

**(12) STANDARD PATENT**  
**(19) AUSTRALIAN PATENT OFFICE**

(11) Application No. **AU 2008213887 B2**

(54) Title  
**Coding pattern comprising tags with x and y coordinate data divided into respective halves of each tag**

(51) International Patent Classification(s)  
**G06K 19/00** (2006.01)                      **G06F 3/00** (2006.01)

(21) Application No: **2008213887**                      (22) Date of Filing: **2008.02.05**

(87) WIPO No: **WO08/095232**

(30) Priority Data

(31) Number                      (32) Date                      (33) Country  
**60/888,775**                      **2007.02.08**                      **US**

(43) Publication Date: **2008.08.14**

(44) Accepted Journal Date: **2010.04.22**

(71) Applicant(s)  
**Silverbrook Research Pty Ltd**

(72) Inventor(s)  
**Lapstun, Paul;Silverbrook, Kia**

(74) Agent / Attorney  
**Silverbrook Research Pty Ltd, 393 Darling Street, Balmain, NSW, 2041**

(56) Related Art  
**US 5412194**  
**US 5661506**  
**US 5652412**  
**US 5852434**  
**US 5477012**

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
14 August 2008 (14.08.2008)

PCT

(10) International Publication Number  
**WO 2008/095232 A1**

(51) International Patent Classification:  
**G06K 19/00** (2006.01) **G06F 3/00** (2006.01)

(74) Agent: **SILVERBROOK RESEARCH PTY LTD**; 393 Darling Street, Balmain, New South Wales 2041 (AU).

(21) International Application Number:  
PCT/AU2008/000124

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date: 5 February 2008 (05.02.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
60/888,775 8 February 2007 (08.02.2007) US

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant (for all designated States except US): **SILVERBROOK RESEARCH PTY LTD** [AU/AU]; 393 Darling Street, Balmain, New South Wales 2041 (AU).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **LAPSTUN, Paul** [NO/AU]; 393 Darling Street, Balmain, New South Wales 2041 (AU). **SILVERBROOK, Kia** [AU/AU]; 393 Darling Street, Balmain, New South Wales 2041 (AU).

Published:  
— with international search report

(54) Title: CODING PATTERN COMPRISING TAGS WITH X AND Y COORDINATE DATA DIVIDED INTO RESPECTIVE HALVES OF EACH TAG

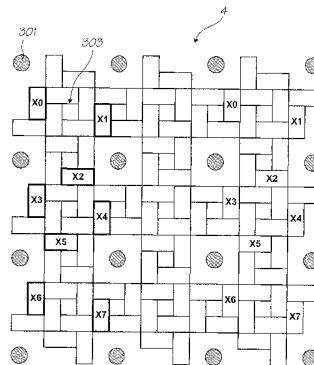


FIG. 11

(57) Abstract: A substrate having a coding pattern disposed on a surface thereof. The coding pattern comprises a plurality of contiguous tags, each tag comprising x-coordinate data and y-coordinate data. A y-axis is nominally defined as north-south and an x-axis is nominally defined as east-west. A plurality of data elements are contained in each tag. The x-coordinate data is represented by a respective set of data elements and the y-coordinate data is represented by a respective set of data elements. The x-coordinate data has two replications within a respective tag, a first replication in a western half of the tag and a second replication in an eastern half of the tag. The y-coordinate data has two replications within a respective tag, a first replication in a northern half of the tag and a second replication in a southern half of the tag. Fragments of the coordinate data are arranged such that any tag-sized portion of the coding pattern is guaranteed to contain the x-coordinate data and the y-coordinate data for a tag irrespective of whether a whole tag is contained in the portion.



WO 2008/095232 A1

**CODING PATTERN COMPRISING TAGS WITH X AND Y COORDINATE DATA  
DIVIDED INTO RESPECTIVE HALVES OF EACH TAG**

**FIELD OF INVENTION**

5           The present invention relates to a position-coding pattern on a surface.

**BACKGROUND**

10           The Applicant has previously described a method of enabling users to access information from a computer system via a printed substrate e.g. paper. The substrate has a coding pattern printed thereon, which is read by an optical sensing device when the user interacts with the substrate using the sensing device. A computer receives interaction data from the sensing device and uses this data to determine what action is being requested by the user. For example, a user may make make handwritten input onto a form or make a selection gesture around a printed item. This input is interpreted by the computer system with reference to a page description corresponding to  
15           the printed substrate.

          It would desirable to improve the coding pattern on the substrate so as to maximize usage of images captured by the sensing device.

20           **SUMMARY OF INVENTION**

In a first aspect the present invention provides a substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:

          a plurality of contiguous tags, each tag comprising x-coordinate data and y-coordinate data, wherein a y-axis is nominally defined as north-south and an x-axis is  
25           nominally defined as east-west; and

          a plurality of data elements contained in each tag, said x-coordinate data being represented by a respective set of data elements and said y-coordinate data being represented by a respective set of data elements,

wherein:

30           said x-coordinate data has two replications within a respective tag, a first replication in a western half of said tag and a second replication in an eastern half of said tag; and

          said y-coordinate data has two replications within a respective tag, a first replication in a northern half of said tag and a second replication in a southern half of said  
35           tag,

and wherein fragments of said coordinate data are arranged such that any tag-sized

portion of said coding pattern is guaranteed to contain said x-coordinate data and said y-coordinate data for a tag irrespective of whether a whole tag is contained in said portion.

Optionally, each tag is square.

5

Optionally, said coding pattern comprises:

a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements and wherein each tag is defined by a plurality of contiguous cells.

10

Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an integer having a value of at least 2.

Optionally, said data elements are macrodots.

15

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of possible positions within a cell, each position representing one of a plurality of possible data values.

20 Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.

Optionally, each cell defines a symbol group, each symbol group comprising a plurality of  
25 Reed-Solomon symbols encoded by a plurality of said data elements.

Optionally, each symbol comprises two halves, each half comprising 2 bits of data represented by a macrodot occupying one of 4 possible positions within said half.

30 Optionally, said x-coordinate data is encoded as an x-coordinate codeword comprised of a respective set of Reed-Solomon symbols, and said y-coordinate data is encoded as a y-coordinate codeword comprised of a respective set of Reed-Solomon symbols

Optionally, each tag comprises one or more common codewords, each common  
35 codeword being comprised of a respective set of said Reed-Solomon symbols, wherein said one or more common codewords are defined as codewords common to a plurality of

contiguous tags.

Optionally, each symbol group comprises a fragment of at least one of said one or more common codewords, and contiguous symbol groups are arranged such that any tag-sized  
5 portion of said coding pattern is guaranteed to contain said one or more common codewords irrespective of whether a whole tag is contained in said portion.

Optionally, said one or more common codewords encode region identity data uniquely identifying a region of said surface.

10

Optionally, said one or more common codewords uniquely identifies said substrate.

Optionally, each cell comprises an orientation symbol encoded by at least one data element, said orientation symbol identifying an orientation of said coding pattern with  
15 respect to said surface.

Optionally, each cell comprises one or more translation symbols encoded by a respective set of said data elements, said translation symbols identifying a translation of said cell relative to a tag containing said cell.

20

Optionally, each cell comprises a pair of orthogonal translation symbols, each orthogonal translation symbol identifying a respective orthogonal translation of said cell relative to a tag containing said cell.

25 Optionally, said target elements are sufficiently large to be distinguishable from said data elements by a low-pass filter.

Optionally, said target elements are target dots and said data elements are macrodots.

30 Optionally, each target dot has a diameter of at least twice that of each macrodot.

In a second aspect the present invention provides a method of imaging a coding pattern disposed on a surface of a substrate, said method comprising the steps of:

(a) operatively positioning an optical reader relative to said surface and capturing  
35 an image of a portion of said coding pattern, said coding pattern comprising:  
a plurality of contiguous tags, each tag comprising x-coordinate data and y-

coordinate data, wherein a y-axis is nominally defined as north-south and an x-axis is nominally defined as east-west; and

a plurality of data elements contained in each tag, said x-coordinate data being represented by a respective set of data elements and said y-coordinate data being represented by a respective set of data elements, wherein:

5

said x-coordinate data has two replications within a respective tag, a first replication in a western half of said tag and a second replication in an eastern half of said tag; and

said y-coordinate data has two replications within a respective tag, a first replication in a northern half of said tag and a second replication in a southern half of said tag;

10

(b) sampling and decoding x-coordinate data and y-coordinate data contained in said imaged portion; and

(c) determining a position of said pen,

wherein said portion has a diameter of at least one tag diameter and less than two tag diameters.

15

Optionally, each tag is square.

Optionally, said coding pattern comprises:

20

a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements and wherein each tag is defined by a plurality of contiguous cells.

Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an integer having a value of at least 2.

25

Optionally, said data elements are macrodots.

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of possible positions within a cell, each position representing one of a plurality of possible data values.

30

Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.

35

Optionally, each cell defines a symbol group, each symbol group comprising a plurality of Reed-Solomon symbols encoded by a plurality of said data elements.

Optionally, each symbol comprises two halves, each half comprising 2 bits of data  
5 represented by a macrodot occupying one of 4 possible positions within said half.

Optionally, said x-coordinate data is encoded as an x-coordinate codeword comprised of a  
respective set of Reed-Solomon symbols, and said y-coordinate data is encoded as a y-  
coordinate codeword comprised of a respective set of Reed-Solomon symbols.  
10

In a further aspect there is provided a system for imaging a coding pattern disposed on a  
surface of a substrate, said system comprising:

(A) said substrate, wherein said coding pattern comprises:

a plurality of contiguous tags, each tag comprising x-coordinate data and y-  
15 coordinate data, wherein a y-axis is nominally defined as north-south and an x-axis  
is nominally defined as east-west; and

a plurality of data elements contained in each tag, said x-coordinate data  
being represented by a respective set of data elements and said y-coordinate data  
being represented by a respective set of data elements, wherein:

20 said x-coordinate data has two replications within a respective tag, a first  
replication in a western half of said tag and a second replication in an eastern half  
of said tag; and

said y-coordinate data has two replications within a respective tag, a first replication in a  
northern half of said tag and a second replication in a southern half of said tag; and

25 (B) an optical reader comprising:

an image sensor for capturing an image of a portion of said coding pattern, said  
image sensor having a field-of-view of at least one tag diameter and less than two tag  
diameters; and

a processor configured for performing the steps of:

30 (i) sampling and decoding x-coordinate data and y-coordinate data within  
said captured image; and

(ii) determining a position of said pen.

Optionally, each tag is square.

35

Optionally, said coding pattern comprises:

a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements and wherein each tag is defined by a plurality of contiguous cells.

- 5 Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an integer having a value of at least 2.

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of possible positions within a cell, each position representing one of a plurality of possible  
10 data values.

Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.

15

Optionally, each cell defines a symbol group, each symbol group comprising a plurality of Reed-Solomon symbols encoded by a plurality of said data elements.

Optionally, each symbol comprises two halves, each half comprising 2 bits of data  
20 represented by a macrodot occupying one of 4 possible positions within said half.

Optionally, said x-coordinate data is encoded as an x-coordinate codeword comprised of a respective set of Reed-Solomon symbols, and said y-coordinate data is encoded as a y-coordinate codeword comprised of a respective set of Reed-Solomon symbols

25

Optionally, said reader is an optically imaging pen having a nib.

In a third aspect the present invention provides a substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:

30

a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements;  
a plurality of data elements contained in each cell; and  
a plurality of tags, each tag being defined by a plurality of contiguous cells, each tag comprising respective local tag data encoded by a respective set of said data  
35 elements,

wherein each tag comprises at least 9 target elements.



Optionally, each tag comprises at least 16 target elements.

Optionally, each tag comprises at least 25 target elements.

5

Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an integer having a value of at least 2.

Optionally, said target elements are configured to facilitate computation of a perspective distortion of said target grid when a portion of said coding pattern is acquired by an optical sensing device.

Optionally, said target elements are sufficiently large to be distinguishable from said data elements by a low-pass filter.

15

Optionally, said target elements are target dots and said data elements are macrodots.

Optionally, each target dot has a diameter of at least twice that of each macrodot.

Optionally, said macrodots encode data values by pulse position modulation.

Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.

25

Optionally, each tag comprises a plurality of replications of said local tag data, such that any tag-sized portion of said coding pattern is guaranteed to contain said local tag data irrespective of whether a whole tag is contained in said portion.

Optionally, each tag is square and comprises four replications of said local tag data, each replication being positioned within a respective quarter of said tag.

Optionally, said local tag data identifies a location of a respective tag.

Optionally, each tag comprises common data encoded by a respective set of said data elements, wherein said common data is defined as data common to a plurality of

35

contiguous tags.

Optionally, each cell comprises a fragment of said common data, and contiguous cells are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain  
5 said common data irrespective of whether a whole tag is contained in said portion.

Optionally, said common data is region identity data uniquely identifying a region of said surface.

10 Optionally, said common data uniquely identifies said substrate.

Optionally, each cell comprises orientation data encoded by a respective set of said data elements, said orientation data identifying an orientation of said coding pattern with respect to said surface.

15

Optionally, each cell comprises translation data encoded by a respective set of said data elements, said translation data identifying a translation of said cell relative to a tag containing said cell.

20 Optionally, each cell defines a symbol group, each symbol group comprising a plurality of Reed-Solomon symbols encoded by a plurality of said data elements.

25 In a fourth aspect the present invention provides a substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:

a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements;

a plurality of data elements contained in each cell; and

30 a plurality of tags, each tag being defined by a plurality of contiguous cells, each tag comprising respective local tag data encoded by a respective set of said data elements,

wherein said data elements encode data values by pulse position modulation.

35 Optionally, said data elements are macrodots.

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of possible positions within a cell, each position representing one of a plurality of possible data values.

- 5 Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.

- Optionally, each cell defines a symbol group, each symbol group comprising a plurality of  
10 Reed-Solomon symbols encoded by a plurality of said data elements.

Optionally, each symbol comprises two halves, each half comprising 2 bits of data represented by a macrodot occupying one of 4 possible positions within said half.

- 15 Optionally, said local tag data is encoded as a local codeword comprised of a set of said Reed-Solomon symbols.

- Optionally, each tag comprises a plurality of replications of said local codeword, such that any tag-sized portion of said coding pattern is guaranteed to contain said local codeword  
20 irrespective of whether a whole tag is contained in said portion.

Optionally, each tag is square and comprises four replications of said local codeword, each replication being positioned within a respective quarter of said tag.

- 25 Optionally, each local codeword identifies a location of a respective tag.

- Optionally, each tag comprises one or more common codewords, each common codeword being comprised of a set of said Reed-Solomon symbols, wherein said one or more common codewords are defined as codewords common to a plurality of contiguous  
30 tags.

- Optionally, each symbol group comprises a fragment of at least one of said one or more common codewords, and contiguous symbol groups are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain said one or more common  
35 codewords irrespective of whether a whole tag is contained in said portion.

Optionally, said one or more common codewords encode region identity data uniquely identifying a region of said surface.

Optionally, said one or more common codewords uniquely identifies said substrate.

5

Optionally, each cell comprises an orientation symbol encoded by at least one data element, said orientation symbol identifying an orientation of said coding pattern with respect to said surface.

10 Optionally, each cell comprises one or more translation symbols encoded by a respective set of said data elements, said translation symbols identifying a translation of said cell relative to a tag containing said cell.

Optionally, each cell comprises a pair of orthogonal translation symbols, each orthogonal  
15 translation symbol identifying a respective orthogonal translation of said cell relative to a tag containing said cell.

Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an integer having a value of at least 2.

20

Optionally, said target elements are sufficiently large to be distinguishable from said data elements by a low-pass filter.

Optionally, said target elements are target dots and said data elements are macrodots,  
25 and wherein each target dot has a diameter of at least twice that of each macrodot.

In a fifth aspect the present invention provides a substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:

30

a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements;  
a plurality of data elements contained in each cell; and  
a plurality of tags, each tag being defined by a plurality of contiguous cells,  
each tag comprising respective tag data encoded by a respective set of said data  
35 elements,

wherein each cell comprises at least one orientation symbol encoded by at least one data

element, such that any tag-sized portion of said coding pattern is guaranteed to contain a plurality of said orientation symbols, each orientation symbol identifying an orientation of a layout of said tag data with respect to said target grid.

- 5   Optionally, each orientation symbol comprises a data element positioned at one of four possible positions within each cell, each position representing one of four possible orientations.

10   Optionally, each orientation symbol is readable by an optical sensing device at any of said four orientations.

Optionally, each tag comprises  $N$  cells, and at least  $N$  orientation symbols form an orientation code with minimum distance  $N$ , wherein  $N$  is an integer having a value of at least 4.

15

Optionally, said cells are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain said orientation code comprising at least  $N$  orientation symbols.

Optionally, said data elements are macrodots.

20

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of possible positions within a cell, each position representing one of a plurality of possible data values.

- 25   Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.

30   Optionally, each cell defines a symbol group, each symbol group comprising a plurality of Reed-Solomon symbols encoded by a plurality of said data elements.

Optionally, each orientation symbol identifies an orientation of a layout of said Reed-Solomon symbols with respect to said target grid.

- 35   Optionally, said tag data is encoded as a local codeword comprised of a set of said Reed-Solomon symbols.

Optionally, each tag comprises a plurality of replications of said local codeword, such that any tag-sized portion of said coding pattern is guaranteed to contain said local codeword irrespective of whether a whole tag is contained in said portion.

5

Optionally, each tag is square and comprises four replications of said local codeword, each replication being positioned within a respective quarter of said tag.

Optionally, each local codeword identifies a location of a respective tag.

10

Optionally, each tag comprises one or more common codewords, each common codeword being comprised of a set of said Reed-Solomon symbols, wherein said one or more common codewords are defined as codewords common to a plurality of contiguous tags.

15

Optionally, each symbol group comprises a fragment of at least one of said one or more common codewords, and contiguous symbol groups are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain said one or more common codewords irrespective of whether a whole tag is contained in said portion.

20

Optionally, said one or more common codewords encode region identity data uniquely identifying a region of said surface.

Optionally, said one or more common codewords uniquely identifies said substrate.

25

Optionally, each cell comprises one or more translation symbols encoded by a respective set of said data elements, said translation symbols identifying a translation of said cell relative to a tag containing said cell.

30

Optionally, each cell comprises a pair of orthogonal translation symbols, each orthogonal translation symbol identifying a respective orthogonal translation of said cell relative to a tag containing said cell.

In a sixth aspect the present invention provides a substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:

35

a plurality of target elements defining a target grid, said target grid

comprising a plurality of cells, wherein neighboring cells share target elements;  
a plurality of data elements contained in each cell; and  
a plurality of tags, each tag being defined by a plurality of contiguous cells,  
each tag comprising respective local tag data encoded by a respective set of said data  
5 elements, each tag comprising common data encoded by a respective set of said data  
elements, said common data being defined as data common to a plurality of contiguous  
tags,  
wherein each cell comprises a fragment of said common data, and contiguous cells are  
arranged such that any tag-sized portion of said coding pattern is guaranteed to contain  
10 said common data irrespective of whether a whole tag is contained in said portion.

Optionally, said common data is region identity data uniquely identifying a region of said  
surface.

15 Optionally, said common data uniquely identifies said substrate.

Optionally, said data elements are macrodots.

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of  
20 possible positions within a cell, each position representing one of a plurality of possible  
data values.

Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$   
possible positions within a cell, each position representing one of  $2^n$  possible data values,  
25 wherein  $n$  is an integer.

Optionally, each cell defines a symbol group, each symbol group comprising a plurality of  
Reed-Solomon symbols encoded by a plurality of said data elements.

30 Optionally, each symbol comprises two halves, each half comprising 2 bits of data  
represented by a macrodot occupying one of 4 possible positions within said half.

Optionally, said common data is encoded as one or more common codewords, each  
common codeword being comprised of a set of said Reed-Solomon symbols.

35

Optionally, each symbol group comprises a fragment of at least one of said one or more

common codewords, and contiguous symbol groups are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain said one or more common codewords irrespective of whether a whole tag is contained in said portion.

- 5 Optionally, said local tag data is encoded as a local codeword comprised of a set of said Reed-Solomon symbols.

Optionally, each tag comprises a plurality of replications of said local codeword, such that any tag-sized portion of said coding pattern is guaranteed to contain said local codeword  
10 irrespective of whether a whole tag is contained in said portion.

Optionally, each tag is square and comprises four replications of said local codeword, each replication being positioned within a respective quarter of said tag.

- 15 Optionally, said local tag data identifies a location of a respective tag.

Optionally, each cell comprises an orientation symbol encoded by at least one data element, said orientation symbol identifying an orientation of said coding pattern with respect to said surface.

20

Optionally, each cell comprises one or more translation symbols encoded by a respective set of said data elements, said translation symbols identifying a translation of said cell relative to a tag containing said cell.

- 25 Optionally, each cell comprises a pair of orthogonal translation symbols, each orthogonal translation symbol identifying a respective orthogonal translation of said cell relative to a tag containing said cell.

Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an  
30 integer having a value of at least 2.

Optionally, said target elements are sufficiently large to be distinguishable from said data elements by a low-pass filter.

- 35 Optionally, said target elements are target dots and said data elements are macrodots, and wherein each target dot has a diameter of at least twice that of each macrodot.



In a seventh aspect the present invention provides substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:

- a plurality of target elements defining a target grid, said target grid
- 5 comprising a plurality of cells, wherein neighboring cells share target elements;
- a plurality of data elements contained in each cell; and
- a plurality of tags, each tag being defined by a plurality of contiguous cells, each tag comprising respective tag data encoded by a respective set of said data elements,
- 10 wherein each cell comprises one or more translation symbols encoded by a respective set of said data elements, said one or more translation symbols identifying a translation of said cell relative to a tag containing said cell.

Optionally, each cell comprises a pair of orthogonal translation symbols, each orthogonal  
15 translation symbol identifying a respective orthogonal translation of said cell relative to a tag containing said cell.

Optionally, each tag is square and comprises  $M^2$  contiguous square cells, wherein  $M$  is an  
integer having a value of at least 2.

20

Optionally,  $M$  translation symbols in a row of  $M$  cells define a cyclic position code having minimum distance  $M$ , said code being defined by a first codeword.

Optionally,  $M$  translation symbols in a column of  $M$  cells define a cyclic position code  
25 having minimum distance  $M$ , said code being defined by a second codeword.

Optionally, each tag comprises  $N$  cells, and at least  $N$  translation symbols form a third codeword with minimum distance  $N$ , wherein  $N$  is an integer having a value of at least 4.

30 Optionally, any tag-sized portion of said coding pattern is guaranteed to contain at least  $N$  translation symbols, thereby capturing said third codeword.

Optionally, each cell comprises at least one orientation symbol encoded by at least one data element, such that any tag-sized portion of said coding pattern is guaranteed to  
35 contain a plurality of said orientation symbols, each orientation symbol identifying an orientation of said coding pattern with respect to said surface.

Optionally, said data elements are macrodots.

Optionally, a portion of data is represented by a macrodot occupying one of a plurality of  
5 possible positions within a cell, each position representing one of a plurality of possible  
data values.

Optionally, a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$   
possible positions within a cell, each position representing one of  $2^n$  possible data values,  
10 wherein  $n$  is an integer.

Optionally, each cell defines a symbol group, each symbol group comprising a plurality of  
Reed-Solomon symbols encoded by a plurality of said data elements.

15 Optionally, each symbol comprises two halves, each half comprising 2 bits of data  
represented by a macrodot occupying one of 4 possible positions within said half.

Optionally, said tag data is encoded as a local codeword comprised of a set of said Reed-  
Solomon symbols.  
20

Optionally, each tag comprises a plurality of replications of said local codeword, such that  
any tag-sized portion of said coding pattern is guaranteed to contain said local codeword  
irrespective of whether a whole tag is contained in said portion.

25 Optionally, each tag is square and comprises four replications of said local codeword,  
each replication being positioned within a respective quarter of said tag.

Optionally, each local codeword identifies a location of a respective tag.

30 Optionally, each tag comprises one or more common codewords, each common  
codeword being comprised of a set of said Reed-Solomon symbols, wherein said one or  
more common codewords are defined as codewords common to a plurality of contiguous  
tags.

35 Optionally, each symbol group comprises a fragment of at least one of said one or more  
common codewords, and contiguous symbol groups are arranged such that any tag-sized

portion of said coding pattern is guaranteed to contain said one or more common codewords irrespective of whether a whole tag is contained in said portion.

Optionally, said one or more common codewords encode region identity data uniquely  
5 identifying a region of said surface.

5

**BRIEF DESCRIPTION OF DRAWINGS**

Preferred and other embodiments of the invention will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

- 10 Figure 1 is a schematic of a the relationship between a sample printed netpage and its online page description;
- Figure 2 shows an embodiment of basic netpage architecture with various alternatives for the relay device;
- Figure 3 shows the structure of a tag;
- 15 Figure 4 shows a group of nine symbols and four targets;
- Figure 5 shows a left-handed symbol unit cell;
- Figure 6 shows a right-handed symbol unit cell;
- Figure 7 shows a centered symbol unit cell;
- Figure 8 shows the spacing of macrodot positions;
- 20 Figure 9 shows the layout of symbols within a symbol group;
- Figure 10 shows an orientation code symbol layout;
- Figure 11 shows a translation code symbol layout;
- Figure 12 shows the layout of orientation and translation code symbols within a symbol group;
- Figure 13 shows a replicated local codeword A with the first copy shown shaded;
- 25 Figure 14 shows common codewords B, C, D and E with codeword B shown shaded;
- Figure 15 shows a data stream fragment codeword F;
- Figure 16 shows the layout of a complete tag;
- Figure 17 shows a local codeword layout;
- Figure 18 is a flowchart of image processing;
- 30 Figure 19 shows a nib and elevation of the pen held by a user;
- Figure 20 shows the pen held by a user at a typical incline to a writing surface;
- Figure 21 is a lateral cross section through the pen;
- Figure 22A is a bottom and nib end partial perspective of the pen;
- Figure 22B is a bottom and nib end partial perspective with the fields of illumination and field of
- 35 view of the sensor window shown in dotted outline;
- Figure 23 is a longitudinal cross section of the pen;

Figure 24A is a partial longitudinal cross section of the nib and barrel molding;

Figure 24B is a partial longitudinal cross section of the IR LED's and the barrel molding;

Figure 25 is a ray trace of the pen optics adjacent a sketch of the ink cartridge;

Figure 26 is a side elevation of the lens;

5 Figure 27 is a side elevation of the nib and the field of view of the optical sensor; and

Figure 28 is a block diagram of the pen electronics.

## DETAILED DESCRIPTION OF PREFERRED AND OTHER EMBODIMENTS

### 10 1.1 Netpage System Architecture

In a preferred embodiment, the invention is configured to work with the netpage networked computer system, a detailed overview of which follows. It will be appreciated that not every implementation will necessarily embody all or even most of the specific details and extensions discussed below in relation to the basic system. However, the system is described in its most complete form to reduce the need for external reference when attempting to understand the context in which the preferred embodiments and aspects of the present invention operate.

15 In brief summary, the preferred form of the netpage system employs a computer interface in the form of a mapped surface, that is, a physical surface which contains references to a map of the surface maintained in a computer system. The map references can be queried by an appropriate sensing device. Depending upon the specific implementation, the map references may be encoded visibly or invisibly, and defined in such a way that a local query on the mapped surface yields an unambiguous map reference both within the map and among different maps. The computer system can contain information about features on the mapped surface, and such information can be retrieved based on map references supplied by a sensing device used with the mapped surface. The information thus retrieved can take the form of actions which are initiated by the computer system on behalf of the operator in response to the operator's interaction with the surface features.

20 In its preferred form, the netpage system relies on the production of, and human interaction with, netpages. These are pages of text, graphics and images printed on ordinary paper, but which work like interactive webpages. Information is encoded on each page using ink which is substantially invisible to the unaided human eye. The ink, however, and thereby the coded data, can be sensed by an optically imaging sensing device and transmitted to the netpage system. The sensing device may take the form of a clicker (for clicking on a specific position on a surface), a pointer having a stylus (for pointing or gesturing on a surface using pointer strokes), or a pen having a marking nib (for marking a surface with ink when pointing, gesturing or writing on the surface). References herein to "pen" or "netpage pen" are provided by way of example only. It will, of course, be appreciated that the pen may take the form of any of the sensing devices described

above.

In one embodiment, active buttons and hyperlinks on each page can be clicked with the sensing device to request information from the network or to signal preferences to a network server. In one embodiment, text written by hand on a netpage is automatically recognized and  
5 converted to computer text in the netpage system, allowing forms to be filled in. In other embodiments, signatures recorded on a netpage are automatically verified, allowing e-commerce transactions to be securely authorized. In other embodiments, text on a netpage may be clicked or gestured to initiate a search based on keywords indicated by the user.

As illustrated in Figure 1, a printed netpage 1 can represent a interactive form which can  
10 be filled in by the user both physically, on the printed page, and “electronically”, via communication between the pen and the netpage system. The example shows a “Request” form containing name and address fields and a submit button. The netpage 1 consists of graphic data 2, printed using visible ink, and a surface coding pattern 3 superimposed with the graphic data. The surface coding pattern 3 comprises a collection of tags 4. One such tag 4 is shown in the shaded  
15 region of Figure 1, although it will be appreciated that contiguous tags 4, defined by the coding pattern 3, are densely tiled over the whole netpage 1.

The corresponding page description 5, stored on the netpage network, describes the individual elements of the netpage. In particular it describes the type and spatial extent (zone) of each interactive element (i.e. text field or button in the example), to allow the netpage system to  
20 correctly interpret input via the netpage. The submit button 6, for example, has a zone 7 which corresponds to the spatial extent of the corresponding graphic 8.

As illustrated in Figure 2, a netpage sensing device 400, such as the pen described in Section 3, works in conjunction with a netpage relay device 601, which is an Internet-connected device for home, office or mobile use. The pen 400 is wireless and communicates securely with the  
25 netpage relay device 601 via a short-range radio link 9. In an alternative embodiment, the netpage pen 400 utilises a wired connection, such as a USB or other serial connection, to the relay device 601.

The relay device 601 performs the basic function of relaying interaction data to a page server 10, which interprets the interaction data. As shown in Figure 2, the relay device 601 may, for  
30 example, take the form of a personal computer 601a, a netpage printer 601b or some other relay device 601c (e.g. personal computer or mobile phone incorporating a web browser).

The netpage printer 601b is able to deliver, periodically or on demand, personalized newspapers, magazines, catalogs, brochures and other publications, all printed at high quality as interactive netpages. Unlike a personal computer, the netpage printer is an appliance which can be,  
35 for example, wall-mounted adjacent to an area where the morning news is first consumed, such as in a user’s kitchen, near a breakfast table, or near the household’s point of departure for the day. It

also comes in tabletop, desktop, portable and miniature versions. Netpages printed on-demand at their point of consumption combine the ease-of-use of paper with the timeliness and interactivity of an interactive medium.

Alternatively, the netpage relay device 601 may be a portable device, such as a mobile  
5 phone or PDA, a laptop or desktop computer, or an information appliance connected to a shared display, such as a TV. If the relay device 601 is not a netpage printer 601b which prints netpages digitally and on demand, the netpages may be printed by traditional analog printing presses, using such techniques as offset lithography, flexography, screen printing, relief printing and rotogravure, as well as by digital printing presses, using techniques such as drop-on-demand inkjet, continuous  
10 inkjet, dye transfer, and laser printing.

As shown in Figure 2, the netpage sensing device 400 interacts with a portion of the tag pattern on a printed netpage 1, or other printed substrate such as a label of a product item 251, and communicates, via a short-range radio link 9, the interaction to the relay device 601. The relay 601 sends corresponding interaction data to the relevant netpage page server 10 for interpretation. Raw  
15 data received from the sensing device 400 may be relayed directly to the page server 10 as interaction data. Alternatively, the interaction data may be encoded in the form of an interaction URI and transmitted to the page server 10 via a user's web browser 601c. The web browser 601c may then receive a URI from the page server 10 and access a webpage via a webserver 201. In some circumstances, the page server 10 may access application computer software running on a  
20 netpage application server 13.

The netpage relay device 601 can be configured to support any number of sensing devices, and a sensing device can work with any number of netpage relays. In the preferred implementation, each netpage sensing device 400 has a unique identifier. This allows each user to maintain a distinct profile with respect to a netpage page server 10 or application server 13.

Digital, on-demand delivery of netpages 1 may be performed by the netpage printer  
25 601b, which exploits the growing availability of broadband Internet access. Netpage publication servers 14 on the netpage network are configured to deliver print-quality publications to netpage printers. Periodical publications are delivered automatically to subscribing netpage printers via pointcasting and multicasting Internet protocols. Personalized publications are filtered and  
30 formatted according to individual user profiles.

A netpage pen may be registered with a netpage registration server 11 and linked to one or more payment card accounts. This allows e-commerce payments to be securely authorized using the netpage pen. The netpage registration server compares the signature captured by the netpage pen with a previously registered signature, allowing it to authenticate the user's identity to an e-  
35 commerce server. Other biometrics can also be used to verify identity. One version of the netpage pen includes fingerprint scanning, verified in a similar way by the netpage registration server.

## 1.2 Netpages

Netpages are the foundation on which a netpage network is built. They provide a paper-based user interface to published information and interactive services.

5 As shown in Figure 1, a netpage consists of a printed page (or other surface region) invisibly tagged with references to an online description 5 of the page. The online page description 5 is maintained persistently by the netpage page server 10. The page description describes the visible layout and content of the page, including text, graphics and images. It also describes the input elements on the page, including buttons, hyperlinks, and input fields. A netpage allows  
10 markings made with a netpage pen on its surface to be simultaneously captured and processed by the netpage system.

Multiple netpages (for example, those printed by analog printing presses) can share the same page description. However, to allow input through otherwise identical pages to be distinguished, each netpage may be assigned a unique page identifier. This page ID has sufficient  
15 precision to distinguish between a very large number of netpages.

Each reference to the page description 5 is repeatedly encoded in the netpage pattern. Each tag (and/or a collection of contiguous tags) identifies the unique page on which it appears, and thereby indirectly identifies the page description 5. Each tag also identifies its own position on the page. Characteristics of the tags are described in more detail below.

20 Tags are typically printed in infrared-absorptive ink on any substrate which is infrared-reflective, such as ordinary paper, or in infrared fluorescing ink. Near-infrared wavelengths are invisible to the human eye but are easily sensed by a solid-state image sensor with an appropriate filter.

A tag is sensed by a 2D area image sensor in the netpage sensing device, and the tag data  
25 is transmitted to the netpage system via the nearest netpage relay device 601. The pen 400 is wireless and communicates with the netpage relay device 601 via a short-range radio link. It is important that the pen recognize the page ID and position on every interaction with the page, since the interaction is stateless. Tags are error-correctably encoded to make them partially tolerant to surface damage.

30 The netpage page server 10 maintains a unique page instance for each unique printed netpage, allowing it to maintain a distinct set of user-supplied values for input fields in the page description 5 for each printed netpage 1.

## 2 NETPAGE TAGS

### 35 2.1 Tag Data Content

Each tag 4 identifies an absolute location of that tag within a region of a substrate.



Each interaction with a netpage should also provide a region identity together with the tag location. In a preferred embodiment, the region to which a tag refers coincides with an entire page, and the region ID is therefore synonymous with the page ID of the page on which the tag appears. In other embodiments, the region to which a tag refers can be an arbitrary subregion of a page or other surface. For example, it can coincide with the zone of an interactive element, in which case the region ID can directly identify the interactive element.

As described in the Applicant's previous applications (e.g. US 6,832,717), the region identity may be encoded discretely in each tag 4. As will be described in more detail below, the region identity may be encoded by a plurality of contiguous tags in such a way that every interaction with the substrate still identifies the region identity, even if a whole tag is not in the field of view of the sensing device.

Each tag 4 should preferably identify an orientation of the tag relative to the substrate on which the tag is printed. Orientation data read from a tag enables the rotation (yaw) of the pen relative to the substrate to be determined

A tag 4 may also encode one or more flags which relate to the region as a whole or to an individual tag. One or more flag bits may, for example, signal a sensing device to provide feedback indicative of a function associated with the immediate area of the tag, without the sensing device having to refer to a description of the region. A netpage pen may, for example, illuminate an "active area" LED when in the zone of a hyperlink.

A tag 4 may also encode a digital signature or a fragment thereof. Tags encoding (partial) digital signatures are useful in applications where it is required to verify a product's authenticity. Such applications are described in, for example, US Publication No. 2007/0108285, the contents of which is herein incorporated by reference. The digital signature may be encoded in such a way that it can be retrieved from every interaction with the substrate. Alternatively, the digital signature may be encoded in such a way that it can be assembled from a random or partial scan of the substrate.

It will, of course, be appreciated that other types of information (e.g. tag size *etc*) may also be encoded into each tag or a plurality of tags, as will be explained in more detail below.

## 2.2 General Tag Structure

As described above in connection with Figure 1, the netpage surface coding generally consists of a dense planar tiling of tags. In the present invention, each tag 4 is represented by a coding pattern which contains two kinds of elements. Referring to Figures 3 and 4, the first kind of element is a target element. Target elements in the form of target dots 301 allow a tag 4 to be located in an image of a coded surface, and allow the perspective distortion of the tag to be inferred. The second kind of element is a data element in the form of a macrodot 302 (see Figure 7). Each macrodot 302 encodes a data value. As described in the Applicant's earlier disclosures

(e.g. US 6,832,717), the presence or absence of a macrodot was be used to represent a binary bit. However, the tag structure of the present invention encodes a data value using pulse position modulation, which is described in more detail in Section 2.3.

5 The coding pattern 3 is represented on the surface in such a way as to allow it to be acquired by an optical imaging system, and in particular by an optical system with a narrowband response in the near-infrared. The pattern 3 is typically printed onto the surface using a narrowband near-infrared ink.

10 Figure 3 shows the structure of a complete tag 4 with target elements 301 shown. The tag 4 is square and contains sixteen target elements. Those target elements 301 located at the edges and corners of the tag (twelve in total) are shared by adjacent tags and define the perimeter of the tag. In contrast with the Applicant's previous tag designs, the high number of target elements 301 advantageously facilitates accurate determination of a perspective distortion of the tag 4 when it is imaged by the sensing device 101. This improves the accuracy of tag sensing and, ultimately, position determination.

15 The tag 4 consists of a square array of nine symbol groups 303. Symbol groups 303 are demarcated by the target elements 301 so that each symbol group is contained within a square defined by four target elements. Adjacent symbol groups 303 are contiguous and share targets.

20 Since the target elements 301 are all identical, they do not demarcate one tag from its adjacent tags. Viewed purely at the level of target elements, only symbol groups 303, which define cells of a target grid, can be distinguished – the tags 4 themselves are indistinguishable by viewing only the target elements. Hence, tags 4 must be aligned with the target grid as part of tag decoding.

25 The tag 4 is designed to allow all tag data, with the exception of an embedded data object (see Section 2.8.3), to be recovered from an imaging field of view no larger than the size of the tag (plus one macrodot unit). This implies that any data unique to the tag 4 must appear four times within the tag — i.e. once in each quadrant or quarter; any data unique to a column or row of tags must appear twice within the tag — i.e. once in each horizontal half or vertical half of the tag respectively; and any data common to a set of tags needs to appear once within the tag.

### 2.3 Symbol Groups

30 As shown in Figure 4, each of the nine symbol groups 303 comprises twelve data symbols 304, each data symbol being part of a codeword. In addition, each symbol group 303 comprises an orientation code ('OR') and one symbol from each of two orthogonal translation codes ('HT' and 'VT'). The orientation code allows the orientation of the tag in the field of view to be determined. The two orthogonal translation codes allow the translation of tag(s) relative to the symbol groups 303 in the field of view to be determined. In other words, the translation codes enable alignment of the 'invisible' tags with the target grid.

35

Each symbol group 304 contains two symbols from a flag code (F). The flag code encodes the active area flag.

Each symbol 304 contains four bits of data. Generally, each symbol 304 is divided into two halves, and each of these two halves  $\{h_0, h_1\}$  is encoded using two-bit pulse position modulation, i.e. using a single macrodot 302 in one of four positions  $\{p_{00}, p_{01}, p_{10}, p_{11}\}$  in the half. The half  $h_0$  encodes the least-significant bits of the symbol; the half  $h_1$  encodes the most-significant bits.

Figure 5 shows the layout of a horizontal rectangle data symbol. Figure 6 shows the layout of a vertical rectangle data symbol.

## 2.4 Targets and Macrodots

The spacing of macrodots 302 in both dimensions, as shown in Figure 7, is specified by the parameter  $s$ . It has a nominal value of  $95\mu\text{m}$ , based on 6 dots printed at a pitch of 1600 dots per inch.

Only macrodots 302 are part of the representation of a symbol 304 in the pattern. The outline of a symbol 304 is shown in, for example, Figures 3 and 4 merely to elucidate more clearly the structure of a tag.

A macrodot 302 is nominally circular with a nominal diameter of  $(4/6)s$ . However, it is allowed to vary in size by  $\pm 15\%$  according to the capabilities of the device used to produce the pattern.

A target 301 is nominally circular with a nominal diameter of  $(12/6)s$ . However, it is allowed to vary in size by  $\pm 15\%$  according to the capabilities of the device used to produce the pattern.

Each tag 4 has a width of  $40s$  and a length of  $40s$ .

The macrodot spacing, and therefore the overall scale of the tag pattern, is allowed to vary by  $\pm 11\%$  according to the capabilities of the device used to produce the pattern. Any deviation from the nominal scale is recorded in each tag (in a tag size ID field) to allow accurate generation of position samples.

These tolerances are independent of one another. They may be refined with reference to particular printer characteristics.

## 2.5 Encoded Codes and Codewords

In the following section, each symbol in Figures 11 to 16 is shown with a unique label. The label consists of an alphabetic prefix which identifies which codeword the symbol is part of, and a numeric suffix which indicates the index of the symbol within the codeword. For simplicity only data symbols 304 are shown, not orientation and translation code symbols.

Although some symbol labels are shown rotated to indicate the symmetry of the layout of

certain codewords, the layout of each symbol is determined by its position within a symbol group and not by the rotation of the symbol label (as described in, for example, the Applicant's US Publication No. 2006/146069).

### 5 2.5.1 Orientation Code

The orientation code consists of a single symbol which contains two bits of data, and is encoded using pulse position modulation. Figure 8 shows the layout of the orientation code symbol.

As shown in Figure 4, the orientation code symbol layout appears once within each symbol group 303 to indicate the orientation of the tag (via the OR symbol).

Each symbol group encodes a one-symbol 4-ary orientation code. The code is defined by the set of codewords  $\{0\}, \{1\}, \{2\}, \{3\}$ . These codewords correspond to clockwise tag rotations of 0, 90, 180 and 270 degrees respectively. Each codeword corresponds to its predecessor read at an orientation of 90 degrees, hence a single codeword gives rise to the entire code when rotated. The code has a minimum distance of 1. The codes of an entire tag form a code with a minimum distance of 9, allowing 4 symbol errors to be corrected. If additional symbols are visible within the field of view then they can be used for additional redundancy and even more robust decoding. A minimum of three orientation codes, with a combined minimum distance of 3, must be decoded to allow a single symbol error to be corrected.

20

### 2.5.2 Translation Code

Each translation code symbol contains two bits of data, and is encoded using pulse position modulation. Figure 8 shows the layout of the translation code symbol.

As shown in Figure 4, the translation code symbol layout appears twice at two orientations within a symbol group to indicate the horizontal and vertical translation of the tag (via the HT and VT symbols respectively).

Each row of symbol groups and each column of symbol groups encodes a three-symbol 4-ary cyclic position code (The Applicant's cyclic position codes are described in US 7,082,562, the contents of which is herein incorporated by reference). The code is defined by the codeword  $\{0,1,2\}$ . A symbol value of 3 can be treated as an erasure. It has a minimum distance of 3, allowing a single symbol error to be corrected. The codes of an entire tag form a code with a minimum distance of 9, allowing 4 symbol errors to be corrected. If additional symbols are visible within the field of view then they can be used for additional redundancy and even more robust decoding.

The top left corner of an un-rotated tag is identified by a symbol group which encodes the first symbol in two orthogonal cyclic position codewords.

35

### 2.5.3 Flag Code

The active area flag symbol consists of one bit of data, and is encoded using 1-bit pulse-position modulation, i.e. using a single macrodot in one of two positions  $\{p_0, p_1\}$ . Figure 10 shows the layout of the flag symbol.

5           The flag symbol is unique to a tag 4 and is therefore coded redundantly in each quadrant of the tag. As Figure 10 shows, the flag symbol is replicated twice but is defined in four ways within each symbol group 303. This guarantees that at least four distinct copies of the flag symbol can be recovered from a quadrant of the tag. Four symbols form a code with a minimum distance of 3, allowing a single error to be corrected. If additional symbols are visible within the field of view  
10 then they can be used for additional redundancy.

### 2.5.4 Coordinate Data

The tag contains an x-coordinate codeword and a y-coordinate codeword used to encode the x and y coordinates of the tag respectively. The codewords are of a punctured  $2^4$ -ary (8,4)  
15 Reed-Solomon code. The tag therefore encodes up to 16 bits of information for each coordinate.

Each x coordinate codeword is replicated twice within the tag — in each horizontal half (“north” and “south”), and is constant within the column of tags containing the tag. Likewise, each y coordinate codeword is replicated twice within the tag — in each vertical half (“east” and “west”), and is constant within the row of tags containing the tag. This guarantees that an image of  
20 the tag pattern large enough to contain a complete tag is guaranteed to contain a complete instance of each coordinate codeword, irrespective of the alignment of the image with the tag pattern. The instance of either coordinate codeword may consist of fragments from different tags.

The layout of the x-coordinate codeword is shown in Figure 11. The layout of the y-coordinate codeword is shown in Figure 12.

25

### 2.5.5 Common Data

The tag 4 contains three codewords B, C and D which encode information common to a set of contiguous tags in a surface region. Each codeword is of a  $2^4$ -ary (15,11) Reed-Solomon code. The tag therefore encodes up to 132 bits of information common to a set of contiguous tags.

30           The common codewords are replicated throughout a tagged region. This guarantees that an image of the tag pattern large enough to contain a complete tag is guaranteed to contain a complete instance of each common codeword, irrespective of the alignment of the image with the tag pattern. The instance of each common codeword may consist of fragments from different tags.

The layout of the common codewords is shown in Figure 13. The codewords have the same  
35 layout, rotated 90 degrees relative to each other.

### 2.5.6 Secret-Key Signature

The tag optionally contains a secret-key digital signature common to a set of contiguous tags in a surface region. The signature consists of fifteen  $2^4$ -ary symbols. The tag therefore optionally encodes up to 60 bits of secret-key signature data.

5 The signature is replicated throughout a tagged region. This guarantees that an image of the tag pattern large enough to contain a complete tag is guaranteed to contain a complete instance of the signature, irrespective of the alignment of the image with the tag pattern. The instance of the signature may consist of fragments from different tags.

The signature has the same (rotated) layout as the three common codewords described in  
10 Section 2.5.5.

The layout of the secret-key signature is shown in Figure 14.

The signature is not redundantly coded. The server that verifies the signature has access to the full signature and can therefore perform error correction at an effective cost of one symbol per corrected symbol rather than the two symbols per corrected symbol required by a Reed-  
15 Solomon code. Deferring error correction to the server allows a longer signature and therefore greater signature strength, or conversely, the same effective signature length with more error correcting capacity.

Digital signatures are discussed further in Section 2.8.4.

### 20 2.5.7 Embedded Data Fragment

The tag optionally contains a codeword which encodes a fragment of a larger data object embedded in the surface coding. The codeword is of a  $2^4$ -ary (15,11) Reed-Solomon code. The tag therefore optionally encodes 44 bits of the data object.

Data embedding is discussed further in Section 2.8.3.

25

### 2.5.8 Complete Tag

Figure 16 shows the layout of the data of a complete tag, with each symbol group comprising twelve data symbols. The orientation and translation codes are not shown in Figure 16.

## 30 2.6 Reed-Solomon Encoding

### 2.6.1 Reed-Solomon Codes

All data is encoded using a Reed-Solomon code defined over  $GF(16)$ . The code has a natural length  $n$  of 15. It is punctured as appropriate to obtain a chosen length. The dimension  $k$  of the code is chosen to balance the error correcting capacity and data capacity of the code, which are  
35  $(n - k)/2$  and  $k$  symbols respectively.

The code has the following primitive polynomial:

$$p(x) = x^4 + x + 1$$

The code has the following generator polynomial:

5

$$g(x) = \prod_{i=1}^{n-k} (x + \alpha^i)$$

10 For a detailed description of Reed-Solomon codes, refer to Wicker, S.B. and V.K. Bhargava, eds., *Reed-Solomon Codes and Their Applications*, IEEE Press, 1994.

**2.6.2 Codeword Organization**

As shown in Figure 17, redundancy coordinates  $r_i$  and data coordinates  $d_i$  of the code are indexed from left to right according to the power of their corresponding polynomial terms. The symbols  $X_i$  of a complete codeword are indexed from right to left to match the bit order of the data. The bit order within each symbol is the same as the overall bit order.

15

**2.6.3 Code Instances**

20 Table 1 defines the parameters of the different codes used in the tag.

**Table 1. Codeword instances**

name	description	length ( $n$ )	dimension ( $k$ )	error-correcting capacity (symbols)	data capacity (bits)
X, Y	coordinate codewords (see Section 2.5.4)	8	4	2	16
B, C, D	common codewords (see Section 2.5.5)	15	11	2	44
E	data fragment codeword (see Section 2.5.7)	15	11	2	44

**25 2.7 Tag Coordinate Space**

The tag coordinate space has two orthogonal axes labelled x and y respectively. When the positive x axis points to the right then the positive y axis points down.

The surface coding does not specify the location of the tag coordinate space origin on a

particular tagged surface, nor the orientation of the tag coordinate space with respect to the surface. This information is application-specific. For example, if the tagged surface is a sheet of paper, then the application which prints the tags onto the paper may record the actual offset and orientation, and these can be used to normalise any digital ink subsequently captured in conjunction with the surface.

The position encoded in a tag is defined in units of tags. By convention, the tag position is taken to be the position of the top left target in each tag.

## 2.8 Tag Information Content

### 2.8.1 Field Definitions

Table 2 defines the information fields embedded in the surface coding.

**Table 2. Field Definitions**

field	width (bits)	description
<b>unique to tag</b>		
active area flag	1	A flag indicating whether the area <sup>a</sup> immediately surrounding a tag intersects an active area. b'1' indicates intersection.
x coordinate	16	The unsigned x coordinate of the tag <sup>b</sup> .
y coordinate	16	The unsigned y coordinate of the tag <sup>b</sup> .
<b>common to tagged region</b>		
encoding format	4	The format of the encoding. 0: the present encoding. Other values are reserved
region flags	12	Flags controlling the interpretation of region data (see Table 3).
macrodot size ID	4	The ID of the macrodot size. 0: the nominal macrodot size <sup>c</sup> .
region ID	96	The ID of the region containing the tags.
secret-key signature	60	A secret-key signature of the region.
CRC (Cyclic Redundancy Check)	16	A CRC <sup>d</sup> of common tag data.

- 15 a. the diameter of the area, centered on the tag, is nominally 2.5 times the diagonal size of the tag; this is to accommodate the worst-case distance between the nib position and the imaged tag
- b. allows a maximum coordinate value of 225m for the nominal tag size of 3.429mm (based on nominal macrodot size and 36 macrodots per tag)
- c. 95 microns (based on 1600dpi and 6 dots per macrodot)
- 20 d. CCITT CRC-16 [see ITU, *Interface between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE) for terminals operating in the packet mode and connected to public data networks by dedicated circuit*, ITU-T X.25 (10/96)], computed in bit order on raw codeword data (see Table 4).



An active area is an area within which any captured input should be immediately forwarded to the corresponding Netpage server 10 for interpretation. This also allows the Netpage server 10 to signal to the user that the input has had an immediate effect. Since the server has access to precise region definitions, any active area indication in the surface coding can be imprecise so long as it is inclusive.

**Table 3. Region flags**

bit	meaning
0	Region ID is an EPC. Used for Hyperlabel (see, for example, US 7,225,979). Otherwise the region ID is a Netpage region ID.
1	Region ID has a secret-key signature (see Section 2.8.4).
2	Region has embedded data (see Section 2.8.3). Otherwise the region contains no embedded data.
3	Embedded data is a public-key signature (see Section 2.8.4). Otherwise the data type is specified in the embedded data block.
4	Embedded public-key signature is short (see Section 2.8.4).
5	EPC contains a layout number. Used for non-serialized Hyperlabel applications, where the serial number is replaced by a layout number (see US2007/0108285). Otherwise the EPC contains a serial number.
6	Region is non-interactive i.e. x and y coordinates are zero. Otherwise x and y coordinates are present.
7	Region is active i.e. the entire region is an active area and the active area flag is not present. Otherwise the active area is indicated by individual tags' active area flags.
other	Reserved for future use. Must be zero.

When a region flag indicates that a particular field is absent, then the field is not coded in the tag pattern, i.e. there are no macrodots coding the value of the field.

**2.8.2 Mapping of Fields to Codewords**

Table 4 defines how the information fields map to codewords.

**Table 3. Mapping of fields to codewords**

codeword	codeword bits	field	width	field bits
X	all	x coordinate	16	all
Y	all	y coordinate	16	all
F	all	active area flag	1	all
B	27:0	region ID	28	27:0
	43:28	CRC <sup>a</sup>	16	all
C	3:0	encoding format	4	all
	15:4	region flags	12	all

	19:16	tag size ID	5	all
	43:20	region ID	24	51:28
D	all	region ID	44	95:52
S	all <sup>p</sup>	secret-key signature	60	all
E	all	data fragment	44	all

- a. the CRC is computed in bit order on the data portions of the B, C and D codewords, in that order, excluding the CRC field itself
- b. entire codeword is used for data i.e. there is no redundancy

**5 2.8.3 Embedded Data Object**

If the “region contains embedded data” flag in the region flags is set then the surface coding contains embedded data. The embedded data is encoded in multiple contiguous tags’ data fragments, and is replicated in the surface coding as many times as it will fit.

The embedded data is encoded in such a way that a random and partial scan of the surface coding containing the embedded data can be sufficient to retrieve the entire data. The scanning system reassembles the data from retrieved fragments, and reports to the user when sufficient fragments have been retrieved without error.

As shown in Table 5, each block has a data capacity of 176-bits. The block data is encoded in the data fragments of a contiguous group of four tags arranged in a 2x2 square. A tag belongs to a block whose integer coordinate is the tag’s coordinate divided by 2. Within each block the data is arranged into tags with increasing x coordinate within increasing y coordinate.

The block parameters are as defined in Table 5. The E codeword of each tag may encode a fragment of the embedded data.

**20 Table 5. Block parameters**

parameter	value	description
<i>w</i>	2	The width of the block, in tags
<i>h</i>	2	The height of the block, in tags.
<i>b</i>	176	The data capacity of the block, in bits

If the E codeword of a particular tag does not contain a fragment of the embedded data, then the pen 101 can discover this implicitly by the failure of the codeword to decode, or explicitly from the tag’s active area flag.

Data of arbitrary size may be encoded into a superblock consisting of a contiguous set of blocks arranged in a rectangle. The size of the superblock may be encoded in each block. A block belongs to a superblock whose integer coordinate is the block’s coordinate divided by the superblock size. Within each superblock the data is arranged into blocks with increasing x coordinate within increasing y coordinate.

The superblock is replicated in the surface coding as many times as it will fit, including partially along the edges of the surface coding.

The data encoded in the superblock may include more precise type information, more precise size information, and more extensive error detection and/or correction data.

5

#### 2.8.4 Digital Signatures

If the “region has secret-key signature” flag in the region flags is set then the signature field contains a secret-key digital signature of the region ID with a maximum width of 64 bits. In an online environment the signature can be verified, in conjunction with the region ID, by querying a server with knowledge of the secret-key signature or the corresponding secret key.

10

If the “region contains embedded data” and “embedded data is a public-key signature” flags in the region flags are set then the surface coding contains an embedded public-key digital signature of the region ID.

If the “embedded public-key signature is short” flag is set, then the embedded public-key signature is a 160-bit signature encoded in a single block consisting of just the signature and a 16-bit CRC, i.e. with the superblock parameters omitted.

15

In an online environment any number of signature fragments can be used, in conjunction with the region ID and optionally the secret-key signature, to validate the public-key signature by querying a server with knowledge of the full public-key signature or the corresponding private key.

20

In an offline (or online) environment the entire public-key signature can be recovered by reading multiple tags, and can then be verified using the corresponding public signature key. The actual length and type of the signature are determined from the region ID during signature validation.

Digital signature verification is discussed in the Applicant’s US Publication No. 2007/0108285, the contents of which are herein incorporated by reference.

25

#### 2.9 Tag Imaging and Decoding

The minimum imaging field of view required to guarantee acquisition of *data* from an entire tag has a diameter of  $53.74s$  (i.e.  $((3 \times 12) + 2)\sqrt{2}s$ ), allowing for arbitrary rotation and translation of the surface coding in the field of view. Notably, the imaging field of view does not have to be large enough to guarantee capture of an entire tag – the arrangement of the data symbols within each tag ensures that any tag-sized field of view captures the requisite information in full, irrespective of whether a whole tag is actually visible.

30

As used herein, the term “tag-sized” is used to mean an area of the same size and dimensions as a tag. In terms of imaging the coding pattern, the imaging field-of-view is typically a circle. The imaging circle should have a diameter which is sufficiently large to contain a tag-sized

35

portion of the coding pattern. Accordingly, the imaging field-of-view should preferably have diameter of at least one tag diameter and less than two tag diameters. Importantly, the field-of-view is not required to be at least two tag diameters, in contrast with prior art tag designs, because it is not essential in the present invention to capture an entire tag in the field of view.

5           Optionally, the field-of-view has a diameter of about one tag diagonal plus one or two macrodot units. The extra macrodot unit ensures that partial macrodots never have to be read at the edge of the field of view. In the present context, a “tag diameter” is given to mean the length of a tag diagonal.

10           Given a maximum macrodot spacing of 106 microns, this gives a required field of view of 5.69mm.

Table 6 gives pitch ranges achievable for the present surface coding for different sampling rates and hence image sensor array sizes.

15           **Table 6. Pitch ranges achievable for present surface coding for different image sensor sizes; dot pitch = 600 dpi, macrodot pitch = 2 dots, field of view = 4.55 mm, viewing distance = 30 mm, nib-to-FOV separation = 1 mm**

pitch range (degrees)	roll range (degrees)	sampling rate	image sensor size	scaled <sup>a</sup> image sensor size
-30 to +38	-34 to +34	2	142	178
		2.5	177	221
-35 to +44	-39 to +39	2	152	190
		2.5	190	238
-40 to +48	-44 to +44	2	166	208
		2.5	207	259
-45 to +53	-48 to +48	2	183	229
		2.5	228	285

a. scaled by 1.25 (i.e. 106 microns/85 microns) to accommodate maximum macrodot spacing

20           Figure 18 shows a tag image processing and decoding process flow up to the stage of sampling and decoding the data codewords. Firstly, a raw image 802 of the tag pattern is acquired (at 800), for example via an image sensor such as a CCD image sensor, CMOS image sensor, or a scanning laser and photodiode image sensor. The raw image 802 is then typically enhanced (at 804) to produce an enhanced image 806 with improved contrast and more uniform pixel intensities. Image enhancement may include global or local range expansion, equalisation, and the like. The enhanced image 806 is then typically filtered (at 808) to produce a filtered image 810. Image filtering may consist of low-pass filtering, with the low-pass filter kernel size tuned to obscure macrodots 302 but to preserve targets 301. The filtering step 808 may include additional filtering (such as edge detection) to enhance target features 301. Encoding of data codewords 304 using

pulse position modulation (PPM) provides a more uniform coding pattern 3 than simple binary dot encoding (as described in, for example, US 6,832,717). Advantageously, this helps separate targets 301 from data areas, thereby allowing more effective low-pass filtering of the PPM-encoded data compared to binary-coded data.

5           Following low-pass filtering, the filtered image 810 is then processed (at 812) to locate the targets 301. This may consist of a search for target features whose spatial inter-relationship is consistent with the known geometry of the tag pattern. Candidate targets may be identified directly from maxima in the filtered image 810, or may be the subject of further characterization and matching, such as via their (binary or grayscale) shape moments (typically computed from pixels in  
10 the enhanced image 806 based on local maxima in the filtered image 810), as described in US 7,055,739, the contents of which is herein incorporated by reference.

          The identified targets 301 are then assigned to a target grid 816. Each cell of the grid 816 contains a symbol group 303, and several symbol groups will of course be visible in the image. At this stage, individual tags 4 will not be identifiable in the target grid 816, since the targets 301  
15 not demarcate one tag from another.

          To allow macrodot values to be sampled accurately, the perspective transform of the captured image must be inferred. Four of the targets 301 are taken to be the perspective-distorted corners of a square of known size in tag space, and the eight-degree-of-freedom perspective transform 822 is inferred (at 820), based on solving the well-understood equations relating the four  
20 tag-space and image-space point pairs. Calculation of the 2D perspective transform is described in detail in, for example, Applicant's US 6,832,717, the contents of which is herein incorporated by reference.

          Since each image will contain at least 9, at least 16 or at least 25 targets arranged in a square grid, the accuracy of calculating the 2D perspective transform is improved compared to the  
25 Applicant's previous tag designs described in, for example, US 6,832,717. Hence, more accurate position calculation can be achieved with the tag design of the present invention.

          The inferred tag-space to image-space perspective transform 822 is used to project each known macrodot position in tag space into image space. Since all bits in the tags are represented by PPM-encoding, the presence or absence of each macrodot 302 can be determined using a local  
30 intensity reference, rather than a separate intensity reference. Thus, PPM-encoding provides improved data sampling compared with pure binary encoding.

          The next stage determines the orientation of the tag(s), or portions thereof, in the field of view. At least 3 orientation codewords are sampled and decoded (at 824) to provide the orientation 826. Robust orientation determination is provided since many symbol groups 303 are contained in  
35 the image, with each symbol group containing an orientation symbol, as described above. Moreover, and as described in Section 2.5.1, since  $N$  orientation symbols in a tag form a code with

minimum distance  $N$ , the code is capable of correcting  $(N-1)/2$  errors. Hence, orientation determination is very robust and capable of correcting errors, depending on the number of orientation symbols sampled.

After determination of the orientation 826, the next stage samples and decodes two or  
 5 more orthogonal translation codewords (at 828) to determine the relative translation 830 of tags(s)  
 in the field of view relative to the target grid. This enables alignment of the tags 4 with the target  
 grid 818, thereby allowing individual tag(s), or portions thereof, to be distinguished in the coding  
 pattern 3 in the field of view. Since each symbol group 303 contains a translation code, multiple  
 translation codes can be sampled to provide robust translation determination. As described in  
 10 Section 2.5.2, the translation code is a cyclic position code. Since each row and each column of a  
 tag contains  $M$  symbol groups, the code has minimum distance  $M \times M$ . This allows very robust  
 determination of the alignment of tags 4 with the target grid 818. The alignment needs to be both  
 robust and accurate since there are many possible alignments when each tag 4 contains multiple  
 symbol groups 303.

15 Once initial imaging and decoding has yielded the 2D perspective transform, the  
 orientation, and the translation of tag(s) relative to the target grid, the data codewords 304 can then  
 be sampled and decoded 836 to yield the requisite decoded codewords 838.

Decoding of the data codewords 304 typically proceeds as follows:

- 20 • sample common Reed-Solomon codewords
- decode common Reed-Solomon codewords
- verify tag data CRC
- on decode error flag bad region ID sample
- determine encoding type, and reject unknown encoding
- determine region flags
- 25 • determine region ID
- sample and decode x and y coordinate Reed-Solomon codewords
- determine tag x-y location from codewords
- determine nib x-y location from tag x-y location and perspective transform
- sample and decode four or more flag symbols to determine active area flag
- 30 • determine active area status of nib location with reference to active area flag
- encode region ID, nib x-y location, and nib active area status in digital ink  
 (“interaction data”)
- route digital ink based on region flags

35 The skilled person will appreciate that the decoding sequence described above represents  
 one embodiment of the present invention. It will, of course, be appreciated that the interaction data

sent from the pen 101 to the netpage system may include other data *e.g.* digital signature (see Section 2.8.4), pen mode (see US 2007/125860), orientation data, pen ID, nib ID *etc.*

An example of interpreting interaction data, received by the netpage system from the netpage pen 101, is discussed briefly above. A more detailed discussion of how the netpage system  
5 may interpret interaction data can be found in the Applicant's previously-filed applications (see, for example, US 2007/130117 and US 2007/108285, the contents of which are herein incorporated by reference).

### 3. Netpage Pen

#### 10 3.1 Functional Overview

The active sensing device of the netpage system may take the form of a clicker (for clicking on a specific position on a surface), a pointer having a stylus (for pointing or gesturing on a surface using pointer strokes), or a pen having a marking nib (for marking a surface with ink when pointing, gesturing or writing on the surface). For a description of various netpage sensing  
15 devices, reference is made to US Patent No. 7,105,753; US Patent No. 7,015,901; US Patent No. 7,091,960; and US Publication No. 2006/0028459, the contents of each of which are herein incorporated by reference.

It will be appreciated that the present invention may utilize any suitable optical reader. However, the Netpage pen 400 will be described herein as one such example.

20 The Netpage pen 400 is a motion-sensing writing instrument which works in conjunction with a tagged Netpage surface (see Section 2). The pen incorporates a conventional ballpoint pen cartridge for marking the surface, an image sensor and processor for simultaneously capturing the absolute path of the pen on the surface and identifying the surface, a force sensor for  
simultaneously measuring the force exerted on the nib, and a real-time clock for simultaneously  
25 measuring the passage of time.

While in contact with a tagged surface, as indicated by the force sensor, the pen continuously images the surface region adjacent to the nib, and decodes the nearest tag in its field of view to determine both the identity of the surface, its own instantaneous position on the surface and the pose of the pen. The pen thus generates a stream of timestamped position samples relative  
30 to a particular surface, and transmits this stream to the Netpage server 10. The sample stream describes a series of strokes, and is conventionally referred to as digital ink (DInk). Each stroke is delimited by a pen down and a pen up event, as detected by the force sensor. More generally, any data resulting from an interaction with a Netpage, and transmitted to the Netpage server 10, is referred to herein as "interaction data".

35 The pen samples its position at a sufficiently high rate (nominally 100Hz) to allow a Netpage server to accurately reproduce hand-drawn strokes, recognise handwritten text, and verify

hand-written signatures.

The Netpage pen also supports hover mode in interactive applications. In hover mode the pen is not in contact with the paper and may be some small distance above the surface of the paper (or other substrate). This allows the position of the pen, including its height and pose to be reported. In the case of an interactive application the hover mode behaviour can be used to move a cursor without marking the paper, or the distance of the nib from the coded surface could be used for tool behaviour control, for example an air brush function.

The pen includes a Bluetooth radio transceiver for transmitting digital ink via a relay device to a Netpage server. When operating offline from a Netpage server the pen buffers captured digital ink in non-volatile memory. When operating online to a Netpage server the pen transmits digital ink in real time.

The pen is supplied with a docking cradle or "pod". The pod contains a Bluetooth to USB relay. The pod is connected via a USB cable to a computer which provides communications support for local applications and access to Netpage services.

The pen is powered by a rechargeable battery. The battery is not accessible to or replaceable by the user. Power to charge the pen can be taken from the USB connection or from an external power adapter through the pod. The pen also has a power and USB-compatible data socket to allow it to be externally connected and powered while in use.

The pen cap serves the dual purpose of protecting the nib and the imaging optics when the cap is fitted and signalling the pen to leave a power-preserving state when uncapped.

### 3.2 Ergonomics and Layout

Figure 19 shows a rounded triangular profile gives the pen 400 an ergonomically comfortable shape to grip and use the pen in the correct functional orientation. It is also a practical shape for accommodating the internal components. A normal pen-like grip naturally conforms to a triangular shape between thumb 402, index finger 404 and middle finger 406.

As shown in Figure 20, a typical user writes with the pen 400 at a nominal pitch of about 30 degrees from the normal toward the hand 408 when held (positive angle) but seldom operates a pen at more than about 10 degrees of negative pitch (away from the hand). The range of pitch angles over which the pen 400 is able to image the pattern on the paper has been optimised for this asymmetric usage. The shape of the pen 400 helps to orient the pen correctly in the user's hand 408 and to discourage the user from using the pen "upside-down". The pen functions "upside-down" but the allowable tilt angle range is reduced.

The cap 410 is designed to fit over the top end of the pen 400, allowing it to be securely stowed while the pen is in use. Multi colour LEDs illuminate a status window 412 in the top edge (as in the apex of the rounded triangular cross section) of the pen 400 near its top end. The status



window 412 remains un-obscured when the cap is stowed. A vibration motor is also included in the pen as a haptic feedback system (described in detail below).

As shown in Figure 21, the grip portion of the pen has a hollow chassis molding 416 enclosed by a base molding 528 to house the other components. The ink cartridge 414 for the ball point nib (not shown) fits naturally into the apex 420 of the triangular cross section, placing it consistently with the user's grip. This in turn provides space for the main PCB 422 in the centre of the pen and for the battery 424 in the base of the pen. By referring to Figure 22Aa, it can be seen that this also naturally places the tag-sensing optics 426 unobtrusively below the nib 418 (with respect to nominal pitch). The nib molding 428 of the pen 400 is swept back below the ink cartridge 414 to prevent contact between the nib molding 428 and the paper surface when the pen is operated at maximum pitch.

As best shown in Figure 22B, the imaging field of view 430 emerges through a centrally positioned IR filter/window 432 below the nib 418, and two near-infrared illumination LEDs 434, 436 emerge from the two bottom corners of the nib molding 428. Each LED 434, 436 has a corresponding illumination field 438, 440.

As the pen is hand-held, it may be held at an angle that causes reflections from one of the LED's that are detrimental to the image sensor. By providing more than one LED, the LED causing the offending reflections can be extinguished.

Specific details of the pen mechanical design can be found in US Publication No. 2006/0028459, the contents of which are herein incorporated by reference.

### 3.3 Pen Feedback Indications

Figure 23 is a longitudinal cross section through the centre-line if the pen 400 (with the cap 410 stowed on the end of the pen). The pen incorporates red and green LEDs 444 to indicate several states, using colours and intensity modulation. A light pipe 448 on the LEDs 444 transmit the signal to the status indicator window 412 in the tube molding 416. These signal status information to the user including power-on, battery level, untransmitted digital ink, network connection on-line, fault or error with an action, detection of an "active area" flag, detection of an "embedded data" flag, further data sampling to required to acquire embedded data, acquisition of embedded data completed etc.

A vibration motor 446 is used to haptically convey information to the user for important verification functions during transactions. This system is used for important interactive indications that might be missed due to inattention to the LED indicators 444 or high levels of ambient light. The haptic system indicates to the user when:

- The pen wakes from standby mode
- There is an error with an action

- To acknowledge a transaction

**3.4 Pen Optics**

The pen incorporates a fixed-focus narrowband infrared imaging system. It utilizes a camera with a short exposure time, small aperture, and bright synchronised illumination to capture sharp images unaffected by defocus blur or motion blur.

**Table 6. Optical Specifications**

Magnification	~ 0.225
Focal length of lens	6.0 mm
Viewing distance	30.5 mm
Total track length	41.0 mm
Aperture diameter	0.8 mm
Depth of field	~ 7 6.5mm
Exposure time	200 us
Wavelength	810 nm
Image sensor size	140 x 140 pixels
Pixel size	10 um
Pitch range	~ 15 to 45 deg
Roll range	~ 30 to 30 deg
Yaw range	0 to 360 deg
Minimum sampling rate	2.25 pixels per macrodot
Maximum pen velocity	0.5 m/s

<sup>1</sup>Allowing 70 micron blur radius

<sup>2</sup>Illumination and filter

<sup>3</sup>Pitch, roll and yaw are relative to the axis of the pen

10

Cross sections showing the pen optics are provided in Figures 24A and 24B. An image of the Netpage tags printed on a surface 548 adjacent to the nib 418 is focused by a lens 488 onto the active region of an image sensor 490. A small aperture 494 ensures the available depth of field accommodates the required pitch and roll ranges of the pen 400.

15

First and second LEDs 434 and 436 brightly illuminate the surface 549 within the field of view 430. The spectral emission peak of the LEDs is matched to the spectral absorption peak of the infrared ink used to print Netpage tags to maximise contrast in captured images of tags. The brightness of the LEDs is matched to the small aperture size and short exposure time required to minimise defocus and motion blur.

20

A longpass IR filter 432 suppresses the response of the image sensor 490 to any coloured

graphics or text spatially coincident with imaged tags and any ambient illumination below the cut-off wavelength of the filter 432. The transmission of the filter 432 is matched to the spectral absorption peak of the infrared ink to maximise contrast in captured images of tags. The filter also acts as a robust physical window, preventing contaminants from entering the optical assembly 470.

5

### 3.5 Pen Imaging System

A ray trace of the optic path is shown in Figure 25. The image sensor 490 is a CMOS image sensor with an active region of 140 pixels squared. Each pixel is  $10\mu\text{m}$  squared, with a fill factor of 93%. Turning to Figure 26, the lens 488 is shown in detail. The dimensions are:

10

$$D = 3 \text{ mm}$$

$$R1 = 3.593 \text{ mm}$$

$$R2 = 15.0 \text{ mm}$$

$$X = 0.8246 \text{ mm}$$

$$Y = 1.0 \text{ mm}$$

15

$$Z = 0.25 \text{ mm}$$

This gives a focal length of 6.15 mm and transfers the image from the object plane (tagged surface 548) to the image plane (image sensor 490) with the correct sampling frequency to successfully decode all images over the specified pitch, roll and yaw ranges. The lens 488 is biconvex, with the most curved surface facing the image sensor. The minimum imaging field of view 430 required to guarantee acquisition of sufficient tag data with each interaction is dependent on the specific coding pattern. The required field of view for the coding pattern of the present invention is described in Section 2.9.

20

The required paraxial magnification of the optical system is defined by the minimum spatial sampling frequency of 2.25 pixels per macrodot for the fully specified tilt range of the pen 400, for the image sensor 490 of  $10\mu\text{m}$  pixels. Typically, the imaging system employs a paraxial magnification of 0.225, the ratio of the diameter of the inverted image at the image sensor to the diameter of the field of view at the object plane, on an image sensor 490 of minimum  $128 \times 128$  pixels. The image sensor 490 however is  $140 \times 140$  pixels, in order to accommodate manufacturing tolerances. This allows up to  $\pm 120\mu\text{m}$  (12 pixels in each direction in the plane of the image sensor) of misalignment between the optical axis and the image sensor axis without losing any of the information in the field of view.

30

The lens 488 is made from Poly-methyl-methacrylate (PMMA), typically used for injection moulded optical components. PMMA is scratch resistant, and has a refractive index of 1.49, with 90% transmission at 810nm. The lens is biconvex to assist moulding precision and features a mounting surface to precisely mate the lens with the optical barrel molding 492.

35

A 0.8 mm diameter aperture 494 is used to provide the depth of field requirements of the

design.

The specified tilt range of the pen is 15.0 to 45.0 degree pitch, with a roll range of 30.0 to 30.0 degrees. Tilting the pen through its specified range moves the tilted object plane up to 6.3 mm away from the focal plane. The specified aperture thus provides a corresponding depth of field of 6.5mm, with an acceptable blur radius at the image sensor of 16µm.

Due to the geometry of the pen design, the pen operates correctly over a pitch range of 33.0 to 45.0 degrees.

Referring to Figure 27, the optical axis 550 is pitched 0.8 degrees away from the nib axis 552. The optical axis and the nib axis converge toward the paper surface 548. With the nib axis 552 perpendicular to the paper, the distance A between the edge of the field of view 430 closest to the nib axis and the nib axis itself is 1.2 mm.

The longpass IR filter 432 is made of CR-39, a lightweight thermoset plastic heavily resistant to abrasion and chemicals such as acetone. Because of these properties, the filter also serves as a window. The filter is 1.5mm thick, with a refractive index of 1.50. Each filter may be easily cut from a large sheet using a CO<sub>2</sub> laser cutter.

### 3.6 Electronics Design

**Table 3. Electrical Specifications**

Processor	ARM7 (Atmel AT91FR40162) running at 80MHz with 256kB SRAM and 2MB flash memory
Digital ink storage capacity	5 hours of writing
Bluetooth Compliance	1.2
USB Compliance	1.1
Battery standby time	12 hours (cap off), >4 weeks (cap on)
Battery writing time	4 hours of cursive writing (81% pen down, assuming easy offload of digital ink)
Battery charging time	2 hours
Battery Life	Typically 300 charging cycles or 2 years (whichever occurs first) to 80% of initial capacity.
Battery Capacity/Type	~340 mAh at 3.7V, Lithium-ion Polymer (LiPo)

Figure 28 is a block diagram of the pen electronics. The electronics design for the pen is based around five main sections. These are:

- the main ARM7 microprocessor 574,
- the image sensor and image processor 576,

- the Bluetooth communications module 578,
- the power management unit IC (PMU) 580 and
- the force sensor microprocessor 582.

### 5 3.6.1 Microprocessor

The pen uses an Atmel AT91FR40162 microprocessor (see Atmel, *AT91 ARM Thumb Microcontrollers - AT91FR40162 Preliminary*,

<http://www.keil.com/dd/docs/datashts/atmel/at91fr40162.pdf>) running at 80MHz. The

AT91FR40162 incorporates an ARM7 microprocessor, 256kBytes of on-chip single wait state

10 SRAM and 2MBytes of external flash memory in a stack chip package.

This microprocessor 574 forms the core of the pen 400. Its duties include:

- setting up the Jupiter image sensor 584,
- decoding images of Netpage coding pattern (see Section 2.9), with assistance from the image processing features of the image sensor 584, for inclusion in the digital ink stream along with force sensor data received from the force sensor microprocessor 582,
- setting up the power management IC (PMU) 580,
- compressing and sending digital ink via the Bluetooth communications module 578, and
- 20 • programming the force sensor microprocessor 582.

The ARM7 microprocessor 574 runs from an 80MHz oscillator. It communicates with the Jupiter image sensor 576 using a Universal Synchronous Receiver Transmitter (USRT) 586 with a 40MHz clock. The ARM7 574 communicates with the Bluetooth module 578 using a

25 Universal Asynchronous Receiver Transmitter (UART) 588 running at 115.2kbaud.

Communications to the PMU 580 and the Force Sensor microProcessor (FSP) 582 are performed using a Low Speed Serial bus (LSS) 590. The LSS is implemented in software and uses two of the microprocessor's general purpose IOs.

The ARM7 microprocessor 574 is programmed via its JTAG port.

30

### 3.6.2 Image Sensor

The 'Jupiter' Image Sensor 584 (see US Publication No. 2005/0024510, the contents of which are incorporated herein by reference) contains a monochrome sensor array, an analogue to digital converter (ADC), a frame store buffer, a simple image processor and a phase lock loop

35 (PLL). In the pen, Jupiter uses the USRT's clock line and its internal PLL to generate all its clocking requirements. Images captured by the sensor array are stored in the frame store buffer.

These images are decoded by the ARM7 microprocessor 574 with help from the 'Callisto' image processor contained in Jupiter. The Callisto image processor performs, *inter alia*, low-pass filtering of captured images (see Section 2.9 and US Publication No. 2005/0024510) before macrodot sampling and decoding by the microprocessor 574.

- 5 Jupiter controls the strobing of two infrared LEDs 434 and 436 at the same time as its image array is exposed. One or other of these two infrared LEDs may be turned off while the image array is exposed to prevent specular reflection off the paper that can occur at certain angles.

### 3.6.3 Bluetooth Communications Module

- 10 The pen uses a CSR BlueCore4-External device (see CSR, *BlueCore4-External Data Sheet rev c*, 6-Sep-2004) as the Bluetooth controller 578. It requires an external 8Mbit flash memory device 594 to hold its program code. The BlueCore4 meets the Bluetooth v1.2 specification and is compliant to v0.9 of the Enhanced Data Rate (EDR) specification which allows communication at up to 3Mbps.

- 15 A 2.45GHz chip antenna 486 is used on the pen for the Bluetooth communications.

The BlueCore4 is capable of forming a UART to USB bridge. This is used to allow USB communications via data/power socket 458 at the top of the pen 456.

Alternatives to Bluetooth include wireless LAN and PAN standards such as IEEE 802.11 (Wi-Fi) (see IEEE, *802.11 Wireless Local Area Networks*,

- 20 <http://grouper.ieee.org/groups/802/11/index.html>), IEEE 802.15 (see IEEE, *802.15 Working Group for WPAN*, <http://grouper.ieee.org/groups/802/15/index.html>), ZigBee (see ZigBee Alliance, <http://www.zigbee.org>), and WirelessUSB Cypress (see *WirelessUSB LR 2.4-GHz DSSS Radio SoC*, <http://www.cypress.com/cfuploads/img/products/cywusb6935.pdf>), as well as mobile standards  
25 such as GSM (see GSM Association, <http://www.gsmworld.com/index.shtml>), GPRS/EDGE, *GPRS Platform*, <http://www.gsmworld.com/technology/gprs/index.shtml>), CDMA (see CDMA Development Group, <http://www.cdg.org/>), and Qualcomm, <http://www.qualcomm.com>), and UMTS (see 3rd Generation Partnership Project (3GPP), <http://www.3gpp.org>).

### 30 3.6.4 Power Management Chip

The pen uses an Austria Microsystems AS3603 PMU 580 (see Austria Microsystems, *AS3603 Multi-Standard Power Management Unit Data Sheet v2.0*). The PMU is used for battery management, voltage generation, power up reset generation and driving indicator LEDs and the vibrator motor.

- 35 The PMU 580 communicates with the ARM7 microprocessor 574 via the LSS bus 590.

### 3.6.5 Force Sensor Subsystem

The force sensor subsystem comprises a custom Hokuriku force sensor 500 (based on Hokuriku, *HFD-500 Force Sensor*, <http://www.hdk.co.jp/pdf/eng/e1381AA.pdf>), an amplifier and  
5 low pass filter 600 implemented using op-amps and a force sensor microprocessor 582.

The pen uses a Silicon Laboratories C8051F330 as the force sensor microprocessor 582 (see Silicon Laboratories, *C8051F330/1 MCU Data Sheet, rev 1.1*). The C8051F330 is an 8051 microprocessor with on chip flash memory, 10 bit ADC and 10 bit DAC. It contains an internal 24.5MHz oscillator and also uses an external 32.768 kHz tuning fork.

10 The Hokuriku force sensor 500 is a silicon piezoresistive bridge sensor. An op-amp stage 600 amplifies and low pass (anti-alias) filters the force sensor output. This signal is then sampled by the force sensor microprocessor 582 at 5kHz.

Alternatives to piezoresistive force sensing include capacitive and inductive force sensing (see Wacom, "Variable capacity condenser and pointer", US Patent Application  
15 20010038384, filed 8 November 2001, and Wacom, *Technology*, <http://www.wacom-components.com/english/tech.asp>).

The force sensor microprocessor 582 performs further (digital) filtering of the force signal and produces the force sensor values for the digital ink stream. A frame sync signal from the Jupiter image sensor 576 is used to trigger the generation of each force sample for the digital ink  
20 stream. The temperature is measured via the force sensor microprocessor's 582 on chip temperature sensor and this is used to compensate for the temperature dependence of the force sensor and amplifier. The offset of the force signal is dynamically controlled by input of the microprocessor's DAC output into the amplifier stage 600.

The force sensor microprocessor 582 communicates with the ARM7 microprocessor 574  
25 via the LSS bus 590. There are two separate interrupt lines from the force sensor microprocessor 582 to the ARM7 microprocessor 574. One is used to indicate that a force sensor sample is ready for reading and the other to indicate that a pen down/up event has occurred.

The force sensor microprocessor flash memory is programmed in-circuit by the ARM7 microprocessor 574.

30 The force sensor microprocessor 582 also provides the real time clock functionality for the pen 400. The RTC function is performed in one of the microprocessor's counter timers and runs from the external 32.768 kHz tuning fork. As a result, the force sensor microprocessor needs to remain on when the cap 472 is on and the ARM7 574 is powered down. Hence the force sensor microprocessor 582 uses a low power LDO separate from the PMU 580 as its power source. The  
35 real time clock functionality includes an interrupt which can be programmed to power up the ARM7 574.

The cap switch 602 is monitored by the force sensor microprocessor 582. When the cap assembly 472 is taken off (or there is a real time clock interrupt), the force sensor microprocessor 582 starts up the ARM7 572 by initiating a power on and reset cycle in the PMU 580.

### 5 3.7 Pen Software

The Netpage pen software comprises that software running on microprocessors in the Netpage pen 400 and Netpage pod.

The pen contains a number of microprocessors, as detailed in Section 3.6. The Netpage pen software includes software running on the Atmel ARM7 CPU 574 (hereafter CPU), the Force  
10 Sensor microprocessor 582, and also software running in the VM on the CSR BlueCore Bluetooth module 578 (hereafter pen BlueCore). Each of these processors has an associated flash memory which stores the processor specific software, together with settings and other persistent data. The pen BlueCore 578 also runs firmware supplied by the module manufacturer, and this firmware is not considered a part of the Netpage pen software.

15 The pod contains a CSR BlueCore Bluetooth module (hereafter pod BlueCore). The Netpage pen software also includes software running in the VM on the pod BlueCore.

As the Netpage pen 400 traverses a Netpage tagged surface 548, a stream of correlated position and force samples are produced. This stream is referred to as DInk. Note that DInk may include samples with zero force (so called "Hover DInk") produced when the Netpage pen is in  
20 proximity to, but not marking, a Netpage tagged surface.

The CPU component of the Netpage pen software is responsible for DInk capture, tag image processing and decoding (in conjunction with the Jupiter image sensor 576), storage and offload management, host communications, user feedback and software upgrade. It includes an operating system (RTOS) and relevant hardware drivers. In addition, it provides a manufacturing  
25 and maintenance mode for calibration, configuration or detailed (non-field) fault diagnosis. The Force Sensor microprocessor 582 component of the Netpage pen software is responsible for filtering and preparing force samples for the main CPU. The pen BlueCore VM software is responsible for bridging the CPU UART 588 interface to USB when the pen is operating in tethered mode. The pen BlueCore VM software is not used when the pen is operating in Bluetooth  
30 mode.

The pod BlueCore VM software is responsible for sensing when the pod is charging a pen 400, controlling the pod LEDs appropriately, and communicating with the host PC via USB.

For a detailed description of the software modules, reference is made to US Publication No. 2006/0028459, the contents of which are herein incorporated by reference.

35 The present invention has been described with reference to a preferred embodiment and number of specific alternative embodiments. However, it will be appreciated by those skilled in the



relevant fields that a number of other embodiments, differing from those specifically described, will also fall within the spirit and scope of the present invention. Accordingly, it will be understood that the invention is not intended to be limited to the specific embodiments described in the present specification, including documents incorporated by cross-reference as appropriate. The scope of the  
5 invention is only limited by the attached claims.

10

15

CLAIMS

1. A substrate having a coding pattern disposed on a surface thereof, said coding pattern comprising:
  - 5 a plurality of contiguous tags, each tag comprising x-coordinate data and y-coordinate data, wherein a y-axis is nominally defined as north-south and an x-axis is nominally defined as east-west; and
  - a plurality of data elements contained in each tag, said x-coordinate data being represented by a respective set of data elements and said y-coordinate data being
  - 10 represented by a respective set of data elements,
  - wherein:
    - said x-coordinate data has two replications within a respective tag, a first replication in a western half of said tag and a second replication in an eastern half of said tag; and
    - 15 said y-coordinate data has two replications within a respective tag, a first replication in a northern half of said tag and a second replication in a southern half of said tag,
  - and wherein fragments of said coordinate data are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain said x-coordinate data and said y-
  - 20 coordinate data for a tag irrespective of whether a whole tag is contained in said portion.
2. The substrate of claim 1, wherein each tag is square.
3. The substrate of claim 1, wherein said coding pattern comprises:
  - 25 a plurality of target elements defining a target grid, said target grid comprising a plurality of cells, wherein neighboring cells share target elements and wherein each tag is defined by a plurality of contiguous cells.
4. The substrate of claim 3, wherein each tag is square and comprises  $M^2$  contiguous
- 30 square cells, wherein  $M$  is an integer having a value of at least 2.
5. The substrate of claim 1, wherein said data elements are macrodots.
6. The substrate of claim 4, wherein a portion of data is represented by a macrodot
- 35 occupying one of a plurality of possible positions within a cell, each position representing one of a plurality of possible data values.

7. The substrate of claim 5, wherein a  $n$ -bit portion of data is represented by a macrodot occupying one of  $2^n$  possible positions within a cell, each position representing one of  $2^n$  possible data values, wherein  $n$  is an integer.
- 5
8. The substrate of claim 3, wherein each cell defines a symbol group, each symbol group comprising a plurality of Reed-Solomon symbols encoded by a plurality of said data elements.
- 10 9. The substrate of claim 8, wherein each symbol comprises two halves, each half comprising 2 bits of data represented by a macrodot occupying one of 4 possible positions within said half.
10. The substrate of claim 1, wherein said x-coordinate data is encoded as an x-  
15 coordinate codeword comprised of a respective set of Reed-Solomon symbols, and said y-coordinate data is encoded as a y-coordinate codeword comprised of a respective set of Reed-Solomon symbols.
11. The substrate of claim 8, wherein each tag comprises one or more common  
20 codewords, each common codeword being comprised of a respective set of said Reed-Solomon symbols, wherein said one or more common codewords are defined as codewords common to a plurality of contiguous tags.
12. The substrate of claim 11, wherein each symbol group comprises a fragment of at  
25 least one of said one or more common codewords, and contiguous symbol groups are arranged such that any tag-sized portion of said coding pattern is guaranteed to contain said one or more common codewords irrespective of whether a whole tag is contained in said portion.
- 30 13. The substrate of claim 11, wherein said one or more common codewords encode region identity data uniquely identifying a region of said surface.
14. The substrate of claim 13, wherein said one or more common codewords uniquely  
35 identifies said substrate.
15. The substrate of claim 3, wherein each cell comprises an orientation symbol

encoded by at least one data element, said orientation symbol identifying an orientation of said coding pattern with respect to said surface.

16. The substrate of claim 3, wherein each cell comprises one or more translation  
5 symbols encoded by a respective set of said data elements, said translation symbols identifying a translation of said cell relative to a tag containing said cell.

17. The substrate of claim 16, wherein each cell comprises a pair of orthogonal  
10 orthogonal translation symbols, each orthogonal translation symbol identifying a respective orthogonal translation of said cell relative to a tag containing said cell.

18. The substrate of claim 3, wherein said target elements are sufficiently large to be distinguishable from said data elements by a low-pass filter.

15 19. A method of imaging a coding pattern disposed on a surface of the substrate according to any one of the preceding claims, said method comprising the steps of:  
(a) operatively positioning an optical reader relative to said surface and capturing an image of a portion of said coding pattern;  
(b) sampling and decoding x-coordinate data and y-coordinate data contained in  
20 said imaged portion; and  
(c) determining a position of said pen,  
wherein said portion has a diameter of at least one tag diameter and less than two tag diameters.

25 20. A system for imaging a coding pattern disposed on a surface of a substrate, said system comprising:  
(A) the substrate according to any one of claims 1 to 18; and  
(B) an optical reader comprising:  
an image sensor for capturing an image of a portion of said coding pattern, said  
30 image sensor having a field-of-view of at least one tag diameter and less than two tag diameters; and  
a processor configured for performing the steps of:  
(i) sampling and decoding x-coordinate data and y-coordinate data within  
said captured image; and  
35 (ii) determining a position of said pen.

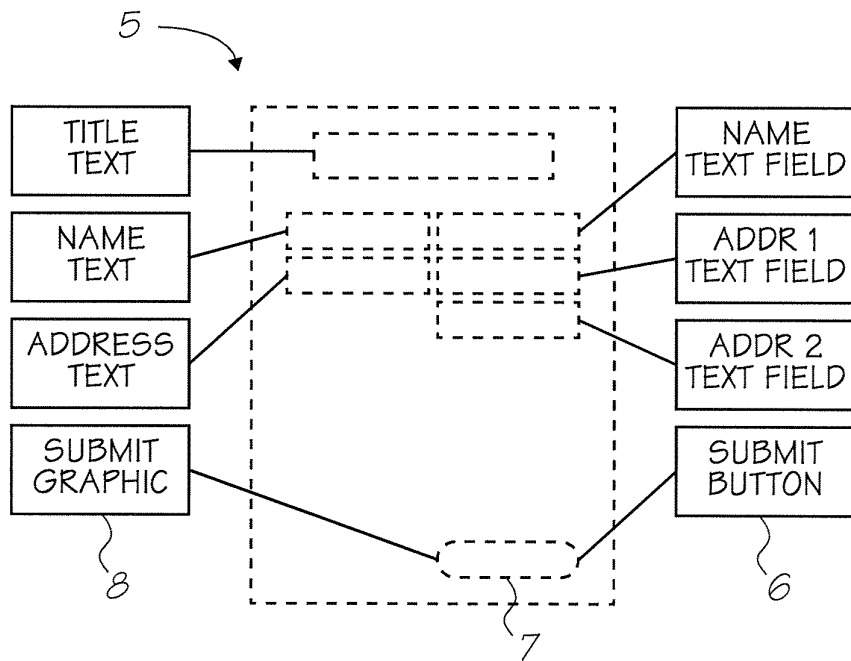
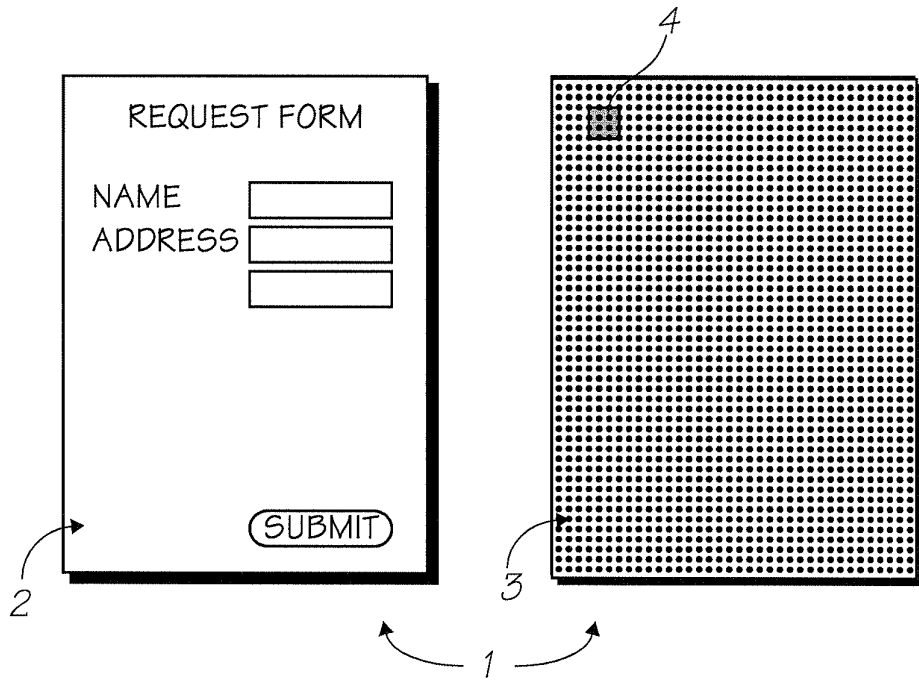


FIG. 1

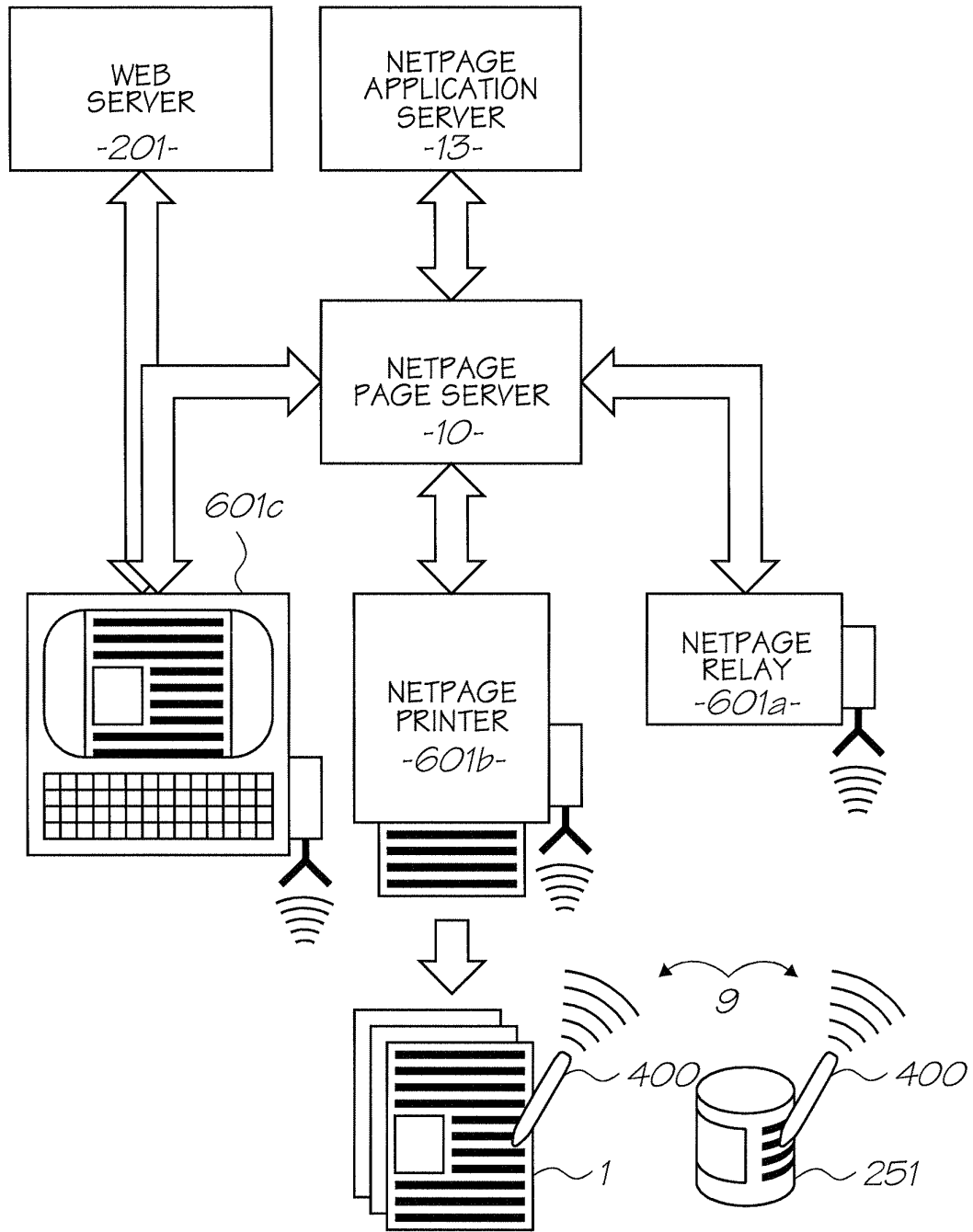


FIG. 2

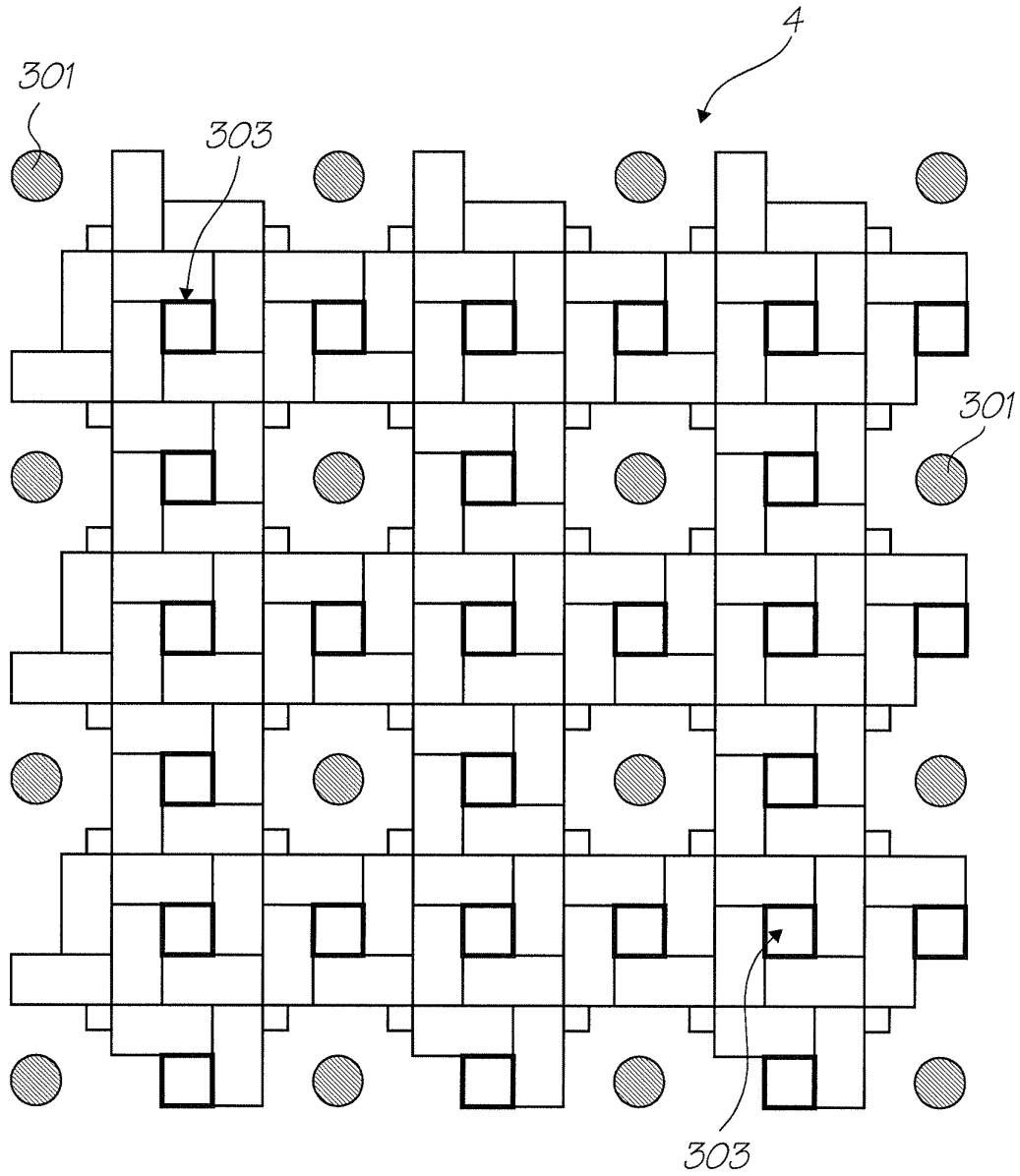


FIG. 3

4/19

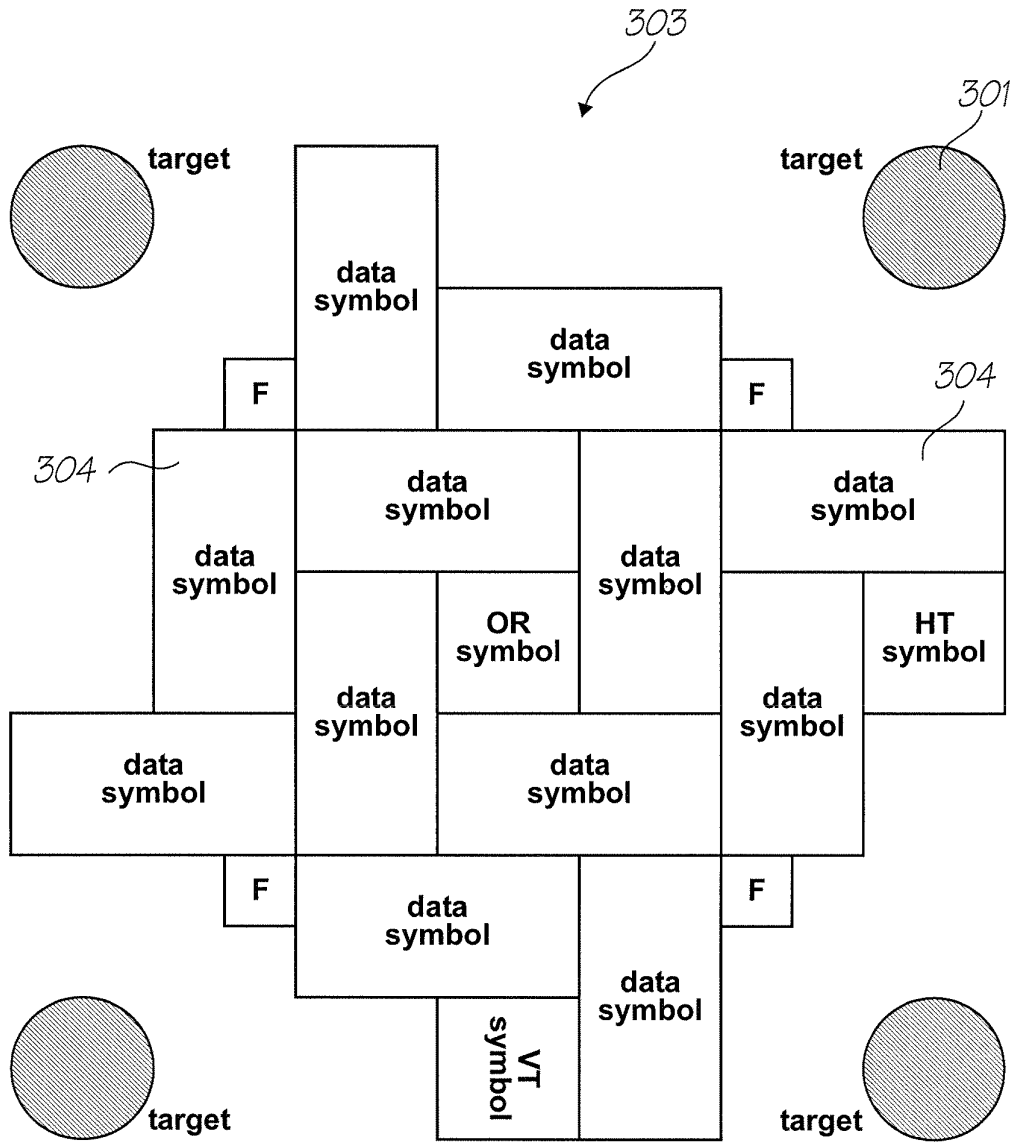


FIG. 4



5/19

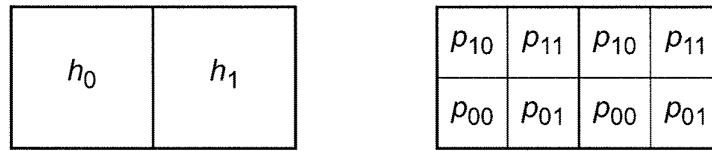


FIG. 5

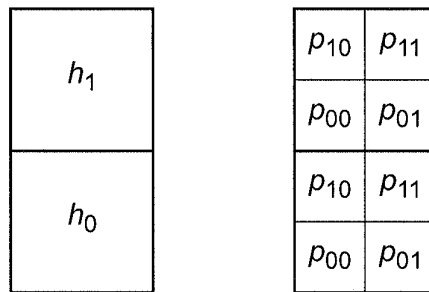


FIG. 6

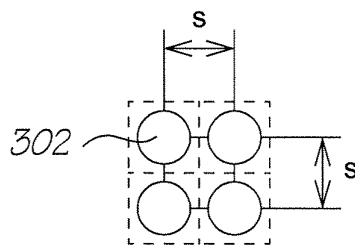


FIG. 7



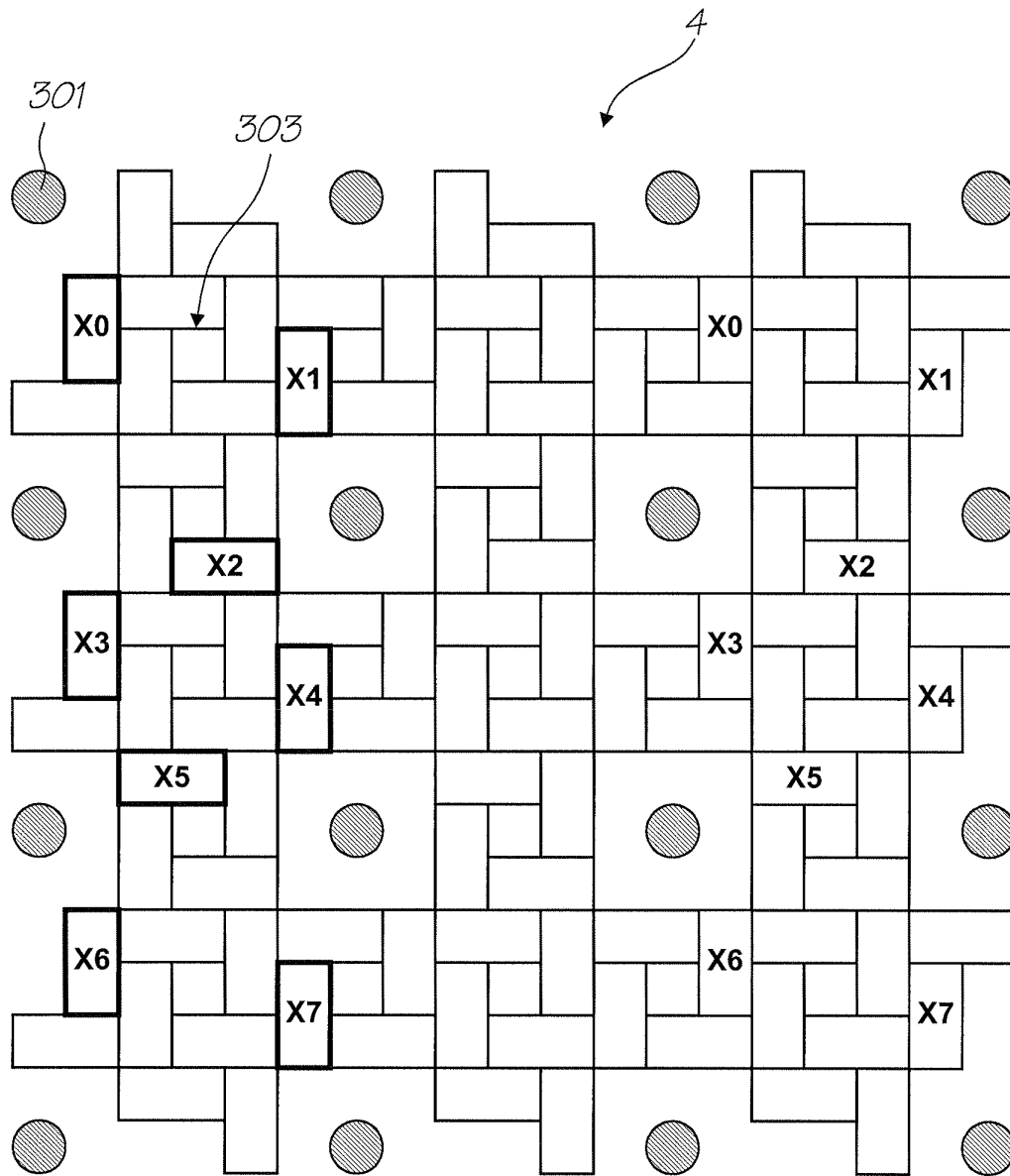


FIG. 11

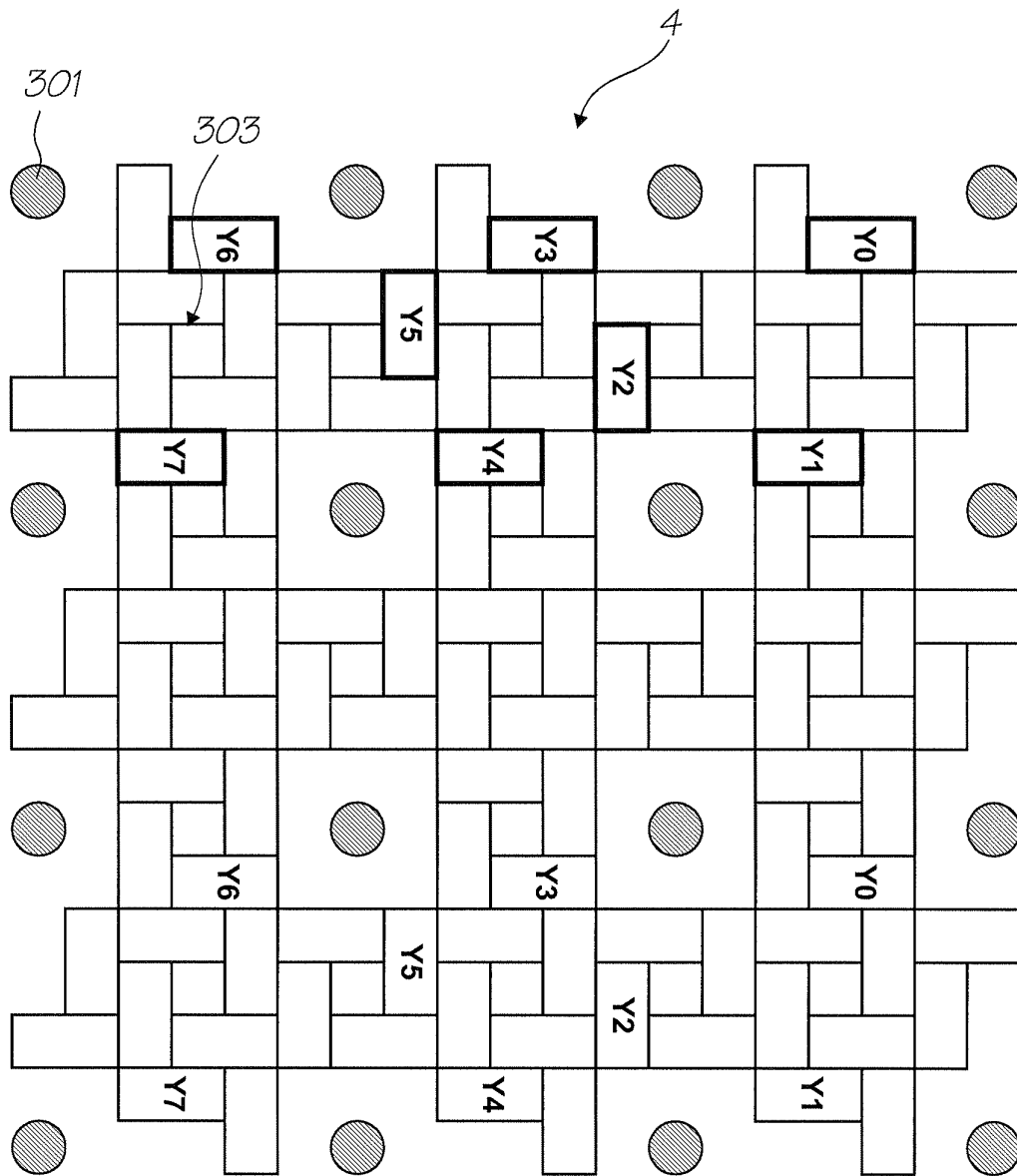


FIG. 12

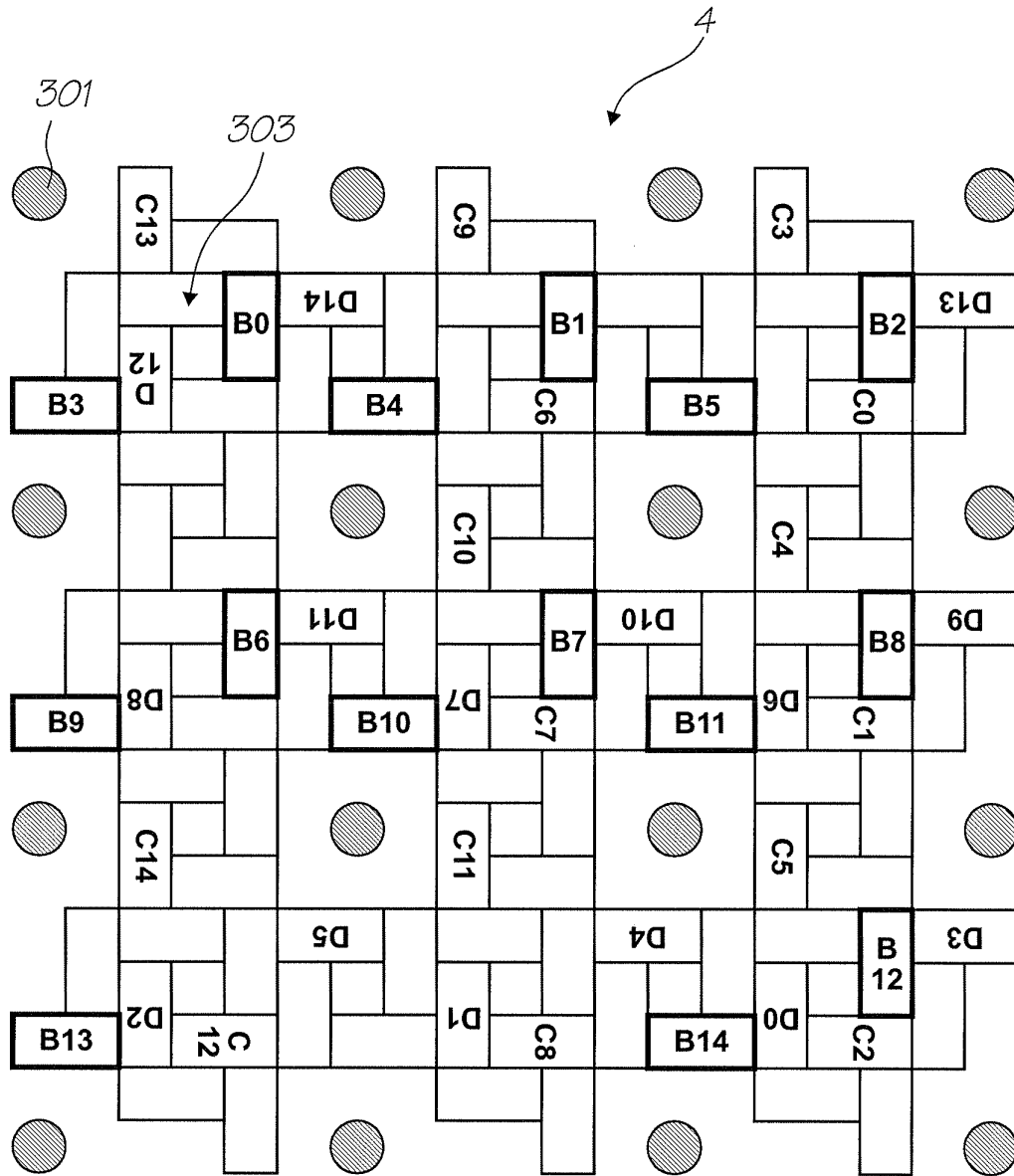


FIG. 13

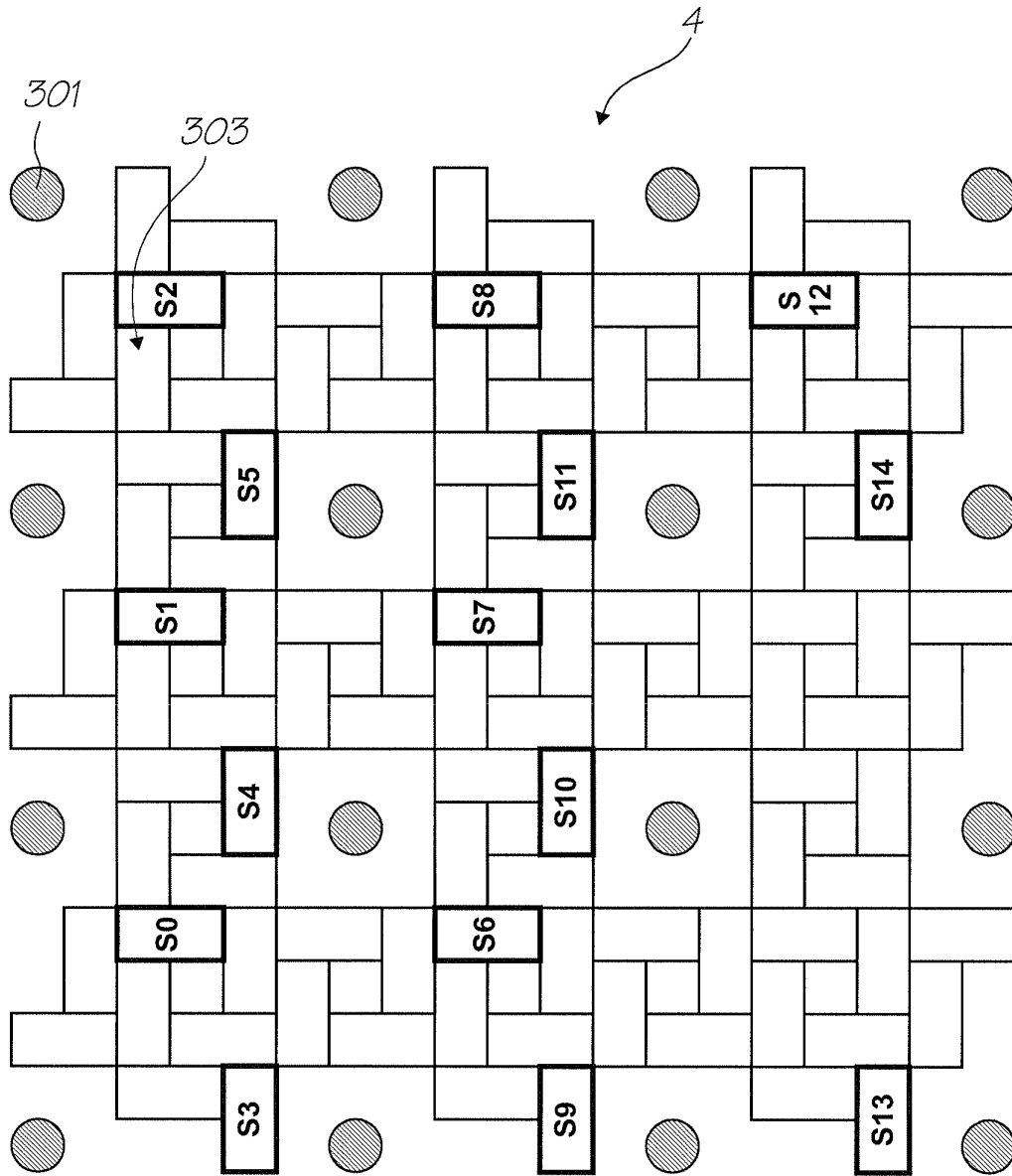


FIG. 14

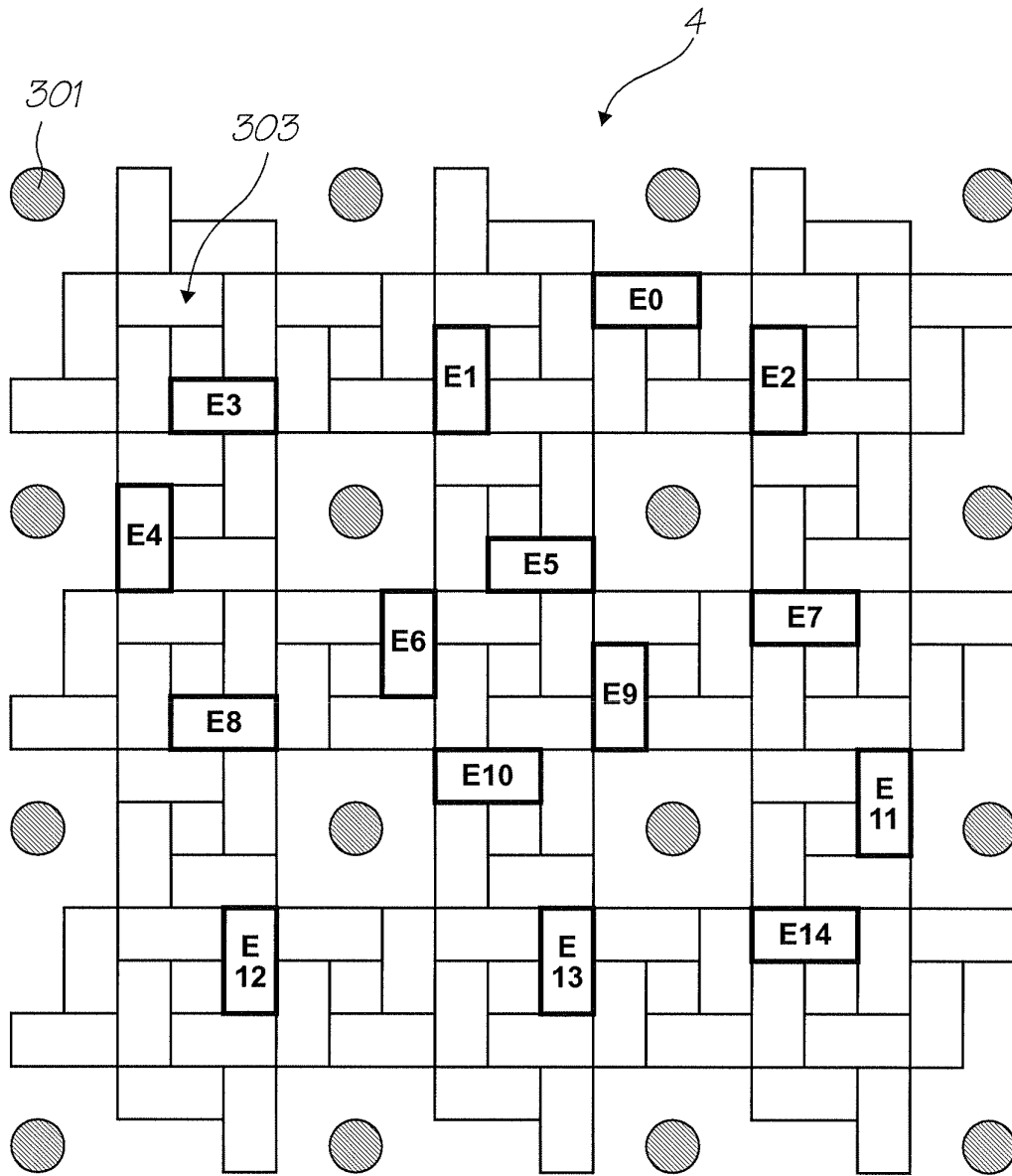


FIG. 15

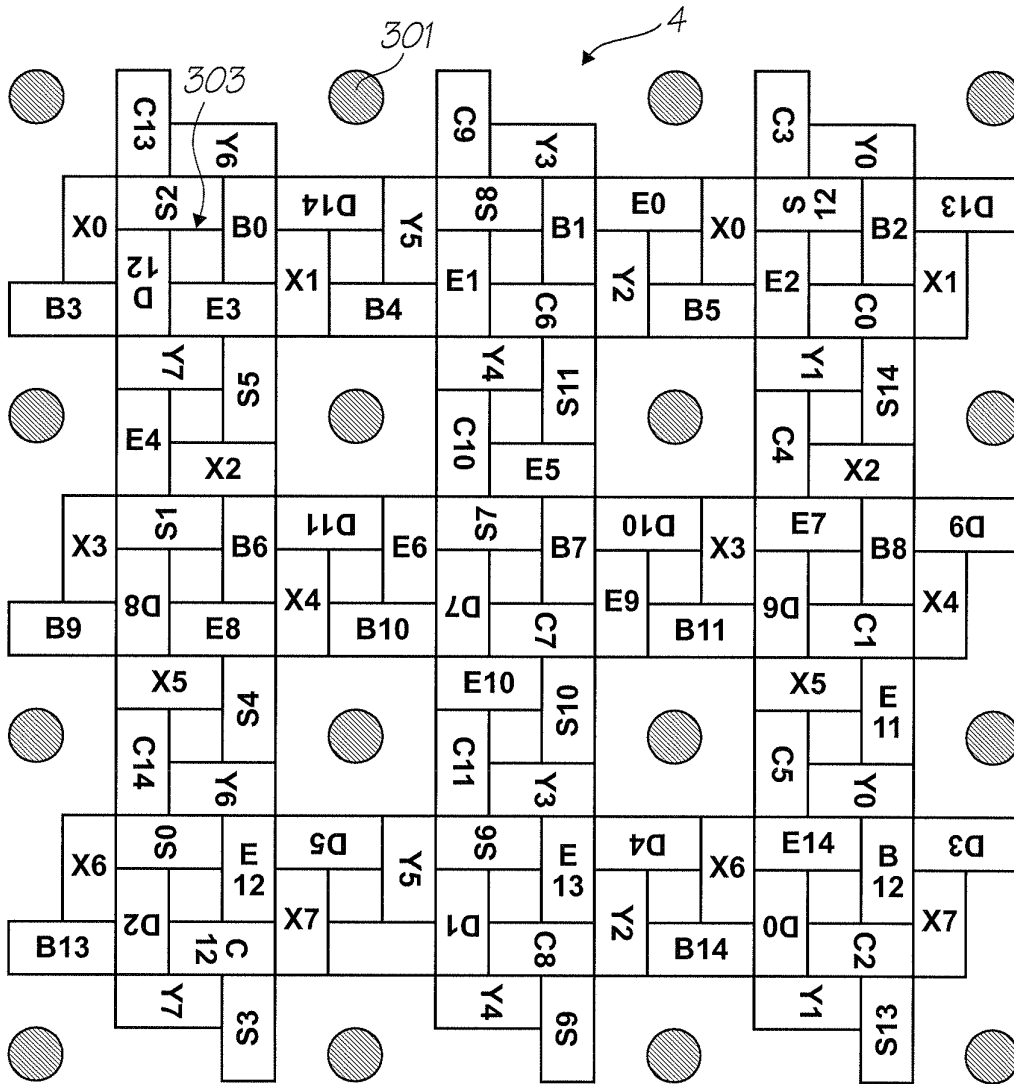


FIG. 16

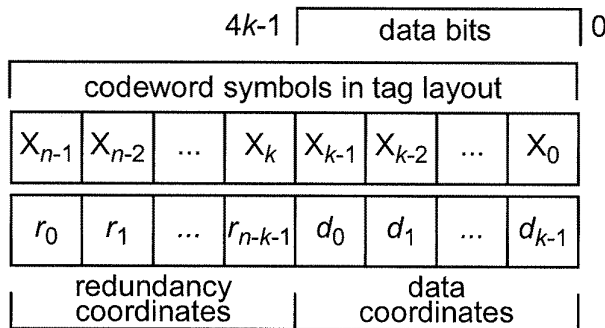


FIG. 17



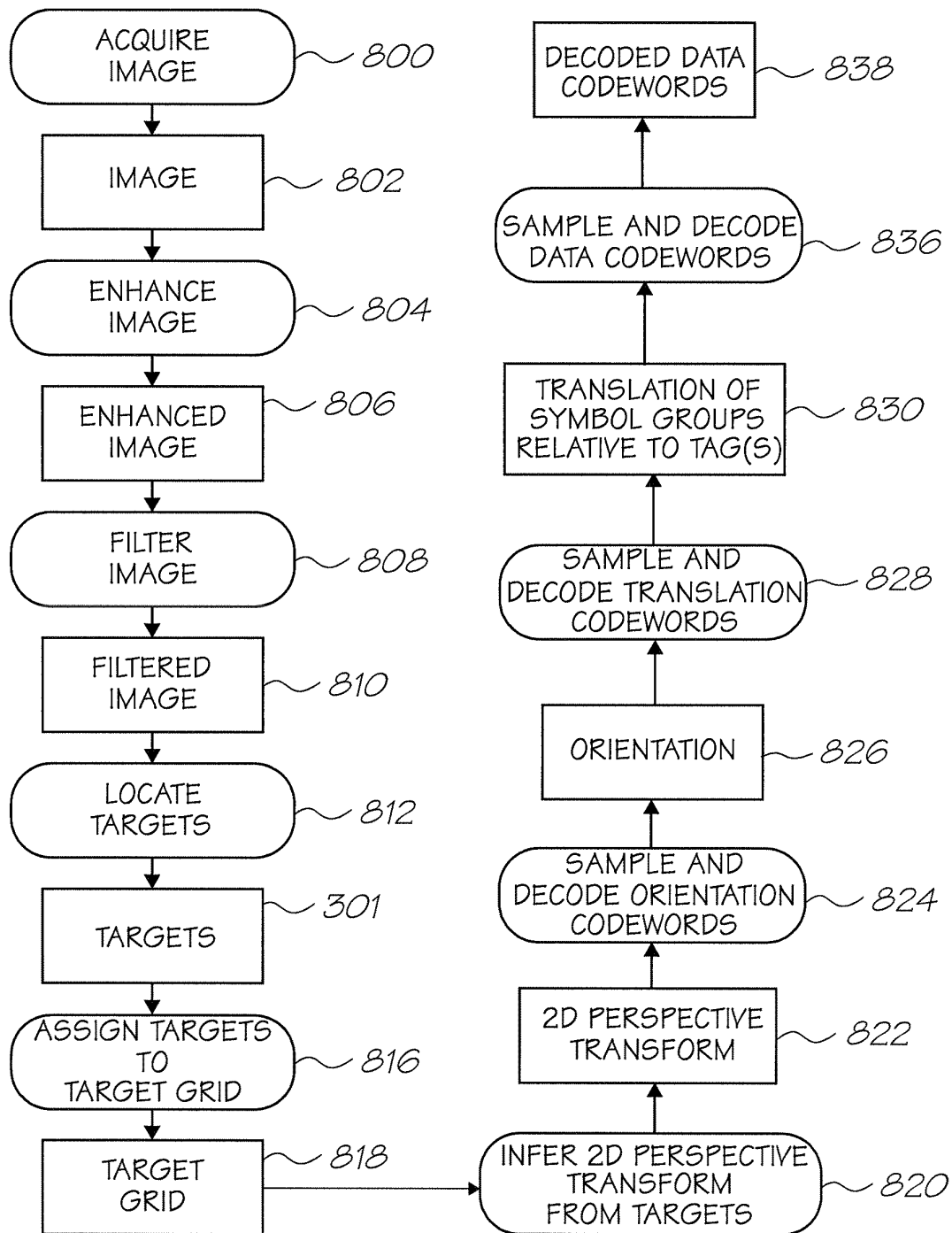


FIG. 18

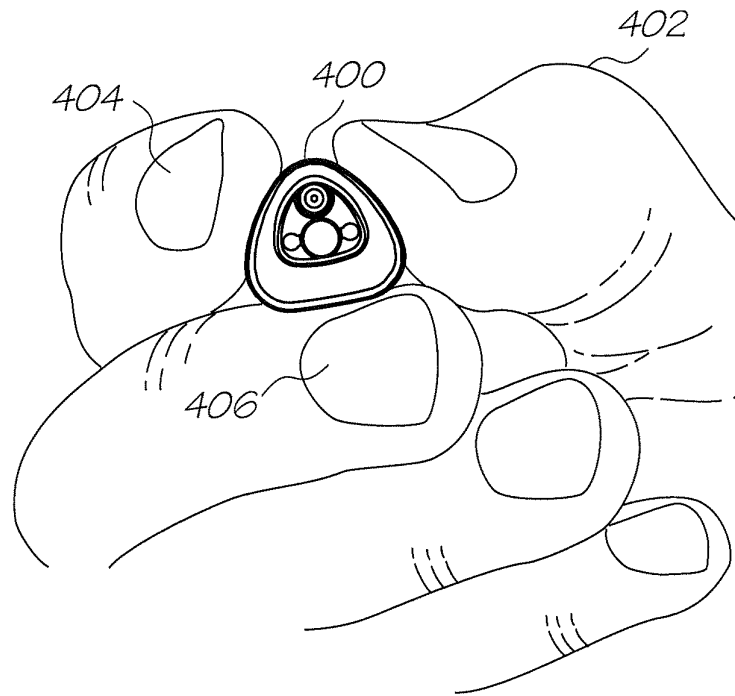


FIG. 19

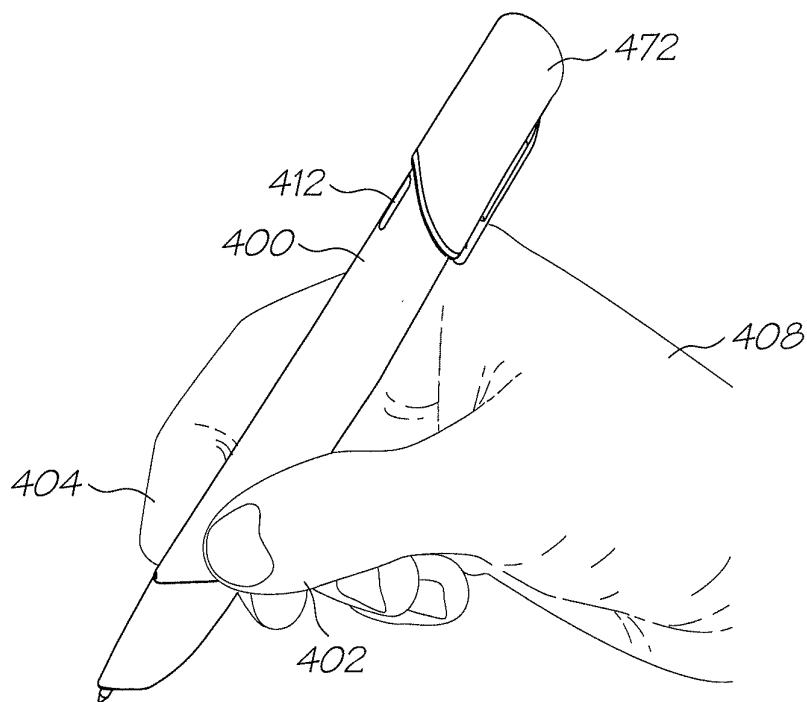


FIG. 20

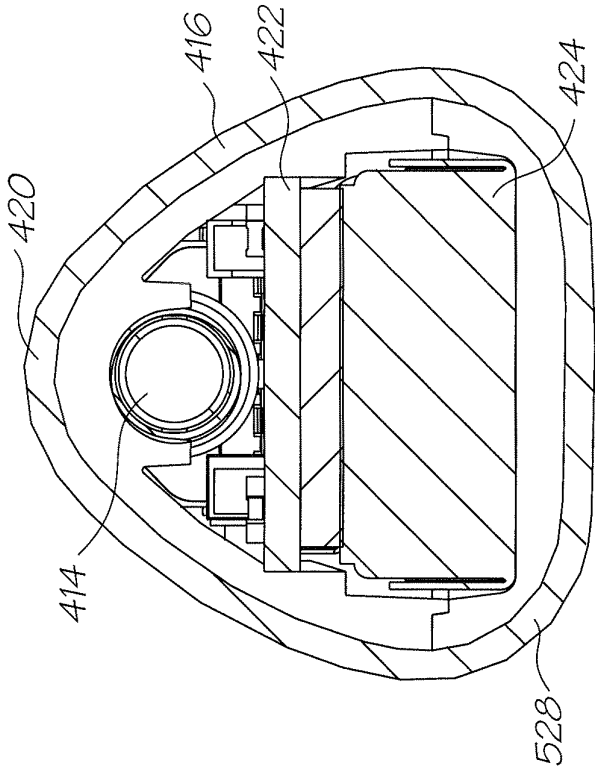


FIG. 21

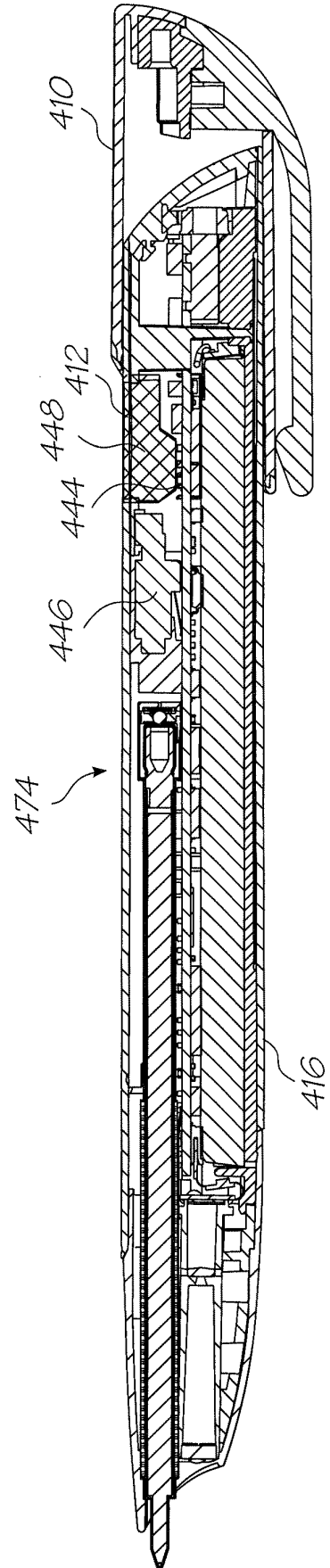


FIG. 23

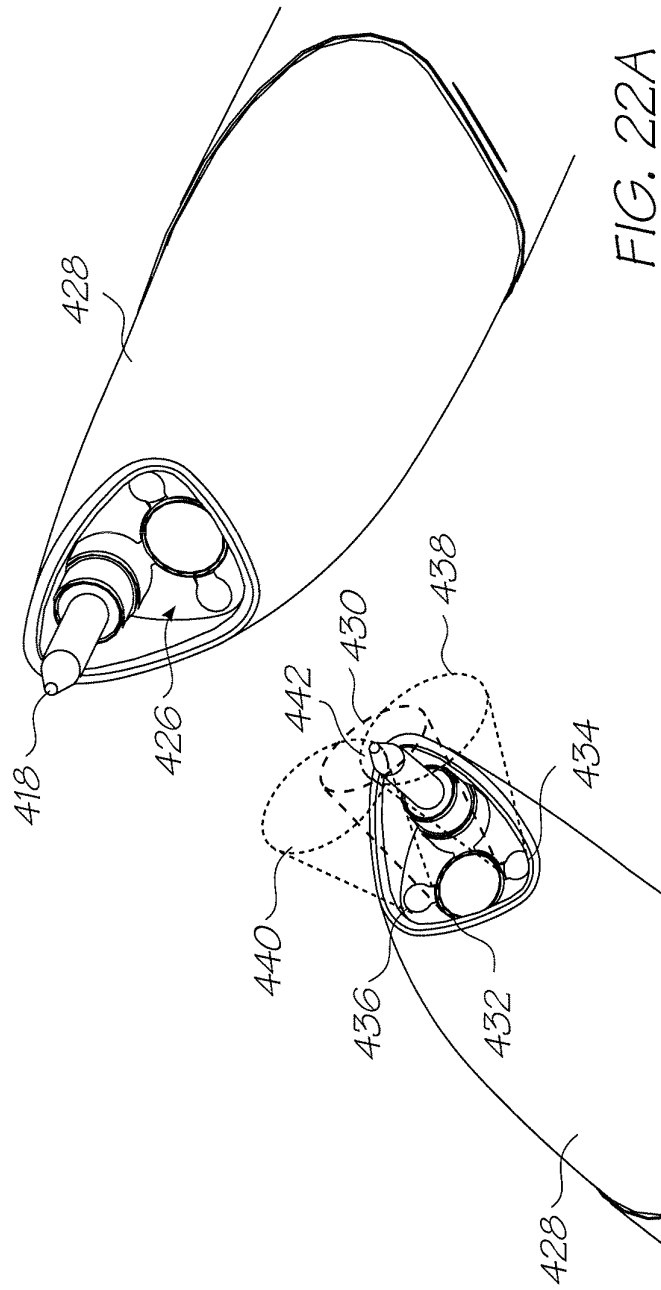


FIG. 22A

FIG. 22B

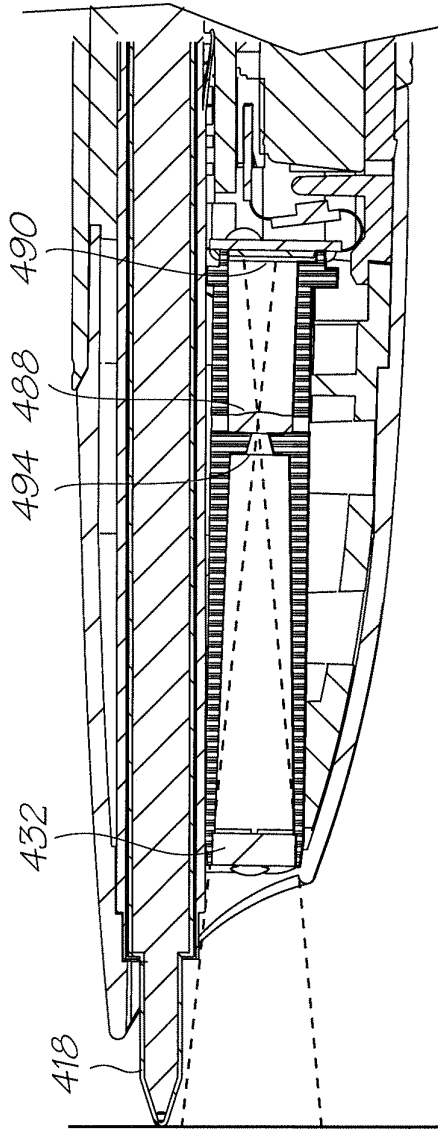


FIG. 24A

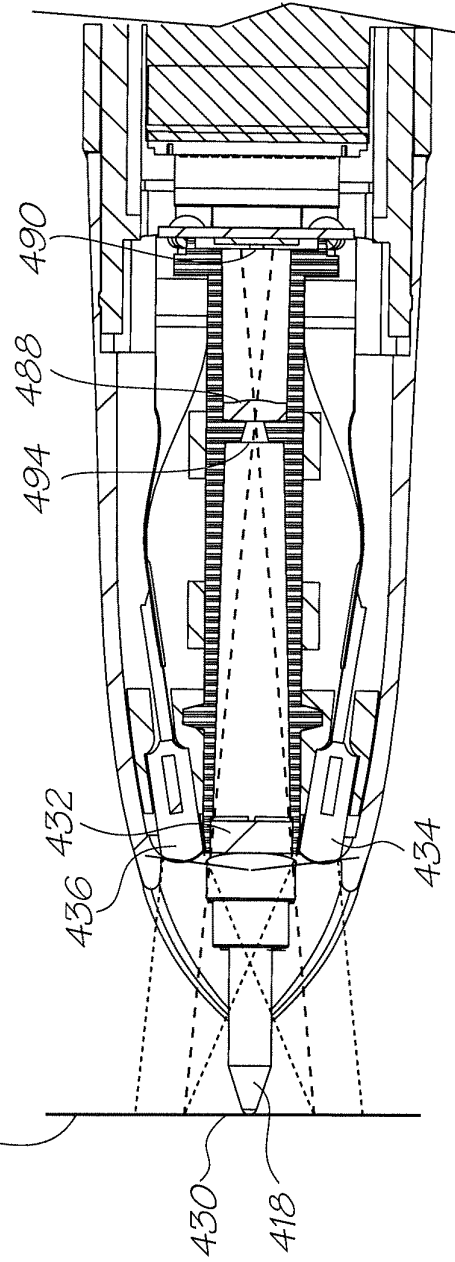


FIG. 24B

548

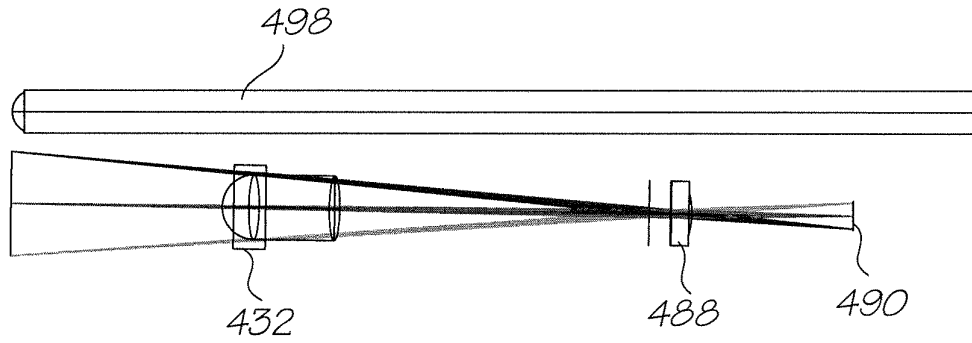


FIG. 25

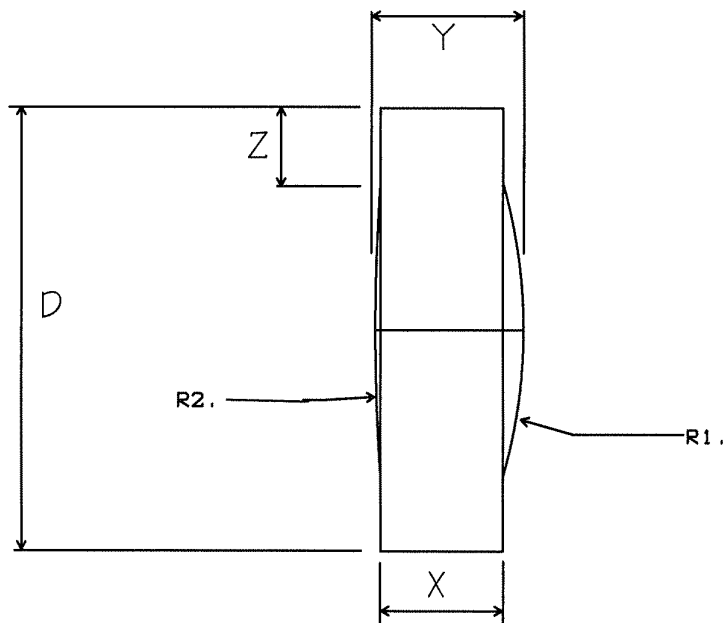


FIG. 26

19/19

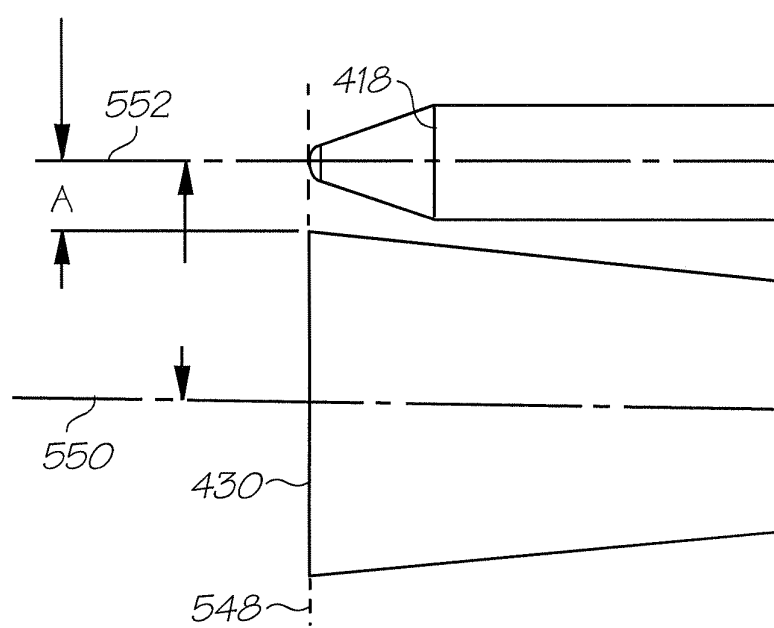


FIG. 27

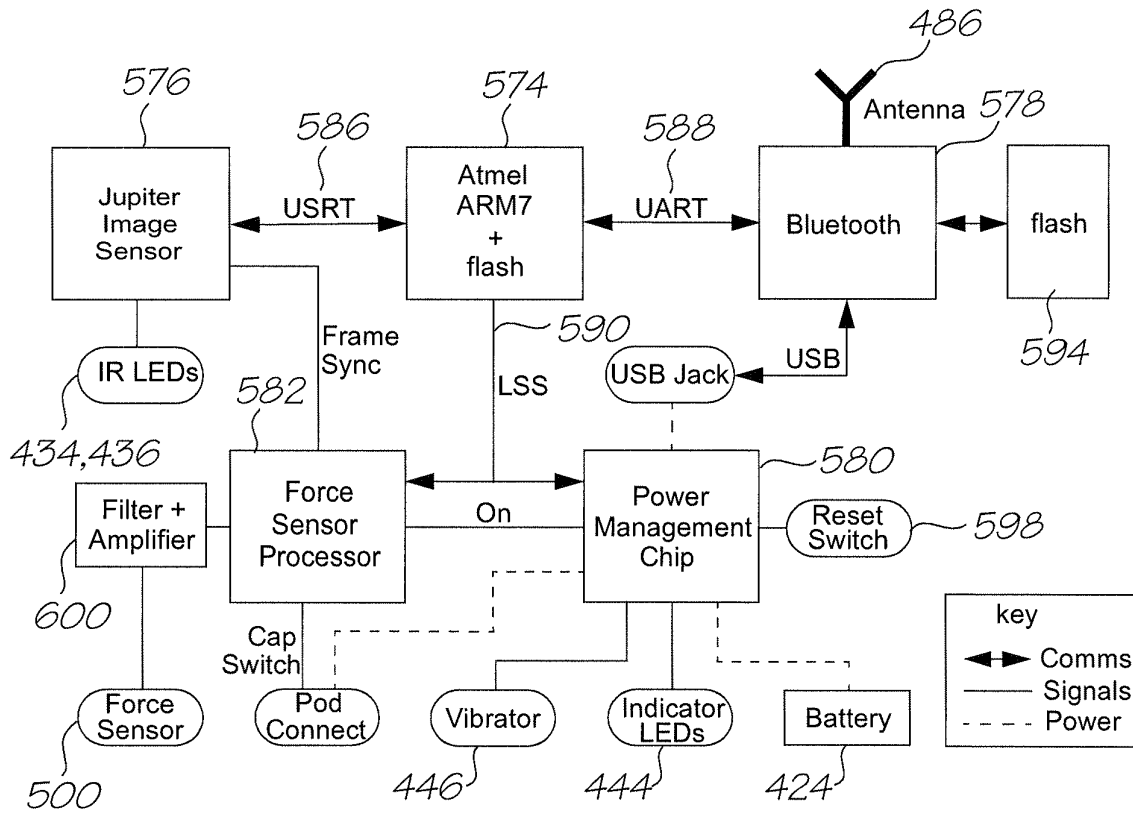


FIG. 28