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Data Input to a computer system defining a three-dimensional model

Field of the invention

The present invention relates to a method for entering data into a computer, and to a computer programmed to receive the data.

5 Background of Invention

Many methods are known for entering data into a computer using a pointing device moving within a 2-dimensional (2D) space, such as a mouse, or a 3-dimensional space, such as a mouse or track ball with an additional input axis (as in US patent no. 5784052 or US patent no. 634878) or a point in a 3D
10 space found by ultrasonic sensing. One application of such methods is for manipulating 3D objects defined in a 3D computational space.

Such systems find the position of a *point* in the 2D/3D space. This is not convenient for 3D object operations, however, because all the input information is based on three-dimensional information: the coordinate of a
15 point.

Summary of the invention

The present inventor has made the observation that for 3D manipulations, the position of a line in the 3D space would be more useful than the position of a point. For example, any rotation of an object can only be defined based on
20 rotation around an axis, and inputting the position of an axis into a computer by specifying the position of a point is not straightforward.

In general terms, the present invention proposes that data is entered into a computer which supports a 3D model in a 3D computer implemented space (the "computer space") by measuring the position (which is defined here to



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include also the orientation) of a line defined within a real world space (the "user space") using a fixed observation means, such as fixed cameras.

For example, the line may be the longitudinal axis of an elongate pointing device which a user manipulates in the user's space. In other words, the manipulation of the pointing device is used to define a line (5D information), or
5 a line and a point on the line (6D information).

Note that it is possible to use the invention to extract information as in the prior art concerning the position of a point in a 2D space, by determining the interaction of the line with a 2D surface. For example, in one form of the
10 invention, the intersection is found between the line in the 3D real-space with a 2D plane, such as a display screen of a computer, and this information is used as input data for a program.

Alternatively, the position of the line can be transformed into a user's 3D coordinate system. The coordinates of this line are further transformed into
15 the PC's co-ordinate system. Two advantages of going through the user's co-ordinate system, rather than directly to the PC's system, are that the analysis is more intuitive and the 3-D calibration is more convenient.

It is possible for the pointing device to be any elongate object, e.g. one without any electronic function. Alternatively, it is possible for the pointing
20 device to include one or more additional data input means, such as buttons. In this case, means exist for transferring the data to the computer system, such as wires, or wireless data communication means.

It is true that certain input methods exist already which measure the orientation of a pointing device within a user space. For example, US patent
25 no. 5237647 and US publication no. 20020036617. However, such systems use is made of position sensors which are mounted inside the device, rather than external fixed observation devices.

A number of virtual reality systems are also known, such as WO 99/60529, which define a three-dimensional computer space which coincides with a user space. The computer displays three-dimensional images of objects of this computer space to the user (e.g. using goggles) superimposed on the real
5 space with which it coincides. The system tracks the full 3D position and 3D orientation of a pointer device moved by the user in the real space, and this corresponds to an identical position and orientation in the computer space. By contrast, in the present invention the three-dimensional computer space preferably has a (fixed or variable) mapping to, but does not coincide with, the
10 user space.

Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following figures in which:

Fig. 1 shows schematically a first data input system which is an
15 embodiment of the invention;

Fig. 2 shows schematically transformations between the different coordinate systems in the system of Fig. 1;

Fig. 3 shows schematically the steps in a method employed by the system of Fig. 1;

20 Fig. 4 shows the structure of a pointing device for use in an embodiment of the invention;

Fig. 5 shows a second data input system which is an embodiment of the invention;

25 Fig. 6 shows a third data input system which is an embodiment of the invention; and

Fig. 7 shows a fourth data input system which is an embodiment of the invention.

Detailed Description of the embodiments

Referring firstly to Fig. 1, a first embodiment of the invention is shown. It includes a two-dimensional display 1 operated by a computer 3 such as a PC.

5 The computer 3 is programmed to define a model in a 3-dimensional space (the "computer space"), comprising one or more 3D objects such as a cube 13. The display device 1 may be any conventional computer display device (e.g. CRT or LCD screen), or it may be a large screen onto which an image is projected.

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Additionally, the system includes at least two cameras 5, 7 directed into a real world space (the "user's space") in which a user manipulates an elongate pointing device 9. The cameras 5, 7 are for sensing the position of the pointing device 9 in real time. The system further includes a processing unit
15 11 for processing the output of the cameras 5, 7 in real time to determine the position of the longitudinal axis of the pointing device 9 in the user's space, and then transform it into a line in the computer's 3D co-ordinate system. The processing unit 11 may optionally be implemented either separately from the computer 3 or as software running on the computer 3.

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The computer 3 is programmed to modify the model in the computer space using information from the processing unit 11, possibly also in dependence on other inputs. The modification may be the manipulation of a 3D object 13 in the computer space. For example, the manipulation may be to change the
25 viewing angle of the 3D objects (i.e. the angle from which the display 1 presents an image of the computer space; that is the mapping between the 2D space of the display screen and the computer space) and/or rotating one or more 3D objects within the 3D computer space.

The system makes use of various co-ordinate systems, which are illustrated in Fig. 2 and explained in more detail below: 1) the 3D co-ordinate system 20 of the computer space, (2) the 2D display co-ordinate system 21 of the display plane, (3) the 3D co-ordinate system 22 of the user space containing the pointing device 9, (4) the 2D co-ordinate system 23 associated with the image plane of the left camera, and (5) the 2D co-ordinate system 24 associated with the image plane of the right camera.

The processing steps performed by the processing unit 11 are shown in Fig. 3, and are as follows:

- 1) Detecting the straight line images of the pointing device 9 in the respective 2D image planes 23, 24 of the cameras 5, 7. This can be done by image processing techniques such as line detection, or colour segmentation (in the case that the pointing device 9 is painted with a special colour). The lines in the left and right image planes are denoted as:

$$l_L : a_L x_L + b_L y_L + c_L = 0 \quad \text{and} \quad l_R : a_R x_R + b_R y_R + c_R = 0,$$

where x_L and y_L are the co-ordinates in the 2D space 23 of the "left" camera 5, x_R and y_R are the co-ordinates in the 2D 24 space of the "right" camera 5, and the values a_L , a_R , b_L , b_R , c_L and c_R are variables. The two ends of the lines are also found, and are denoted in left image plane as $(x_{1L}, y_{1L}), (x_{2L}, y_{2L})$ and in right image plane as $(x_{1R}, y_{1R}), (x_{2R}, y_{2R})$ respectively.

- 2) Using the results of (1) and a standard 3D vision method, the pointing direction in the user space 22 is calculated. This is done using two pre-calculated 3x2 matrices M_L and M_R (having the components shown in Fig. 2),

which define the transformation from the user's space 21 to the left and right image planes 23, 24, and a 3x4 matrix T^1 , which converts from the image planes to the user's space 22. Specifically, the pointing direction in the user's space 22, can be denoted as:

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$$l_{user} : \begin{pmatrix} x_{user} \\ y_{user} \\ z_{user} \end{pmatrix} = \begin{pmatrix} x_{1user} \\ y_{1user} \\ z_{1user} \end{pmatrix} + k \begin{pmatrix} x_{2user} - x_{1user} \\ y_{2user} - y_{1user} \\ z_{2user} - z_{1user} \end{pmatrix}, \text{ where } x_{user}, y_{user}, z_{user}, x_{1user}, y_{1user},$$

$z_{1user}, x_{2user}, y_{2user}$ and z_{2user} are the co-ordinates in the user's space.

The coefficients $\begin{pmatrix} x_{1user} \\ y_{1user} \\ z_{1user} \end{pmatrix}$ and $\begin{pmatrix} x_{2user} - x_{1user} \\ y_{2user} - y_{1user} \\ z_{2user} - z_{1user} \end{pmatrix}$ can be determined by substituting:

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$$\begin{bmatrix} x_{1user} \\ y_{1user} \\ z_{1user} \end{bmatrix} = \begin{bmatrix} T_{11}^1 & T_{12}^1 & T_{13}^1 & T_{14}^1 \\ T_{21}^1 & T_{22}^1 & T_{23}^1 & T_{24}^1 \\ T_{31}^1 & T_{32}^1 & T_{33}^1 & T_{34}^1 \end{bmatrix} \begin{bmatrix} x_{1L} - m_{L14} \\ y_{1L} - m_{L18} \\ x_{1R} - m_{R14} \\ y_{1R} - m_{R18} \end{bmatrix} \quad \text{and}$$

$$\begin{bmatrix} x_{2user} \\ y_{2user} \\ z_{2user} \end{bmatrix} = \begin{bmatrix} T_{11}^1 & T_{12}^1 & T_{13}^1 & T_{14}^1 \\ T_{21}^1 & T_{22}^1 & T_{23}^1 & T_{24}^1 \\ T_{31}^1 & T_{32}^1 & T_{33}^1 & T_{34}^1 \end{bmatrix} \begin{bmatrix} x_{2L} - m_{L14} \\ y_{2L} - m_{L18} \\ x_{2R} - m_{R14} \\ y_{2R} - m_{R18} \end{bmatrix}$$

15 into the equation for l_{user} , where $m_{L12}, m_{L18}, m_{R14}$ and m_{R18} are parameters in the two matrices ML and MR respectively.

3) The line in the user space 22 is transformed into the computer's space 20. Note that the transform (mapping) between the computer space 20 and the user space 22 is initially set be calibration before the present method is carried out, and furthermore the transform may be changing. The computer 3

registers the transformation (rotation and/or translation) between the computer's current coordinate system 20 and a reference (defined as "initial") co-ordinate system, such as the space 21 formed by the x-axis and y-axis (x_{disp} , y_{disp}) of the 2D display co-ordinate system 1 and an axis perpendicular

5 to the 2D display defined based on the right-hand law. Using this registered information, a transformation matrix T can be defined at any moment between the user space 22 and the computer space 20. Thus, by multiplying by T, the pointing direction l_{user} can be transformed into a line in the computer's co-ordinate system.

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Based on this information, a line 15 in the display space 21 can be generated from a transformation M, which is determined by "cameras' parameters" and "position parameters". The camera's parameters are projective (or affine) parameters, and refer to the matrix that transforms a 3D co-ordinate system into a 2D coordinate system via a projective transformation. The matrix is
 15 determined by how the 2D "image" is "projected". So, when the 3D co-ordinate system rotates and translates (with regarding to the reference co-ordinate system), the projective parameters change accordingly. The camera parameters can be calibrated. The position parameters are parameters
 20 registered in the computer's memory which determine the relationship between two 3D coordinate systems, including rotation (3x3 matrix) and translation (3x1 vector). The line 15 is displayed on the display device 1, and thus the display is augmented. This can be done continuously by a feedback mechanism.

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Note that the pointing direction (i.e. the full positioning of the line: its orientation and position with the user space) serves as the main information for commands to be sent to the computer. At the same time, the position of the pointing device is also known since the co-ordinates of two ending points

are also calculated in the processing. This information may also be used in the manipulation of 3D objects, such as in translation.

A first operating mode of the computer is referred to the 3D operating mode of the computer. In this mode, the line l_{PC} is used directly to modify the objects in the computer space. For example, the line may be used to define an axis of rotation, to change the viewing angle, or to select an object.

A second operating mode is referred to as the 2D operating mode of the computer. In this operating mode, the line is used to select a point on a 2D surface, i.e. the intersection between the line and the surface.

In either operating mode, the pointing device 9 can optionally be a simple elongate object having no intrinsic electronic function.

Alternatively, in either operating mode, other information can be obtained from the pointing device 9 to perform operations on the 3D space. For example, mechanical/optical encoders can be used to sense the twisting of the pointing device along its own axis, to input a rotation angle into a computer. Buttons can be added to the pointing device to define zooming, selection of objects, selection of operational modes, etc.

A suitable pointing device is illustrated in Fig. 4. It includes a body part 31 which is elongate having a longitudinal axis 36. It further includes an optical/mechanical encoder 33 which measures the rotation of the pointing device around its axis 36 and transmits this information wirelessly to the processing unit 11. The pointing device further includes buttons 35 (or other input devices such as slider(s), roller(s) or dial(s)) which the user may use to transmit information (e.g. wirelessly) to the processing unit 11. These buttons can allow the user to input selections or confirmations, for example. The

wireless transmission may be by an electromagnetic (IR or radio) signal, for example, or using ultrasonic signals.

In one variation of the above system within the scope of the invention, there
5 may be multiple pointing devices 9, each having a longitudinal axis which is measured, e.g. using the cameras 5, 7.

Turning now to Fig. 5, a second embodiment of the invention is shown.
Elements of the system of Fig. 1 which are equivalent to elements of the
10 second system are denoted by the same reference numerals. In the second embodiment, the cameras 5, 7 are replaced by at least 3 fixed ultrasonic transducers 41, 43, 45. The pointing device 9 is also provided with at least 2 ultrasonic transducers 47, 49. The transducers 41, 43, 45 are each capable of establishing their respective distances to each of the ultrasonic transducers
15 47, 49, which, using straightforward calculations and the knowledge of the coordinates of the transducers 41, 43, 45 in the user's space, makes it possible to determine the positioning (i.e. location and orientation) of the pointing device 9 in the user's space.

20 Turning now to Fig. 6, a third embodiment of the invention is shown. The third embodiment is similar to the second embodiment, except that the transducers 47, 49, instead of being attached to each other via the pointing device 9, are mounted on tools 51, 53 which are independently moved by a user (e.g. in his or her respective hands). The line 53 in the user space connecting their
25 centres (and shown dashed on Fig. 6) plays the role of the longitudinal axis 36 of the pointing device 9 of the first two embodiments.

Finally, Fig. 7 shows a fourth embodiment of the invention. As in the first embodiment, the fourth embodiment includes two cameras 5, 7. However, in
30 this case the role of the transducers 47, 49 in the third embodiment is played

by two visual markers 57, 59, which can be moved independently in the user space (e.g. by the user's respective hands). The rational line 58 in the user space connecting the two visual markers 57, 59 is equivalent to the longitudinal axis 36 of the pointing device 9 of the first two embodiments of the invention. The two cameras 5, 7 can each determine the positions in the image planes of the two visual markers 57, 59, and determine the position in those image planes of the respective straight lines in the image planes connecting those positions. These lines are then treated equivalently to the lines l_L and l_R in the first embodiment of the invention.

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Note that by means of any of these four embodiment systems, information can be input into a computer by an intuitive interaction with the computer 3. Although the invention has been described above with reference to only four embodiments, many other embodiments are possible within the scope of the invention, as will be clear to a skilled reader.

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Claims

1. A data input system for a computer system, the computer system including processing means defining a three-dimensional model in a 3-dimensional computational space having a mapping to a 3-dimensional user space, the system including:

one or more tools for manipulation by a user in the user space, the positioning of the tool or tools defining a line in the user space;

observation means having a fixed position and being arranged to observe the position of the tool in the user space to determine the position of the line in the user space; and

the processing means being arranged to modify the three-dimensional model in accordance with the position of the line.

2. A system according to claim 1 which further includes transformation means for transforming the line into the computational space, the processing means being arranged to modify the three dimensional model in accordance with the transformed position of the line.

3. A system according to claim 1 in which the processing means is arranged to determine the position on a two-dimensional surface of an intersection of the surface with the line, and modify the three-dimensional model in accordance with the position of the intersection.

4. A system according to claim 1, claim 2 or claim 3 in which the observation means include at least two cameras for forming a visual image of the tool or tools.

5. A system according to any preceding claim in which the observation means include at least three fixed ultrasonic sensing devices, the tool or tools including at least two ultrasonic transducers.
6. A system according to any preceding claim in which the tool or tools
5 include a pointing device having a longitudinal axis which defines the line in the user space.
7. A system according to claim 6 in which the pointing device includes an optical or mechanical encoder to detect rotation of the pointing device about the longitudinal axis and thereby obtain additional information, the processing
10 means making use of the additional information to modify the three-dimensional model.
8. A system according to claim 6 or claim 7 in which the pointing device includes one or more data input devices operable by the user to input additional information, the processing means making use of the additional
15 information to modify the three-dimensional model.
9. A system according to claim 7 or claim 8 in which the pointing device includes wireless transmission means for transmitting the additional information to reception means in communication with the processing means.
10. A system according to any preceding claim in which there are two tools
20 independently movable by the user in the user space.
11. A system according to any preceding claim in which the computer space does not coincide with the user space.
12. A method of inputting data to a computer system which includes processing means defining a three-dimensional model in a three-dimensional
25 computational space having a mapping to a three-dimensional user space, the method including:

manipulating one or more tools in the user space, the positioning of the tool or tools defining a line in the user space;

using fixed observation means to measure the positioning of the tool or tools, to determine the position of the line in the user space; and

5 modifying the three-dimensional model in accordance with the determined position of the line.

13. A method according to claim 12 in which the modification includes transforming the line into the computation space and determining the modifying the model based on the position of the transformed line.

10 14. A method according to claim 12 further including determining the position on a two-dimensional surface of an intersection of the surface with the line, said modification being performed using the position of this intersection.

15 15. A method according to claim 12, claim 13 or claim 14 in which the positioning of the tool or tools is measured using fixed optical cameras.

16. A method according to claim 12, claim 13 or claim 14 in which the positioning of the tool or tools is measured using at least three fixed ultrasonic sensing devices, the tool or tools including at least two ultrasonic transducers.

20 17. A method according to any of claims 12 to 16 in which the tool or tools include a pointing device having a longitudinal axis which defines the line in the user space.

18. A method according to claim 17 in which the pointing device includes an optical or mechanical encoder to detect rotation of the pointing device about the longitudinal axis and thereby obtain additional information, the

modification making use of the additional information to modify the three-dimensional model.

19. A method according to claim 17 or claim 18 which further includes the user operating one or more data input devices located on the pointing device
5 to input additional information which is used in the modification of the three-dimensional model.

20. A method according to claim 18 or claim 19 in which the pointing device transmits the additional information as a wireless signal.

21. A method according to any of claims 12 to 20 in which the user moves
10 two tools independently, the positions of the two tools together determining the position of the line.

22. A method according to any of claims 12 to 21 in which the computer space does not coincide with the user space.

23. A method according to any of claims 12 to 22 including an initial step of
15 calibrating the computer space with an image space of the display device and/or with the user space.