices depends in part on the basic mechanical and firmware architecture of each device. In particular, it depends upon whether the basic operating system provides for efficient addressing of different mask patterns to different segments of the overall nozzle array.

Another way to use the same print mode is to apply one mask pattern to the entire pen, but to change that mask pattern from pass to pass. This is so-called "sweep rotated" masking -- still using the same abbreviated representation for purposes of illustration:

pass 1 pass 2 pass 3 pass 4 pass 5

| |
| |
| |

xoxo oxox
oxox xoxo
xoxo oxox
oxox xoxo

<- first printed row

oxox xoxo
xoxo oxox
oxox xoxo
xoxo oxox
xoxo oxox
oxox xoxo

<- fifth printed row

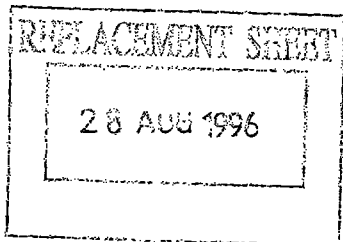
oxox xoxo
xoxo oxox
oxox xoxo
xoxo oxox

| |

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Substitute sheet - 27 August 1996

- 11 -



In both these diagrams -- as in the basic "pattern 1" and "pattern 2" diagrams discussed just before, it can be seen by reading all the way across any row that after both passes at each row all positions in that row are filled -- but by comparing the space- and sweep-rotation diagrams it will now be appreciated that the order in which some of the positions are filled in sweep rotation is opposite to that in which they are filled in space rotation. For example, in the fifth printed row the left-hand column is printed in the second pass (and the adjacent column left blank for printing later) in space rotation -- but is printed in the third pass (after the adjacent column) in sweep rotation.

This can be shown more compactly by a different notation that allows comparison of space and sweep rotation side by side. In this notation, "0" represents nozzle groups that are not fired at all -- at the top and bottom scans of the page -- while "1" and "2" represent not individual pixel rows but rather half-swaths, in "pattern 1" and "pattern 2" as defined above.

Space rotation

```
0
1 2
  1 2
    1 2
      1 2
        1 2
          0
```

Sweep rotation

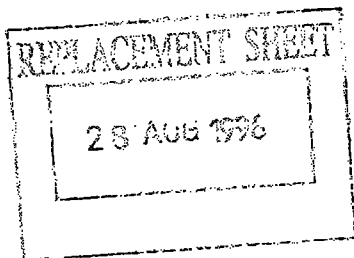
```
0
1 2
  2 1
    1 2
      2 1
        1 2
          0
```

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Now in these abbreviated forms it is easier to see that within the printed image every half-swath receives one "1" and one "2" -- but not always in the same order. Thus in

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Substitute sheet - 27 August 1996

- 12 -

the second half-swath the "1" goes down first in space rotation, but second in sweep rotation.

(f) Autorotating print-mode masks -- Operating parameters can be selected in such a way that, in effect, rotation occurs even though the pen pattern is consistent over the whole pen array and is never changed between passes. Figuratively speaking this can be regarded as "automatic" rotation or simply "autorotation".

To understand what produces this condition, it is necessary first to take note of what constitutes a basic cell or unit of the print-mode mask, and then to note its height h_c in pixels. It is also necessary to note the number of pixels (or the length measured in number of nozzles) by which the paper moves m_p in each of its advances. For example, in the simple cases diagrammed above, since each mask repeats every two rows, $h_c = 2$; and the paper advances by fifty nozzles at a time, so $m_p = 50$ (or as in the abbreviated-notation diagram the paper advances four diagrammed nozzles at a time, so $m_p = 4$).

The next step is to determine whether the ratio m_p/h_c of these two parameters is integral. If so, as in this case, since $m_p/h_c = 50/2 = 25$ actually (or $4/2 = 2$ as illustrated), the mask will not autorotate.

If however, in the two-pass example the paper advances by three diagrammed pixel rows instead of four -- but the basic cell remains two pixels tall -- then for this case as diagrammed the ratio $m_p/h_c = 3/2$ is nonintegral and at each pass the mask will "automatically" fill in the blank spaces left by the previous pass:

pass 1 pass 2 pass 3 pass 4 pass 5

xoxo

oxox

xoxo

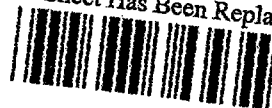
oxox

xoxo

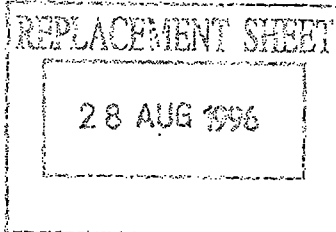
xoxo

oxox

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Substitute sheet - 27 August 1996

- 13 -

OXOX	XOXO	
	OXOX	XOXO
	XOXO	OXOX
	OXOX	XOXO
		OXOX
		XOXO
		OXOX
		XOXO
		OXOX
		XOXO
		OXOX
		XOXO

(This diagrammatic example symbolizes a real case of, for instance, three passes, a total of ninety-six nozzles used in the pen, thirty-two nozzles used in each of three sections of the pen, thirty-two-nozzle printing-medium advance -- and a basic-pattern cell three pixels tall. In algebraic notation, $m_p/h_c = 32/3$, a nonintegral ratio. This three-pass mode is discussed in the next section.)

The print mode produced in this way is essentially a space-rotation mode (though in a sense that condition is not specifically called for). For example, if the pen is a six-row pen as diagrammed above, the first three rows are in "pattern 1" and the second three are in "pattern 2":

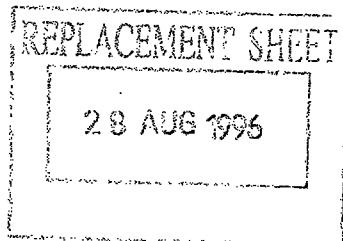
XOXO	
OXOX	pattern 1
<u>XOXO</u>	
OXOX	
XOXO	pattern 2
OXOX	

For an autorotating case, either "pattern 1" or "pattern 2" may be used all down the pen. Thus the paper advance turns one simple pattern into a space-rotated mask "automatically". In the shorthand notation introduced above, the pen provides the following periodic behavior as the paper advances.

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Substitute sheet - 27 August 1996

- 14 -

autorotation

0
1 2
1 2
1 2
1 2
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(g) Three-pass modes -- Heretofore, one highly favored print mode has specified a one-third-density-per-pass pattern that constructs dots in a diagonal pattern --

xoo
oxo
oox

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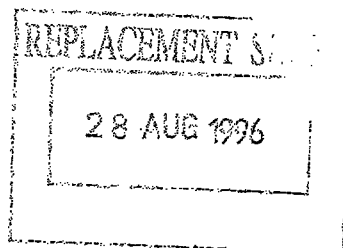


-- rather than the one-half-density-per pass checkerboard modes discussed above. The diagonals, however, remain at forty-five degrees as in the checkerboard mode.

This pattern has been considered advantageous because it worked well with software dithering algorithms and had minimal tendency to create moire patterns when printing partial-density-shaded and gradient area fills. The use of forty-five-degree diagonals was considered particularly beneficial for its tendency to distribute error-hiding capability equally between vertical and horizontal axes of the pixel array to be constructed on the printing medium.

Generally a printing apparatus is characterized -- through its basic hardware and firmware design architecture -- by a general maximum-size print mask or mode pattern that can be formed with the apparatus in one pen pass; any mask pattern to be used with a printing apparatus must fit within its maximum pattern. For example, in a particular one printing device (of the Hewlett Packard Company) which produces high-quality images, that maximum mask or pattern size is eight rows tall and four columns

THIS SHEET HAS BEEN
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Substitute sheet - 27 August 1996

- 15 -

This Sheet Has Been Replaced



wide -- and will readily accommodate, among other possibilities, a mask that is three rows tall ($h_c = 3$) and three columns wide.

Just such a mask produces the one-third-density diagonal three-pass pattern introduced at the beginning of this section. If that mask is used in conjunction with a unit paper advance of thirty-two nozzles -- for a printing-medium advance movement $m_p = 32$ -- then the previously introduced ratio $m_p/h_c = 32/3$, which is not integral.

This combination of conditions accordingly provides autorotation of the three-row mask pattern shown above (as noted parenthetically in the preceding section). No mask rotation sequence is required; and a mask specification for the three passes accordingly might read "111" to indicate that the first column of the pattern should be used in common to begin each sweep -- that is, printing the pixel in column number one of the top row of the swath (assuming that there is any image information to print there). Equally well a mask specification might read "222" or "000", as indeed the pattern may begin with printing in any of the three columns of the basic cell.

If instead the number of dot rows were an integral multiple of the pattern height, then as previously explained the printer would have to be instructed to use a rotation sequence telling it how to build the pattern in each succession of sweeps. For example, using the same three-row pattern but thirty-three-nozzle advance -- which is to say, a printing-medium-advance movement of thirty-three dot rows -- the ratio $m_p/h_c = 33/3$ is integral, and a rotation sequence must be specified.

Such a sequence might be "012". The numbers are the swath or pass numbers in which the respective columns of the base pattern will start a page. The printer will form so-called "swath number zero" (the first swath) using the first column of the pattern as the first column at top of the page, swath one (the second swath) using the second column as the first column at top of the page, and swath two (the third swath) using the third column, as follows.

THIS SHEET HAS BEEN
REPLACED

28 AUG 1996

Substitute sheet - 27 August 1996

- 16 -

<u>pass 1</u>	<u>pass 2</u>	<u>pass 3</u>	<u>PASS 1</u>	<u>PASS 2</u>	<u>PASS 3</u>
x00	0x0	00x	x00	0'0 x	0 x 0
0x0	00x	x00	0 x 0	x 0 0	0 0 x
00x	x00	0x0	0 0 x	0 x 0	x 0 0
0	1	2	0	1	2

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The other equally acceptable sequences would be "021", "102", and all the other six rotations ("120", "201"; etc.) of these three root sequences. Now if a printer is stopped halfway through a page, using this cell and a diagrammatic six-dot-row paper advance, a pattern something like the following will be found -- regardless of whether space or sweep rotation is in use.

XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

completely filled

XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

XXOXXOXXOXXOXX

0X0X0X0X0X0X

XOXOXOXOXOXOXO

XXXXXXXXXX

two-thirds filled

0X00X0X0X0X0X0X

XXXXXXXXXXXX

0X00X00X00X00X

00X00X00X00X00

XXXXXXXXXXXX

0X00X00X00X00X

one-third filled

00X00X00X00X00

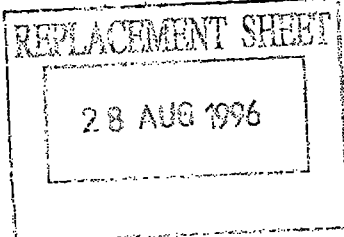
XXXXXXXXXXXX

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As before, this abbreviated diagram symbolizes the modern-ly more interesting practical case of thirty-three-nozzle advance. That case if fully pictured would appear as

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Substitute sheet - 27 August 1996

- 17 -

thirty-three rows fully filled, another thirty-three two-thirds filled, and thirty-three more one-third filled.

(h) Print-quality defects on transparency and glossy stock -- As mentioned earlier, known techniques have not been entirely successful in eliminating bulk-colorant problems on transparent and other glossy media. Dividing the total desired amount of ink into three passes has been considered the limit for application of print-mode techniques in attempts to solve this problem.

As noted earlier, evaporation from these media -- because they are relatively much less absorbent -- is necessarily more important than from plain paper. Some evaporation can be obtained straightforwardly by convection (stimulated by an air-circulating fan), but inducing evaporation by applying radiative heat takes on greater importance with plastic media.

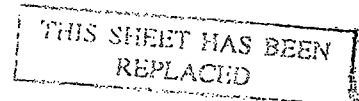
Heat, however, is most straightforwardly applied from below (the opposite direction from that of ink application). These media present more thermal mass and therefore an effectively longer thermal path than does plain paper.

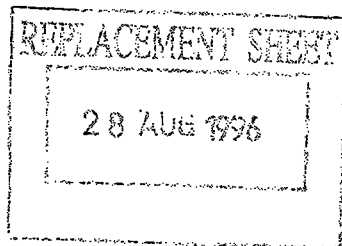
Accordingly with these media a much greater fraction of applied heat radiation ends up absorbed in the printing medium as compared with the ink carrier; this adverse energy distribution is compounded by the previously mentioned dimensional hypersensitivity of these media to heat. Generally speaking, as can be seen from the foregoing discussion, the application of heat is more problematic for glossy and transparent stock than for plain paper.

Heretofore the lower liquid absorption, higher heat absorption, and higher dimensional sensitivity to heating, of these media has defied efforts to obtain adequate liquid removal. Accordingly the prior art has left considerable room for refinement in this area.

(i) Black-ink detail -- Printing-machine users often prefer to present lettering and certain other types of

This Sheet Has Been Replaced





Substitute sheet - 27 August 1996

- 18 -

finely detailed image elements in black, and the eye is capable of discerning black-inked elements (and defects in them) quite sensitively -- as compared with elements and defects marked in other colors. It would therefore be desirable to use finer position control for black inking than for other colors, even within the same image.

Such a strategy, however, is difficult to implement. Generally speaking, the fineness of position control, or to put it another way the pitch of the pixel array, is commonly set by the frequency of a waveform derived by electrooptically reading, while the pen scans, a special scale extended across the printing medium.

Within a printing machine of reasonable cost it is preferable to employ multiplexing techniques for control of the pens. In other words, a single set of signal lines -- and control signals time-sharing or otherwise coexisting in those lines -- is used to operate all of the pens.

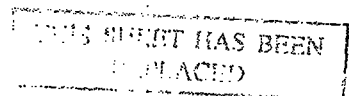
Providing finer position control for printing of black in direct conjunction with other colors would require somehow establishing a separate such waveform for black. That waveform would have to be provided simultaneously with the position-establishing waveform for the other colors -- but at a different, higher frequency.

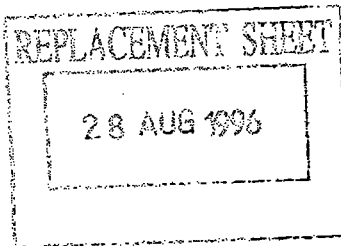
It would also require arranging for the signals of different frequencies to share the same basic position-signal transmitting system. These special provisions, to accommodate established multiplexing arrangements, would be awkward or at least costly. In engineering jargon, electrically it would be hard to "talk" to a color pen (for instance, a cyan pen) and a black pen at the same time.

An alternative would be to print black in a separate sweep, between sweeps for the chromatic-color pens. This alternative would pay a heavy price in reduced throughput and accordingly would be very undesirable.

(j) Conclusion -- End-of-page print-quality defects on paper, as well as bulk-colorant problems on glossy and

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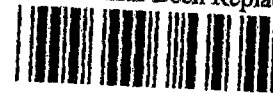


Substitute sheet - 27 August 1996

- 19 -

transparent media, heretofore have continued to impede achievement of uniformly excellent inkjet printing -- at high throughput -- on all industrially important printing media. Awkwardness of overprinting fine detail in black is another adverse limitation of the prior art. Thus important aspects of the technology used in the field of the invention remain amenable to useful refinement.

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SUMMARY OF THE DISCLOSURE

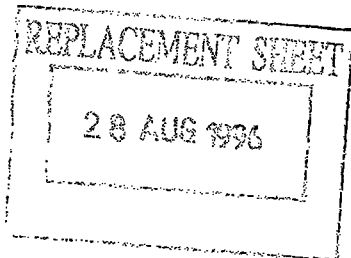
The present invention introduces such refinement. In its preferred embodiments, the present invention has several aspects or facets that can be used independently, although they are preferably employed together to optimize their benefits.

In preferred embodiments of a first facet or aspect of its aspects, the invention is a method of printing desired images on a printing medium by construction from individual marks formed in pixel arrays. The marks are formed by a scanning print head that operates in conjunction with a printing-medium advance mechanism.

The method includes the step of scanning the head repeatedly along a pen-scanning axis that is substantially orthogonal to a printing-medium-advance axis. The method also includes the step of, during each scan of the head along the pen-scanning axis, forming marks in a pattern that approximates at least portions of a large number of generally parallel, separated lines that are relatively steeply angled relative to the pen-scanning axis and relatively shallowly angled relative to the printing-medium-advance axis.

This first facet or aspect of the invention also includes the steps of (1) during one or more earlier scans with respect to each segment of an image, leaving unprinted regions between the angled lines; and (2) during one or more later scans with respect to each segment, filling in the unprinted regions.

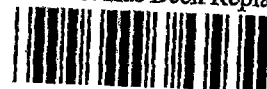
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Substitute sheet - 27 August 1996

- 20 -

This Sheet Has Been Replaced



A second aspect of the invention differs from the first in that it expressly includes -- instead of the two steps recited in the preceding paragraph:

- forming the marks with a liquid-based colorant; and
- substantially concurrently with the mark-forming step, heating the medium to accelerate drying of the liquid-based colorant -- this heating step having a tendency to create an end-of-page paper-shrink defect that accentuates positional error components parallel to the printing-medium-advance axis.

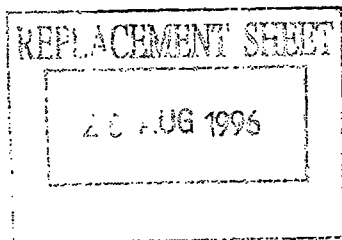
The relatively steeply angled lines have a tendency to minimize the positional error components parallel to the printing-medium-advance axis.

The foregoing may constitute descriptions or definitions of each of these two different facets of the invention in its broadest or more general form. Even in these general forms, however, it can be seen that these aspects of the invention significantly mitigate the difficulties left unresolved by the prior art.

In particular, the use of patterns with lines generally close in orientation to the paper-advance direction tends to minimize the conspicuousness of positional errors along that direction. This minimization of such errors in turn permits use of heat to accelerate drying of the print medium -- and thereby facilitates operation at high throughput, but with minimal apparent degradation of image quality.

Although the features or characteristics expressly included in these two different aspects of the invention are subject to practice independently of each other, nevertheless as mentioned above they are preferably practiced together to maximize and optimize the benefits of the invention. In addition, they are preferably practiced





Substitute sheet - 27 August 1996

- 21 -

This Sheet Has Been Replaced



in conjunction with certain other features or characteristics that further enhance enjoyment of overall benefits.

For example, it is preferred that the mark-forming step include placing marks only at selected pixel locations where marks are desired for construction of a particular such desired image. By virtue of this provision, the angled lines are incomplete where marks are not desired for construction of such particular desired image. Similarly it is preferred that the filling-in step include placing marks only at other selected pixel locations where marks are desired for construction of a desired image.

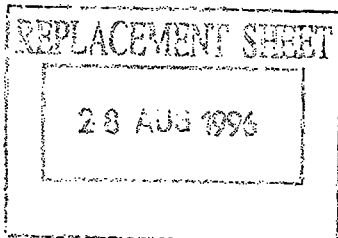
It is also preferred that the mark-forming step include forming the angled lines at substantially a steepest angle possible within design architecture of the scanning print head and printing-medium-advance mechanism. Stated more generally, it is preferred that the mark-forming step include forming the angled lines at substantially a steepest angle possible that:

- is within design architecture of the scanning print head and print-medium-advance mechanism;
- also provides at least approximately an equal number of marks per print-head scan, for desired images in which all pixel locations are to be marked;
- does not contribute significantly to other types of error.

Such other error types include, for example, interference with dithering patterns; and diagonal lines that are so vertical as to introduce significant print-quality aberrations relative to the print-head scanning axis.

Preferably the mark-forming step includes forming the angled lines at a slope much greater than 1:1 relative to the pen-scanning axis. Even more highly preferable is forming the angled lines at a slope of at least 2:1 rela-





Substitute sheet - 27 August 1996

- 22 -

tive to that axis. As will be seen, the specific pattern that is now most highly preferred provides a slope in the range of at least approximately 2.5:1 to 3:1 -- or very roughly 3:1 -- relative to the pen-scanning axis.

In this now-most-highly-preferred embodiment of the invention, the mark-forming step includes forming the angled lines in a basic pattern cell that is three pixels wide and eight pixels tall. Within this embodiment, advantageously during one of the scans the cell is printed with:

- a mark in one column of the cell for each of three rows in direct succession;
- a mark in another column of the cell for each of three other rows in direct succession; and
- a mark in still another column of the cell for each of two other rows in direct succession.

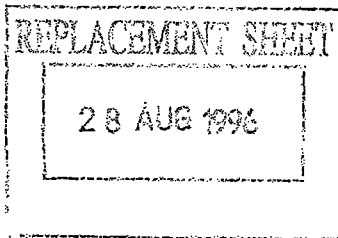
The same embodiment can be implemented in another way that is particularly advantageous in printing on glossy or transparent media. Here the total number of pen scans with respect to each segment of the image is multiple, i. e., a relatively high number, in any event greater than about four; and the mark-forming step comprises, during each of selected pairs of said multiple scans, printing the cell with:

- two marks in one column of the cell for each of three rows in direct succession,
- two marks in another column of the cell for each of three other rows in direct succession, and
- two marks in still another column of the cell for each of two other rows in direct succession.

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Substitute sheet - 27 August 1996

- 23 -

This Sheet Has Been Replaced



This manner of practicing the invention provides superior drying properties; if in addition the printing medium is advanced relative to the marking head between each pair of successive scans, of the multiple scans, then positional error along the direction of the medium-advance direction is relieved numerous times per swath, yielding very high image quality.

At least four and preferably more scans are needed to obtain the benefits of this manner of practicing the invention. The number of scans now regarded as most highly preferred is six.

In a third basic aspect or facet, the invention is an apparatus for printing desired images on a printing medium by construction from individual marks formed in pixel arrays. The apparatus includes some means for supporting such a printing medium; for purposes of generality and breadth in expressing the invention these means will be called simply the "supporting means".

The apparatus further includes a print head mounted for motion along a direction across the medium; and some means for scanning the head across the medium. Once again for breadth and generality these will be designated the "scanning means".

Also included are some means for providing relative motion of the printing medium with respect to the print head (the "relative-motion-providing means") along a direction of movement that is substantially orthogonal to the print head motion. The apparatus of this third facet of the invention also includes some means for heating the medium ("heating means"); and some means for forming marks in a particular pattern ("mark-forming means").

More specifically that pattern is one which was introduced in regard to the first two aspects of the invention. It is a pattern that approximates at least portions of a large number of generally parallel, separated lines that are relatively steeply angled relative to the print-head motion and relatively shallowly angled

THIS SHEET HAS BEEN
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28 AUG 1996

Substitute sheet - 27 August 1996

-24-

relative to the direction of relative movement of the printing medium with respect to the print head.

As to the apparatus of the third facet of the invention, the mark-forming means form this pattern while the relative-motion-providing means are not operating. In other words, while the pen forms a particular swath of dots or ink spots constituting a partially inked pixel array having the lines just described, there is no relative motion -- along the orthogonal direction -- of the printing medium with respect to the pen.

In preferred embodiments of a fourth of its aspects, the invention is a method of printing desired images on a low-liquid-absorption printing medium, by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism. The method includes the step scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen; in this system each nozzle corresponds to one pixel row.

The method also includes the step of periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen. The method further includes the step of, in each scanning of the head across the medium, firing at most one-third of the nozzles in each pixel-position column and thereby depositing, over the total number of scans at each pixel row, at least two drops of ink in each pixel position that is inked.

This method is thus in effect a double-density or 200% form of a six-pass printing mode, which has been found to effectuate a particularly advantageous balance between high quality and throughput. Indeed for optimum

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28 AUG 1996

Substitute sheet - 27 August 1996

- 25 -

benefit this method is preferably practiced in conjunction with six printing-medium advances per full swath height.

As to preferred embodiments of a fifth of its aspects, the invention is similarly a method of printing desired images on a low-liquid-absorption printing medium, by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism. This method too includes the step of scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen, each nozzle corresponding to one pixel row; and periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen.

This method differs from that of the fourth aspect or facet of the invention, however, in that it includes the step of -- in each scanning of the head across the medium -- firing at most one-sixth of the nozzles in each pixel-position column. This method is thus more straightforwardly recognized as a six-pass printing mode, and like the fourth is preferably practiced with a one-sixth-swath advance distance.

A sixth aspect or facet of the invention is, in its preferred embodiments, a method of printing a desired image, which has two ends, on a printing medium by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism. The printing medium is held taut beneath the pen between two sets of rollers except while printing near top and bottom edges of the printing medium, when it is



REPLACEMENT SHEET

28 AUG 1996

Substitute sheet - 27 August 1996

- 26 -

This Sheet Has Been Replaced



constrained from only one direction by one of said sets of rollers.

This method includes the step of scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen. Here as before, each nozzle corresponds to one pixel row.

In addition the method includes the step of -- when the pen is not substantially at either end of the desired image, and while the medium is held taut between two sets of rollers -- periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis. Each such step operates to bring a fresh portion of the medium within the swath that is exposed to the pen, whereby the pen moves stepwise from one end of the image to the other.

The method also includes a further step that is performed when the pen is substantially at either end of the desired image, and at least until completion of full inking for the swath of pixel rows that is exposed to the nozzles of the pen. This step is holding the printing medium substantially stationary relative to the pen while performing a plurality of said scanning steps.

This step is performed at least if the medium is constrained from only one direction by one set of rollers. Preferably this step is performed only while the medium is constrained by one set of rollers, since its performance is less robust with respect to tolerance of nozzle failures; however, this step need not be strictly limited to performance under these conditions, as stationary-medium operation can also be performed in a generally satisfactory fashion at the end of the image even if the paper is still taut.

The method of this sixth facet of the invention is particularly beneficial in suppressing print-quality defects that arise from print-medium positioning errors due to mechanical tolerances. The method has this benefi-

THIS SHEET HAS BEEN
REPLACED

28 AUG 1996

Substitute sheet - 27 August 1996

- 27 -

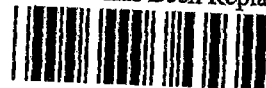
cial effect because -- while the stationary-medium operation is being used -- in fact no print-medium positioning takes place, and accordingly no error in positioning can occur.

Although this method even as thus broadly couched serves an excellent purpose, nevertheless preferably it is performed with certain additional features or characteristics. During the holding-stationary step, the scanning steps preferably include employing a sequence of print masks in rotation to progressively provide full inking for the swath of pixel rows that is exposed to the nozzles of the pen; and preferably that sequence of masks is such as to compensate for absence of printing-medium advance.

Also it is preferred that the mask-sequence-employing step comprise changing nozzle printing patterns between substantially every pair of scans of the pen.

All of the foregoing operational principles and advantages of the present invention will be more fully appreciated upon consideration of the following detailed description, with reference to the appended drawings, of which:

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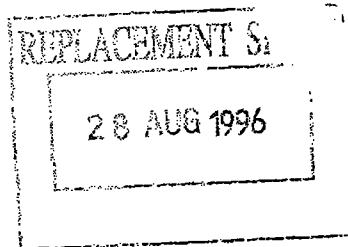


BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block-diagrammatic representation of a hardware system according to the invention; and

Figs. 2a through 2d are diagrammatic print-mask representations of inking patterns used in, respectively: (a) special top-of-page sweep mask rotation to enable suppression of printing-medium advance in that region, (b) midpage space rotation with one-third advance, (c) bottom-of-page handoff space rotation with one-sixth advance, and (d) special bottom-of-page sweep rotation to enable suppression of advance in that region.

THIS SHEET HAS BEEN
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Substitute sheet - 27 August 1996

- 28 -

DETAILED DESCRIPTION
OF THE PREFERRED EMBODIMENTS

1. STEEPER DIAGONAL

The print mask of the present invention forms diagonal lines that are skewed more toward the printing-medium advance direction than those of prior-art masks. This is beneficial because in this direction there tends to be more error due to paper advancement and paper shrinkage.

In at least some commercial printers the above-mentioned largest permissible pattern, within the basic architectural constraint of the printing apparatus that is in use, is rectangular and vertically oriented -- in other words, longer in the direction of the printing-medium advance. In this case, preferably the diagonals formed by the invention approximate the longest diagonal line possible within that vertically oriented largest permissible pattern.

Within the previously mentioned eight-by-four pattern constraint of one Hewlett Packard printer, a particularly desirable print mode creates the following eight-by-three pattern cell or "base pattern".

```
xoo
xoo
xoo
oxo      base pattern
oxo      or cell
oxo
oox
oox
```

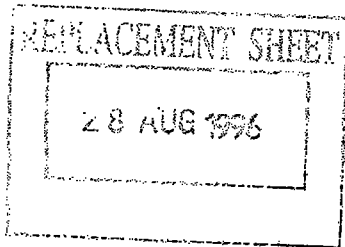
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012 <- column number within the base pattern

The resulting pattern still appears as diagonal lines when printed on the page, but now they are angled at roughly seventy degrees from the pen-scan axis -- or, as

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Substitute sheet - 27 August 1996

- 29 -

This Sheet Has Been Replaced



it may be called, the "horizontal". The pattern alignment is now more vertical than horizontal, and this more effectively masks dot dislocation due to error in printing-medium shrinkage or advance.

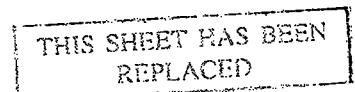
The diagram above shows that within the eight-row cell or base pattern there are three rows of the repeating subpattern "xoo" and three of the subpattern "oxo", but only two of the bottom subpattern "oox". This asymmetry is without substantive consequence, or may possibly aid slightly in suppressing undesirable moire patterns and the like due to excessively regular cell structure.

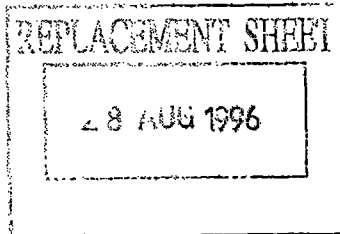
The slope of the diagonal is probably best defined as the angle from any point (for example, the first dot) along the repeating unit to the same point on the next diagonally adjacent repeating unit. Using this definition, the slope is the ratio of eight vertical units to three horizontal units, or 8:3, corresponding to an angle of about $69\frac{1}{2}$ degrees. Other reasonable candidate methods of defining the slope generally will yield comparable values between roughly 68 and $71\frac{1}{2}$ degrees.

In any event it will be understood that the apparent slope of the diagonals created by this mask is roughly (within ten percent) 2.67 -- which is much greater than the 1:1 value provided by the checkerboard or three-by-three cells of the prior art. The angle of the diagonals relative to the pen-scan axis or "horizontal" is approximately (within three percent) seventy degrees.

While the invention in this preferable form accordingly is very beneficial, a great advance over the performance of the prior art in hiding paper-shrinkage and paper-advance errors can be enjoyed even with considerably less-emphatic vertical orientation. Any slope over about 2:1 (or angle over about sixty degrees), for instance, produces much better error-hiding properties than the 1:1 forty-five-degree diagonals of the prior art.

If the above-illustrated eight-dot-row pattern is used with a printing-medium advance of thirty-two nozzles, then the determining ratio m_p/h_c is 32/8, which is inte-





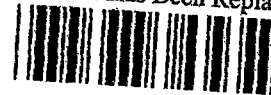
Substitute sheet - 27 August 1996

- 30 -

gral -- so the mode is not autorotating. Therefore the order in which the columns create the print patterns must be specified. The order normally is not critical. One acceptable sequence is shown in the following example.

<u>pass 1</u>	<u>pass 2</u>	<u>pass 3</u>	
012	120	201	<- internal rotation sequences
xoo	oox	oxo	
xoo	oox	oxo	
xoo	oox	oxo	
oxo	xoo	oox	
oxo	xoo	oox	
oxo	xoo	oox	
oox	oxo	xoo	
oox	oxo	xoo	<- last row in first cell
oox xoo	oxo oox	xoo oxo	<- starting next 8-row cell
oox xoo	oxo oox	xoo oxo	
oox xoo	oxo oox	xoo oxo	
oox xoo	oxo oox	xoo oxo	
oox xoo	oxo oox	xoo oxo	
oox xoo	oxo oox	xoo oxo	
oox xoo	oxo oox	xoo oxo	

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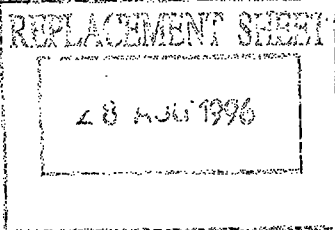
Handwritten signature/initials

These patterns correspond to a rotation sequence of "012". The phrase "rotation sequence" actually is used in two different senses, but as will be seen 012 is the rotation sequence for at least part of the above diagrams in both senses.

One definition of "rotation sequence" is entirely internal to the cell -- that is to say, the rotation sequence is the order in which pixel rows are printed within the cell or basic pattern. Thus "sequence 012" means that -- as shown above for the first pass:

- 0 is the number of the column in which the first group of rows (rows 1 through 3) within the cell is printed;

THIS SHEET HAS BEEN REPLACED



Substitute sheet - 27 August 1996

- 31 -

This Sheet Has Been Replaced



- 1 is the column (the second column) in which the second group (rows 4 through 6) is printed; and
- 2 is the number of the column (the third) in which the third group of rows (rows 7 and 8) is printed.

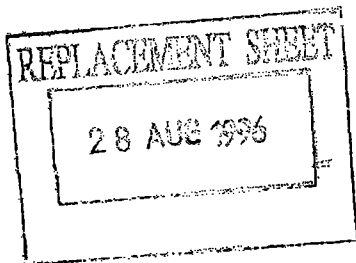
(As will be noted, in keeping with customary computer-science practice the rows are numbered starting with zero.) Correspondingly for the second pass, as marked in the tabulation above, the (internal) rotation sequence is 120; and for the third pass the sequence is 201.

The other sense in which the phrase "rotation sequence" is used is partly external to the base pattern. Here the rotation sequence identifies a series of swath or path numbers in which the consecutive columns of the base pattern are used in starting positions, so defining the swath pattern: thus in the tabulated case, swath number:

- 0 (the first pass) is assigned to begin with the first column of the base pattern;
- 1 (the second swath) takes the second column of the base pattern for its beginning column; and
- 2 (the third) uses the third column of the base pattern as the first column of the swath.

Now if the printer is stopped halfway down a page, a pattern generally like the following abbreviated diagram can be seen (not starting at the left-hand edge of the image) -- except that the eight-nozzle cell shown above repeats four times within each swath, rather than occurring only once as suggested by the diagram. Due to this repetition the height of each band of fill, measured in number of nozzles, is thirty-two dot rows rather than eight as diagrammed.

THIS SHEET HAS BEEN
REPLACED



Substitute sheet - 27 August 1996

- 32 -

XXXXXXXXXXXXXX

XXXXXXXXXXXXXX

XXXXXXXXXXXXXX

XXXXXXXXXXXXXX

XXXXXXXXXXXXXX completely filled

XXXXXXXXXXXXXX

XXXXXXXXXXXXXX

XXXXXXXXXXXXXX

OXOXOXOXOXOXO

OXOXOXOXOXOXO

OXOXOXOXOXOXO

XOXOXOXOXOXOX

XOXOXOXOXOXOX two-thirds filled

XOXOXOXOXOXOX

XXOXOXOXOXOXO

XXOXOXOXOXOXO

OXOXOXOXOXOXO

OXOXOXOXOXOXO

OXOXOXOXOXOXO

OXOXOXOXOXOXO

OXOXOXOXOXOXO one-third filled

OXOXOXOXOXOXO

XOXOXOXOXOXOX

XOXOXOXOXOXOX

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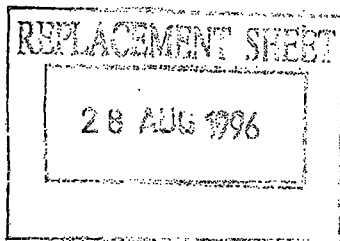


Another potentially useful cell might be an eight-by-four pattern -- the maximum permitted within the system architecture mentioned earlier. Such a cell contains thirty-two pixels, which cannot be divided up equally among three passes.

Equal division among the number of passes selected is desirable to avoid other types of artifacts. This principle might suggest that an eight-by-four pattern would work moderately well with four passes; but for best throughput on plain paper four passes is less desirable because it would be slower.

Also the slope in that case would be definitely 8:4 = 2 (an angle of about sixty degrees). That slope would be

THIS SHEET HAS BEEN
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Substitute sheet - 27 August 1996

- 33 -

a distinct improvement over the prior art -- but has not been tested, and possibly would be noticeably less effective than 8:3 in hiding vertically oriented errors. For these various reasons an eight-by-four cell is now regarded as at least no more advantageous -- and possibly less advantageous -- than an eight-by-three.

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2. SIX PASSES FOR PLASTIC MEDIA

As mentioned earlier, in the prior art three print passes were considered ideal. The present invention, however, recognizes that the number of passes used by a system represents a tradeoff between throughput and quality (particularly distribution of paper-advance error over a large number of passes so as to hide that error).

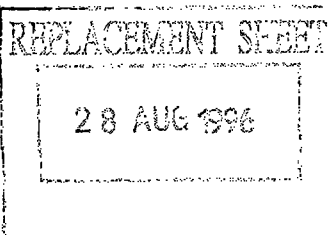
Thus in principle, if only quality were needed, each swath could be printed using a thousand pen passes, with one ink spot deposited in each pass; this print mode might produce virtually flawless images but also might require an hour per page. Typical draft-mode printing does the opposite -- laying down an entire swath in just one pass.

The present invention further recognizes that in balancing throughput and quality, it is desirable to take into account the properties of different media. In other words, the ideal compromise may call for a different number of passes with some media than with other media.

In accordance with the present invention, for use on transparent and glossy media, six passes has been found highly preferable to three. A higher number of passes is more optimal for glossies and transparencies than for paper because -- as explained in the "PRIOR ART" section of this document -- in practice the other parameters (quantity of heat, and effectiveness of convection and absorption) used to mitigate bulk-colorant problems cannot be set as high for these media as for paper.

To put it another way, the present invention proceeds from the recognition or discovery that the drying charac-

THIS SHEET HAS BEEN
REPLACED



Substitute sheet - 27 August 1996

- 34 -

teristics of these media shift the optimum tradeoff point toward a greater number of printing passes.

Different numbers of ink drops of the various primaries are desirable for these two different media types respectively. In this regard the ink application considered ideal is quite complicated -- encompassing use of fractional average numbers of drops for certain colorants. These best-known modes of practice of the invention are set forth in considerable detail in the Askeland et al. document identified above.

In addition to using six passes and employing the inking arrangements set forth in that document, it is also highly preferable to incorporate the maximum-diagonal aspects of the invention described in the preceding section. The basic three-pass eight-row cells are in essence repeated, making two passes over every pixel location rather than one -- to provide double density.

In addition it is highly preferred to halve the advance distance. Thus whereas the three-pass embodiment of the invention is now believed to operate ideally with advance by thirty-two pixel rows (about $32/24 = 1.33$ mm) at each step, the six-pass embodiment operates instead with advance by sixteen rows ($16/24 = 0.67$ mm) per step.

The resulting masking patterns may appear as shown.

<u>pass 1</u>	<u>pass 2</u>	<u>pass 3</u>	<u>pass 4</u>	<u>pass 5</u>	<u>pass 6</u>
xoo	oox	oxo	xoo	oox	oxo
xoo	oox	oxo	xoo	oox	oxo
xoo	oox	oxo	xoo	oox	oxo
oxo	xoo	oox	oxo	xoo	oox
oxo	xoo	oox	oxo	xoo	oox
oxo	xoo	oox	oxo	xoo	oox
oox	oxo	xoo	oox	oxo	xoo
oox	oxo	xoo	oox	oxo	xoo
012	120	201	012	120	201
(rotation sequence)					

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REPLACEMENT SHEET

28 AUG 1996

Substitute sheet - 27 August 1996

If as before the printer is halted partway down a page the developing pattern can be seen from the following representative rows. Capital letters represent double inking:

200% filled,

after passes 1 through 6

XXXXXXXXXXXXXXXXXXXX

167% filled.

after passes 2 through 6

XXXXXXXXXXXXXXXXXXXX

xXxxXxxXxxXxxXx

133% filled.

after passes 3 through 6

XxxXxxXxxXxxXxx

XxxXxxXxxXxxXxx

XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

100% filled,

XXXXXXXXXXXXXXXXXXXX

after passes 4 through 6

XXXXXXXXXXXXXXXXXXXX

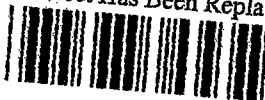
XXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

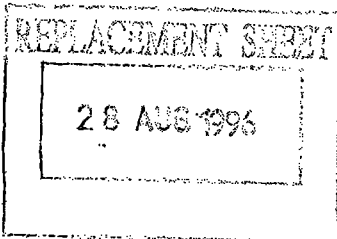
OXXXXXXOXXXXX

0X X 0X X 0X X 0X X 0X X

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



Substitute sheet - 27 August 1996

- 36 -

0xx0xx0xx0xx0xx

x0xx0xx0xx0xx0x

x0xx0xx0xx0xx0x

x0xx0xx0xx0xx0x

xx0xx0xx0xx0xx0

xx0xx0xx0xx0xx0

0x00x00x00x00x0

0x00x00x00x00x0

0x00x00x00x00x0

00x00x00x00x00x

00x00x00x00x00x

00x00x00x00x00x

x00x00x00x00x00

x00x00x00x00x00

67% filled,

after passes 5 and 6

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33% filled,

after pass 6 only

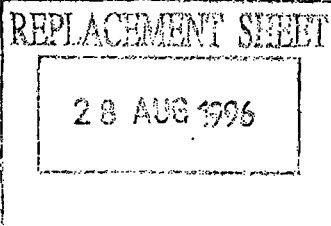
The inking arrangements outlined above provide double-drop-per-pixel coverage of all pixel positions. For primary colors (in preferred embodiments those are cyan, magenta and yellow), this is a now-preferred treatment for images on transparency or glossy stock as well as on paper.

In accordance with the aforementioned Askeland document, however, it may be preferable to ink certain pixel positions more than two times, for example three times, in a single image -- or through use of spatial averaging arrangements to provide a mean deposition of fractional drops. More-than-double fractional inking has been found particularly useful for secondary colors (red, green and blue in preferred embodiments) on transparency and glossy stock -- and can be achieved by, for instance, "stripping" selected data bits from the pattern.

Preferably such data stripping is introduced starting in the fourth pass (pass 4 in the tabulation above). As an example, suppose that a particular pixel is to receive 2.5 dots, on the average, of red ink.

In other words, in half of the passes that pixel is to receive one yellow and one magenta (symbolized "YM") and in the other half of the passes it is to receive one





Substitute sheet - 27 August 1996

-37-

yellow and two of magenta (YMM), instead of the simplest-case four dots (YMYM). To implement this plan, that pixel would receive the first "YM" in the first three passes; and in the remaining passes that pixel would be given a single-bit-stripped treatment to add one more dot of magenta and so yield YMM.

Secondaries ordinarily in each position receive two drops (one of each of two different colors), so by this treatment secondaries if not data-stripped would receive four. Colors produced in this way are very rich, but such excess colorant deposition produces blocking etc. as described earlier; an extra alternating firmware switch or so-called "filter" can be put into operation to suppress or strip the alternate drops.

The result can be tailored to produce either two or four drops at selected pixels -- and thus three, or two and a half, etc. per position on the average. Further detail appears in the Askeland document.

If in addition to inking each swath in six passes the printing medium is advanced relative to the pen after each pass -- in other words, if the medium is advanced six times per swath -- then besides improved drying the invention also relieves medium-advance-direction positioning error each one-sixth swath.

That is, advance errors are smaller since the step size is only half as large (0.67 mm rather than 1.33 mm); and the advance errors are averaged over six advances rather than only three. In addition to these benefits, six-pass modes as outlined above facilitate use of fractional-dot techniques to optimize hue and chroma for each color and printing medium.

An overall result of a six-pass method is to balance the need for high quality and high throughput. Although taking more passes (eight, twelve, etc.) would accomplish the same or better quality goals, throughput would be significantly degraded. Conversely, as mentioned earlier four, or preferably more than four, passes will produce some improvement in quality and are considered within the

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REPLACEMENT SHEET

28 AUG 1996

Substitute sheet - 27 August 1996

- 38 -

scope of ce in of the appended claims but the quality provided by six passes is believed to be significantly better.

3. DOUBLE-FREQUENCY BLACK ON RETRACE

It has been found that finer control of black inking at high throughput can be provided with reasonable economy through use of a higher-frequency positioning waveform for black -- and actual printing of black -- only during each return sweep of the pen. The return pass of the pen is known as the "retrace".

An additional interpolation stage can be put into operation -- and the resulting signal transmitted on the pen signal bus -- straightforwardly on retrace. As no other precise-pen-position signals are in use then, there is no interference with control signals for other colors.

Preferably the position waveform for black on retrace is at twice the frequency used for other colors on the forward sweep. The result is twice as many pixel positions -- with corresponding ability to represent finer detail -- and the pen discharge signals can be correspondingly adjusted to make the resulting ink spots smaller.

Whereas a pixel spacing of about twelve per millimeter (three hundred dots per inch) is appropriate for the color-ink spots, the double-frequency black-ink positioning signal produces a spacing of about twenty-four dots per millimeter (six hundred per inch). In printing of text alone, in black and without any color printing, the higher frequency and the finer pixel spacing are preferably used in both directions rather than only on retrace.

While this system of printing black on retrace, when it is part of a color image, resolves the difficult problem of multiplexing different pens that are operating at different frequencies, other factors too militate in favor of this method. One such factor is that positional preci-

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REPLACED

28 AUG 1996

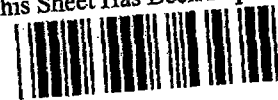
Substitute sheet - 27 August 1996

- 39 -

sion in bidirectional operation is in fact adequate for such operation; this high precision is obtained through use of a related invention disclosed in the previously mentioned document of Raskin et al.

Another factor is that this system very significantly enhances throughput, as the time required to print black on retrace is considerably less than the time required to print black in a separate forward sweep plus the time required for two nonprinting return slews. This advantage is particularly notable in comparison with the major alternative of printing black in a separate forward sweep, between color passes.

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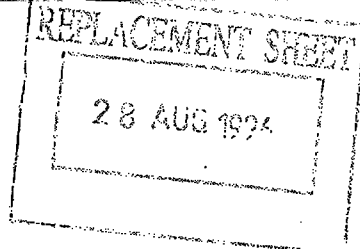


4. SUMMARY OF PRINT MODES

In its most highly preferred practice, the invention makes use of several different, complicated combinations of operating parameters and characteristics to accommodate various operating requirements. These combinations are summarized below.

<u>mode</u>	<u>passes</u>	<u>thru- put pg/min</u>	<u>RET</u>	<u>di- rec- tions</u>	<u>scan speed cm/sec</u>	<u>re- trace cm/sec</u>	<u>heat W</u>	<u>den- si- ton.</u>	<u>max.freq. kHz</u>	<u>split text</u>
FAST:										
text	1	6	no	bi	67.6	67.6	73	yes	8	OK
graph- ics	1	1.4	no	uni	33.8	88.9	73	yes	4	
NORMAL:										
text	1	6	no	bi	67.6	67.6	73	yes	8	no
graph- ics	3	0.56	no	uni	50.8	88.9	73	yes	2 2	

THIS SHEET HAS BEEN
REPLACED



Substitute sheet - 27 August 1996

- 40 -

HIGH-QUALITY:

text	1	4	yes	bi	33.8	33.8	73	yes	8	no
------	---	---	-----	----	------	------	----	-----	---	----

graph-

ics	3	0.45	yes	bi	50.8	50.8	73	yes	2	4
-----	---	------	-----	----	------	------	----	-----	---	---

- color forward;
- black on retrace

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TRANSPARENCY:

6	0.33	no	uni	50.8	88.9	63	no	2	2
---	------	----	-----	------	------	----	----	---	---

GLOSSY:

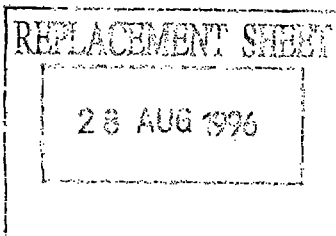
6	0.33	no	uni	50.8	88.9	27	no	2	2
---	------	----	-----	------	------	----	----	---	---

In this tabulation, the column heading "RET" represents "resolution-enhanced technology" -- the system described above in which black is printed at a pixel spacing of twenty-four pixels per millimeter along the pen-scan axis, rather than the standard twelve. In the preferred system described here, the pixel spacing along the printing-medium-advance axis remains twelve whether RET is in use or not.

The column heading "densitom." refers to a subsystem by which the firmware preevaluates on a swath-by-swath basis the optical density of image areas not yet reached in actual printing -- but to be printed soon. If the optical density (and therefore quantity of ink) will shortly be high, then the printing is decelerated gradually to accommodate the anticipated higher drying demands while at the same time avoiding abrupt speed-change-generated image discontinuities. In fast and normal modes the turn-on threshold is much higher and the slowdown is much smaller than those used for high-quality mode.

The column headings "CMY" and "K" refer to ink color: CMY represents the chromatics cyan, magenta and yellow respectively; and K represents black. The machine preferably switches to three-pass "graphics" printing automatically in normal or high-quality mode whenever (a) the

THIS SHEET HAS BEEN
REPLACED



Substitute sheet - 27 August 1996

- 41 -

swath contains color or (b) black text or graphics cross the swath boundary. The sole distinction between single-pass "text" printing as between the fast and normal modes appears in the right-hand column: only in the fast mode is text split.

As drying of transparencies and glossy media must rely more heavily upon convection, a drying fan is operated in those modes. Transparency stock can accept considerable warping; therefore in transparency mode the heater power is almost as high as for the paper modes tabulated above. Glossy stock, however, being hypersensitive to warp, is best heated only slightly as indicated.

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5. HARDWARE FOR IMPLEMENTING THE INVENTION

Fig. 1 illustrates the general preferred layout of a programmed-microprocessor-based printing machine according to the invention. An input stage 41, which may include manual controls, provides information defining the desired image. The output 42 of this stage may proceed to a display 43 if desired to facilitate esthetic or other such choices; and, in the case of color printing systems, to a color-compensation stage 44 to correct for known differences between characteristics of the display 43 and/or input 41 system vs. the printing system 47-61-31-32-33.

An output 45 from the compensator 44 proceeds next to a rendition stage 46 that determines how to implement the desired image at the level of individual pixel-position printing decisions -- for each color, if applicable. The resulting output 47 is directed to a circuit 61 that determines when to direct a firing signal 77 to each pen 31.

The pens discharge ink 32 to form images on paper or some other printing medium 33. Meanwhile typically a medium-advance module 78 provides relative movement 79 of the medium 33 in relation to the pens 31.

In developing its firing-signal determination, the firing circuit 61 must take into account the position of

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REPLACEMENT SHEET

28 AUG 1996

Substitute sheet - 27 August 1996

- 42 -

the pen carriage 62, pen mount 75 and pen 31. Such accounting is enabled by operation of an electrooptical sensor 64 that rides on the carriage 62 and reads a code-strip 10.

A timing module 72 is positioned in the line between the sensor 64 and firing circuit 61. The timing module 72 provides for various special positioning functions, including encoder-signal inversion or equivalent, during scanning in one of two directions.

It also provides for backing off by one pulse and then delay in pen firing, also during scanning in one of two directions. Most particularly for purposes of the present invention the timing module 72 switches into use the interpolated, double-frequency positioning signal mentioned above, for use only in printing black on re-trace, when colors are being printed in the alternating forward sweeps. (As noted earlier, this signal is also used in printing black bidirectionally, when colors are not being printed; but in this case the use of the interpolated signal is not switched by the timing module.)

Operation of this timing module 72 thus is not desired at all times, but rather only synchronously with the directional reversals of the carriage 62. Specifically, the timing module 72 is to be inserted during operation in one direction only, and replaced by a straight-through bypass connection 73 during operation in the other direction -- in other words, operated asymmetrically -- and this is the reason the timing module 72 is labelled in Fig. 1 "asymmetrical".

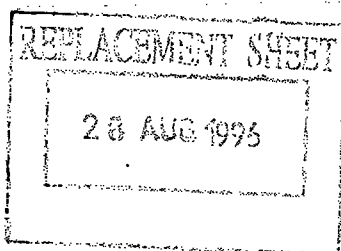
This synchronous insertion and removal is symbolized in Fig. 1 by a switch 67 which selects between the conventional connection 73 and a timing-module connection 71. This switch 67 is shown as controlled by a signal 66 that is in turn derived from backward motion 63_b of the pen carriage 62.

Thus the switch 67 is operated to select the timing-module connection 71 during such backward motion 63_b, and to select the bypass or conventional route 73 during

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Substitute sheet - 27 August 1996

- 43 -

forward motion 63_p. This representation is merely symbolic for tutorial purposes; people skilled in the art will understand that the switch 67 may not exist as a discrete physical element, and/or may instead be controlled from the forward motion 63_p and/or -- as will much more commonly be the case -- can be controlled by some upstream timing signal which also controls in common the pen-carriage motion 63_p, 63_p. Further the synchronous switch 67 need not be at the input side of the timing module 72 but instead at the output side -- where in Fig. 1 a common converging signal line 74 is shown as leading to the firing circuit 61 -- or may in effect be at both sides.

Use of a system as illustrated in Fig. 1, at least as most naturally interpreted, will result in the encoder-signal inversion, the pulse "backing off" step and the firing delay step all being performed during pen motion in the same, common ("backward") direction. This limitation while preferred is not required for successful practice of the invention.

6. TOP/BOTTOM-OF-PAGE MASK ROTATION ONLY

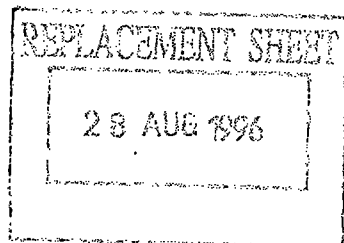
At the bottom of each sheet of print medium, a relatively tall region, that may be called the bottom-of-page "handoff" zone, is defined by the distance between sets of rollers that hold the medium taut. As noted earlier -- and as explained in greater detail in the above-mentioned Broder *et al.* document -- preferably for printing on paper in this region the printing-medium advance height is lowered to half (Fig. 2c) its normal midpage value (Fig. 2b).

For example, in a preferred embodiment each pen has ninety-six nozzles and so makes a ninety-six-pixel swath; the normal advance distance (except for plastic media, per this invention) is one third of this height, or thirty-two pixels -- 1.33 mm, for a preferred pixel spacing of 1/24 mm (Fig. 2b). When the medium cannot be tensioned, as set

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Substitute sheet - 27 August 1996

- 44 -

forth by Broder et al. the advance preferably is halved to sixteen pixels or about 0.7 mm (Fig. 2c).

In shallower end zones consisting of the single top (Fig. 2a) and bottom (Fig. 2d) swaths on each sheet of medium, however, according to the present invention the advance height is reduced to zero -- i. e., eliminated entirely. This is done when the pen (or set of pens) is at either end of the data, but most preferably only if that occurs while the medium is untensioned -- either in the "handoff" zone or an analogous one at the top.

This operating mode is particularly important when the pen is actually printing along the top or bottom edge of the sheet. Ordinarily good performance is not obtained with the pen skimming partly on and partly off the edge, but space rotation would demand starting or ending in just that condition, to provide three or six passes in a fractional-swath zone along the edge. Under these circumstances, since space rotation can no longer be made to occur, in effect, as a consequence of print-medium advance, it is provided through sweep rotation -- changing the inking pattern between pen scans.

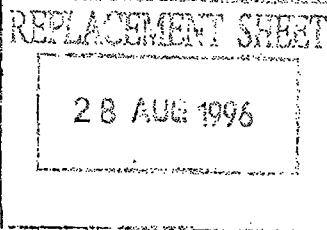
On each page the mask is first sweep-rotated on the pen by firmware, for the first two sweeps, while the pen is stationary (Fig. 2a); then the mask is fixed on the pen and paper advance begins (Fig. 2b), producing space rotation -- that is, the mask does not change relative to the pen -- and most of the page is printed in this normal three-pass mode. In the handoff zone, but not yet at the end of data, the system makes a transition to one-sixth advance, and only half (forty-eight) of the nozzles print, but the mask is still space rotated (Fig. 2c). When final data are reached, advance again halts and the remaining two passes are flushed out -- with firmware sweep-rotating the mask (Fig. 2d).

The above disclosure is intended as merely exemplary, and not to limit the scope of the invention -- which is to be determined by reference to the appended claims.

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Substitute sheet - 27 August 1996

- 45 -

WHAT IS CLAIMED IS:

1. A method of printing desired images on a low-liquid-absorption printing medium, by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism; said method comprising the steps of:

scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen, each nozzle corresponding to one pixel row;

periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen; and

in each scanning of the head across the medium, firing at most one-third of the nozzles in each pixel-position column and thereby depositing, over the total number of scans at each pixel row, at least two drops of ink in each pixel position that is inked.

2. The method of claim 1, wherein:

for portions of a desired image in which a mark is desired in every pixel position, the firing step comprises firing substantially one-third of the nozzles in substantially every pixel-position column.

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3. The method of claim 2, wherein:

the medium-advancing step comprises advancing the medium between substantially every pair of scans of the pen.



REPLACEMENT SHEET

28 AUG 1996

Substitute sheet - 27 August 1996

- 46 -

4. The method of claim ¹⁰⁴2, wherein:
the medium-advancing step comprises advancing the medium by a number of pixel rows equal to substantially one-sixth of the number of operating nozzles of the pen, between substantially every pair of scans of the pen.

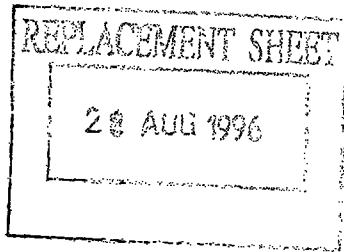
5. The method of claim 1, wherein:
the medium-advancing step comprises advancing the medium by a number of pixel rows equal to an integral multiple of one-sixth of the number of operating nozzles of the pen, between substantially every pair of scans of the pen.



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Substitute sheet - 27 August 1996

- 47 -

6. A method of printing desired images on a low-liquid-absorption printing medium, by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism; said method comprising the steps of:

scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen, each nozzle corresponding to one pixel row;

periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen; and

in each scanning of the head across the medium, firing at most one-sixth of the nozzles in each pixel-position column.

7. The method of claim 6, wherein:

for portions of a desired image in which a mark is desired in every pixel position, the firing step comprises firing substantially one-sixth of the nozzles in substantially every pixel-position column.



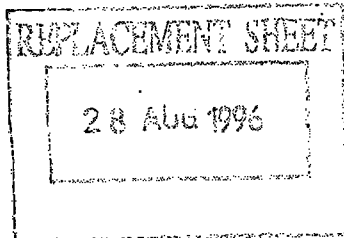
8. The method of claim 7, wherein:

the medium-advancing step comprises advancing the medium between substantially every pair of scans of the pen.

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Substitute sheet - 27 August 1996

- 48 -

9. The method of claim ^{6 or} 7, wherein:
the medium-advancing step comprises advancing the medium by a number of pixel rows equal to substantially one-sixth of the number of operating nozzles of the pen, between substantially every pair of scans of the pen.

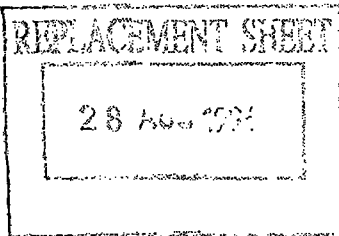
10. The method of claim 6, wherein:
the medium-advancing step comprises advancing the medium by a number of pixel rows equal to an integral multiple of one-sixth of the number of operating nozzles of the pen, between substantially every pair of scans of the pen.



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Substitute sheet - 27 August 1996

- 49 -

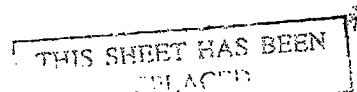
||. A method of printing a desired image, which has two ends, on a printing medium by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism; said printing medium being held taut beneath the pen between two sets of rollers except while printing near top and bottom edges of the printing medium, when it is constrained from only one direction by one of said sets of rollers; said method comprising the steps of:

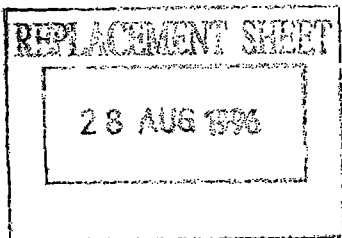
scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen, each nozzle corresponding to one pixel row;

when the pen is not substantially at either end of the desired image, and while the medium is held taut between two sets of rollers, periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen; whereby the pen moves stepwise from one end of the image to the other; and

when the pen is substantially at either end of the desired image, at least if the medium is constrained from only one direction by one set of rollers and at least until completion of full inking for the swath of pixel rows that is exposed to the nozzles of the pen: holding the printing medium substantially stationary relative to the pen while performing a plurality of said scanning steps.

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Substitute sheet - 27 August 1996

- 50 -

12. The method of claim 11, wherein:

during the holding-stationary step, said scanning steps comprise employing a sequence of print masks in rotation to progressively provide full inking for the swath of pixel rows that is exposed to the nozzles of the pen; and

said sequence of masks is such as to compensate for absence of printing-medium advance.

13. The method of claim 12, wherein:

the mask-sequence-employing step comprises changing nozzle printing patterns between substantially every pair of scans of the pen.

14. The method of claim 13, wherein:

each said scanning step comprises firing at most one-third of the nozzles in each pixel-position column and thereby depositing, over the total number of scans at each pixel row, at least two drops of ink in each pixel position that is inked.

15. The method of claim 13, wherein:

each said scanning step comprises firing at most one-sixth of the nozzles in each pixel-position column.

16. The method of claim 11, wherein:

the periodically-advancing step comprises advancing the printing medium between substantially every pair of scans of the pen.

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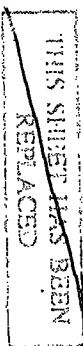


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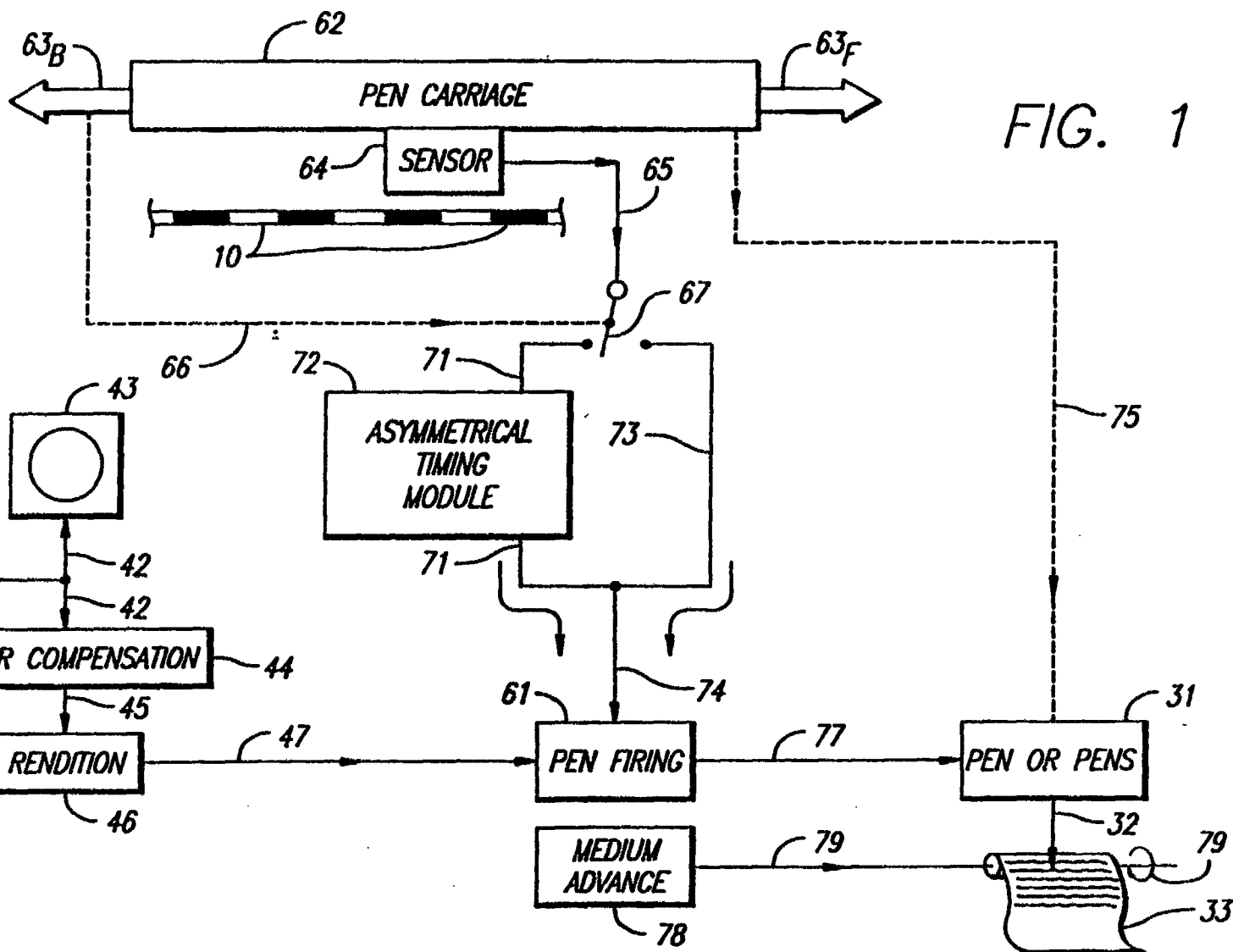




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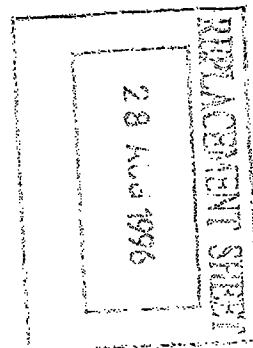


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Substitute sheet - 27 August 1996



28 AUG 1996

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Substitute sheet - 27 August 1996

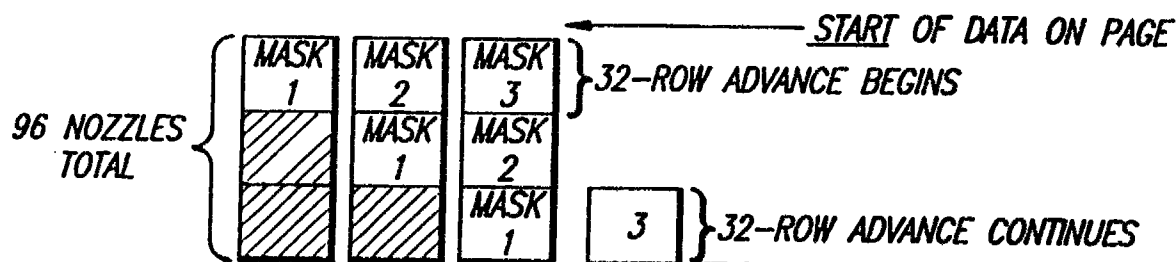


FIG. 2a

- SWEEP ROTATION
- NO ADVANCE

FIG. 2b

- 3-PASS NORMAL MODE
- 32-NOZZLE ADVANCE
- 96 NOZZLES PRINTING
- SPACE ROTATION

/// = NOZZLES DISABLED

FIG. 2c

- HANDOFF ZONE
- TRANSITION TO 16-NOZZLE ADVANCE
- 48 NOZZLES PRINTING
- SPACE ROTATION

FINAL DATA REACHED

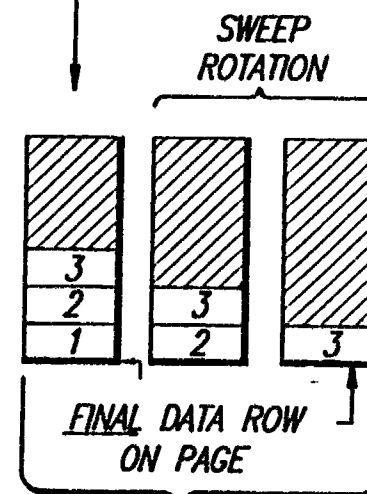
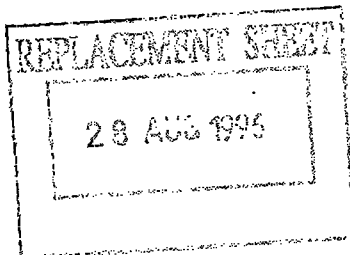


FIG. 2d

- NO ADVANCE

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Substitute sheet - 27 August 1996

ABSTRACT

INKJET PRINTING: MASK-ROTATION-ONLY AT PAGE EXTREMES: MULTIPASS MODES FOR QUALITY & THROUGHPUT ON PLASTIC MEDIA

Images are printed using marks formed in pixel arrays by a scanning print head. For transparent and glossy media, with poor absorbance, drying is enhanced by a multipass (preferably six-pass) print mode in which the total number of ink drops or spot is allocated among correspondingly multiple masks, though some may be duplicates. To further hasten drying, heat is applied -- through the medium, from the opposite side as that on which ink is deposited -- but the amount of heat is strictly moderated, particularly for nontransparent glossy media, to accommodate the hypersensitivity of these media to heat-induced warping. Heating for glossy media is preferably restricted to about one-third the power used for drying plain paper. Convective drying too is promoted, by operating a fan over the printed image. Certain special techniques well-suited for plain-paper printing have been found undesirable for use with plastic media; these techniques include so-called "resolution-enhanced technology", bidirectional printing (particularly of black), and optical-density controlled printing speed. At top and bottom of each page or sheet of printing medium, where it is undesirable to operate with the pen partly off the edge of the sheet, and where also the printing medium is constrained from only one direction rather than being held taut beneath the pen, the print mask is rotated while the printing medium is held stationary -- thereby entirely avoiding reliance upon accuracy of print-medium advance.

(Figure 2)

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||. A method of printing a desired image, which has two ends, on a printing medium by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism; said printing medium being held taut beneath the pen between two sets of rollers except while printing near top and bottom edges of the printing medium, when it is constrained from only one direction by one of said sets of rollers; said method comprising the steps of:

scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen, each nozzle corresponding to one pixel row;

when the pen is not substantially at either end of the desired image, and while the medium is held taut between two sets of rollers, periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen; whereby the pen moves stepwise from one end of the image to the other; and

when the pen is substantially at either end of the desired image, at least if the medium is constrained from only one direction by one set of rollers and at least until completion of full inking for the swath of pixel rows that is exposed to the nozzles of the pen: holding the printing medium substantially stationary relative to the pen while performing a plurality of said scanning steps.

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12. The method of claim 11, wherein:

during the holding-stationary step, said scanning steps comprise employing a sequence of print masks in rotation to progressively provide full inking for the swath of pixel rows that is exposed to the nozzles of the pen; and

said sequence of masks is such as to compensate for absence of printing-medium advance.

13. The method of claim 12, wherein:

the mask-sequence-employing step comprises changing nozzle printing patterns between substantially every pair of scans of the pen.



14. The method of claim 13, wherein:

each said scanning step comprises firing at most one-third of the nozzles in each pixel-position column and thereby depositing, over the total number of scans at each pixel row, at least two drops of ink in each pixel position that is inked.

15. The method of claim 13, wherein:

each said scanning step comprises firing at most one-sixth of the nozzles in each pixel-position column.

16. The method of claim 11, wherein:

the periodically-advancing step comprises advancing the printing medium between substantially every pair of scans of the pen.



23 AUG 1999

Substitute sheet - 23 August 1999

- 1 -

INKJET PRINTING:-MASK-ROTATION-ONLY AT PAGE EXTREMES;
MULTIPASS MODES FOR QUALITY & THROUGHPUT ON PLASTIC MEDIA

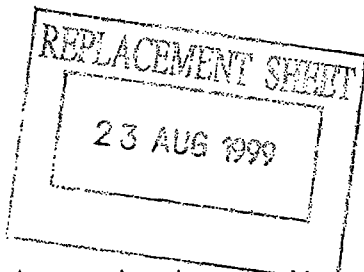
RELATED PATENT DOCUMENTS

Three closely related documents are other, coowned U. S. utility-patent applications filed in the United States Patent and Trademark Office substantially contemporaneously with this document -- and also hereby incorporated by reference in its entirety into this document. One is in the names of Ronald A. Askeland et al., and identified as Hewlett Packard Company docket number PD-1093053-1, and entitled "INKING FOR COLOR-INKJET PRINTERS, USING NONINTEGRAL DROPS, MEDIA-DEPENDENT INKING, OR MORE THAN 2 DROPS/PIXEL" -- and subsequently assigned utility-patent application serial 08/____,____, and issued as U. S. Patent 5,____,____ on _____, 199____. Another such document is in the names of Gregory D. Raskin et al., and identified as Hewlett Packard Company docket number PD-189492, and entitled "DIRECTION-INDEPENDENT ENCODER READING; POSITION LEADING & DELAY, & UNCERTAINTY TO IMPROVE BIDIRECTIONAL PRINTING" -- and subsequently assigned utility-patent application serial 08/____,____, and issued as U. S. Patent 5,____,____ on _____, 199____. A third related document is in the names of Broder et al., and identified as Hewlett Packard Company docket PD-1092153-1, and entitled "COMBINED CENTRAL AND LATERAL HOLD-DOWN PLATES, AND END-OF-PAGE ADVANCE-DISTANCE DECREASE, IN LIQUID-INK PRINTERS" -- and subsequently assigned utility-patent application serial 08/____,____, and issued as U. S. Patent 5,____,____ on _____, 199____.

BACKGROUND

1. FIELD OF THE INVENTION

This invention relates generally to machines and procedures for printing text or graphics on printing media such as paper, transparency stock, or other glossy media;



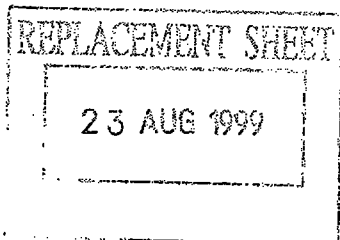
in the printing-medium advance, particularly near the bottom or end of each page. ~~That system and its benefits are described in the Broder et al. document mentioned earlier; although that system represents a major contribution to attainment of good print quality near the bottom of the page, nevertheless precision is not improved to the level enjoyed in regions where the medium is held taut.~~

(d) Known technology of print modes: general introduction -- One particularly simple way to divide up a desired amount of ink into more than one pen pass is the checkerboard pattern mentioned above: every other pixel location is printed on one pass, and then the blanks are filled in on the next pass.

To avoid the banding problem (and sometimes minimize the moire patterns) discussed above, a print mode may be constructed so that the paper advances between each initial-swath scan of the pen and the corresponding fill-swath scan or scans. In fact this can be done in such a way that each pen scan functions in part as an initial-swath scan (for one portion of the printing medium) and in part as a fill-swath scan.

Once again this technique tends to distribute rather than accumulate print-mechanism error that is impossible or expensive to reduce. The result is to minimize the conspicuousness of -- or, in simpler terms, to hide -- the error at minimal cost.

For instance a two-pass print mode may start a page by printing with only some of the nozzles in an array of only half of the pen's nozzles, all positioned at one end of the pen -- as an example, selected ones of the nozzles consecutively numbered one through fifty, on a hundred-nozzle pen. This first pass may be in a checkerboard pattern -- thus actually using, e. g., for example, exclusively odd-numbered nozzles 1, 3, . . . in the first row, and then only even-numbered nozzles 12, 14, . . . in the second row, next selecting only odd-numbered nozzles 21,



23, . . . again in the third row, etc. -- and thus printing in half of the pixel locations in the swath area.

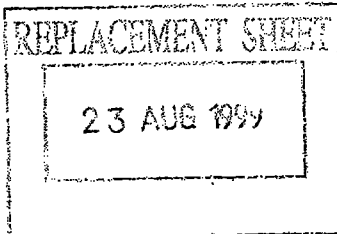
The paper then advances by a distance equal to the length of the half-array of nozzles (in other words, the height of fifty nozzles), and the pen would print in both ends of its nozzle array -- but again only printing a fifty-percent checkerboard pattern. Now, however, while the forward end of the pen (selected ones of nozzles one through fifty) as before prints on fresh paper, the rearward end (selected ones of nozzles numbered fifty-one through one hundred) fills in the area already printed.

This behavior is then repeated all down the page until the last swath -- which is a fill-in swath only, again using selected nozzles of those numbered fifty-one through one hundred.

(e) Space- and sweep-rotated print-mode masks -- The pattern used in printing each nozzle section is known as the "print-mode mask". The term "print mode" is more general, usually encompassing a description of a mask, the number of passes required to reach full density and the number of drops per pixel defining "full density".

In the two-pass example above, the second half of the pen (certain ones of nozzles numbered fifty-one through one hundred) filled in the blank spaces left by the first half. For each pass, this may be symbolized using a letter "x" for each pixel that is printed and a letter "o" for each pixel that is not, as follows. as shown in Figure 3.

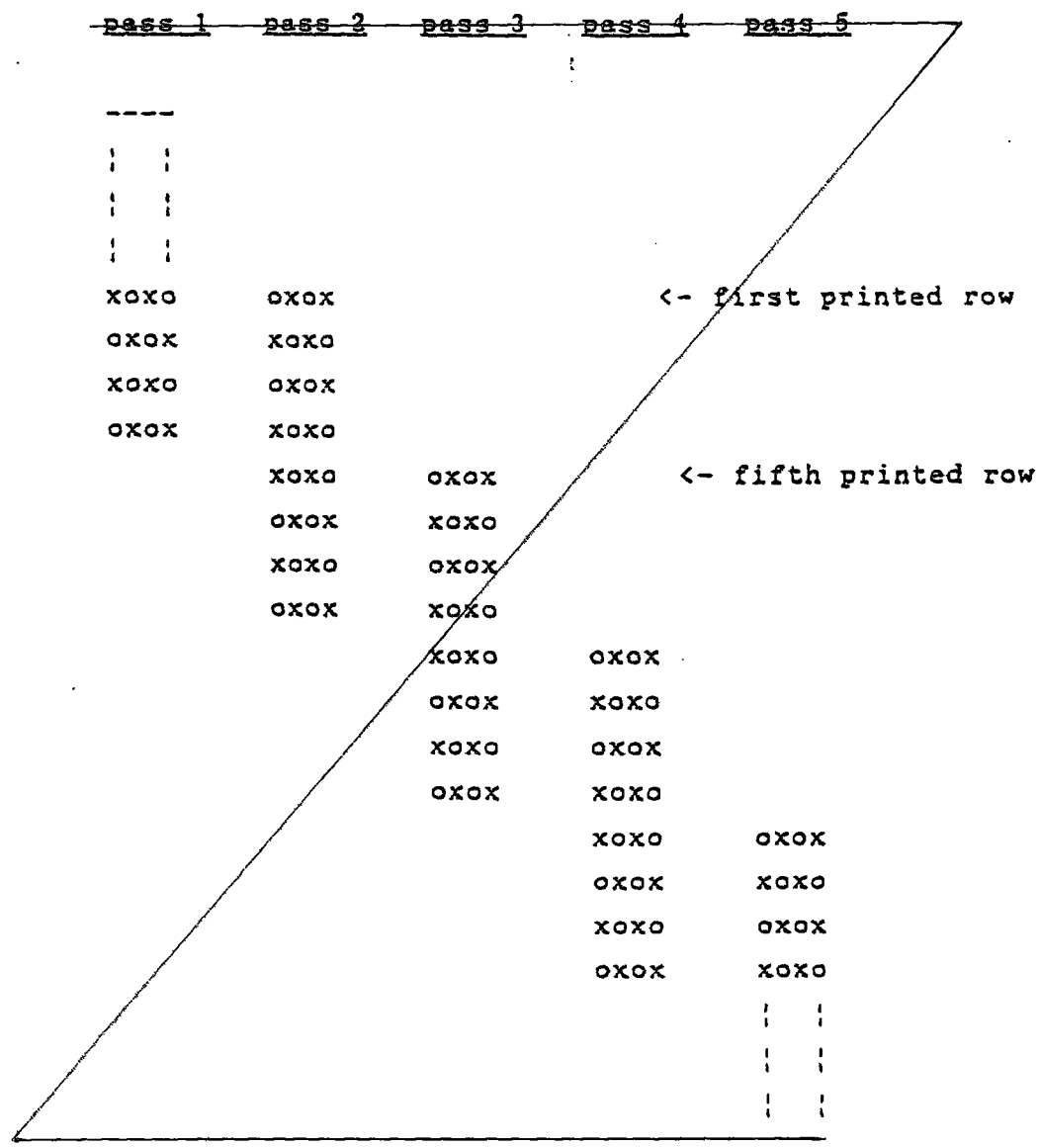
<u>pattern 1:</u>	<u>pattern 2:</u>
<u>nozzles 1 through 50</u>	<u>nozzles 51 through 100</u>
xoxoxoxoxo	oxoxoxoxox
oxoxoxoxox	xoxoxoxoxo
xoxoxoxoxo	oxoxoxoxox
oxoxoxoxox	xoxoxoxoxo
xoxoxoxoxo	oxoxoxoxox



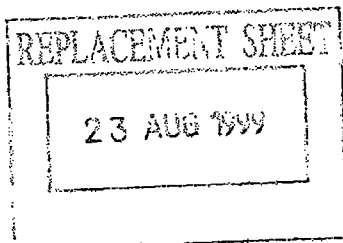
Substitute sheet - 23 August 1999

- 9 -

nozzles fifty-one through one hundred in "pattern 2". This is known as "space rotated" masking; using this method to print down the page would progressively produce these patterns -- illustrated ^{in Figure 4} here too using an abbreviated vertical nozzle-array representation of just eight nozzles rather than one hundred:



In this mode, the pen uses the same pattern all down the page, but the mask is different in different portions of the pen: "pattern 1" for nozzles one through fifty (represented in the abbreviated drawing by the lower four



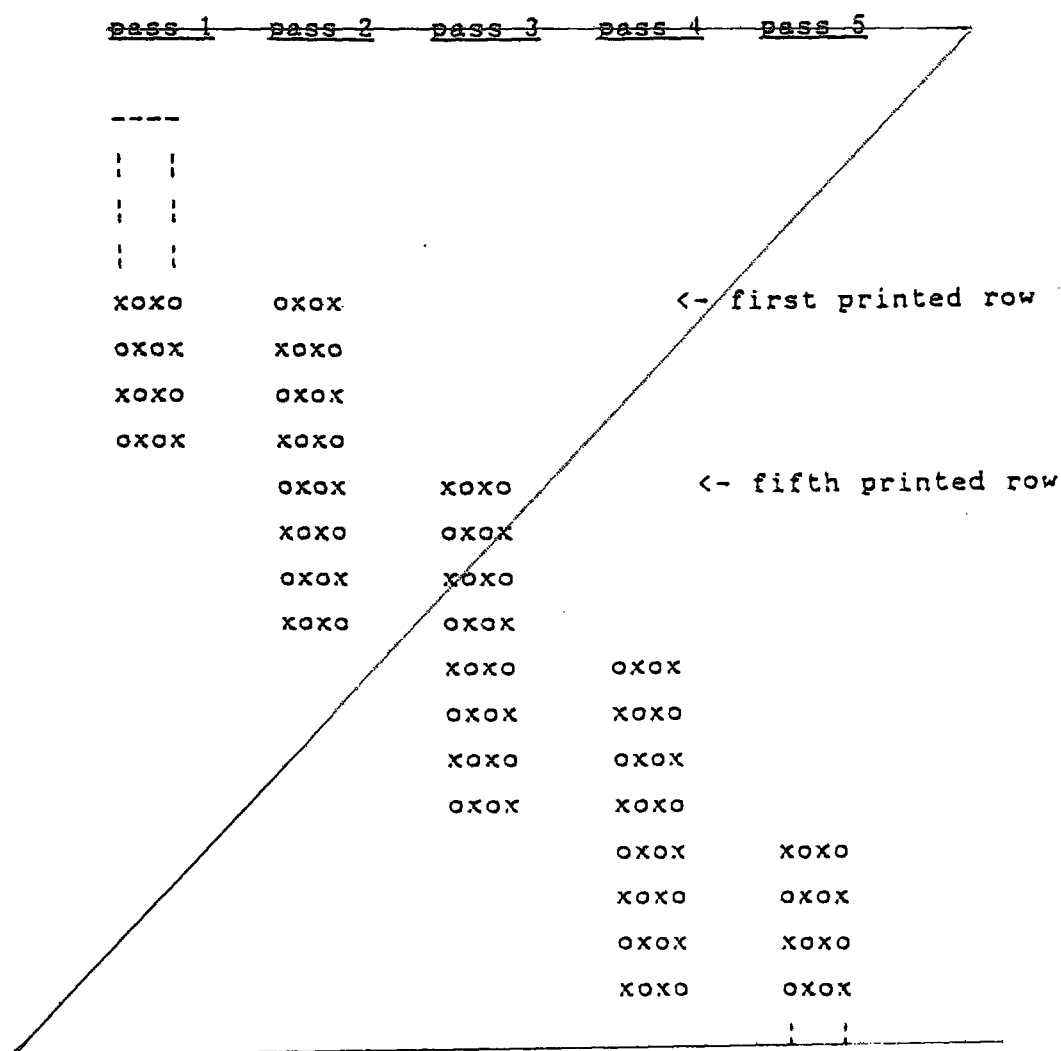
Substitute sheet - 23 August 1999

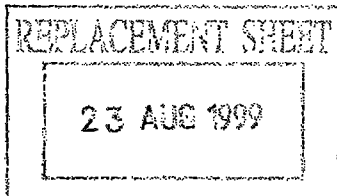
- 10 -

positions in each eight-nozzle group); vs. "pattern 2" for nozzles number fifty-one through one hundred (represented by the upper four positions in each group).

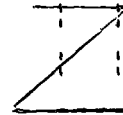
The availability of this method of masking for various printing devices depends in part on the basic mechanical and firmware architecture of each device. In particular, it depends upon whether the basic operating system provides for efficient addressing of different mask patterns to different segments of the overall nozzle array.

Another way to use the same print mode is to apply one mask pattern to the entire pen, but to change that mask pattern from pass to pass. This is so-called "sweep rotated" masking -- still using the same abbreviated representation for purposes of illustration+is shown in Figure 5.





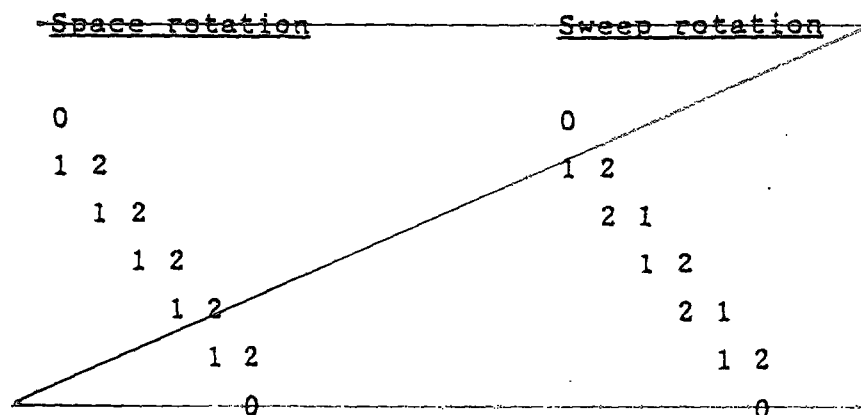
- 11 -



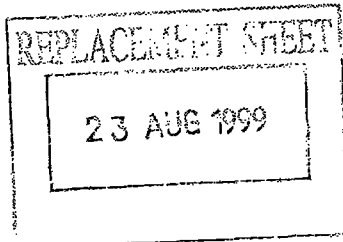
In both these diagrams -- as in the basic "pattern 1" and "pattern 2" diagrams discussed just before, it can be seen by reading all the way across any row that after both passes at each row all positions in that row are filled -- but by comparing the space- and sweep-rotation diagrams it will now be appreciated that the order in which some of the positions are filled in sweep rotation is opposite to that in which they are filled in space rotation. For example, in the fifth printed row the left-hand column is printed in the second pass (and the adjacent column left blank for printing later) in space rotation -- but is printed in the third pass (after the adjacent column) in sweep rotation.

, in Figure 6,

This can be shown more compactly by a different notation that allows comparison of space and sweep rotation side by side. In this notation, "0" represents nozzle groups that are not fired at all -- at the top and bottom scans of the page -- while "1" and "2" represent not individual pixel rows but rather half-swaths, in "pattern 1" and "pattern 2" as defined above.



Now in these abbreviated forms it is easier to see that within the printed image every half-swath receives one "1" and one "2" -- but not always in the same order. Thus in



Substitute sheet - 23 August 1999

- 12 -

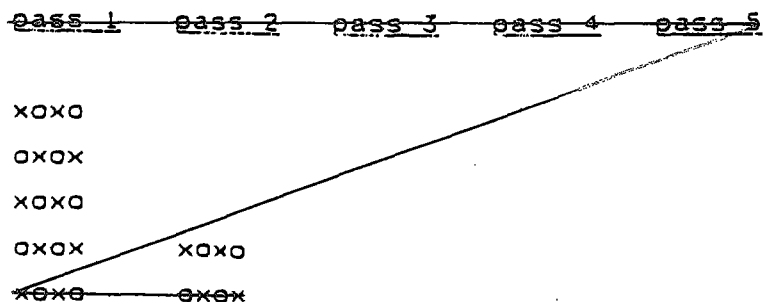
the second half-swath the "1" goes down first in space rotation, but second in sweep rotation.

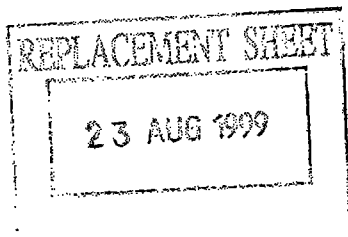
(f) Autorotating print-mode masks -- Operating parameters can be selected in such a way that, in effect, rotation occurs even though the pen pattern is consistent over the whole pen array and is never changed between passes. Figuratively speaking this can be regarded as "automatic" rotation or simply "autorotation".

To understand what produces this condition, it is necessary first to take note of what constitutes a basic cell or unit of the print-mode mask, and then to note its height h_c in pixels. It is also necessary to note the number of pixels (or the length measured in number of nozzles) by which the paper moves m_p in each of its advances. For example, in the simple cases diagrammed above, since each mask repeats every two rows, $h_c = 2$; and the paper advances by fifty nozzles at a time, so $m_p = 50$ (or as in the abbreviated-notation diagram the paper advances four diagrammed nozzles at a time, so $m_p = 4$).

The next step is to determine whether the ratio m_p/h_c of these two parameters is integral. If so, as in this case, since $m_p/h_c = 50/2 = 25$ actually (or $4/2 = 2$ as illustrated), the mask will not autorotate.

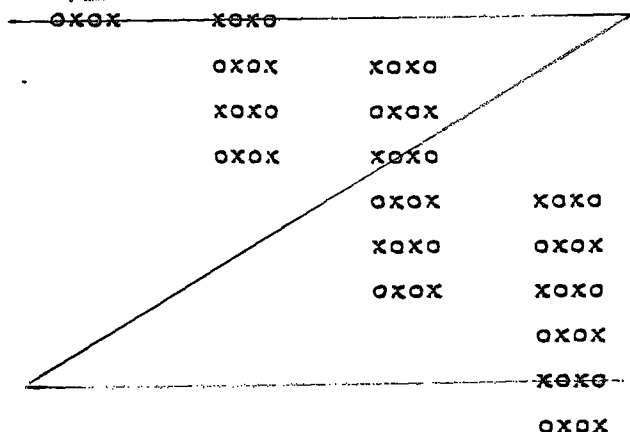
If however, in the two-pass example the paper advances by three diagrammed pixel rows instead of four -- but the basic cell remains two pixels tall -- then for this case as diagrammed the ratio $m_p/h_c = 3/2$ is nonintegral and at each pass the mask will "automatically" fill in the blank spaces left by the previous pass, as shown in Figure 7.





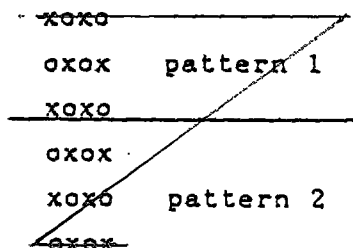
Substitute sheet - 23 August 1999

- 13 -

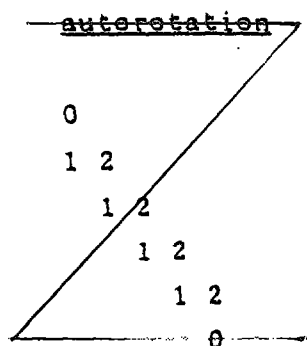


(This diagrammatic example symbolizes a real case of, for instance, three passes, a total of ninety-six nozzles used in the pen, thirty-two nozzles used in each of three sections of the pen, thirty-two-nozzle printing-medium advance -- and a basic-pattern cell three pixels tall. In algebraic notation, $m_p/h_c = 32/3$, a nonintegral ratio. This three-pass mode is discussed in the next section.)

The print mode produced in this way is essentially a space-rotation mode (though in a sense that condition is not specifically called for). For example, if the pen is a six-row pen as diagrammed above, the first three rows are in "pattern 1" and the second three are in "pattern 2", as shown in Figure 8.



For an autorotating case, either "pattern 1" or "pattern 2" may be used all down the pen. Thus the paper advance turns one simple pattern into a space-rotated mask "automatically". In the shorthand notation introduced above, the pen provides the following periodic behavior as the paper advances, as shown in Figure 9.



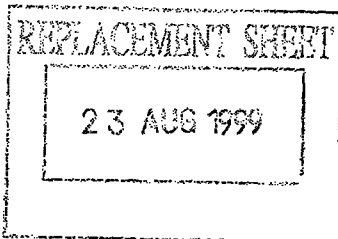
(g) Three-pass modes -- Heretofore, one highly favored print mode has specified a one-third-density-per-pass pattern that constructs dots in a diagonal pattern, as shown in Figure 10,

xoo
-ox-
oox

// rather than the one-half-density-per pass checkerboard modes discussed above. The diagonals, however, remain at forty-five degrees as in the checkerboard mode.

This pattern has been considered advantageous because it worked well with software dithering algorithms and had minimal tendency to create moire patterns when printing partial-density-shaded and gradient area fills. The use of forty-five-degree diagonals was considered particularly beneficial for its tendency to distribute error-hiding capability equally between vertical and horizontal axes of the pixel array to be constructed on the printing medium.

Generally a printing apparatus is characterized -- through its basic hardware and firmware design architecture -- by a general maximum-size print mask or mode pattern that can be formed with the apparatus in one pen pass; any mask pattern to be used with a printing apparatus must fit within its maximum pattern. For example, in a particular one printing device (of the Hewlett Packard Company) which produces high-quality images, that maximum mask or pattern size is eight rows tall and four columns



Substitute sheet - 23 August 1999

- 15 -

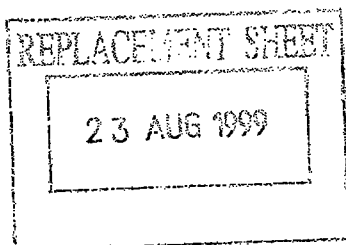
wide -- and will readily accommodate, among other possibilities, a mask that is three rows tall ($h_c = 3$) and three columns wide.

Just such a mask produces the one-third-density diagonal three-pass pattern introduced at the beginning of this section. If that mask is used in conjunction with a unit paper advance of thirty-two nozzles -- for a printing-medium advance movement $m_p = 32$ -- then the previously introduced ratio $m_p/h_c = 32/3$, which is not integral.

This combination of conditions accordingly provides autorotation of the three-row mask pattern shown above (as noted parenthetically in the preceding section). No mask rotation sequence is required; and a mask specification for the three passes accordingly might read "111" to indicate that the first column of the pattern should be used in common to begin each sweep -- that is, printing the pixel in column number one of the top row of the swath (assuming that there is any image information to print there). Equally well a mask specification might read "222" or "000", as indeed the ^{base} pattern may begin with printing in any of the three columns of the basic cell.

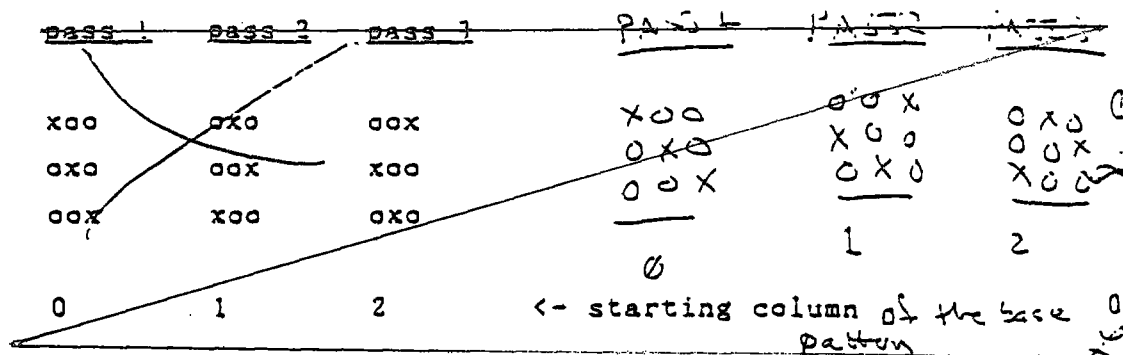
If instead the number of dot rows were an integral multiple of the pattern height, then as previously explained the printer would have to be instructed to use a rotation sequence telling it how to build the pattern in each succession of sweeps. For example, using the same three-row pattern but thirty-three-nozzle advance -- which is to say, a printing-medium-advance movement of thirty-three dot rows -- the ratio $m_p/h_c = 33/3$ is integral, and a rotation sequence must be specified.

Such a sequence might be "012". The numbers are the swath or pass numbers in which the respective columns of the base pattern will start a page. The printer will form so-called "swath number zero" (the first swath) using the first column of the pattern as the first column at top of the page, swath one (the second swath) using the second column as the first column at top of the page, and swath two (the third swath) using the third column, as follows, as shown in Figure 11.



Substitute sheet - 23 August 1999

- 16 -



The other equally acceptable sequences would be "021", "102", and all the other six rotations ("120", "201"; etc.) of these three root sequences. Now if a printer is stopped halfway through a page, using this cell and a diagrammatic six-dot-row paper advance, a pattern something like the following will be found -- regardless of whether space or sweep rotation is in use, as shown in Figure 12.

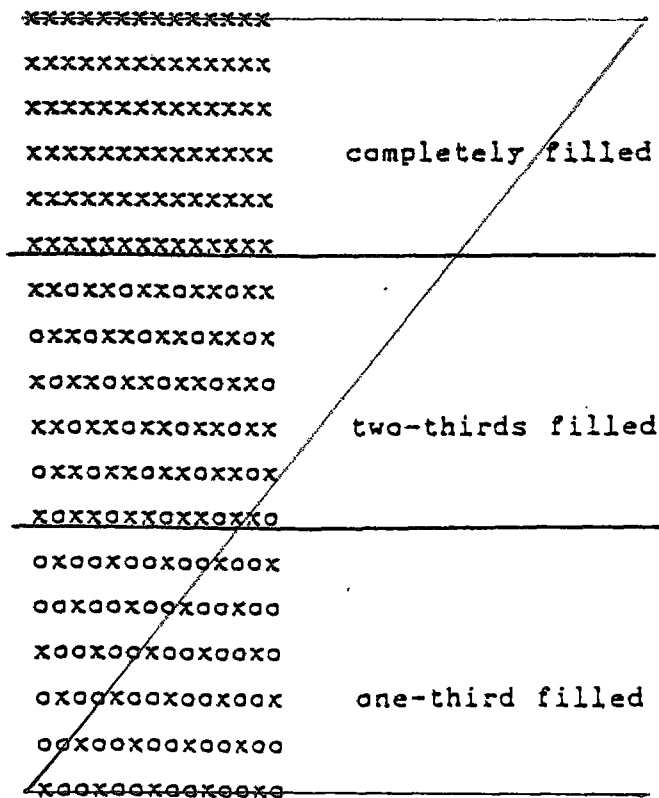


Figure 12

As before, this abbreviated diagram symbolizes the modern-ly more interesting practical case of thirty-three-nozzle advance. That case if fully pictured would appear as

23 AUG 1999

- 19 -

transparent media, heretofore have continued to impede achievement of uniformly excellent inkjet printing -- at high throughput -- on all industrially important printing media. Awkwardness of overprinting fine detail in black is another adverse limitation of the prior art. Thus important aspects of the technology used in the field of the invention remain amenable to useful refinement.

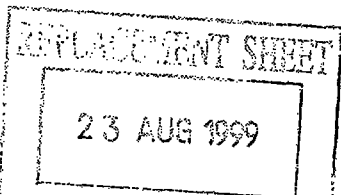
SUMMARY OF THE DISCLOSURE

The present invention introduces such refinement. According to the present invention there are provided methods of printing desired images as defined in independent claims 1 and 6. In its preferred embodiments, the present invention has several aspects or facets that can be used independently, although they are preferably employed together to optimize their benefits.

In preferred embodiments of a first facet or aspect of its aspects, the invention is a method of printing desired images on a printing medium by construction from individual marks formed in pixel arrays. The marks are formed by a scanning print head that operates in conjunction with a printing-medium advance mechanism.

The method includes the step of scanning the head repeatedly along a pen-scanning axis that is substantially orthogonal to a printing-medium-advance axis. The method also includes the step of, during each scan of the head along the pen-scanning axis, forming marks in a pattern that approximates at least portions of a large number of generally parallel, separated lines that are relatively steeply angled relative to the pen-scanning axis and relatively shallowly angled relative to the printing-medium-advance axis.

This first facet or aspect of the invention also includes the steps of (1) during one or more earlier scans with respect to each segment of an image, leaving unprinted regions between the angled lines; and (2) during one or more later scans with respect to each segment, filling in the unprinted regions.



cial effect because -- while the stationary-medium operation is being used -- in fact no print-medium positioning takes place, and accordingly no error in positioning can occur.

Although this method even as thus broadly couched serves an excellent purpose, nevertheless preferably it is performed with certain additional features or characteristics. During the holding-stationary step, the scanning steps preferably include employing a sequence of print masks in rotation to progressively provide full inking for the swath of pixel rows that is exposed to the nozzles of the pen; and preferably that sequence of masks is such as to compensate for absence of printing-medium advance.

Also it is preferred that the mask-sequence-employing step comprise changing nozzle printing patterns between substantially every pair of scans of the pen.

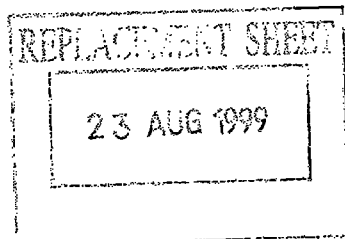
All of the foregoing operational principles and advantages of the present invention will be more fully appreciated upon consideration of the following detailed description, with reference to the appended drawings, of which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block-diagrammatic representation of a hardware system according to the invention; and

Figs. 2a through 2d are diagrammatic print-mask representations of inking patterns used in, respectively: (a) special top-of-page sweep mask rotation to enable suppression of printing-medium advance in that region, (b) midpage space rotation with one-third advance, (c) bottom-of-page handoff space rotation with one-sixth advance, and (d) special bottom-of-page sweep rotation to enable suppression of advance in that region.

Figs. 3 to 17A and 17B are diagrams of various print patterns.



Substitute sheet - 23 August 1999

-28-

DETAILED DESCRIPTION
OF THE PREFERRED EMBODIMENTS

1. STEEPER DIAGONAL

The print mask of the present invention forms diagonal lines that are skewed more toward the printing-medium advance direction than those of prior-art masks. This is beneficial because in this direction there tends to be more error due to paper advancement and paper shrinkage.

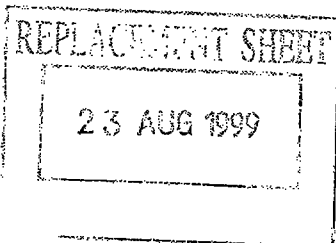
In at least some commercial printers the above-mentioned largest permissible pattern, within the basic architectural constraint of the printing apparatus that is in use, is rectangular and vertically oriented -- in other words, longer in the direction of the printing-medium advance. In this case, preferably the diagonals formed by the invention approximate the longest diagonal line possible within that vertically oriented largest permissible pattern.

Within the previously mentioned eight-by-four pattern constraint of one Hewlett Packard printer, a particularly desirable print mode creates the following eight-by-three pattern cell or "base pattern", as shown in Figure 13.

```
xex
xex
xex
xex      base pattern
xex      or cell
xex
xex
xex
```

~~012 ← column number within the base pattern~~

The resulting pattern still appears as diagonal lines when printed on the page, but now they are angled at roughly seventy degrees from the pen-scan axis -- or, as



it may be called, the "horizontal". The pattern alignment is now more vertical than horizontal, and this more effectively masks dot dislocation due to error in printing-medium shrinkage or advance.

Figure 13

~~The diagram above~~ shows that within the eight-row cell or base pattern there are three rows of the repeating subpattern "xoo" and three of the subpattern "oxo", but only two of the bottom subpattern "oox". This asymmetry is without substantive consequence, or may possibly aid slightly in suppressing undesirable moire patterns and the like due to excessively regular cell structure.

The slope of the diagonal is probably best defined as the angle from any point (for example, the first dot) along the repeating unit to the same point on the next diagonally adjacent repeating unit. Using this definition, the slope is the ratio of eight vertical units to three horizontal units, or 8:3, corresponding to an angle of about $69\frac{1}{2}$ degrees. Other reasonable candidate methods of defining the slope generally will yield comparable values between roughly 68 and $71\frac{1}{2}$ degrees.

In any event it will be understood that the apparent slope of the diagonals created by this mask is roughly (within ten percent) 2.67 -- which is much greater than the 1:1 value provided by the checkerboard or three-by-three cells of the prior art. The angle of the diagonals relative to the pen-scan axis or "horizontal" is approximately (within three percent) seventy degrees.

While the invention in this preferable form accordingly is very beneficial, a great advance over the performance of the prior art in hiding paper-shrinkage and paper-advance errors can be enjoyed even with considerably less-emphatic vertical orientation. Any slope over about 2:1 (or angle over about sixty degrees), for instance, produces much better error-hiding properties than the 1:1 forty-five-degree diagonals of the prior art.

If the ~~above-illustrated~~ eight-dot-row pattern is used with a printing-medium advance of thirty-two nozzles, then the determining ratio m_p/h_c is $32/8$, which is inte-

23 AUG 1999

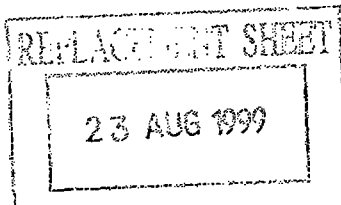
- 30 -

Figure 14.

BA

One definition of "rotation sequence" is entirely internal to the cell -- that is to say, the rotation sequence is the order in which pixel rows are printed within the cell or basic pattern. Thus "sequence 012" means that -- as shown above for the first pass:

- 0 is the number of the column in which the first group of rows (rows 1 through 3) within the cell is printed;



Substitute sheet - 23 August 1999

-31-

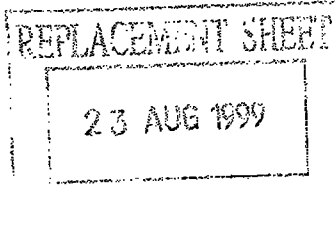
- 1 is the column (the second column) in which the second group (rows 4 through 6) is printed; and
- 2 is the number of the column (the third) in which the third group of rows (rows 7 and 8) is printed.

(As will be noted, in keeping with customary computer-science practice the rows are numbered starting with zero.) Correspondingly for the second pass, as marked in the tabulation above, the (internal) rotation sequence is 120; and for the third pass the sequence is 201.

The other sense in which the phrase "rotation sequence" is used is partly external to the base pattern. Here the rotation sequence identifies a series of swath or pass numbers in which the consecutive columns of the base pattern are used in starting positions, so defining the swath pattern: thus in the tabulated case, swath number:

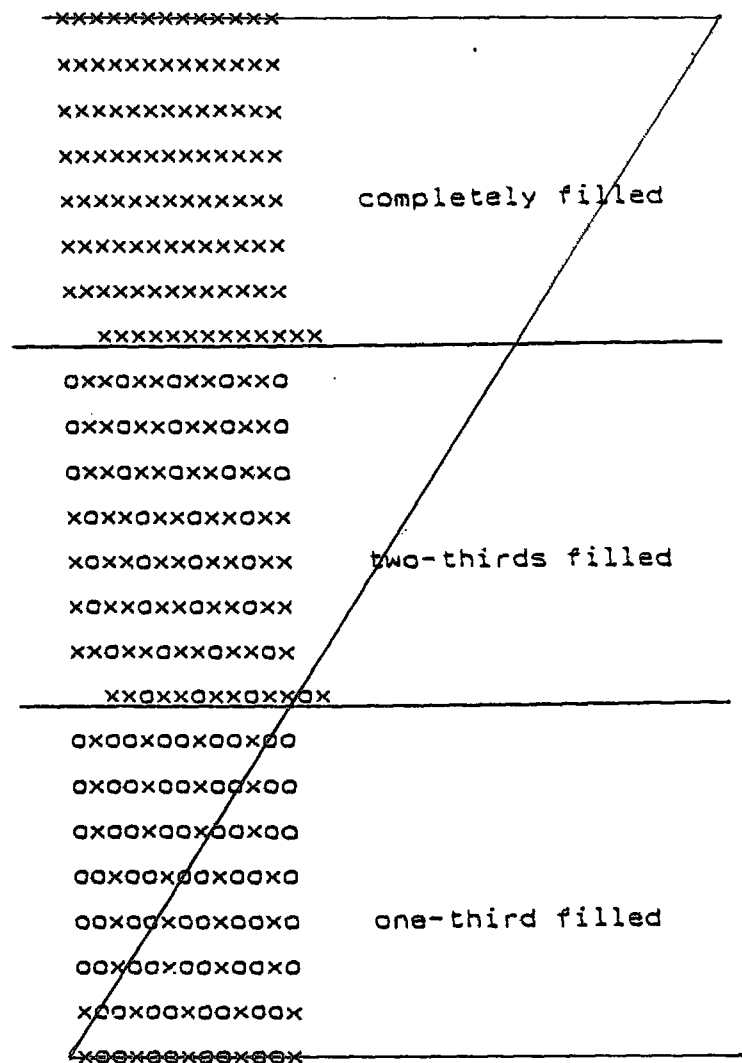
- 0 (the first pass) is assigned to begin with the first column of the base pattern;
- 1 (the second swath) takes the second column of the base pattern for its beginning column; and
- 2 (the third) uses the third column of the base pattern as the first column of the swath.

Now if the printer is stopped halfway down a page, a pattern generally like the ~~following abbreviated diagram~~ ^{of Figure 15} can be seen (not starting at the left-hand edge of the image) -- except that the eight-nozzle cell shown above repeats four times within each swath, rather than occurring only once as suggested by the diagram. Due to this repetition the height of each band of fill, measured in number of nozzles, is thirty-two dot rows rather than eight as diagrammed.



Substitute sheet - 23 August 1999

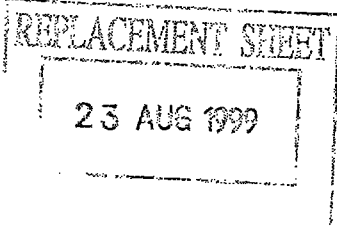
- 32 -



Another potentially useful cell might be an eight-by-four pattern -- the maximum permitted within the system architecture mentioned earlier. Such a cell contains thirty-two pixels, which cannot be divided up equally among three passes.

Equal division among the number of passes selected is desirable to avoid other types of artifacts. This principle might suggest that an eight-by-four pattern would work moderately well with four passes; but for best throughput on plain paper four passes is less desirable because it would be slower.

Also the slope in that case would be definitely $8:4 = 2$ (an angle of about sixty degrees). That slope would be



teristics of these media shift the optimum tradeoff point toward a greater number of printing passes.

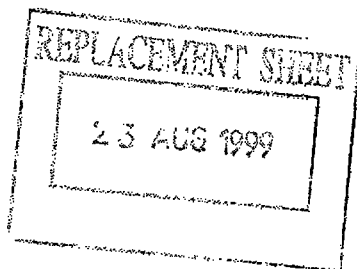
Different numbers of ink drops of the various primaries are desirable for these two different media types respectively. In this regard the ink application considered ideal is quite complicated -- encompassing use of fractional average numbers of drops for certain colorants. ~~These best-known modes of practice of the invention are set forth in considerable detail in the Askeland et al. document identified above.~~

In addition to using six passes and employing the inking arrangements set forth in that document, it is also highly preferable to incorporate the maximum-diagonal aspects of the invention described in the preceding section. The basic three-pass eight-row cells are in essence repeated, making two passes over every pixel location rather than one -- to provide double density.

In addition it is highly preferred to halve the advance distance. Thus whereas the three-pass embodiment of the invention is now believed to operate ideally with advance by thirty-two pixel rows (about $32/24 = 1.33$ mm) at each step, the six-pass embodiment operates instead with advance by sixteen rows ($16/24 = 0.67$ mm) per step.

The resulting masking patterns may appear as shown in Figure 16.

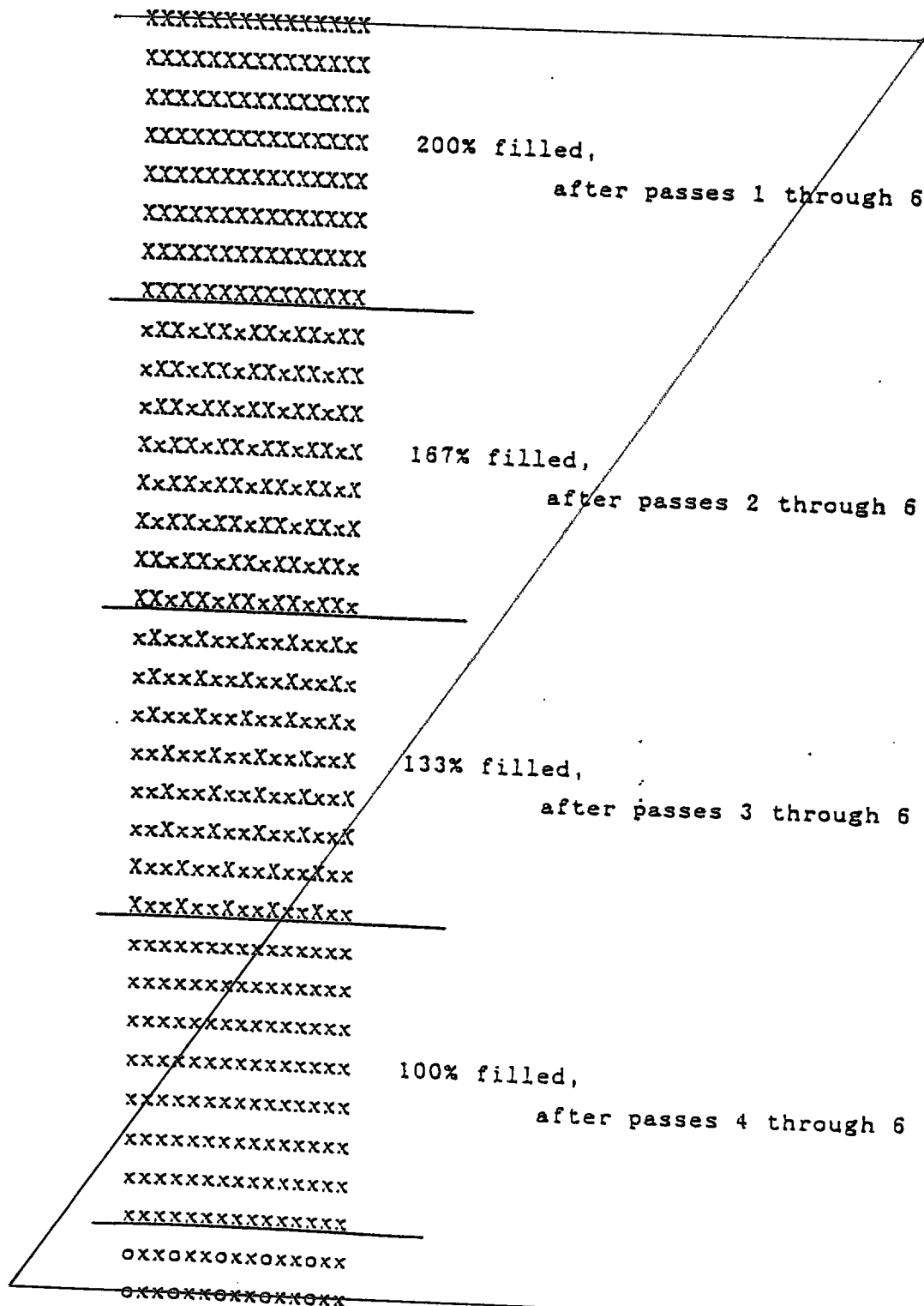
~~pass 1~~	~~pass 2~~	~~pass 3~~	~~pass 4~~	~~pass 5~~	~~pass 6~~
xoo	oox	oxo	xoo	oox	oxo
xoo	oox	oxo	xoo	oox	oxo
xoo	oox	oxo	xoo	oox	oxo
oxo	xoo	oox	oxo	xoo	oox
oxo	xoo	oox	oxo	xoo	oox
oxo	xoo	oox	oxo	xoo	oox
oox	oxo	xoo	oox	oxo	xoo
oox	oxo	xoo	oox	oxo	xoo
012	120	201	012	120	201
(rotation sequence)					

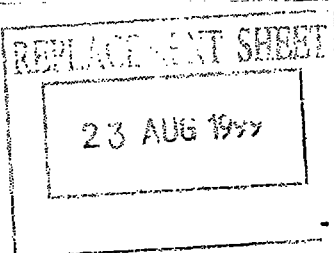


Substitute sheet - 23 August 1999

-35-

If as before the printer is halted partway down a page the developing pattern ^{is as in Figure 17A and 17B.} ~~can be seen from the following representative rows.~~ Capital letters represent double inking:





Substitute sheet - 23 August 1999

-36-

```

-xxxxxxxxxxxx-
xxxxxxxoxxxxx 67% filled,
xxxxxxxoxxxxx after passes 5 and 6
xxxxxxxoxxxxx
xxoxxxxxxxoxxx
xxoxxxxxxxoxxx
oxxxxxxxoxxxx
oxxxxxxxoxxxx
oxxxxxxxoxxxx
oxxxxxxxoxxx 33% filled,
oxxxxxxxoxxx after pass 6 only
oxxxxxxxoxxx
xooxxxxxxxoxx
-xxxxxxxxxxxx-

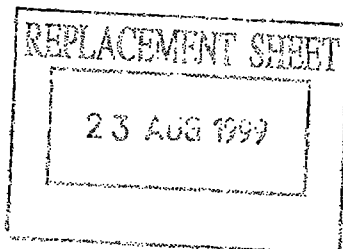
```

The inking arrangements outlined above provide double-drop-per-pixel coverage of all pixel positions. For primary colors (in preferred embodiments those are cyan, magenta and yellow), this is a now-preferred treatment for images on transparency or glossy stock as well as on paper.

~~In accordance with the aforementioned Askeland document, however, it~~ ^{It} may be preferable to ink certain pixel positions more than two times, for example three times, in a single image -- or through use of spatial averaging arrangements to provide a mean deposition of fractional drops. More-than-double fractional inking has been found particularly useful for secondary colors (red, green and blue in preferred embodiments) on transparency and glossy stock -- and can be achieved by, for instance, "stripping" selected data bits from the pattern.

Preferably such data stripping is introduced starting in the fourth pass (pass 4 in the tabulation above). As an example, suppose that a particular pixel is to receive 2.5 dots, on the average, of red ink.

In other words, in half of the passes that pixel is to receive one yellow and one magenta (symbolized "YM") and in the other half of the passes it is to receive one



Substitute sheet - 23 August 1999

-37-

yellow and two of magenta (YMM), instead of the simplest-case four dots (YMYM). To implement this plan, that pixel would receive the first "YM" in the first three passes; and in the remaining passes that pixel would be given a single-bit-stripped treatment to add one more dot of magenta and so yield YMM.

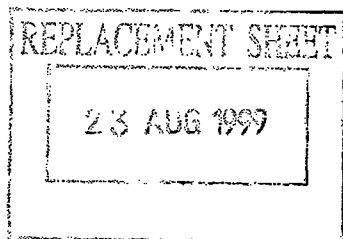
Secondaries ordinarily in each position receive two drops (one of each of two different colors), so by this treatment secondaries if not data-stripped would receive four. Colors produced in this way are very rich, but such excess colorant deposition produces blocking etc. as described earlier; an extra alternating firmware switch or so-called "filter" can be put into operation to suppress or strip the alternate drops.

The result can be tailored to produce either two or four drops at selected pixels -- and thus three, or two and a half, etc. per position on the average. ~~Further detail appears in the Askeland document.~~

If in addition to inking each swath in six passes the printing medium is advanced relative to the pen after each pass -- in other words, if the medium is advanced six times per swath -- then besides improved drying the invention also relieves medium-advance-direction positioning error each one-sixth swath.

That is, advance errors are smaller since the step size is only half as large (0.67 mm rather than 1.33 mm); and the advance errors are averaged over six advances rather than only three. In addition to these benefits, six-pass modes as outlined above facilitate use of fractional-dot techniques to optimize hue and chroma for each color and printing medium.

An overall result of a six-pass method is to balance the need for high quality and high throughput. Although taking more passes (eight, twelve, etc.) would accomplish the same or better quality goals, throughput would be significantly degraded. ~~Conversely, as mentioned earlier four, or preferably more than four, passes will produce some improvement in quality and are considered within the~~



Substitute sheet - 23 August 1999

- 38 -

~~scope of claim of the appended claims but the quality provided by six passes is believed to be significantly better.~~

3. DOUBLE-FREQUENCY BLACK ON RETRACE

It has been found that finer control of black inking at high throughput can be provided with reasonable economy through use of a higher-frequency positioning waveform for black -- and actual printing of black -- only during each return sweep of the pen. The return pass of the pen is known as the "retrace".

An additional interpolation stage can be put into operation -- and the resulting signal transmitted on the pen signal bus -- straightforwardly on retrace. As no other precise-pen-position signals are in use then, there is no interference with control signals for other colors.

Preferably the position waveform for black on retrace is at twice the frequency used for other colors on the forward sweep. The result is twice as many pixel positions -- with corresponding ability to represent finer detail -- and the pen discharge signals can be correspondingly adjusted to make the resulting ink spots smaller.

Whereas a pixel spacing of about twelve per millimeter (three hundred dots per inch) is appropriate for the color-ink spots, the double-frequency black-ink positioning signal produces a spacing of about twenty-four dots per millimeter (six hundred per inch). In printing of text alone, in black and without any color printing, the higher frequency and the finer pixel spacing are preferably used in both directions rather than only on retrace.

While this system of printing black on retrace, when it is part of a color image, resolves the difficult problem of multiplexing different pens that are operating at different frequencies, other factors too militate in favor of this method. One such factor is that positional preci-

sion in bidirectional operation is in fact adequate for such operation, ~~this high precision is obtained through use of a related invention disclosed in the previously mentioned document of Raskin et al.~~

Another factor is that this system very significantly enhances throughput, as the time required to print black on retrace is considerably less than the time required to print black in a separate forward sweep plus the time required for two nonprinting return slews. This advantage is particularly notable in comparison with the major alternative of printing black in a separate forward sweep, between color passes.

4. SUMMARY OF PRINT MODES

In its most highly preferred practice, the invention makes use of several different, complicated combinations of operating parameters and characteristics to accommodate various operating requirements. These combinations are summarized below.

		thru- put		di- rec-	scan speed	re- trace		den- si- ty	max.freq.		split
<u>mode</u>	<u>passes</u>	<u>pg/min</u>	<u>RET</u>	<u>tions</u>	<u>cm/sec</u>	<u>cm/sec</u>	<u>W</u>	<u>ton.</u>	<u>CMY</u>	<u>K</u>	<u>text</u>
FAST:											
text	1	6	no	bi	67.6	67.6	73	yes	8		OK
graph- ics											
1	1.4	no	uni	33.8	88.9	73	yes	4			
NORMAL:											
text	1	6	no	bi	67.6	67.6	73	yes	8		no
graph- ics											
3	0.56	no	uni	50.8	88.9	73	yes	2	2		

23 AUG 1999

Substitute sheet - 23 August 1999

- 43 -

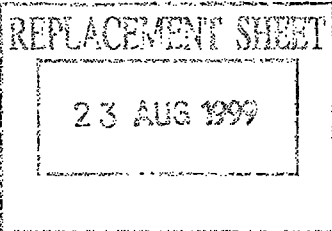
forward motion 63_p. This representation is merely symbolic for tutorial purposes; people skilled in the art will understand that the switch 67 may not exist as a discrete physical element, and/or may instead be controlled from the forward motion 63_p and/or -- as will much more commonly be the case -- can be controlled by some upstream timing signal which also controls in common the pen-carriage motion 63_p, 63_p. Further the synchronous switch 67 need not be at the input side of the timing module 72 but instead at the output side -- where in Fig. 1 a common converging signal line 74 is shown as leading to the firing circuit 61 -- or may in effect be at both sides.

Use of a system as illustrated in Fig. 1, at least as most naturally interpreted, will result in the encoder-signal inversion, the pulse "backing off" step and the firing delay step all being performed during pen motion in the same, common ("backward") direction. This limitation while preferred is not required for successful practice of the invention.

6. TOP/BOTTOM-OF-PAGE MASK ROTATION ONLY

At the bottom of each sheet of print medium, a relatively tall region, that may be called the bottom-of-page "handoff" zone, is defined by the distance between sets of rollers that hold the medium taut. ~~As noted earlier~~
~~and as explained in greater detail in the above-mentioned~~
~~Broder et al. document~~ Preferably preferably for printing on paper in this region the printing-medium advance height is lowered to half (Fig. 2c) its normal midpage value (Fig. 2b).

For example, in a preferred embodiment each pen has ninety-six nozzles and so makes a ninety-six-pixel swath; the normal advance distance (except for plastic media, per this invention) is one third of this height, or thirty-two pixels -- 1.33 mm, for a preferred pixel spacing of 1/24 mm (Fig. 2b). When the medium cannot be tensioned, as set



Substitute sheet - 23 August 1999

- 44 -

~~forth by Broder et al.~~ the advance preferably is halved to sixteen pixels or about 0.7 mm (Fig. 2c).

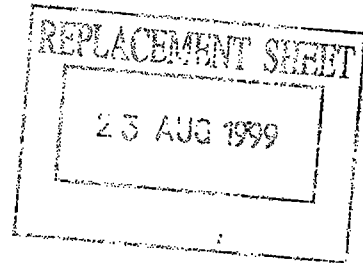
In shallower end zones consisting of the single top (Fig. 2a) and bottom (Fig. 2d) swaths on each sheet of medium, however, according to the present invention the advance height is reduced to zero -- i. e., eliminated entirely. This is done when the pen (or set of pens) is at either end of the data, but most preferably only if that occurs while the medium is untensioned -- either in the "handoff" zone or an analogous one at the top.

This operating mode is particularly important when the pen is actually printing along the top or bottom edge of the sheet. Ordinarily good performance is not obtained with the pen skimming partly on and partly off the edge, but space rotation would demand starting or ending in just that condition, to provide three or six passes in a fractional-swath zone along the edge. Under these circumstances, since space rotation can no longer be made to occur, in effect, as a consequence of print-medium advance, it is provided through sweep rotation -- changing the inking pattern between pen scans.

On each page the mask is first sweep-rotated on the pen by firmware, for the first two sweeps, while the pen is stationary (Fig. 2a); then the mask is fixed on the pen and paper advance begins (Fig. 2b), producing space rotation -- that is, the mask does not change relative to the pen -- and most of the page is printed in this normal three-pass mode. In the handoff zone, but not yet at the end of data, the system makes a transition to one-sixth advance, and only half (forty-eight) of the nozzles print, but the mask is still space rotated (Fig. 2c). When final data are reached, advance again halts and the remaining two passes are flushed out -- with firmware sweep-rotating the mask (Fig. 2d).

The above disclosure is intended as merely exemplary, and not to limit the scope of the invention -- which is to be determined by reference to the appended claims.

- 45 -

CLAIMSWHAT IS CLAIMED IS:

1. A method of printing desired images on a low-liquid-absorption printing medium⁽³³⁾, by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen⁽³¹⁾ that operates in conjunction with a printing-medium advance mechanism⁽⁷⁸⁾; said method comprising the steps of:

scanning the pen⁽³¹⁾ repeatedly along a pen-scanning axis across the medium⁽³³⁾ to place marks on the medium⁽³³⁾ within a swath of pixel rows that is exposed to the multiple nozzles of the pen⁽³¹⁾, each nozzle corresponding to one pixel row_i, wherein the total number of scans at each pixel row is exactly six; periodically advancing the printing medium⁽³³⁾ relative to the pen⁽³¹⁾ along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium⁽³³⁾ within the swath that is exposed to the pen⁽³¹⁾; and

in each scanning of the pen⁽³¹⁾ head across the medium⁽³³⁾, firing at most one-third of the nozzles in each pixel-position column and thereby depositing, over the total number of scans at each pixel row, at least two drops of ink in each pixel position that is inked.

2. The method of claim 1, wherein:

for portions of a desired image in which a mark is desired in every pixel position, the firing step comprises firing substantially one-third of the nozzles in substantially every pixel-position column.

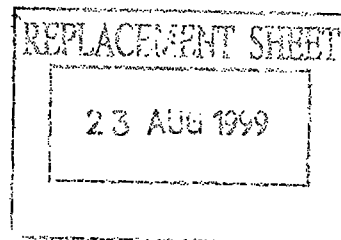
3. The method of claim 2, wherein:

the medium-advancing step comprises advancing the medium⁽³³⁾ between substantially every pair of scans of the pen⁽³¹⁾.



* C L M S *

- 46 -



4. The method of claim ¹⁰2, wherein:
the medium-advancing step comprises advancing the
medium₍₃₃₎ by a number of pixel rows equal to substantially ⁽³¹⁾
one-sixth of the number of operating nozzles of the pen₍₃₁₎,
between substantially every pair of scans of the pen₍₃₁₎.

5. The method of claim 1, wherein:
the medium-advancing step comprises advancing the
medium₍₃₃₎ by a number of pixel rows equal to an integral
multiple of one-sixth of the number of operating nozzles
of the pen₍₃₁₎ between substantially every pair of scans of
the pen₍₃₁₎.



REPLACEMENT SHEET

23 AUG 1999

6. A method of printing desired images on a low-liquid-absorption printing medium, by construction from individual marks formed in pixel column-and-row arrays by a scanning multiple-nozzle pen that operates in conjunction with a printing-medium advance mechanism; said method comprising the steps of:

(31) scanning the pen repeatedly along a pen-scanning axis across the medium, to place marks on the medium within a swath of pixel rows that is exposed to the multiple nozzles of the pen, each nozzle corresponding to one pixel row, wherein the total number of scans at each pixel row is exactly six.

(31) periodically advancing the printing medium relative to the pen, along a printing-medium-advance axis that is substantially orthogonal to the pen-scanning axis, to bring a fresh portion of the medium within the swath that is exposed to the pen; and

(31) in each scanning of the pen head across the medium, firing at most one-sixth of the nozzles in each pixel-position column.

7. The method of claim 6, wherein:

for portions of a desired image in which a mark is desired in every pixel position, the firing step comprises firing substantially one-sixth of the nozzles in substantially every pixel-position column.

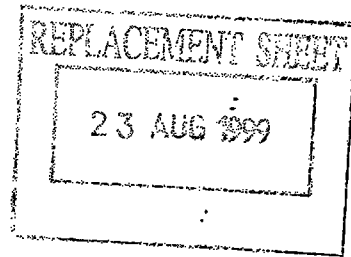
8. The method of claim 7, wherein:

the medium-advancing step comprises advancing the medium between substantially every pair of scans of the pen.



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- 48 -



6_{or}
9. The method of claim 7, wherein:
the medium-advancing step comprises advancing the
medium by a number of pixel rows equal to substantially ⁽³¹⁾
one-sixth of the number of operating nozzles of the pen ⁽³¹⁾_A
between substantially every pair of scans of the pen _A.

10. The method of claim 6, wherein:
the medium-advancing step comprises advancing the
medium ⁽³³⁾_A by a number of pixel rows equal to an integral
multiple of one-sixth of the number of operating nozzles
of the pen ⁽³¹⁾_A between substantially every pair of scans of
the pen _A (31).

