

Title**METHOD AND APPARATUS FOR DETERMINING
POSITION AND AZIMUTH OF AN OBJECT**Scope of the Invention

The invention presents a method and apparatus for determining position and azimuth of an object in a three-dimensional space.

Field of the Invention

A method and apparatus to provide accurate and precise position and azimuth determination of an object, in which a machine vision image acquisition apparatus acquires an image, processes the acquired image, and computes the position and orientation azimuth of the object.

Background

Determining position and/or azimuth of an object within a defined area or volume is an engineering problem that has brought about many solutions, each dedicated toward solving the specific requirements of an application. The determination of location for items placed in indoor or outdoor storage areas presents practical problems. An object's position must be recorded to facilitate returning to that location for later retrieval. Outdoor storage yards, warehouse floors, storerooms, factory floors, ship's holds, railcars, and truck trailers share this need. Many methods are used to record objects' positions, including grids, aisles, or lanes painted on flooring or pavement, vertical stanchions such as light posts labeled to identify storage regions, or markers placed on area boundaries or perimeters. These methods are aimed at providing position identification for human use, and all suffer from deficiencies.

A well known problem exists, for example, where labels or imprinting, especially bar code labels or imprinted bar codes, denote floor positions within a designated storage area. Floor markings can become obscured by stored objects and are subject to physical damage which can reduce or destroy their readability. This invention overcomes such shortcomings by providing position reference near to the designated area, but not on it.

Automatic determination of position and/or azimuth by machine is even more difficult than human-based methods. Automated systems which must determine position and/or azimuth without human intervention exists but these, too, suffer significant shortcomings. For example, global

positioning systems (GPS) provide inadequate resolution for sub-meter measurements and suffer from signal attenuation and reflections indoors. Similarly, ultrasonic-based systems must deal with signal attenuation and reflection. Magnetic methods are known, but most require embedding wires in flooring, which is not practical for many applications. Markers are also used, whereby the mobile object follows a pattern of markers to navigate its path or determine its position. All of these methods allow machines to determine position, but all present particular disadvantages for a given application.

Still more complex methods are used to automatically guide vehicles, or to determine vehicle or robot locations. Radio beacons, reflective markers, ultrasonic acoustical waves, global positioning systems (GPS), and laser scanning systems have been applied. Each system is dedicated to functioning not only as a position determining device, but as a real-time component providing position data to a host system where accuracy and reliability is paramount. A number of machine vision-based systems exist, especially for vehicle and robot guidance, but most analyze physical surroundings by viewing downward toward floor markings, or horizontally toward local scenery or reflective markers. A well known system used for automatic guided vehicle (AGV) guidance is based on a rotating laser scanner and optical targets placed on surrounding walls. This method achieves satisfactory accuracy, but is unsuitable for applications where an object such as a stack of cartons could be placed between the AGV and optical target(s), suddenly rendering the system unusable or creating blind spots within the operating area. This invention overcomes obscuring problems by providing a position reference in a location that is most often not obscured - for example, overhead.

Azimuth determination capability is not available in most methods, and becomes important in the warehousing applications for several reasons. Lift truck, robot, or AGV orientation, (directional heading relative to the designated area) must be known in order for a guidance system to properly direct it. Items may be stored in a chosen orientation, for example with carton labels aligned in a particular direction or pallet openings aligned to facilitate lift truck access from a known direction.

Position and azimuth determination techniques offer varying degrees of capability, resolution, complexity, and cost. An improved method and apparatus for precise determination of position and azimuth that reduces or removes the shortcomings of current methods and provides general applicability is needed.

The present invention provides a reliable and accurate method and apparatus that can be used in many situations. The present invention is believed suitable for stationary or mobile objects, slow or fast motion, incremental or continuous measurement, indoor or outdoor use, and can serve as the sensory apparatus and method for a guidance system, navigation system, or position monitoring system.

Summary of the Invention

The present invention provides a method and an apparatus for determining position and azimuth within a predefined coordinate system, such as a designated area or volume. The present invention can be employed to determine the location (in one, two, or three dimensions) and azimuth orientation (in one, two, or three degrees of freedom) of a stationary or mobile object as it moves freely within a designated area or volume.

The method of the present invention determines a coordinate position and azimuth orientation (i.e., directional heading) of an object within a coordinate space. The method comprises the steps of:

- a) providing a plurality of unique position markers having identifying indicia and angular orientation indicia thereupon, the markers being arranged in a predetermined positional pattern within the coordinate space so that at least one position marker is within view of the object;
- b) using an image acquisition system mounted on the object, acquiring an image of the at least one position marker within view;
- c) processing the image to determine the identity of each position marker and the position of each position marker relative to the object, and to determine the orientation of each position marker relative to the object;
- d) calculating the position of the object and the azimuth orientation of the object in the coordinate space and storing the position and azimuth orientation information in a memory.

In a preferred embodiment, the processing step c) selects the position marker nearest to the center of the image and uses the selected position marker for the calculation of step d). Alternatively, more than one position marker may be selected, and the position and azimuth orientation of the object may be calculated for each selected position marker to verify the calculation and improve the precision of the position and azimuth determination.

Position and azimuth are determined by acquiring images of position markers which are placed at known locations in or near the coordinate space, i.e., the region of interest. Subsequent image analysis is performed by commercially available machine vision equipment consisting of one or more cameras and digital processing device(s). The position and azimuth of one or more position markers relative to a camera's view are

determined by the machine vision equipment; the position and azimuth in "real" space are then computed from machine vision data using a series of programmed instructions which translate the relative positional and azimuth data to "real" coordinates. Results are stored, displayed, and/or transmitted to another system, where data may be used to record object location, to direct vehicle guidance, or for other navigation or control purposes.

In an exemplary embodiment, image processing equipment and data reduction equipment are attached to the object, such as a vehicle. Alternate embodiments may provide local image capture and transmission of the image information for remote processing.

Brief Description of the Drawings

Figure 1 shows the overall system of one embodiment in accordance with the present invention and identifies key elements of a coordinate, or position, reference 1, position markers 2, 3 and machine vision system data processing device 5.

Figure 2 illustrates a net/mesh/screen embodiment of the coordinate reference 1, showing position markers 2, 3.

Figure 3 illustrates the transparent/translucent web or film embodiment of the coordinate reference 1 showing position markers 2, 3.

Figure 4 illustrates details of a position marker 2, showing a one-dimensional barcode example.

Figure 5 provides details of a position marker 3, showing a two-dimensional barcode example.

Figure 6 shows a typical 2-dimensional Datamatrix barcode symbol.

Figure 7 identifies the key geometric points of figure 5, identified as A, B, and C.

Figure 8 shows a Datamatrix symbol, illustrating a method of angular determination using key geometric points A, B, C, relative to the field of view, and a Point E, the midpoint of line segment AC.

Figure 9 shows a typical field of view where background objects, such as the coordinate reference, have been removed for clarity. Angle CBD is defined.

Figure 10 shows the same field of view of Figure 9 and illustrates line segment AC and Point E.

Figure 11 shows Line Segment OE, and Angle OE for the same field of view of Figure 9.

Figure 12 shows a software flow diagram for image processing and feature extraction steps.

Figure 13 shows a software flow diagram for position and azimuth determination in pixel space.

Figure 14 shows a software flow diagram for position and azimuth correction and conversion to real space.

Detailed Description

The method and apparatus of the present invention present a general solution to the problem of object location and may be applied to many fields of use. Two application examples are given.

Application example #1 - storage area location determination

Objects are frequently stored on floors or in outdoor areas where storage devices such as bins, racks, and shelves are not available. Such areas are sometimes marked to designate locations, so that the objects can be placed and later found with some degree of precision.

This invention provides a method of determining precise position and azimuth (rotation or alignment) within a designated area or volume. It is suitable for indoor and outdoor use, and can be applied to stationary or mobile objects to provide a high degree of precision for position and azimuth measurements.

Application example #2 - robot or automatic guided vehicle (AGV) guidance system

Many methods are used to guide robots and automatic guided vehicles (AGV). Guidance systems are often designed to navigate the robot through predetermined paths using embedded wiring, fixtures, or other means. This invention allows vehicles freedom of movement and freedom of rotation while maintaining the ability to determine position and azimuth at any location and at any rotational azimuth within the designated area or volume.

This invention provides a novel method of determining position and azimuth through the following steps.

1. The determination of position and azimuth in a designated area is accomplished by contemporary machine vision equipment using a coordinate reference, comprising a plurality of unique position markers,

which is placed within or near to the designated area or volume. Sufficient position markers are provided so that at least one position marker of the coordinate reference is visible to the determination system from each and every location within the designated area or volume.

2. Machine readable symbols, such as one-dimensional or two-dimensional barcodes, encode the identity of each position marker of the coordinate reference, allowing automated devices such as barcode scanners 7 (Figure 1) to read the identities of the symbols. Position data in human readable form (such as text) may also be imprinted, attached, or otherwise affixed to the position markers if desired. Printed text allows people to determine approximate locations by simply viewing the coordinate reference and reading the text on the nearest position marker.

3. Machine recognizable symbols are arranged on the position markers of the coordinate reference in a predetermined pattern at predetermined positions, allowing machine vision technology to determine position by analyzing the shapes and symbols on the position markers. Exact position coordinates and azimuth (i.e., the directional orientation of the object) are determined through computer programmed instructions and are based upon geometric analysis of the acquired image data.

4. In a preferred embodiment, two-dimensional non-concentric barcode symbols are utilized to serve the dual purpose of machine readable position location codes and geometric position markers.

Referring to Figure 1, one embodiment of the invention will now be described in detail. Coordinate reference 1 may be constructed of any of several materials, such as: netting (examples: fish net, basketball net); screen (examples: window screen, tent screen); mesh (examples: garment lining, landscaping mesh); or web (examples: polyolefin film, non-woven synthetic material, paper). The coordinate reference 1 is sized to match the predefined coordinate space, i.e., the designated control area. The purpose of the coordinate reference 1 is to provide a surface on which a plurality of unique position markers 2, 3 can be imprinted, attached or affixed. The coordinate reference may be a ceiling, roof, wall, or other structure, or it may be suspended, supported, or attached to nearby structure. For example, in a warehouse overhead beams, ceiling fixtures, or roof attachments may serve as attachment points if the coordinate reference is to be suspended overhead. Free standing fixtures or other fixed structure may be used for other orientations.

The coordinate reference is imprinted with markings which comprise position markers 2, 3. The markings can be dark on a light or transparent background, light on a dark or opaque background, or of one or more colors. Alternatively, the position markers can be constructed in the fashion of labels which are imprinted before application to the coordinate reference, or three dimensional structures which are attached to the coordinate reference. Attachment may be by fasteners such as screws or

clips, adhesives such as glue or pressure sensitive label adhesive. The coordinate reference may be substantially planar or non-planar, as long as the positions of the position markers relative to the designated area or volume are established.

The coordinate reference may be constructed of air-permeable, e.g., perforated material (example: netting) as in Figure 2 or solid material (example: plastic sheet) as in Figure 3. Perforated materials offer the advantage of allowing air to pass through, for example, for ventilation. Perforated, transparent, and translucent material offer the advantage of allowing light to pass through the coordinate reference, for example to allow room lighting to be transmitted. Solid materials, which may also be perforated (example: paper with punched holes), may be used and may be opaque, translucent, or transparent, depending on lighting and ventilation requirements for the application. Either construction can be readily accommodated by the method of the present invention.

The coordinate reference may be marked with optional grid, sector, coordinate, or other separation markings 8, for example, to form lanes, radials, or other identification markings to aid in manual (i.e., human visual) position determination (see Figures 2 and 3).

The position markers 2, 3 are imprinted or attached to the coordinate reference 1 in a prescribed pattern; for example, in rows and columns corresponding to a desired coordinate plan for the designated area. The position marker 2, shown in Figure 4, comprises three components: text 10 to aid manual identification of each grid location (example: "AA01" = Row "AA", Column "01"), a one-dimensional (i.e., linear) barcode 11 which encodes the marker location "AA01" in any of several common bar code symbologies; and position symbols 9 which serve as position and angular orientation references (i.e., optical targets) for the machine vision system.

The position marker 3 of Figure 5 provides information equivalent to that of position marker 2, comprising text 10 and a non-concentric code, a two-dimensional barcode 12, which serves the dual purpose of encoding the marker identity in any one of several two-dimensional barcode symbologies and serves as a position and angular orientation reference.

Figure 1 illustrates a typical application in a warehouse, where materials are stored on the floor. Coordinate reference 1, based on the net/screen/mesh design with open perforations, is suspended from overhead, and is placed adequately high above the working area so as not to inhibit operations. Suspension is provided by angular supports and the material is stretched tightly into a substantially planar form. The open structure allows light to pass from overhead light fixtures to the work area, and air to flow freely for heating and ventilation considerations.

The position markers 2, 3 on the coordinate reference 1 identify coordinate locations. Each marker is comprised of human readable text, a

barcode, and one or more position symbols. Lift truck vehicle, i.e., the object to be located, 6 has affixed to it a machine vision camera 4 and a computational device 5, such as a portable computer. In this example, the lift truck has freedom of motion in two dimensions within the operating area. To store an item, the lift truck acquires a parcel, proceeds to a particular location within the designated area and deposits the item. The position and azimuth determination system is active at all times when the vehicle is within the designated area beneath the position reference 1. The images from the camera 4 may be captured continuously, or on command, such as when the vehicle stops, or at a time chosen by the operator. When the camera 4 captures an image of the overhead position reference 1 the image is transmitted to the machine vision system computational device 5 for analysis. In the case where three dimensional position measurement is needed, the camera would be mounted on the lift mechanism, e.g., the movable forks, instead of the cab.

Image Analysis

Contemporary machine vision technology offers sophisticated image processing capabilities which can be applied to a multitude of tasks such as presence or absence detection, dimensional measurement, and object shape identification. Machine vision systems are typically comprised of a video camera, a computing device, and a set of software routines which are provided by the machine vision vendor. The equipment is commercially available and suitable for industrial environments.

In order to develop an application the user chooses certain subroutines, combines them into a sequence or procedure, and stores the procedure in the memory or storage device of the machine vision computing device. The system operates by running the procedure when called to do so. Output data are available at the conclusion of the procedure, and may be similarly stored or transferred to another device.

The method of the preferred embodiment utilizes callable vendor-supplied subroutines to analyze position markers and store data obtained from this analysis. Azimuth and position are then calculated from these data and stored or transferred to other devices.

The preferred embodiment applies a commercial machine vision system such as Model 5100 or Model 5400 from Cognex, Incorporated. "In-Sight Explorer™" software provided with this system offers a wide array of feature extraction, mathematical, geometric, object identification, and barcode symbol decoding subroutines.

The following functional steps analyze the image within the field of view (FOV), decode the position markers' encoded position information, calculate X-Y coordinates in pixel space, and convert the results to actual "real space" positions.

Image Processing and Feature Extraction

Referring to Figure 12, the following steps take place within the machine vision software.

The camera 4 continuously, or on command, captures analog and/or digital images of the position markers 2,3 of the coordinate reference 1. One or more position markers 2,3 are partially or fully visible within the camera's field of view (FOV) at any given time. Once an image is captured, the software analyzes it as follows:

Image data 20 is manipulated by preprocessing routines 21 to enhance image features such as sharpness, contrast, and brightness. The resulting processed image is tested 22 and returned for additional processing 23 if not adequate for interpretation. Once the image has passed preprocessing, it is analyzed 24 to locate all position markers. This stage determines whether single or multiple position markers appear within the FOV, and superfluous image data such as position marker printed text, and background objects such as the coordinate reference net are discarded or ignored. Position markers 2,3 found fully visible within the FOV are analyzed for readability 25. If a single marker is found, selected image data are passed to a decoder 27; if multiple markers are present, image data are passed to a readability test 26, which determines which marker is most readable and passes the selected image data to the decoder 27. Alternatively, the readability test may select the marker closest to the center of the image and pass that image data to the decoder 27. Decoder 27 "reads" the encoded unique identification code of the position marker and returns alphanumeric data which are stored as decoded position marker data 28. An example of an encoded two-dimensional position marker is shown in Figure 6. Selected image data for a single marker are also passed to position marker key point locator 29 which analyzes image data to locate key points A, B, and C of the position marker symbol (Figure 7). Key points are then stored 30 as pixel coordinates.

In the case of the position marker 2 of Figure 4, having a one-dimensional barcode, the decoder 27 "reads" the encoded unique identification code of the position marker and returns alphanumeric data which are stored as decoded position marker data 28. Selected image data for a single marker are also passed to position marker key point locator 29 which analyzes image data to locate the geometric positional references 9. The key points for this position marker are, for example, a pair of corresponding apexes of the triangular positional references 9.

Position and Azimuth Determination in Pixel Space

Referring to Figure 13, the following steps begin after completion of image processing and feature extraction steps.

The Position Marker Look-Up Table (LUT) 31 is a database containing actual X, Y, Z coordinate positions and actual azimuth angles that are recorded for all position markers at the time of coordinate reference manufacture. Coordinate values are recorded in "real space", such as feet or meters and angles in degrees, such as a compass heading. Decoded marker position data 28 is used 32 to search LUT 31. Actual (i.e., real space) X, Y, Z coordinates for the chosen position marker are returned from LUT 31, and are stored as the approximate X, Y, Z position 33. Pixel coordinates of Key Points B and C, 30, are used to calculate angle CBD, 34, the rotation angle of the position marker relative to the FOV, from which the approximate (uncorrected) azimuth 36 is calculated in step 35.

Angle CBD is illustrated in Figure 8 and shown in the context of the FOV in Figure 9. X and Y values of pixel coordinates A and C, 30, are summed and divided by two (37) to establish Point E (Figure 10), the midpoint of line segment AC, and the center of the position marker. Point E coordinates are used to calculate: (a) angle OE, Figure 11, the radial angle between the center of the image and the center of the position marker; and (b) the length of line segment OE, which is equal to the radial distance from the center of the image (center of the camera) O to the center of the position marker E. Once these two values have been established, it is possible to calculate 40 a more accurate X, Y position using plane geometry. The results of this calculation are stored in memory 41. To determine the Z coordinate and position, Key Points A and B are used to calculate the length of Line Segment AB of the image. Since the distance AB on the position marker 3 is known and the focal length of the lens of the camera 4 is known, the distance from the camera 4 to the position marker can be determined from the ratio of the length of Line Segment AB in the image to the distance AB on the position marker 3. Since the Z coordinate of the position marker 3 is also known, the Z coordinate of the object may be readily calculated. The Z coordinates are stored in memory 43.

Correction and Conversion to Real Space

Referring to Figure 14, at this point, X, Y, Z coordinate values, and azimuth values have been established in terms of pixels or degrees. To complete the determination, correction values must be applied for variations in the true position of the position markers - small errors which may have been present during fabrication of the coordinate reference 1. Approximate azimuth 36 and the LUT 31, which provides azimuth correction data for the marker being analyzed, are used to determine the correct azimuth 44. Adjusted Position in Pixels 41 is converted to real space values by knowing the ratio of pixels to real units of measure (e.g.; 240 pixels per foot). This is done in step 45 and the result is modified in step 46 by the Position Correction Data from the LUT 31. As with the azimuth calculation, the adjusted coordinates are corrected for variation

recorded during manufacture. Z coordinates in pixels 43 are converted into real space units 47 in a similar proportional fashion.

The final step is the combination 48 of corrected azimuth, corrected X-Y coordinates, and Z coordinate into a single unit of data which can be stored in local memory or transmitted to other devices.

Post Processing

Azimuth and position data derived from the image processing steps may be optionally transformed into alternate terms to indicate specific regions in real space such as a zones, sectors, or areas. With or without post-processing, position and azimuth information may be utilized by other systems such as a navigation system, guidance system, or material management system.

What is claimed is:

XC1210

1. A method of determining a coordinate position and azimuth orientation (i.e., directional heading) of an object within a predefined coordinate space, the method comprising:
 - a) providing a plurality of unique position markers having identifying indicia and positional reference indicia thereupon, the markers being arranged at predetermined positional locations within the coordinate space so that at least one position marker is within view of the object;
 - b) using an image acquisition system mounted on the object, acquiring an image of the at least one position marker within view;
 - c) processing the image to determine the identity of each position marker and the position of each position marker relative to the object, and to determine the orientation of each position marker relative to the object;
 - d) calculating the position of the object and the azimuth orientation of the object in the coordinate space and storing the position and azimuth orientation information in a memory.
2. The method of claim 1, wherein the position marker is first identified and the absolute position and azimuth of the object in the coordinate space are calculated from the position reference indicia in the acquired image of the position marker and from the corresponding known location and angular orientation of the identified position marker.
3. The method of claim 2, further comprising the step of translating the information encoded in the selected position marker within the field of view to a coordinate location of the selected marker and then calculating the coordinate location of the object within the predefined coordinate space.
4. The method of claim 2 further comprising the step of translating the information encoded in the selected position marker within the field of view to determine an azimuth of the selected marker and then calculating the an azimuth of the object.
5. The method of claim 1, further comprising, in step c) determining and selecting the position marker nearest to the center of the image and using the selected position marker for the calculation of step d).
6. The method of claim 1, further comprising, in step c) determining the image quality of each position marker in the image and selecting the position marker having the highest image quality and using the selected position marker for the calculation of step d).
7. The method of claim 1, wherein the processing of the acquired image in step c) comprises the decoding of a one- or two-dimensional barcode, and wherein the decoded data identifies the position marker.

8. The method according to the apparatus of claim 141, wherein the processing of the acquired image includes the decoding of a one- or two-dimensional barcode, and wherein the decoded data identifies position coordinates within the coordinate reference of the position marker.
9. The method of claim 1, further comprising, after step c) selecting the position marker nearest to the center of the image and using the selected position marker for the calculation of step d).
10. The method of claim 1, further comprising, after step d), combining the X, Y, Z position and azimuth data into a single numerical sequence and then transmitting the position and azimuth orientation information to a navigation system or to an inventory management system.
11. The method of claim 7, wherein a look-up-table containing actual X and Y coordinates and azimuth corrections of all position markers within the coordinate reference is maintained.
12. The method of claim 11, wherein an approximate position of the object is determined by retrieving the coordinates of the decoded identity of the position marker from said look-up-table.
13. The method of claim 11, wherein two key points are located within the image of the position marker.
14. The method of claim 13, wherein the two key points found in the position marker are used to calculate the center of the position marker.
15. The method of claim 14, wherein a line from the center of the field of view to the center of the position marker is determined and a length and angle of this line relative to the field of view are determined by plane geometry.
16. The method of claim 15 wherein an adjusted position of the object is calculated by correcting the approximate position of the object by using the length and angle of the line to calculate a position offset.
17. The method of claim 16 wherein the adjusted position of the object is corrected to a true position by applying small variations recorded in the look-up table for the position marker.
18. The method of claim 13, wherein an approximate azimuth is determined by locating and calculating the angle formed by said two key points relative to the field of view.
19. The method of claim 18, wherein a correction is made to the approximate azimuth angle by retrieving stored azimuth data for the

decoded position marker from the look-up table and adjusting the azimuth accordingly.

20. The method of claim 17, wherein the true position coordinates are mathematically converted to units of real space by using predetermined multiplication or division factors.

21. The method of claim 15, wherein the Z coordinate position of the object is determined from the length of the line between the two key points and then calculating the proportional distance between the camera and the marker by proportionally scaling the line length into units of real space.

22. The method of claim 1, wherein each position marker is unique in either shape, color, or pattern.

23. The method of claim 22, wherein each position marker has a predetermined shape different from the other position markers.

24. The method of claim 22, wherein each position marker has a predetermined color different from the other position markers.

25. The method of claim 22, wherein each position marker has a predetermined pattern of light and dark shapes different from the other position markers.

26. The method of claim 22, wherein each position marker has at least an axis of symmetry.

27. The method of claim 26, wherein each position marker encodes the identity of said marker in digital form using a linear one-dimensional barcode symbology.

28. The method of claim 27, wherein the linear one-dimensional barcode symbology is selected from a group of symbologies consisting of Interleaved 2 of 5 code, Code 39, Code 128, Code 93, UPC code, or Codabar.

29. The method of claim 22, wherein each position marker is asymmetric in shape.

30. The method of claim 29, wherein each position marker is shaped in the format of a two-dimensional barcode providing both identity and angular orientation information.

31. The method of claim 1, wherein each position markers encodes the identity of said marker in digital form using a two-dimensional asymmetric symbology.

32. The method of claim 31, wherein the linear two-dimensional barcode symbology is selected from a group of symbologies comprising DataMatrix, Code One, PDF417, Array Tag, and QR Code.

33. The method of claim 22, wherein the two-dimensional asymmetric symbology encodes the angular orientation of said marker.

34. The method of claim 1, wherein the position markers are arranged substantially in a plane located relative to a boundary of the coordinate space.

35. The method of claim 1, wherein the position markers are arranged at predetermined three-dimensional coordinate positions.

36. An apparatus useful for determining a coordinate position and azimuth orientation of an object within a predefined coordinate space, the apparatus comprising:

- a) a plurality of unique position markers arranged in at predetermined positional locations within the coordinate space such that at least one position marker is within view of the object;
- b) an image acquisition system mounted on the object, for acquiring an image of the position markers within view;
- c) an image processing system for processing pixels in the acquired image to determine the identity of each position marker, the position of each position marker relative to the object, the azimuth orientation of each position marker relative to the object;
- d) a post processing system for calculating the position of the object and the azimuth orientation of the object in the coordinate space.

37. The apparatus of claim 36, wherein the position markers are arranged in a grid (row and column) pattern corresponding to a predetermined mapping of the predefined coordinate space.

38. The apparatus of claim 36, wherein the position markers are imprinted on or attached to a support structure, the support structure being in a predetermined positional relationship with a boundary of the predefined coordinate space.

39. The apparatus of claim 36, wherein the support structure comprises a grid of support material, said material being substantially transparent and permeable to air, the position markers being substantially opaque and air impermeable.

40. The apparatus of claim 39, the support structure comprising a web, a mesh, a screen, or a net.

41. The apparatus of claim 40, wherein the position marker comprises a substantially planar material.

42. The apparatus of claim 41, wherein the substantially planar material is imprinted with an asymmetric pattern which encodes the identity and angular orientation of the position marker.

43. The apparatus of claim 42, wherein the asymmetric pattern which encodes the identity and angular orientation of the position marker is printed in a first color and the position marker further comprises human readable text imprinted in a second color facilitating removal of said text from the captured image through the use of spectral filtering.

44. The apparatus of claim 41, wherein the position marker further comprises a pressure sensitive adhesive backing.

45. The apparatus of claim 41, wherein the position marker is optically retro reflective.

46. The apparatus of claim 41, wherein the position marker further comprises human readable text indicating the relative position of the position marker within the predefined coordinate space.

47. The apparatus of claim 41, wherein the position marker comprises geometric symbols placed in a predetermined pattern and rotational orientation.

48. The apparatus of claim 36, wherein the image acquisition system comprises a machine vision system, the machine vision system comprising a camera, a light source, and image capture electronics

49. The apparatus of claim 36, wherein the light source of the machine vision system is located adjacent to the camera.

50. The apparatus of claim 49, wherein the light source is pulsed.

51. The apparatus of claim 49, wherein the light source is continuous.

52. The apparatus of claim 49, wherein the light source emits a narrow wavelength band of illumination.

53. The apparatus of claim 48, wherein the camera of the machine vision system further comprises a spectral filter to limit wavelength ranges imaged by the camera.

Title

**METHOD AND APPARATUS FOR DETERMINING
POSITION AND AZIMUTH OF AN OBJECT**

Abstract

A method and apparatus for determining position and azimuth of an object within a predetermined area or volume is disclosed. Position markers, encoded with identity and rotational information are viewed with a camera, images captured and processed, and the position and azimuth of the object are calculated.

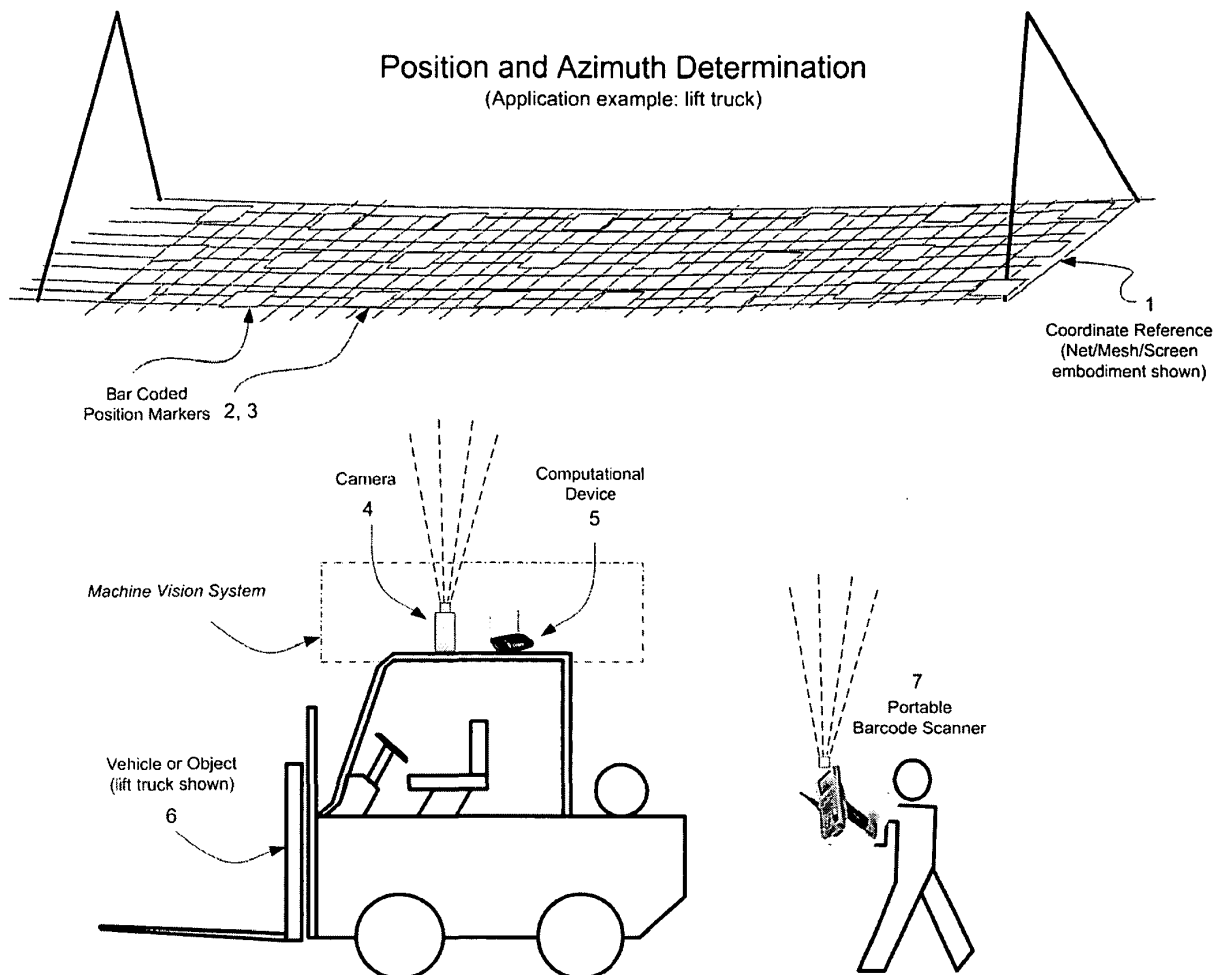


Figure 1.

Position & Azimuth Determination

Coordinate Reference with Position Markers

(Net/screen/mesh embodiment is shown)

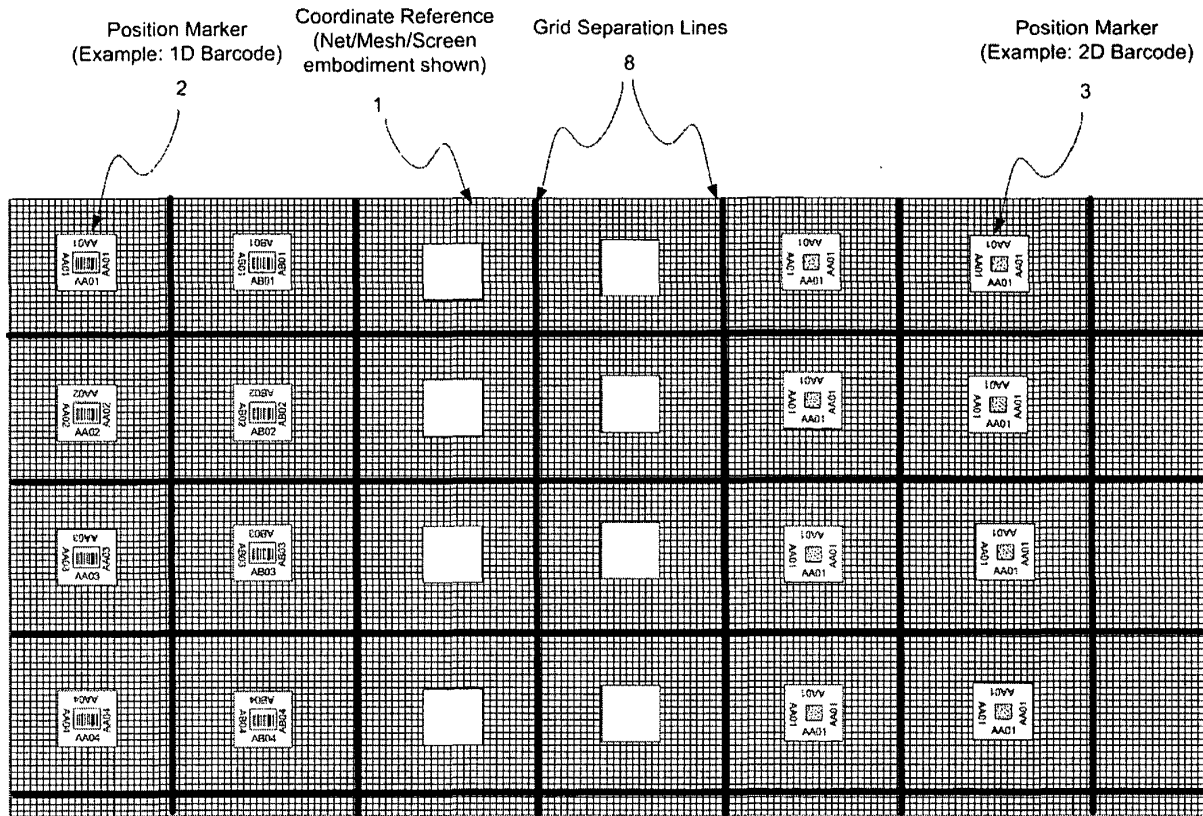


Figure 2.

Position & Azimuth Determination
Coordinate Reference with Position Markers
(Transparent or Translucent web embodiment is shown)

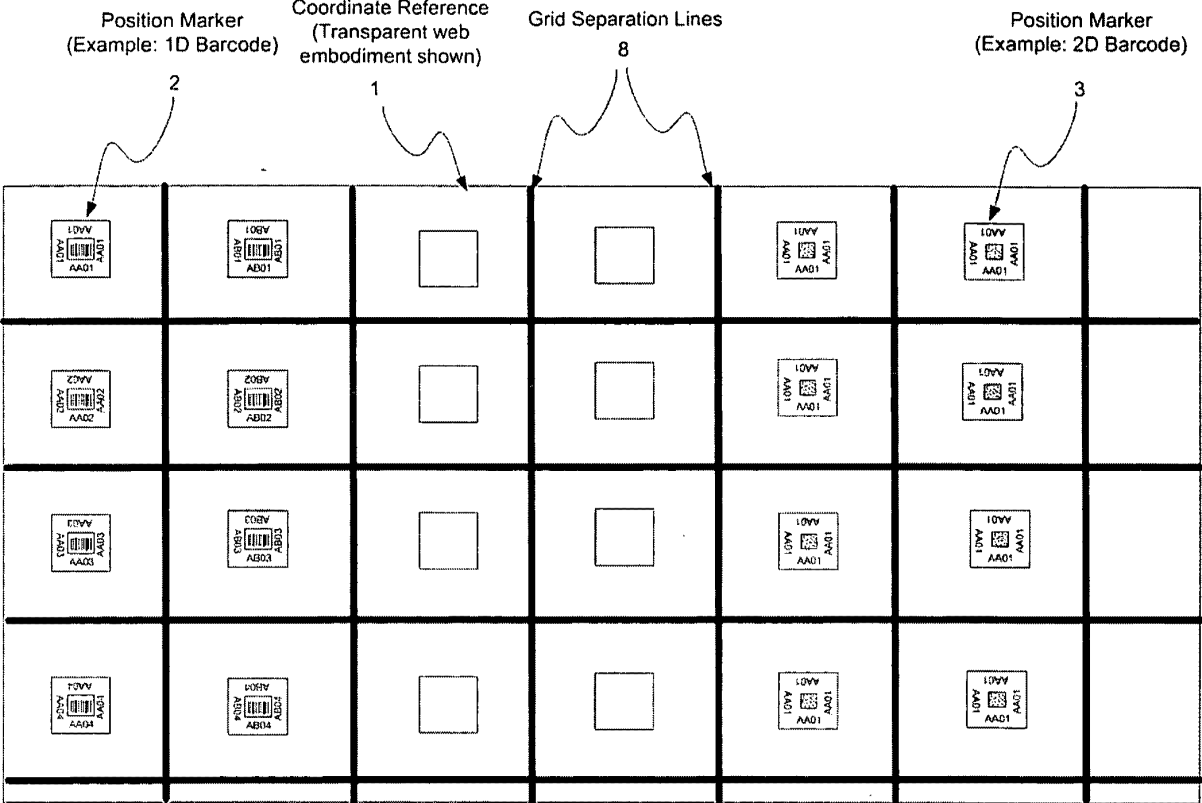


Figure 3.

Position and Azimuth Determination

Position Marker Detail

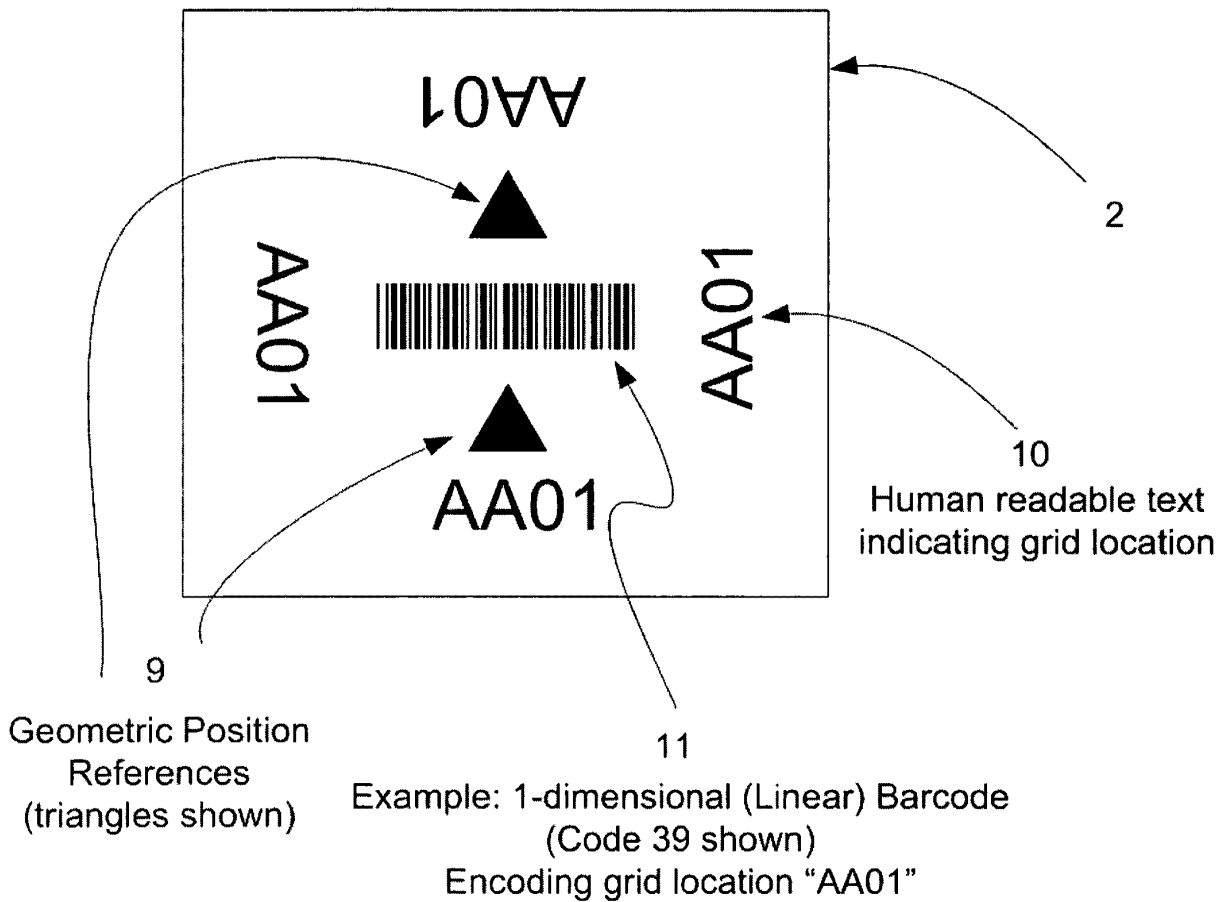


Figure 4.

Position and Azimuth Determination

Position Marker Detail

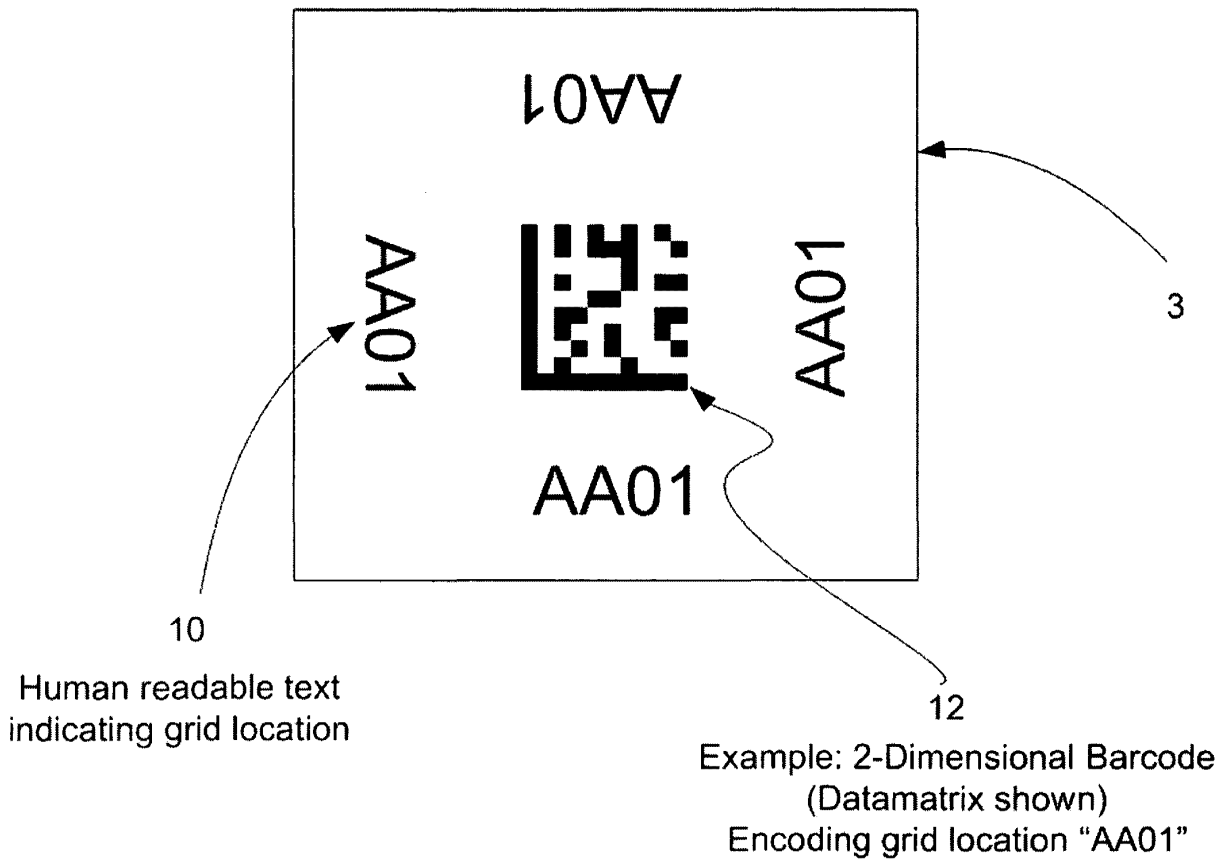


Figure 5.

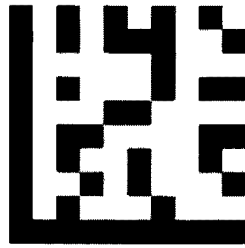


Figure 6.

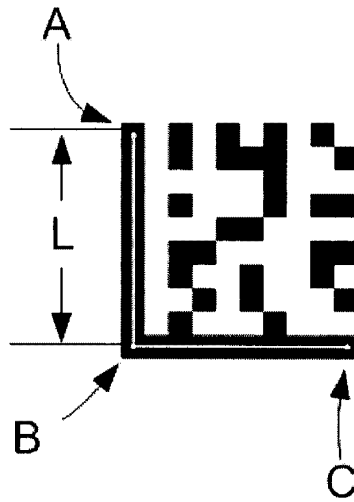


Figure 7.

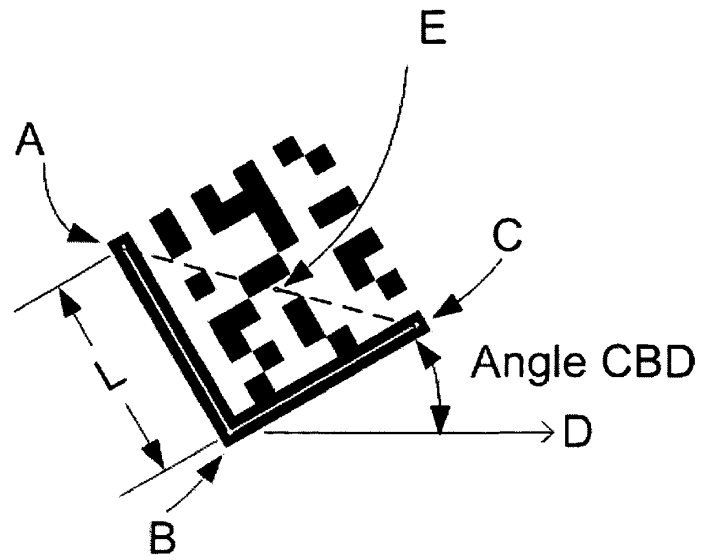


Figure 8.

Field Of View (FOV)

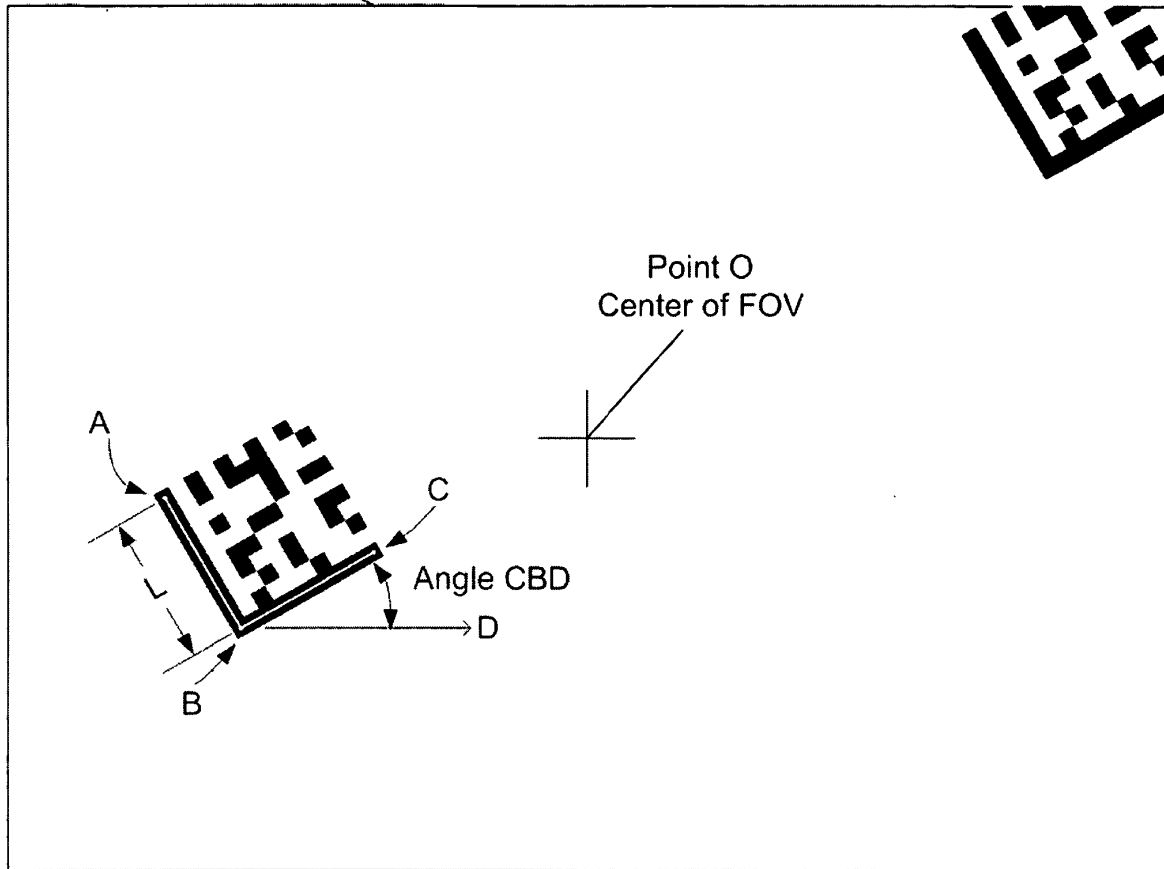


Figure 9.

Field Of View (FOV)

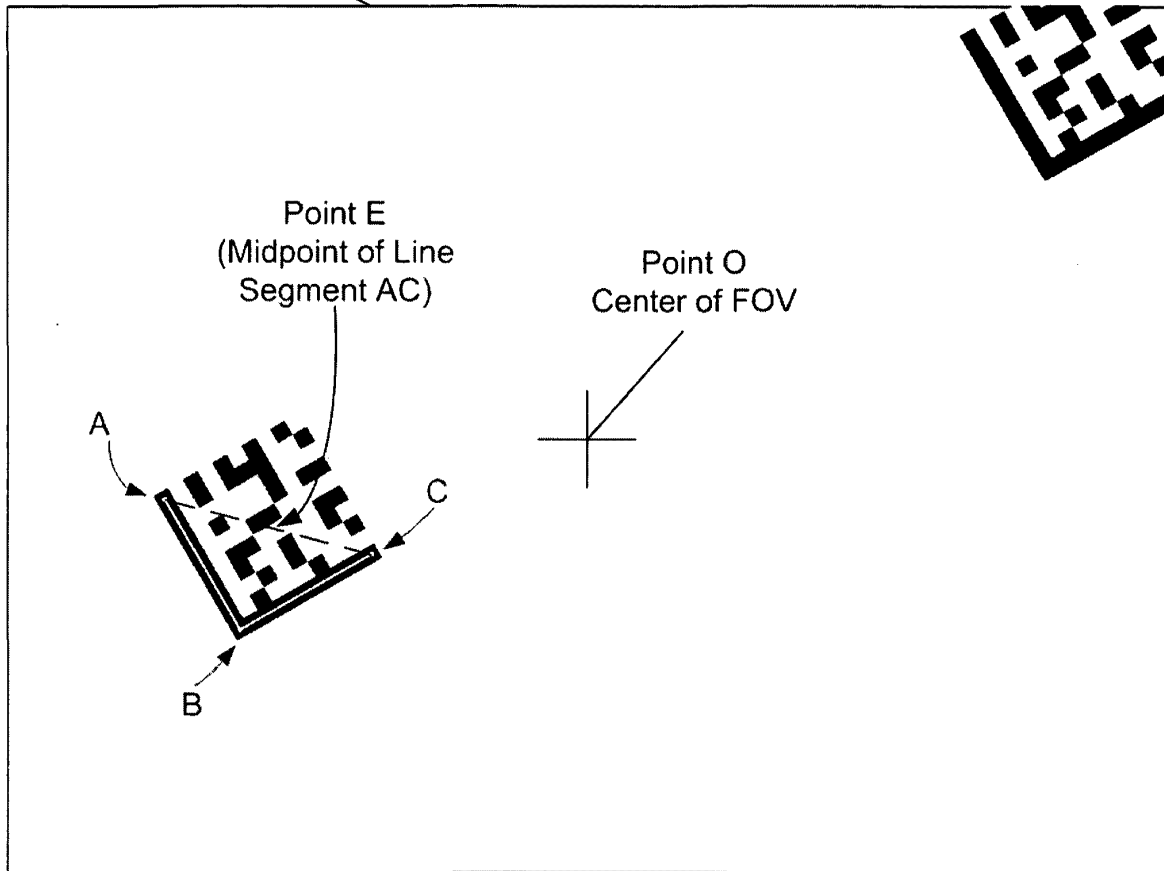


Figure 10.

Field Of View (FOV)

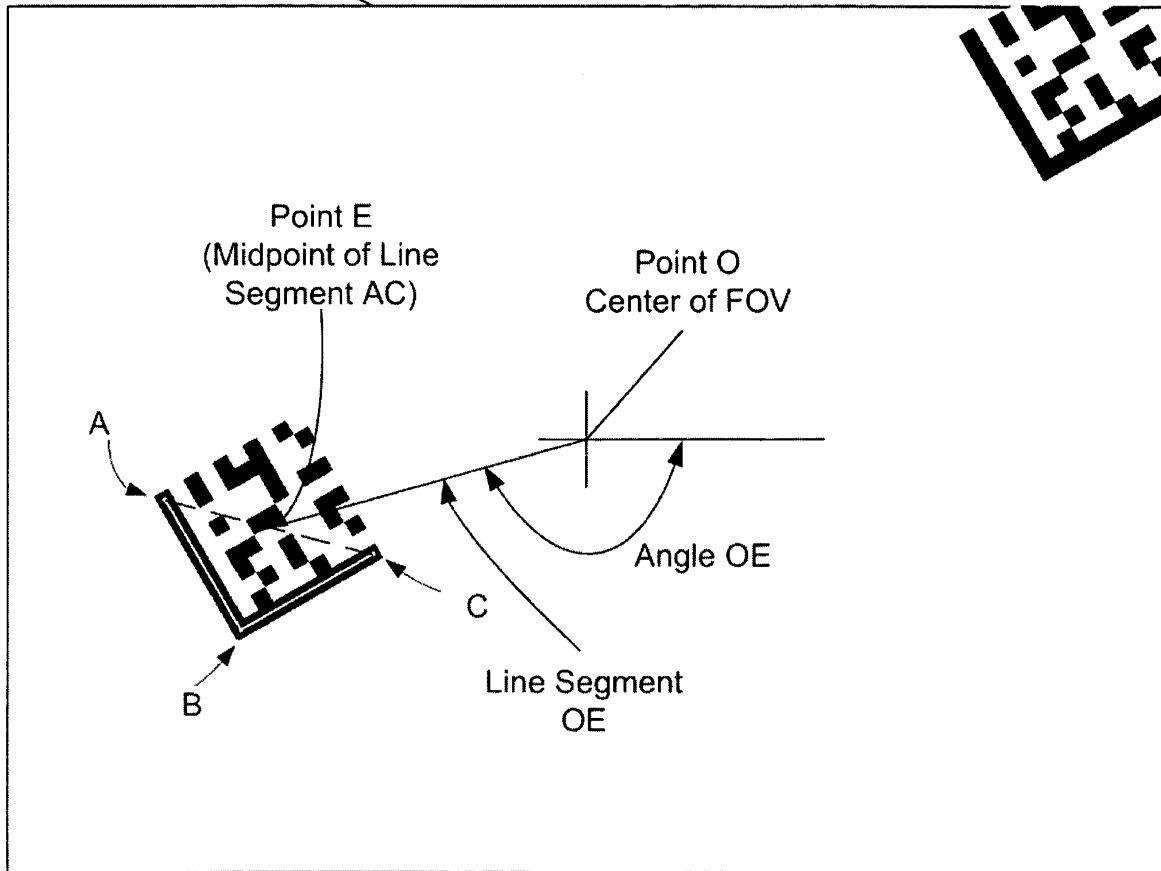


Figure 11.

Position and Azimuth Determination from Image Data

Image Processing & Feature Extraction

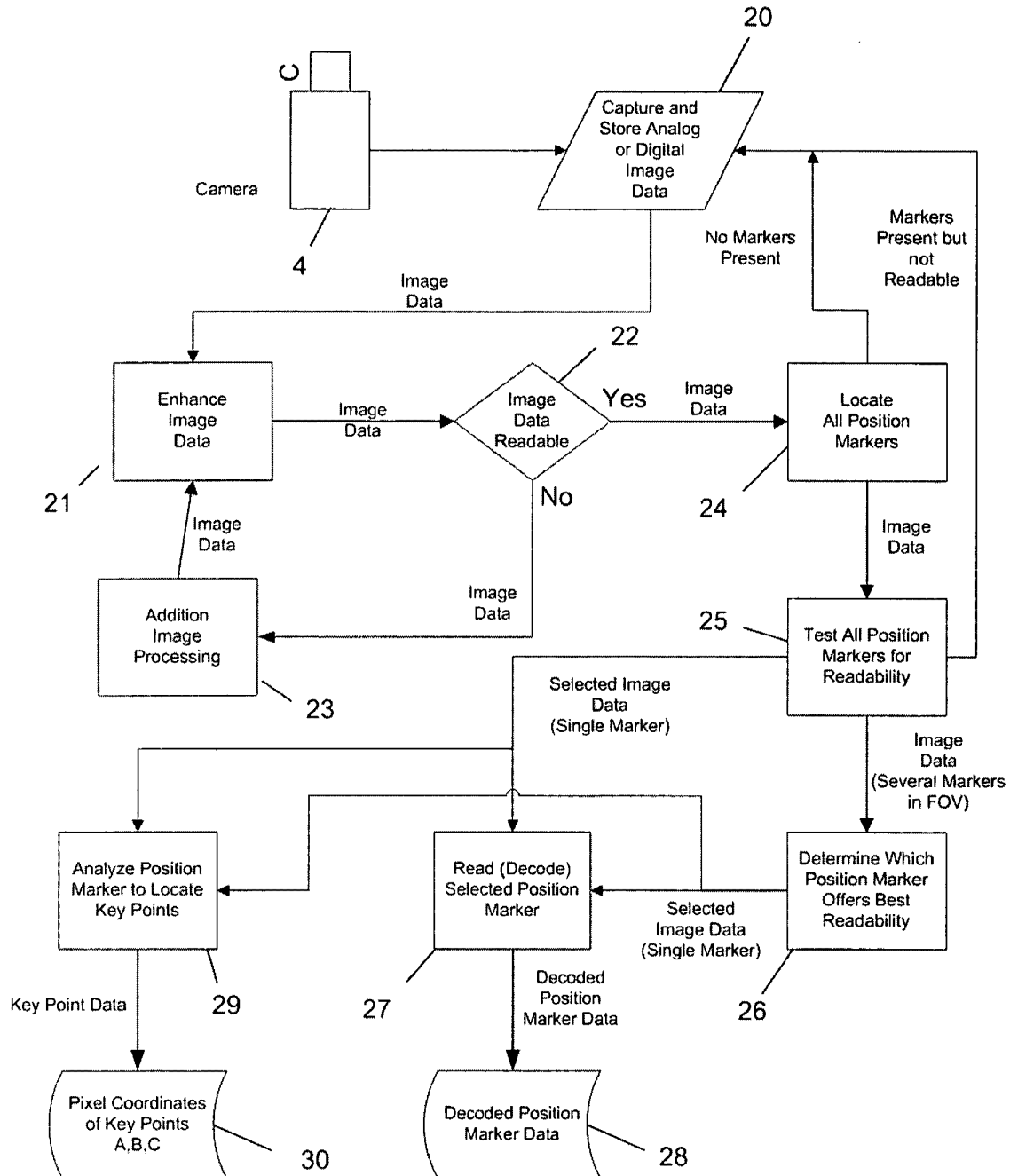


Figure 12.

Position and Azimuth Determination from Image Data

Position and Azimuth Determination in Pixel Space

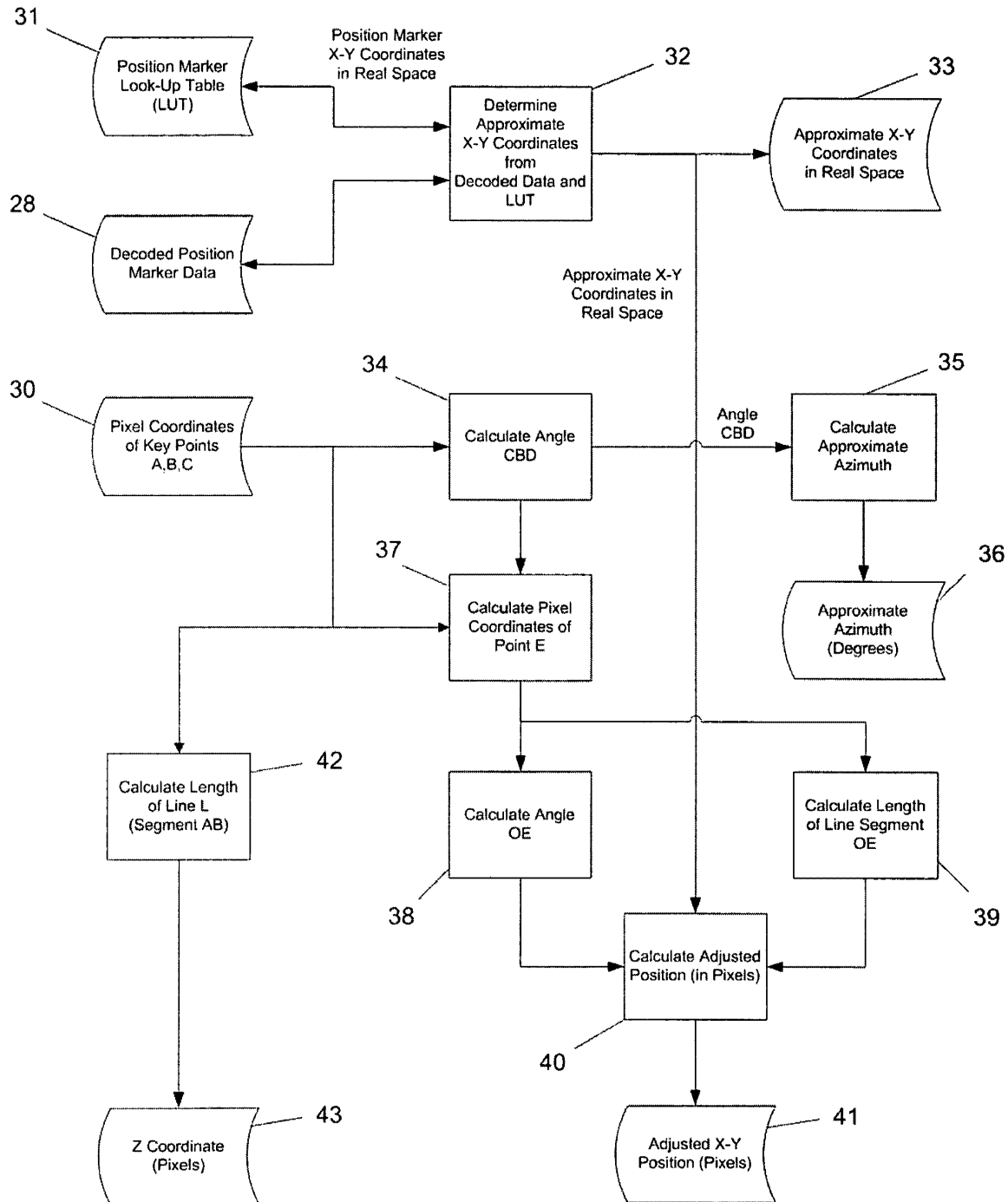


Figure 13.

• Position and Azimuth Determination
from Image Data
Correction and Conversion to Real Space

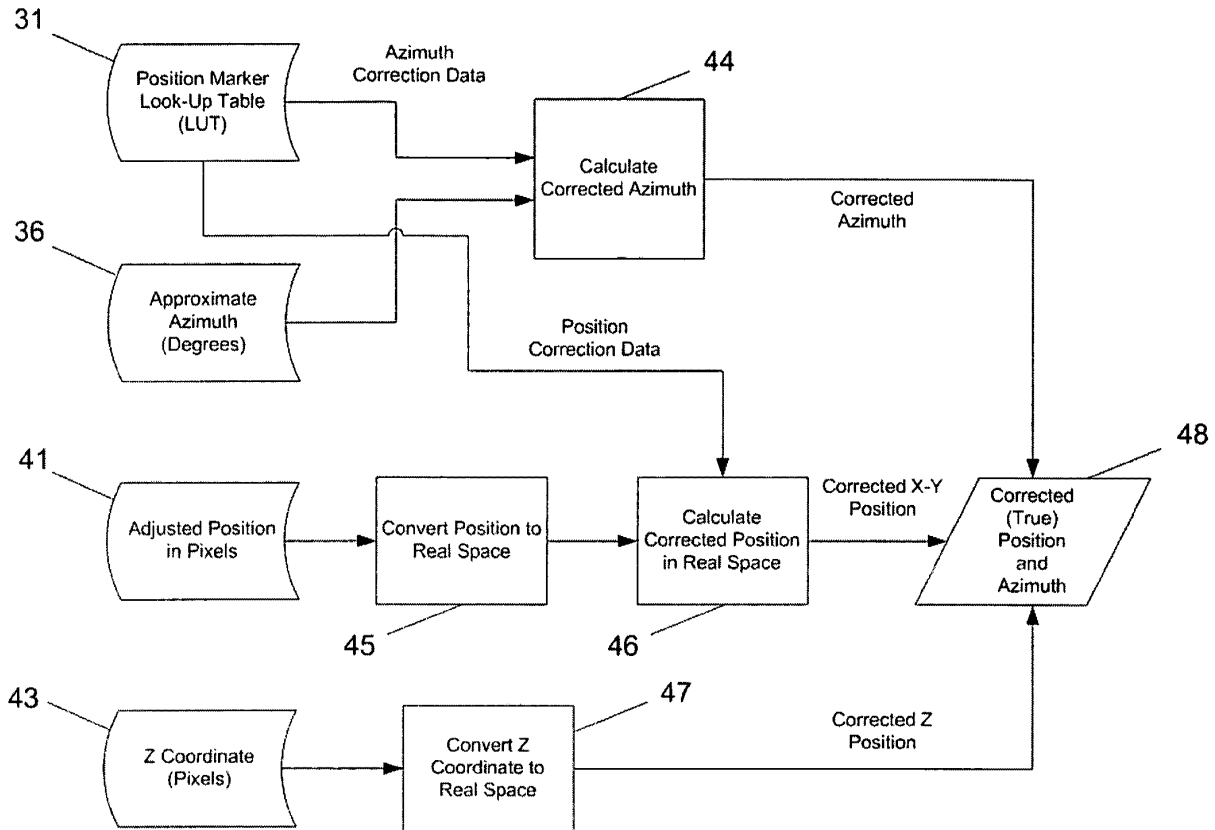


Figure 14.