Title: METHOD AND DEVICE FOR DETERMINING THE POSITION IN THREE-DIMENSIONAL SPACE OF ONE OR MORE COMPUTER POINTING DEVICES

Abstract: Disclosed is a method designed to determine the position in three-dimensional space of one or more computer pointing devices, for example pen-shaped pointing devices, and to send information relating to the spatial coordinates thereof to a user apparatus such as a computer, and a device for implementing the said method.
METHOD AND DEVICE FOR DETERMINING THE POSITION IN THREE-DIMENSIONAL SPACE OF ONE OR MORE COMPUTER POINTING DEVICES

This invention relates to a method designed to determine the position in three-dimensional space of one or more computer pointing devices, for example pen-shaped pointing devices, and to send information relating to the spatial coordinates thereof to a user apparatus such as a computer, and a device for implementing the said method.

The said device can be advantageously used in computer applications which require three-dimensional data, as in the case of three-dimensional graphics for civil, cinematographic, artistic or sound use.

At present, the spatial position of a computer pointing device can only be detected with complicated use of two-dimensional sensors, such as a graphic tablet or a mouse, using a system that is not immediate and above all not user-friendly.

Consequently, certain three-dimensional software applications which would be very popular with users have not been developed.

The method in accordance with the invention and the device for implementation of the said method solve the problem of rapid detection of the position of a computer pointing device in accordance with a simple, intuitive procedure.

This paves the way for a series of major new applications which have never been developed before, such as moving graphic objects closer and further away on screen and their spatial positioning and rotation with a few gestures, real-time programming of three-dimensional events, drawings in air, three-dimensional video-sculpture, etc.

The spatial position of the pointing device is determined by simple
trigonometric calculations when the distance between the said pointing device and a plurality of points of known position has been determined, the number of the said points being equal to or greater than three.

The distance between the said pointing device and the said points of known position is determined by measuring the time taken by a sound signal to cross the space between the said pointing device and each of the said points of known position.

In practice, the said pointing device emits an electromagnetic signal and a sound signal simultaneously. As the time taken by the electromagnetic signal to reach a sensor of the device is negligible, the delays with which the sound signal reaches the various points of known position will be the times taken by the said signal to reach each of the said points.

The propagation speed of sound waves in air being known, the distance between the said pointing device and the said points of known position is determined by applying kinematic formulae.

Once the said distances are known, the position of the pointing device in relation to the said sensors is determined with geometrical formulae.

The method of detecting the position of the pointing device in accordance with the invention and the corresponding device are described below, by way of example but not of limitation, in accordance with a preferred embodiment, by reference to the annexed figures, wherein:

- figure 1 (a, b) shows the geometrical diagram for calculation of the position of the pointing device
- figure 2 shows the block diagram of the entire device
- figure 3 shows the block diagram of the control unit

In fig. 1, nos. (2), (3), (4) and (5) indicate the positions of four ultrasound sensors, while no. (20) indicates the position of a computer pointing device.
In accordance with a preferred embodiment described herein, the said sensors are four in number, located at the vertices of a square; however, the number of the said sensors could be any number equal to or greater than three, and they may be located in any position in space, provided that the position of the said pointing devices is known.

In accordance with the said preferred embodiment, the said sensors and the said pointing device are positioned at the vertices of a pyramid with a square base, the said base being identified by the four sensors and the vertex being identified by the pointing device. The orthogonal projection of the said vertex on the base may fall inside (fig. 1a) or outside (fig. 1b) the said base.

The lengths of the sides of the base of the said pyramid are known. The lengths of the other sides, namely those which join the pointing device to the sensors, will be determined by the device in accordance with the invention.

If two sides of the base of the pyramid are made to coincide with the x and y axes of an orthogonal Cartesian reference system (for example with the x axis coinciding with side 2-5 and the y axis with side 4-5), coordinates X, Y and Z of pointing device (20) can be determined using the formulae set out below.

Once the sides are known, the area of the triangle is given by Heron’s formula, p being the semi-perimeter and a, b being the sides of the triangle:

F1) \[ A = \sqrt{p(p-A)(p-B)(p-C)} \]

or if the base and height of the triangle are known, b being the base and h the height:

F2) \[ A = \frac{bh}{2} \]

Calculation of the value of X

In the calculation pyramid it will be seen that the x axis is part of triangle AVB. As the three sides are known, the area of the triangle can be
calculated with Heron’s formula 1, and the height of triangle AVB (h1) can be calculated with formula 2, by dividing twice the area by the base side, namely AB:

\[ P_1 \text{ (semi-perimeter of AVB)} = \frac{AB + AV + VB}{2} \]

Area of AVB = \[\sqrt{P_1(P_1 - AB)(P_1 - AV)(P_1 - VB)}\]

\[ H_1 = \frac{\text{AreaAVB}}{AB} \]

As will be seen from the calculation pyramid (Table 1), value x sought is simply one of two catheti of a right-angled triangle whose hypotenuse is side AB, and whose other cathetus is the height of triangle AVB, both of which are known. To calculate x, it is therefore sufficient to apply Pythagoras’ theorem:

\[ x = \sqrt{AV^2 - h_1^2} \]

Calculation of value of Y

In the calculation pyramid, it will be seen that the y axis is part of triangle BVC. As the three sides are known, the area of the triangle can be calculated with Heron’s formula 1, and the height of triangle BVC (h2) with formula 2, by dividing twice the area by the base side, namely BC:

\[ P_2 \text{ (semi-perimeter of BVC)} = \frac{BC + BV + VC}{2} \]

Area of BVC = \[\sqrt{P_2(P_2 - BC)(P_2 - BV)(P_2 - VC)}\]

\[ H_2 = \frac{\text{AreaBVC}}{BC} \]

As will be seen from the calculation pyramid (Table 1), value y sought is simply one of two catheti of a right-angled triangle whose hypotenuse is side BV, and whose other cathetus is the height of triangle BVC, both of which are known. To calculate y, it is therefore sufficient to apply Pythagoras’ theorem:
\[ Y = \sqrt{BV^2 - h_2^2} \]

Calculation of value of Z

In the calculation pyramid it will be seen that the z axis is the height of triangle A'V'B', perpendicular to the bases of calculation pyramid ABCD (because the angle in B' with B and V is a right angle), formed by base side A'B' with the same value as side AB, and by two sides which are also the heights of the two triangles BVC and AVD. One (h2) is already known; to calculate the other height (h3) it is necessary to resolve triangle AVD, as follows:

\[ P3 \text{ (semi-perimeter of AVD)} = \frac{AV + AD + VD}{2} \]

Area of AVD = \[ \sqrt{P3(P3-AD)(P3-VD)} \]

\[ H3 = \frac{Area_{AVD}^2}{AD} \]

To calculate the height of triangle A'VB' (h4) and therefore the value of z we must first calculate the area of triangle A'VB' with formula 1:

\[ P4 \text{ (semi-perimeter of A' V B')} = \frac{A'B' + h_2 + h_3}{2} \]

Area of A'V B' = \[ \sqrt{P4(P4-h_2)(P4-h_3)(P4-A'B')} \]

and then divide twice the resulting area by the base of the triangle, namely A'B', hence:

\[ Z = h_4 = \frac{Area_{A'VB}^{'}}{A'B'} \]

As shown in fig. 2, the device in accordance with the invention comprises:

- a computer pointing device (20) whose spatial position is to be determined, which said pointing device is designed to capture a signal emitted by a radio modulator (7) and consequently generate an electromagnetic signal, for example an infrared ray signal, and a sound signal, for example an
ultrasound signal

- a timing, receiving, calculation and data transmission unit (1) designed to control the entire process of detecting the position of the said pointing device (20) in accordance with the procedures specified below, and to send the results of the said detection to a user, for example a computer

- sound sensors (2), (3), (4) and (5), for example ultrasound sensors, designed to receive ultrasound signals emitted by the said pointing device (20) and to generate an electrical signal as a result

- an electromagnetic radiation sensor (6), for example an infrared ray sensor, designed to receive infrared ray signals emitted by the said pointing device (20) and to generate an electrical signal as a result

- a radio modulator (7) designed to emit a radio frequency signal

the said sound sensors being connected to the said control unit with wiring (8), (9), (10) and (11), the said infrared sensor being connected to the said unit with wiring (12), the said radio modulator being connected to the said unit with wiring (13), and the said control unit (1) being equipped with a serial output (14) and a parallel output (15).

As shown in fig. 3, the said unit (1) comprises:

- an amplifier/detector (6a) designed to receive an electrical signal originating from infrared sensor (6) via the said wiring (12), and amplify it

- four amplifier/detectors (2a), (3a), (4a) and (5a) designed to receive electrical signals originating from the corresponding ultrasound sensors (2), (3), (4) and (5) via the corresponding wiring (8), (9), (10) and (11), and amplify them

- four flip-flop circuits (2b), (3b), (4b) and (5b) designed to drive electronic counters (2c), (3c), (4c) and (5c) on the basis of the signals originating from the infrared and ultrasound sensors, the said flip-flop circuits being connected with their “set” terminal to amplifier (6a) via wiring (12),
with their "clear" terminal to amplifiers (2a), (3a), (4a) and (5a) via the corresponding wiring (8a), (9a), (10a) and (11a), and with their output terminal to the corresponding electronic counters (2c), (3c), (4c) and (5c) via the corresponding wiring (8b), (9b) (10b) and (11b)

- four electronic counters (2c), (3c), (4c) and (5c) with a high clock frequency designed to count the pulses generated by the said clock in the time interval between the moment at which the infrared pulse emitted by pointing device (20) reaches infrared sensor (6) and the moment at which the ultrasound pulse emitted by pointing device (20) simultaneously with the electromagnetic pulse reaches the corresponding ultrasound sensor (2), (3), (4) or (5), the said counters being connected via the corresponding wiring (8b), (9b), (10b) and (11b) to the corresponding flip-flop circuits (2b), (3b), (4b) and (5b) by which the said counters are driven

- a microprocessor (17) designed (i) to drive an encoded electrical signal which allows modulator (7) to generate a corresponding radio frequency signal, the said microprocessor being connected to the said radio modulator (7) via wiring (13), (ii) to receive the counts from electronic counters (2c), (3c), (4c) and (5c) via the corresponding wiring (8d), (9d), (10d) and (11d) and process them, applying the calculation method in accordance with the invention described below, and (iii) to supply the results of the processing to a user via outputs (14) and (15), the said user being driven by a sequencer circuit (16)

- a sequencer circuit (16) designed to enable the said microprocessor (17) (i) to obtain the data originating from the electronic counters on the basis of timing conforming to the method in accordance with the invention, the said sequencer circuit being connected with its "calculation output" terminal to the said microprocessor (17), and (ii) to prepare the counters for a subsequent count, the said sequencer circuit being connected with its "reset" output
terminal to the "reset" terminals of the said electronic counters (2c), (3c), (4c) and (5c), and being driven in turn by infrared sensor (6) to which it is connected with its "input" terminal via wiring 12a and amplifier/detector (6a).

The device in accordance with the invention is able to detect the position of pointing device (20) and follow its movements by means of successive position detections performed by cyclic repetitions of the procedure described below.

The entire process is controlled by sequencer circuit (16), which subsequently enables the components of the control unit.

In practice, the detection cycle is initiated by sequencer (16), which enables microprocessor (17) to generate an encoded signal that is transmitted to pointing device (20) by radio modulator (7). The said encoded signal is recognised by the pointing device, which in response emits an infrared ray signal and an ultrasound signal. The infrared ray pulse emitted by pointing device (20) and transformed into an electrical signal by sensor (6) reaches amplifier (6a) of control unit (1) via wiring (13).

The ultrasound pulse emitted by pointing device (20) reaches ultrasound sensors (2), (3), (4) and (5) at different times, depending on the distance between pointing device (20) and each of the said ultrasound sensors, each of which generates an electrical signal and sends it, via the corresponding wiring (8, 9), (10) or (11), to the corresponding amplifier (2a), (3a), 4a or (5a) of control unit (1).

In accordance with the procedure described, the said electrical signals emitted by each of the ultrasound sensors (2), (3), (4) and (5) reach the corresponding amplifier (2a), (3a), (4a) or (5a) with a delay compared with the electrical signal sent by infrared sensor (6) to the corresponding amplifier (6a).
The said delays will be measured in accordance with the procedure described below, and will be processed to determine the position of pointing device (20) in relation to ultrasound sensors (2), (3), (4) and (5) by applying the calculation procedure in accordance with the invention.

As shown in fig. 3, the device in accordance with the invention then measures the said delay by applying the following procedure:

- the electrical signal which originates from the infrared sensors and reaches amplifier (6a) sets the four flip-flop circuits (2b), (3b), 4(b) and (5b), which in turn enable the four digital counters (2c), (3c), (4c) and (5c).

- the electrical signals which originate from the ultrasound sensors and reach the corresponding amplifiers (2a), (3a), (4a) and (5a), each with a delay compared with the electrical signal originating from the infrared sensor (6), are sent, with the same delay, to the corresponding flip-flop circuits (2b), (3b), (4b) and (5b), which stop the count performed by digital counters (2c), (3c), (4c) and (5c).

The counts performed by digital counters (2c), (3c), (4c) and (5c) are based on the time delay with which the ultrasound signal emitted by pointing device (20) reaches each of sensors (2), (3), (4) and (5).

The electrical signal originating from the infrared ray sensor also reaches sequencer circuit (16) via wiring (12a), and the sequencer circuit, thus activated, generates two pulses after a pre-set time interval:

- a calculation pulse, which orders the microprocessor to fetch data from the counters and perform calculations to determine the position of pointing device (20) and send the related information to outputs (14) and (15);

- a reset pulse, which is sent to the counters to prepare them for the subsequent count.

The said pre-set time interval is longer than the longest delay with which the ultrasound pulse emitted by the pointing device reaches ultrasound
sensors (2), (3), (4) and (5), with the result that microprocessor (1) fetches the data from the electronic counters after they have finished the count.

Immediately thereafter, the sequencer generates a second reset pulse which clears the counters and prepares them for a new reading cycle.

When a detection cycle has been completed, the control unit initiates a new cycle to determine the new position (if any) of the pointing device.

The device described herein is able to detect the position of a number of pointing devices simultaneously. In this case, each pointing device will be designed to detect an encoded signal originating from radio modulator (7) so as to respond by emitting infrared ray and ultrasound pulses if and only if the said encoded signal corresponds to a pre-set pattern.

In the case of the simultaneous presence of a number of pointing devices, the detection procedure involves sequentially activating detection cycles for each pointing device.

In order to prevent cancellation of the signal due to waves in antiphase during reception, the ultrasounds will be generated in bursts: a short pulse repeated at a high frequency chosen in such a way as to eliminate the risk of overlap of the direct wave with the residual environmental reflections produced by the preceding pulse.
CLAIMS

1. Method for determining the position in three-dimensional space of one or more computer pointing devices, characterised in that it includes the following stages:
   - emission by the pointing device of the electromagnetic signal and a simultaneous sound signal
   - detection of the said electromagnetic and sound signals by a plurality of detectors arranged on a plane
   - calculation by each detector of the delay with which the sound signal is received, compared with the electromagnetic signal
   - determination of the spatial position of the pointing device on the basis of the said detected delays.

2. Method as claimed in claim 1, wherein the said electromagnetic signals are light signals, in particular infrared ray signals, and the said sound signals are ultrasound signals.

3. Method as claimed in claim 1, wherein the said electromagnetic signals are radio frequency signals and the said sound signals are ultrasound signals.

4. Method as claimed in each of the preceding claims, wherein the said detectors are installed at the vertices of the base of a pyramid at the upper vertex of which the pointing device is located.

5. Method as claimed in each of the preceding claims, wherein the said operations are repeated cyclically to trace the movements of the said pointing device.

6. Method as claimed in each of the preceding claims, wherein an encoded signal is generated and transmitted to the pointing device via radio frequency devices, and the said code is recognised by the pointing device which emits an electromagnetic wave signal and a sound signal in response.
7. Method as claimed in each of the preceding claims, wherein a time interval longer than the greatest of the delays with which the sound pulse emitted by the pointing device reaches the sensors elapses between one stage
of generation of signals by the pointing device and detection thereof by the
sensors and the subsequent stage.

8. Method as claimed in the preceding claim, wherein the ultrasounds are
generated at repeated high-frequency pulses selected in such a way as to
eliminate the risk of overlap of the direct wave with residual environmental
reflections produced by the preceding pulse.

9. Apparatus for determining the position in three-dimensional space of
one or more computer pointing devices, characterised in that it includes:
   • at least one computer pointing device designed to generate an
electromagnetic signal and a sound signal simultaneously
   • a plurality of sensors designed to detect the said electromagnetic signals
and consequently generate electrical signals
   • a plurality of sensors designed to detect the said sound signals and
consequently generate an electrical signal
   • means designed to calculate the delay with which the said signals are
received by the corresponding sensors and consequently determine the spatial
position of the pointing device.

10. Apparatus as claimed in claim 9, characterised in that it also includes a
radio modulator designed to emit a radio frequency signal, the said computer
pointing device being equipped with means designed to capture the said
signal and control the consequent generation of the said electromagnetic and
sound signals.

11. Apparatus as claimed in claim 10, characterised in that it includes a
timing, receiving, calculation and data transmission unit to control the
computer pointing device position detection process, which said control unit
comprises:
- an amplifier designed to receive an electrical signal originating from the said electromagnetic signal sensors
- a plurality of amplifiers designed to receive electrical signals originating from sound sensors
- a set of flip-flop circuits designed to drive counters on the basis of signals originating from the said electromagnetic and sound signal sensors
- a plurality of electronic counters designed to count the pulses generated by a clock in the interval between the moment at which the electromagnetic signal is detected and the moment at which the sound signal is detected.

12. Apparatus as claimed in the preceding claim, characterised in that it also includes means designed to generate an encoded radio frequency signal and a sequencer circuit designed to enable data to be fetched cyclically for processing.

13. Method and device for determining the position in three-dimensional space of one or more computer pointing devices, as described and illustrated.