

METHOD AND SYSTEM FOR IDENTIFYING A FIDUCIAL MARKER IN AN IMAGE.

FIELD OF INVENTION

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The present invention generally relates to a method and system for identifying the fiducial marker in an image and to a fiducial marker.

BACKGROUND

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Camera-based fiducial tracking has been widely used as a method to implement tangible interactive systems. While markerless object detection techniques that utilize e.g. scale-invariant feature transform (SIFT) and its family are rapidly gaining popularity among the augmented reality art, marker-based fiducial tracking techniques still maintain a considerable importance for tangible interaction. Marker-based fiducial tracking can achieve considerably faster processing speed and more easily identify a large number of the objects with their own unique identifications (IDs) than currently available markerless tracking techniques. Such features of marker-based tracking remain important for tangible interactive systems, e.g. to detect quick user gestures that are applied to many tangible objects at once.

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In some conventional fiducial tracking systems, for example, CyberCode, ARToolkit Plus and ARTag, matrix patterns are used to encode marker IDs. Also, there are other conventional fiducial tracking systems, such as ARToolkit, that use pattern-matching to detect a fiducial. Figure 1(a)-(d) show examples of conventional markers, including (a) CyberCode, (b) ARToolkit, (c) ARToolkit Plus and (d) ARTag respectively. As will be appreciated by persons skilled in the art, all of the markers shown in Figure 1 can provide six degree-of-freedom (6DoF) information.

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Generally, the markers based on a matrix pattern (Figures 1(a), 1(c), 1(d)) usually encode one binary digit into each cell of the marker and have a larger data capacity than e.g. those based on a topology-based approach described below. On the other hand, markers based on pattern-matching methods (Figure 1(b)) have the

merit of providing visually meaningful marker designs. In ARToolkit (Figure 1(b)), to identify a particular marker, the similarity between the pattern inside square-shaped objects in the input image and a pre-registered marker pattern is computed by comparing the respective cells located in the same positions in the squares.

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However, the robustness against false positives of these marker systems is relatively low. For instance, a white cell in a marker might disappear and be misinterpreted as black when the quality of the input image is not sufficiently good. Thus, matrix-based tracking systems usually need to employ digital techniques such as cyclic redundancy check (CRC), hamming distance and the like to improve the robustness to
10 against false detections.

In other conventional fiducial tracking systems, e.g. RAG target, D-Touch and
15 reactIVision, a topological region adjacency tree is used to map a marker to its ID. Among these, D-Touch and reactIVision are mainly for tangible tabletop interaction. Figure 2(a) – 2(c) show examples of conventional fiducial markers employing a topological region adjacency tree approach, including (a) RAG target, (b) reactIVision, and (c) D-Touch respectively.

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For example, in reactIVision, such a tree of topological region adjacency is interpreted into a canonical sequence called left heavy depth sequence and used to map a tree structure to an ID of a fiducial. Such a canonical sequence is necessary since the region adjacency tree does not supply anything more than the
25 containership information. Figure 3 shows the conventional marker of Figure 2(b) and its corresponding topological region adjacency tree. In Figure 3, the containership information of the marker on the left can be expressed as a tree on the right having a left heavy depth sequence of 012212212121111111 which is typically used to map to its own ID.

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While there are some other techniques to map a region adjacency tree to an ID, generally, in such an approach based only on the topological region adjacency tree, the range of unique IDs is essentially limited by the possible combinations of sub-trees with different topological features. This is one of the reasons why

topology-based fiducial tracking systems have fewer unique IDs than matrix-based systems. A narrow ID range can be an obstacle for collaborative interaction especially when many personalized objects owned by the users need to be distinguished uniquely.

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A need therefore exists to provide a method and system for identifying a fiducial marker in an image that seeks the address at least one of the above problems, or to provide an alternative.

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SUMMARY

In accordance with a first aspect of the present invention, there is provided a method for identifying a fiducial marker in an image, the method comprising the steps of:

- converting the image into a binarized image;
- segmentising the binarized image;
- detecting one or more fiducial candidates based on topological region adjacency information obtained from the segmentized image;
- determining geometric information of the one or more detected fiducial candidates; and
- identifying the fiducial marker from the one or more detected fiducial candidates based on the geometric information.

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Determining geometric information of the one or more detected fiducial candidates may comprise, for each fiducial candidate:

- calculating coordinates of a center of a first reference region;
- calculating coordinates of a center of a second reference region disposed within the first region; and
- forming a reference vector from the center of the first reference region to the center of the second reference region.

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The method may further comprise identifying the first and second reference regions based on the topological region adjacency information from the segmented image.

- 5 The method may further comprise:
 identifying bit-encoding dots of the marker; and
 eliminating fiducial candidates based on angular information of the identified
 bit-encoding dots relative to the reference vector.
- 10 The method may further comprise sorting the bit-encoding dots based on the
 reference vector for decoding.

Detecting the one or more fiducial candidates based on the topological region adjacency information obtained from the segmented image may comprise:

- 15 identifying one or more candidate regions having a number of adjacent
 regions equal to or greater than a threshold value.

In accordance with a second aspect of the present invention, there is provided a system for identifying a fiducial marker in an image, comprising:

- 20 means for converting the image into a binarized image;
 means for segmentising the binarized image;
 means for detecting one or more fiducial candidates based on topological
 region adjacency information obtained from the segmented image;
 means for determining geometric information of the one or more detected
25 fiducial candidates; and
 means for identifying the fiducial marker from the one or more detected
 fiducial candidates based on the geometric information.

- 30 For each fiducial candidate, the means for determining geometric information
 of the one or more detected fiducial candidates may calculate coordinates of a
 center of a first reference region; calculate coordinates of a center of a second
 reference region disposed within the first region; and form a reference vector from
 the center of the first reference region to the center of the second reference region.

The system may further comprise means for identifying the first and second reference regions based on the topological region adjacency information from the segmented image.

5 The system may further comprise:
 means for identifying bit-encoding dots of the marker; and
 means for eliminating fiducial candidates based on angular information of the identified bit-encoding dots relative to the reference vector.

10 The system may further comprise means for sorting the bit-encoding dots based on the reference vector for decoding.

 The means for detecting the one or more fiducial candidates based on the topological region adjacency information obtained from the segmented image may
15 identify one or more candidate regions having a number of adjacent regions equal to or greater than a threshold value.

 In accordance with a third aspect of the present invention, there is provided a fiducial marker configured to be identifiable from a segmented image based on
20 topological region adjacency information and geometric information of the fiducial marker.

25 **BRIEF DESCRIPTION OF THE DRAWINGS**

 Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

30 Figure 1(a) – 1(d) show examples of conventional fiducial markers employing a matrix pattern or pattern-matching approach.

Figure 2(a) – 2(c) show examples of conventional fiducial markers employing a topological region adjacency tree approach.

Figure 3 shows the conventional marker of Figure 2(b) and its corresponding topological region adjacency tree.

Figure 4 shows a flow chart illustrating a method for identifying a fiducial marker in an image according to an example embodiment.

Figures 5(a) – 5(d) show images illustrating the successive steps of Figure 4 according to an example embodiment.

Figures 6(a) – 6(c) show example fiducial markers according to an example embodiment.

Figure 6(d) shows an example fiducial marker according to an example embodiment and its corresponding region adjacency graph.

Figure 7 shows images illustrating overlaying an object over an identified fiducial marker having 6DoF information.

Figures 8(a) – 8(c) shows example fiducial markers according to another example embodiment.

Figure 9 shows example 16-bit fiducial markers according to an embodiment and a corresponding topological region adjacency tree.

Figures 10(a) – 10(d) shows images illustrating the steps for identifying fiducial markers in an input image according to an example embodiment.

Figure 11 shows a schematic diagram illustrating a computer system for implementing the method and system of the example embodiment.

DETAILED DESCRIPTION

The following example embodiments describe a method and system for identifying a fiducial marker in an image which exploit topological region adjacency techniques and geometric characteristics of a marker. Advantageously, the method and system of the example embodiments can provide a wide unique ID range and enable 6DoF pose estimation, while also providing fast processing speed and robustness.

Figure 4 shows a flow chart 400 illustrating a method for identifying a fiducial marker in an image. At step 402, the image is converted into a binarized image. At step 404, the binarized image is segmentized. At step 406, one or more fiducial candidates are detected based on topological region adjacency information obtained from the segmentized image. At step 408, geometric information of the one or more detected fiducial candidates is determined. At step 410, the fiducial marker is identified from the one or more detected fiducial candidates based on the geometric information.

Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

Unless specifically stated otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as "scanning", "calculating", "determining", "replacing", "generating", "initializing", "outputting", or the like, refer to the action and processes of a computer system, or similar electronic device, that manipulates and transforms data represented as physical quantities within the computer system into other data similarly represented as physical

quantities within the computer system or other information storage, transmission or display devices.

The present specification also discloses apparatus for performing the operations of the methods. Such apparatus may be specially constructed for the required purposes, or may comprise a general purpose computer or other device selectively activated or reconfigured by a computer program stored in the computer. The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose machines may be used with programs in accordance with the teachings herein. Alternatively, the construction of more specialized apparatus to perform the required method steps may be appropriate. The structure of a conventional general purpose computer will appear from the description below.

In addition, the present specification also implicitly discloses a computer program, in that it would be apparent to the person skilled in the art that the individual steps of the method described herein may be put into effect by computer code. The computer program is not intended to be limited to any particular programming language and implementation thereof. It will be appreciated that a variety of programming languages and coding thereof may be used to implement the teachings of the disclosure contained herein. Moreover, the computer program is not intended to be limited to any particular control flow. There are many other variants of the computer program, which can use different control flows without departing from the spirit or scope of the invention.

Furthermore, one or more of the steps of the computer program may be performed in parallel rather than sequentially. Such a computer program may be stored on any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices suitable for interfacing with a general purpose computer. The computer readable medium may also include a hard-wired medium such as exemplified in the Internet system, or wireless medium such as exemplified in the GSM mobile telephone system. The computer program when loaded and executed on such a general-purpose computer effectively results in an apparatus that implements the steps of the preferred method.

Figures 5(a) – 5(d) show images illustrating the successive steps of Figure 4 according to an example embodiment. Figure 5(a) shows an input image, e.g. from a video camera (not shown). Figure 5(b) shows a grayscale image of the input image of Figure 5(a). Figure 5(c) shows a black and white (i.e. binarized) image of the grayscale image of Figure 5(b). Figure 5(d) shows the identification results in which the IDs of the respective fiducial markers are superimposed.

Figures 6(a) – 6(c) show example fiducial markers 610, 620, 630 respectively according to an example embodiment. As can be seen in Figure 6(a), the fiducial marker 610 is in the form of a square with rounded corners. A black square 612 is disposed at the center of the fiducial marker 610 and completely encloses a white circle 614, which is disposed at a slight offset from the center of the black square 612. In the example embodiment, this is used to obtain a rough angle of the fiducial marker 610 in the video input image, using a vector 622 (Figure 6(b)) from the center of the minimum bounding box of the black square 612 to the white circle 614. The black square 612 and the white circle form the center area of the fiducial marker 610.

In addition, a data area comprising black and white regions 616, 618 respectively surround the central black square 612, forming alternate black and white bands. In the example embodiment, a plurality of dots 619 are disposed in regions 616, 618. As can be seen from Figure 6(b), using the center of the black square as the origin, each dot 619 forms a respective known angle A with the reference vector 622. It will be appreciated that the angle A may be implemented as a predetermined range of values, depending on e.g. the density of the dots, to provide some flexibility in the design. Preferably, each predetermined range of values does not overlap with the previous and next ranges.

In the example embodiment, each dot 619 in regions 616, 618 encodes a bit, e.g. 0 for a black dot and 1 for a white dot. These bits are arranged in a clockwise order in the example embodiment, starting from the rough angle obtained from the white circle 614, to encode the ID of the fiducial marker. That is, the bit with the smallest angle A to the reference vector 622 (Figure 6(b)) is the least significant bit and the bit with the largest angle is the most significant bit. For example, the encoded unique IDs of the fiducial markers 610, 620, 630 of Figures 6(a) – (c) are

48115, 64407 and 40879 respectively. It will be appreciated that a different arrangement may be used in alternate embodiments, e.g. the bit with the smallest angle is the most significant bit and the bit with the largest angle is the least significant bit.

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It will be appreciated by a person skilled in the art that all the fiducials 610, 620, 630 of Figures 6(a) – (c) have the same topological structure of 4 black bit-encoding dots and 12 white bit-encoding dots. That is, the method and system of the example embodiment can advantageously encode different IDs into the fiducials that have the same topological region adjacency tree by using the geometric characteristics. More particular, in this embodiment, the angle information associated with the marker is used. Preferably, this can keep the complexity of the region adjacency graph and the required physical size of the fiducial relatively low. For example, in the case of 16-bit fiducial markers, while the fiducial ID can range between 0-65535, there are only 17 different topological structures since the number of black or white bit-encoding nodes can vary only between 0-16.

In the example embodiment, a topological structure that contains 16 bit-encoding dots and a center black square is considered a fiducial candidate. The method of the example embodiment also uses constraints in the topological region adjacency feature of the fiducial design. For example, the regions with a large number of the adjacent regions are relatively rare in images of real scenes. Furthermore, the topological region adjacency tree of the fiducial markers has the depth of 4 with 20 nodes in a 16-bit data capacity setting, i.e. such topological structure typically does not exist in images of real scenes except in an actual fiducial marker. Advantageously, the method of the example embodiment reduces the number of fiducial candidates to be examined by using such relatively rare features to find a candidate.

More specifically, since each bit of an ID is encoded as a black/white leaf node in the region adjacency graph, there is usually a region that has at least 10 adjacent regions in the example embodiment. This is because when a 16-bit ID is expressed as a binary number, it should contain at least 8 ones or 8 zeros, since those digits which are not '1' must be '0' and vice versa. Even in the case of 8 black

bit-encoding dots and 8 white bit-encoding dots, the white region 618 is further adjacent to the black region 616 and the center black square 612 (Figure 6(a)), i.e. the white region 618 has 10 adjacent regions. In any other case, either the black region 616 or the white region 618 has at least 10 adjacent regions. That is, an area with at least 10 ($= 8 + 2$) adjacent regions can always be found in the 16-bit fiducials of the example embodiment. Using this search strategy, the method of the example embodiment advantageously limits the number of the fiducial candidates and the number of traverses. It will be appreciated that other methods for finding the fiducial candidates may be used in alternate embodiments, including existing methods such as reactIVision, as described in [Bencina, R., Kaltenbrunner, M. and Jorda, S. (2005). Improved Topological Fiducial Tracking in the reactIVision System. *Proc of IEEE Procams '05*].

Figure 6(d) shows an example fiducial marker 640 according to an example embodiment and its corresponding region adjacency graph. In the fiducial marker 640 of Figure 6(d), the inner white region 618 with 11 adjacent regions (black bit-encoding dots 619) is found first in the example embodiment. The graph is then traversed to decode an ID if the fiducial marker 640 is a valid fiducial.

After a fiducial candidate is found, in the decoding step, a reference vector 622 (Figure 6(b)) from the center of the black square 612 to the center of the white circle 614 (Figure 6(a)) is determined. In the example embodiment, the black square 612 is identified based on the position of the white circle 614 in the topological region adjacency tree. Typically, the white circle 614 is the only region at the lowest node level of a sorted topological region adjacency tree. Once the white circle 614 is found, the black square 612 can be identified as it is the region adjacent to the white circle 614.

Also, in the example embodiment, information on the area/centroid/bounding-rectangle of each region is obtained during the segmentation step. The actual information being gathered during the segmentation step in the example embodiment includes area, the sum of X coordinates of each pixel in a region and the sum of Y coordinates of each pixel in a region. The centroid of a region in the input image can be computed by dividing the sum of X and the sum of Y by the area

of the region, i.e. (the sum of X / area , the sum of Y / area) = position of the centroid of the region.

The centroid information is used for ID-decoding and 6DoF pose estimation.

5 It will be appreciated that, instead of using centroids, other techniques may be used. For example, the centres of the respective bounding-rectangles can be used. While this may result in less precise 6DoF pose estimation compared to using centroids, the time cost may be reduced.

10 More particularly, in this embodiment, the angles A (Figure 6(b)) of the respective bit-encoding dots 619 clockwise relative to the reference vector 622 are then sorted, starting from the dot with smallest angle to the dot with the largest angle, and checked for validity. For example, if the angle A of one or more dot is outside the predetermined range from the fiducial design, the fiducial candidate is rejected. Advantageously this
15 can further eliminate unsuitable fiducial candidates, thereby minimising false positives. The dots are then decoded, i.e. a black dot gives a value of 0 and a white dot gives a value of 1, to determine the ID of the fiducial marker.

Advantageously, the method of the example embodiment is capable of
20 providing 6DoF information for pose estimation. It will be appreciated that, generally, at least 4 coplanar points (which are not disposed on the same straight line) are required as basis for pose estimation. In example embodiments, 4 or more of the bit-encoding dots are used for pose estimation. For example, the 4 corner bit-encoding dots can be used for matching input coordinate and object coordinate. More bit-
25 encoding dots, e.g. all 16 bit-encoding dots, can be used for a more accurate matching without significantly increasing the computational costs. Figure 7 shows images illustrating overlaying an object over an identified fiducial marker embodying the present invention and providing 6DoF information.

30 Figure 8(a) – 8(c) shows example fiducial markers 810, 820, 830 respectively according to another example embodiment. The sizes of the fiducial markers 810, 820, 830 are 16 bits, 12 bits and 8 bits respectively.

As can be seen in Figures 8(a), the fiducial marker 810 is substantially circular. Again, the fiducial marker 810 comprises two main components, a centre area and a data area. The first component comprises the black circle 812 in the centre that completely encloses a white circle 814. The positions of the black circle 812 and the white circle 814 are also used to estimate the approximate rotation angle, which is typically required in the decoding phase.

The data area surrounds the centre area and comprises an inner white ring-like region 818 that contains black dots and an outer black ring-like region 816 that contains white dots in the example embodiment. Similar to the discussion above with respect to Figure 6, the black and white dots 819 are bit-encoding dots and each dot encodes 1-bit of data, 0 for black and 1 for white in clockwise order. For example, the encoded unique IDs of the fiducial markers 810, 820, 830 of Figures 8(a) – (c) are 43690, 1017, 115 respectively.

Figure 9 shows example 16-bit fiducial markers 910, 920, 930 and a corresponding common topological region adjacency tree. As described above with respect to Figure 6, the method and system of the example embodiment can advantageously encode different IDs into the fiducials that have the same topological region adjacency tree by using the geometric characteristics. More particular, in this embodiment, the angle information associated with the marker is used. Preferably, this can keep the complexity of the region adjacency graph and the required physical size of the fiducial relatively low. In Figure 9, the fiducial markers 910, 920, 930 have the same topological structure shown on the right, but each with a different unique ID (58563, 43690, and 37662 respectively). Again, 6DoF information for pose estimation can be obtained, for example, by using at least 4 of the coplanar bit-encoding dots (which are not disposed on the same straight line) for matching input coordinate and object coordinate.

Advantageously, there is minimal computational cost to generate a large number of fiducial markers as it only requires very simple translation and placement of bit data into black/white bit-encoding dots in clockwise order, for example.

Figures 10(a) – (d) show images illustrating the steps for identifying fiducial markers according to an example embodiment. The steps are substantially the same as those as described with respect to Figures 5(a) – (d).

5 In the method and system of the example embodiments, digital techniques can be used to further improve the robustness against inter-marker confusion. As an ID is encoded directly to a fiducial, such digital techniques as CRC, parity-bit, check-sum and hamming distance can be applied in the method and system of the example embodiments as already done with matrix-based markers. While the
10 unique ID range may be reduced by applying such digital techniques, the unique ID range is still substantially wider compared to existing topology-based systems. For example, even if 4 bits in the 16-bit fiducial markers of the example embodiments are used for CRC, there are still $2^{12} = 4096$ unique fiducials.

15 Experiments to evaluate the method and system of the example embodiments have been performed. The results of the experiments have shown that, in addition to providing a wide range of unique IDs, the number of false positives in the method and system of the example embodiment is significantly reduced compared to reactIVision, as shown in Table 1, without a significant
20 increase in processing time.

Table 2: Number of false positives observed

	room	outdoor	film	anime
our system	0	0	0	0
reactIVision	2	0	129(31)	21

25 The method and system of the example embodiment can be implemented on a computer system 1100, schematically shown in Figure 11. It may be implemented as software, such as a computer program being executed within the computer system 1100, and instructing the computer system 1100 to conduct the method of the example embodiment.

The computer system 1100 comprises a computer module 1102, input modules such as a keyboard 1104 and mouse 1106 and a plurality of output devices such as a display 1108, and printer 1110.

5 The computer module 1102 is connected to a computer network 1112 via a suitable transceiver device 1114, to enable access to e.g. the Internet or other network systems such as Local Area Network (LAN) or Wide Area Network (WAN).

10 The computer module 1102 in the example includes a processor 1118, a Random Access Memory (RAM) 1120 and a Read Only Memory (ROM) 1122. The computer module 1102 also includes a number of Input/Output (I/O) interfaces, for example I/O interface 1124 to the display 1108, and I/O interface 1126 to the keyboard 1104.

15 The components of the computer module 1102 typically communicate via an interconnected bus 1128 and in a manner known to the person skilled in the relevant art.

20 The application program is typically supplied to the user of the computer system 1100 encoded on a data storage medium such as a CD-ROM or flash memory carrier and read utilising a corresponding data storage medium drive of a data storage device 1130. The application program is read and controlled in its execution by the processor 1118. Intermediate storage of program data maybe accomplished using RAM 1120.

25 It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to
30 be illustrative and not restrictive.

CLAIMS

1. A method for identifying a fiducial marker in an image, the method comprising the steps of:

- 5 converting the image into a binarized image;
 segmentising the binarized image;
 detecting one or more fiducial candidates based on topological region
adjacency information obtained from the segmentized image;
 determining geometric information of the one or more detected fiducial
10 candidates; and
 identifying the fiducial marker from the one or more detected fiducial
candidates based on the geometric information.

2. The method as claimed in claim 1, wherein determining geometric
15 information of the one or more detected fiducial candidates comprises, for each
fiducial candidate:

- calculating coordinates of a center of a first reference region;
 calculating coordinates of a center of a second reference region disposed
within the first region; and
20 forming a reference vector from the center of the first reference region to the
center of the second reference region.

3. The method as claimed in claim 2, further comprising identifying the
first and second reference regions based on the topological region adjacency
25 information from the segmentized image.

4. The method as claimed in claims 2 or 3, further comprising:
 identifying bit-encoding dots of the marker; and
 eliminating fiducial candidates based on angular information of the identified
30 bit-encoding dots relative to the reference vector.

5. The method as claimed in claim 4, further comprising sorting the bit-
encoding dots based on the reference vector for decoding.

6. The method as claimed in any one of the preceding claims, wherein detecting the one or more fiducial candidates based on the topological region adjacency information obtained from the segmentized image comprises:

identifying one or more candidate regions having a number of adjacent
5 regions equal to or greater than a threshold value.

7. A system for identifying a fiducial marker in an image, comprising:

means for converting the image into a binarized image;

means for segmentising the binarized image;

10 means for detecting one or more fiducial candidates based on topological region adjacency information obtained from the segmentized image;

means for determining geometric information of the one or more detected fiducial candidates; and

15 means for identifying the fiducial marker from the one or more detected fiducial candidates based on the geometric information.

8. The system as claimed in claim 7, wherein, for each fiducial candidate, the means for determining geometric information of the one or more detected fiducial candidates calculates coordinates of a center of a first reference
20 region; calculates coordinates of a center of a second reference region disposed within the first region; and forms a reference vector from the center of the first reference region to the center of the second reference region.

9. The system as claimed in claim 8, further comprising means for
25 identifying the first and second reference regions based on the topological region adjacency information from the segmentized image.

10. The system as claimed in claims 8 or 9, further comprising:

means for identifying bit-encoding dots of the marker; and

30 means for eliminating fiducial candidates based on angular information of the identified bit-encoding dots relative to the reference vector.

11. The system as claimed in claim 10, further comprising means for sorting the bit-encoding dots based on the reference vector for decoding.

12. The system as claimed in any one of claims 7 to 11, wherein the means for detecting the one or more fiducial candidates based on the topological region adjacency information obtained from the segmented image identifies one or more candidate regions having a number of adjacent regions equal to or greater than a threshold value.

13. A fiducial marker configured to be identifiable from a segmented image based on topological region adjacency information and geometric information of the fiducial marker.