University of Kentucky
UKnowledge

6-13-2017

2D and 3D Pointing Device Based on a Passive Lights Detection Operation Method Using One Camera

Fuhua Cheng

University of Kentucky, cheng@cs.uky.edu

Right click to open a feedback form in a new tab to let us know how this document benefits you.

Follow this and additional works at: https://uknowledge.uky.edu/cs_patents

Part of the Computer Sciences Commons

Recommended Citation

(12) **United States Patent**
    Cheng

(10) **Patent No.:** **US 9,678,583 B2**
(45) **Date of Patent:** **Jun. 13, 2017**

(54) **2D AND 3D POINTING DEVICE BASED ON A PASSIVE LIGHTS DETECTION OPERATION METHOD USING ONE CAMERA**

(71) Applicant: **University of Kentucky Research Foundation**, Lexington, KY (US)

(72) Inventor: **Fuhua Cheng**, Lexington, KY (US)

(73) Assignee: **UNIVERSITY OF KENTUCKY RESEARCH FOUNDATION**, Lexington, KY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/339,090**

(22) Filed: **Jul. 23, 2014**

(65) **Prior Publication Data**

US 2015/0029100 A1   Jan. 29, 2015

Related U.S. Application Data

(60) Provisional application No. 61/857,290, filed on Jul. 23, 2013.

(51) **Int. Cl.**
    G06F 3/033   (2013.01)
    G06F 3/0354   (2013.01)
            (Continued)

(52) **U.S. Cl.**
    CPC *G06F 3/03543* (2013.01); *G06F 3/0325* (2013.01); *G06F 3/0346* (2013.01)

(58) **Field of Classification Search**
    CPC G06F 3/03; G06F 3/0304; G06F 3/0308; G06F 3/0325; G06F 3/033; G06F 3/0354; G06F 3/03543
            (Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,297,061 A	*	3/1994	Dementhon	.... G06F 3/0346
				345/156
5,532,777 A		7/1996	Zanen	

(Continued)

FOREIGN PATENT DOCUMENTS

EP	2226707 B1	1/2013	
GB	2388418 A	* 11/2003	.... G06F 3/0325

OTHER PUBLICATIONS

Pranav Mistry; Mouseless, the 'invisible' computer mouse (w/Video); Phys.org; Jul. 8, 2010; 2 pages; http://phys.org/news197792915.html.

(Continued)

Primary Examiner — Jason Mandeville
(74) *Attorney, Agent, or Firm* — King & Schickli, PLLC

(57)   **ABSTRACT**

Systems for surface-free pointing and/or command input include a computing device operably linked to an imaging device. The imaging device can be any suitable video recording device including a conventional webcam. At least one pointing/input device is provided including first, second, and third sets of actuable light sources, wherein at least the first and second sets emit differently colored light. The imaging device captures one or more sequential image frames each including a view of a scene including the activated light sources. One or more computer program products calculate a two-dimensional or three-dimensional position and/or a motion and/or an orientation of the pointing/input device in the captured image frames by identifying a two-dimensional or three-dimensional position of the activated light sources of the first, second, and/or third sets of light sources. Certain activation patterns of light sources are mapped to particular pointing and/or input commands.

17 Claims, 11 Drawing Sheets
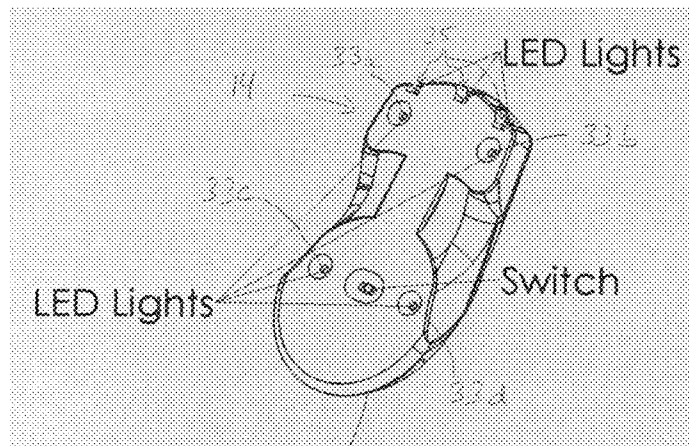
(51) **Int. Cl.**
    G06F 3/03   (2006.01)
    G06F 3/0346   (2013.01)

(58) **Field of Classification Search**
    USPC 345/156, 157, 158, 163–166
    See application file for complete search history.

(56)   **References Cited**

U.S. PATENT DOCUMENTS

5,581,276 A *	12/1996	Cipolla	G06F 3/017
			345/156
5,909,209 A	6/1999	Dickinson	
6,057,540 A	5/2000	Gordon et al.	
6,525,306 B1	2/2003	Bohn	
6,603,865 B1 *	8/2003	Yagi	G06T 7/70
			382/103
6,643,396 B1	11/2003	Hendriks et al.	
7,274,800 B2	9/2007	Nefian et al.	
7,849,421 B2	12/2010	Yoo et al.	
8,062,126 B2 *	11/2011	Marks	G06F 3/017
			382/103
8,224,024 B2 *	7/2012	Foxlin	G06T 7/73
			348/135
8,269,721 B2	9/2012	Lin	
8,686,939 B2 *	4/2014	Mao	A63F 13/06
			345/156
9,201,519 B2 *	12/2015	Cheng	G06F 3/0325
9,507,437 B2 *	11/2016	Cheng	G06F 3/0346
2004/0063480 A1 *	4/2004	Wang	A63F 13/02
			463/8
2007/0080940 A1 *	4/2007	Aoki	G06F 3/0304
			345/158
2007/0081695 A1 *	4/2007	Foxlin	G06T 7/73
			382/103
2007/0117625 A1 *	5/2007	Marks	G06F 3/017
			463/30
2008/0001951 A1 *	1/2008	Marks	A63F 13/06
			345/474
2008/0100825 A1 *	5/2008	Zalewski	A63F 13/06
			356/29
2009/0174657 A1 *	7/2009	Miyazaki	G06F 3/01
			345/158
2009/0315825 A1	12/2009	Cauchi	
2010/0017115 A1	1/2010	Gautama	
2010/0105475 A1 *	4/2010	Mikhailov	A63F 13/06
			463/33
2011/0169734 A1	7/2011	Cho et al.	
2011/0310230 A1	12/2011	Cheng	
2014/0359536 A1 *	12/2014	Cheng	G06F 1/169
			715/848
2015/0022449 A1 *	1/2015	Cheng	G06F 3/0346
			345/163
2015/0049021 A1 *	2/2015	Cheng	G06F 3/03543
			345/163

OTHER PUBLICATIONS

Pranav Mistry and Pattie Maes; "Mouseless"; MIT Media Laboratory, Oct. 2010, pp. 441-442.

"Mouse (computing)"; Wikipedia; Sep. 25, 2013; 8 pages; http://en.wikipedia.org/wiki/Mouse_(computing).

Freanz Madritsch; "CCD-Camera Based Optical Tracking for Human-Computer Interaction"; Proceedings 1st European Conference on Disability, Virtual Reality and Associated Technologies, Maidenhead; pp. 161-170 (1996).

Richard Hartley, et al.; "Triangulation"; Computer Vision and Image Understanding, vol. 68, No. 2, pp. 146-157 (1997); Article No. IV970547.

Philips; "uWand technology"; How uWand Works—Intuitive3 Remotes for SmartTV; 1 page printed on Sep. 16, 2014; http://www.uwand.com/how-uwand-works.html.

Wii from Wikipedia; 33 pages printed on Sep. 16, 2014; http://en.wikipedia.org/wiki/Wii.

U.S. Appl. No. 14/089,881, filed Nov. 26, 2013 entitled Algorithms, Software and an Interaction System That Support the Operation of an on the Fly Mouse.
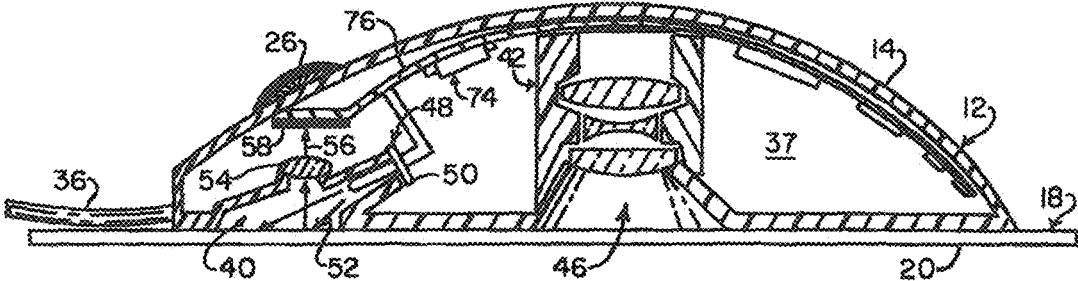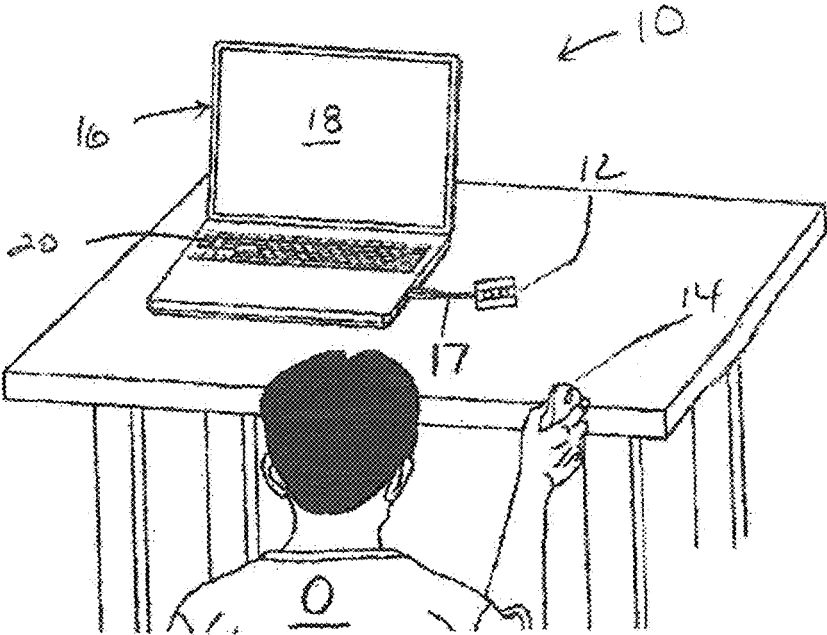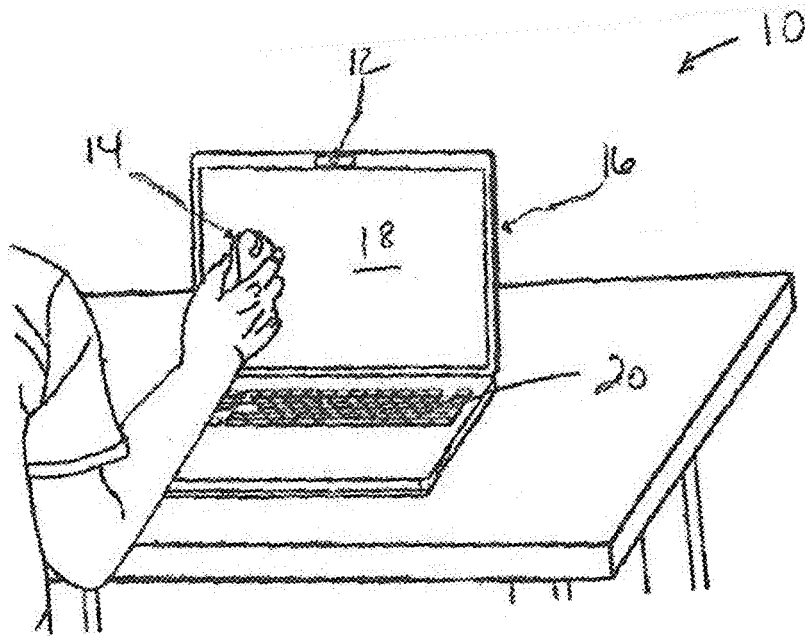
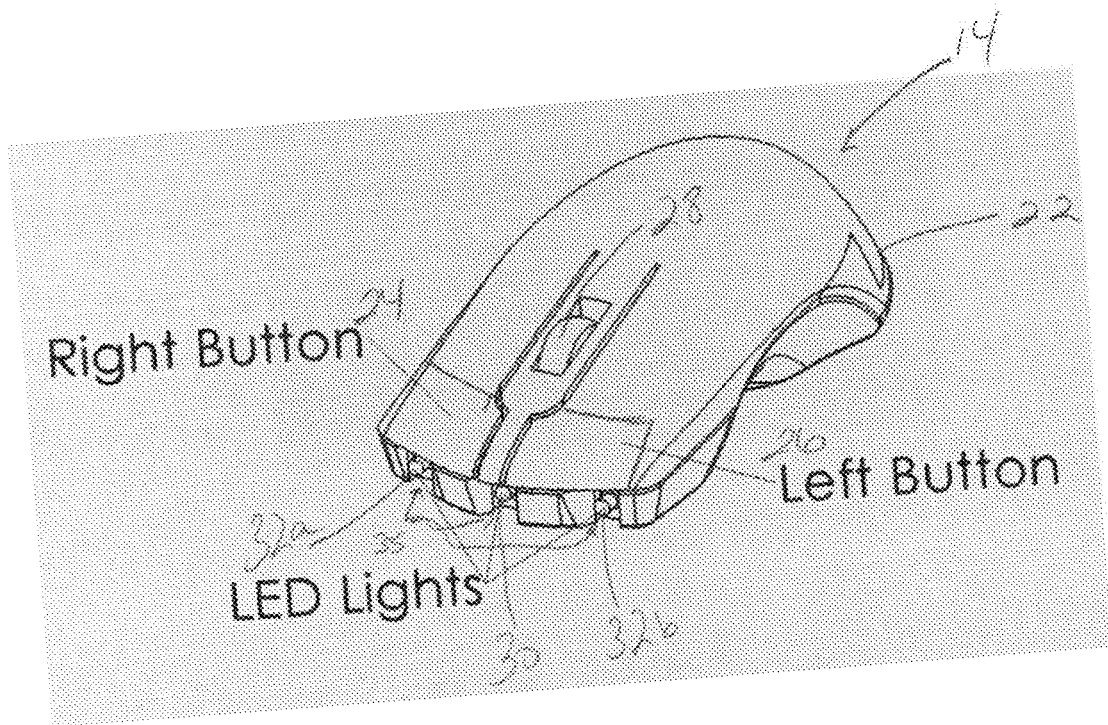* cited by examiner

Fig. 1
(Prior Art)

Fig. 2

Fig. 3

Right Button

LED Lights

Left Button
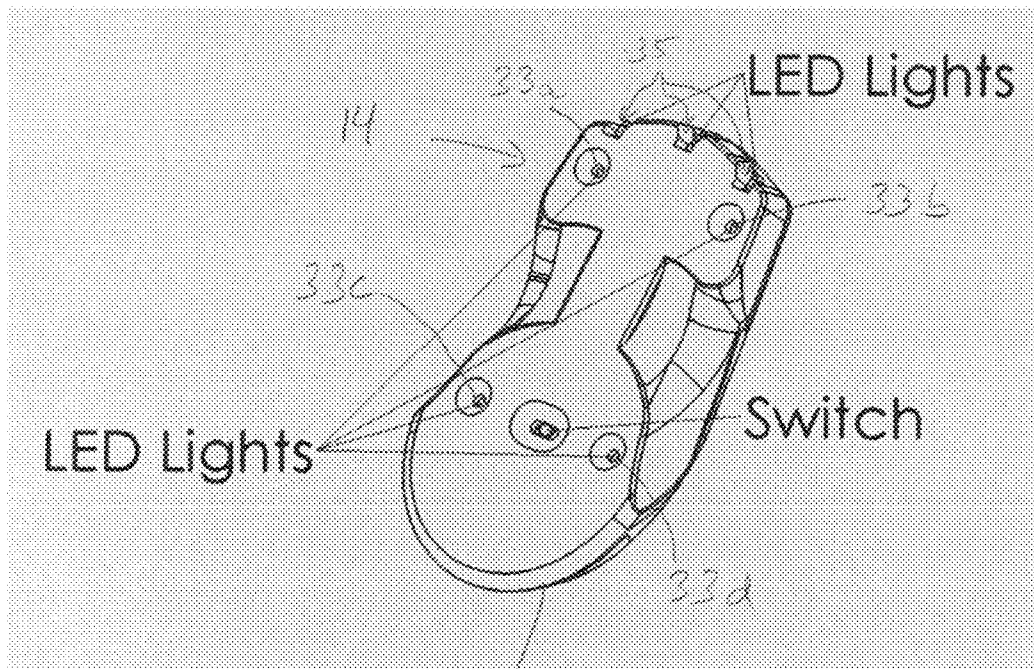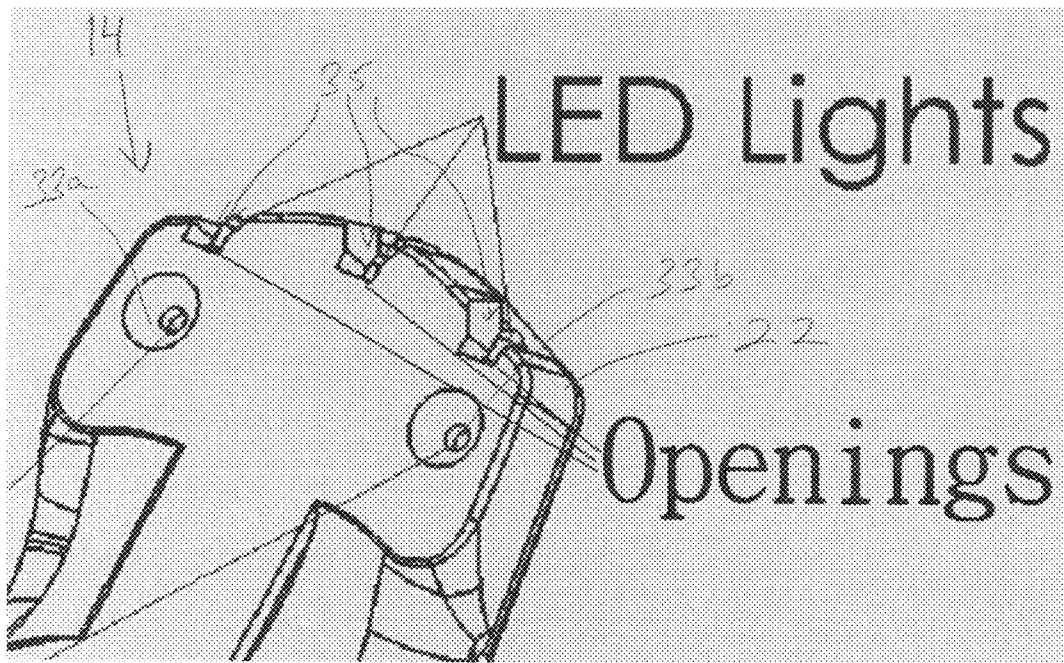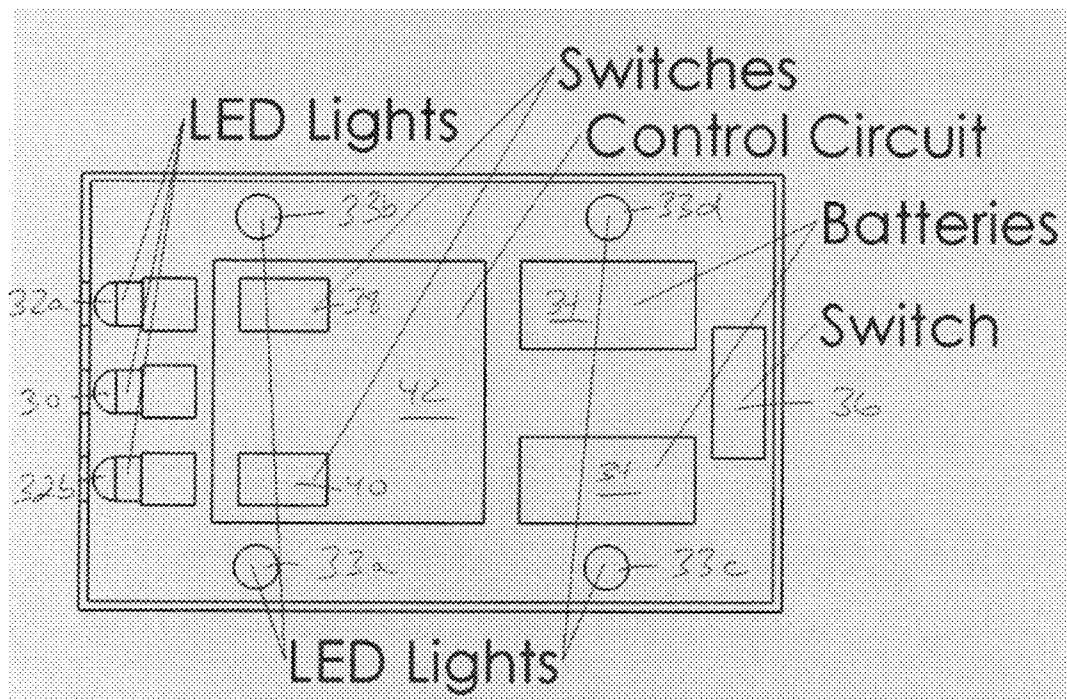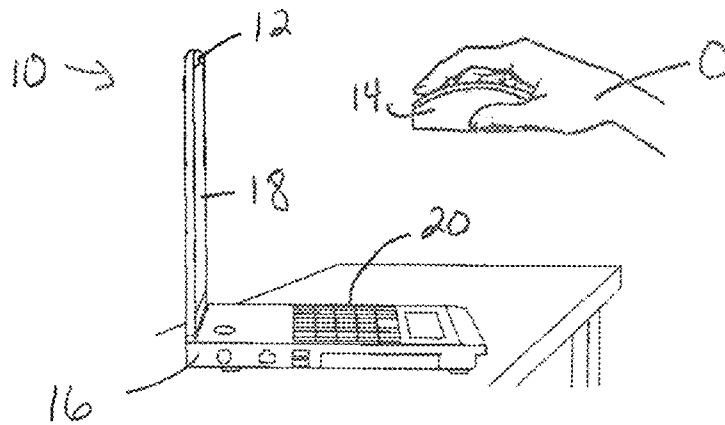
Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8
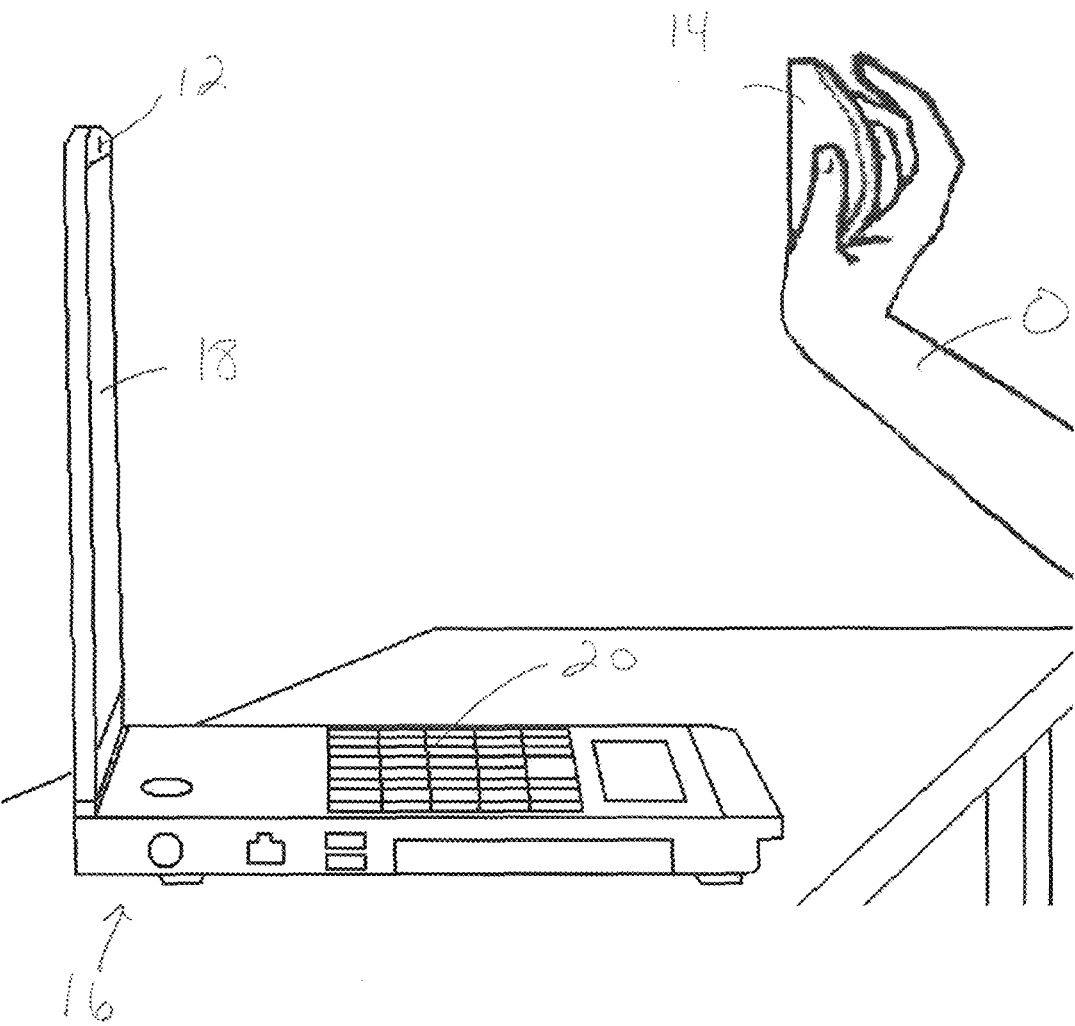
Fig. 9

Fig. 10

Fig. 11

$\overline{V1}=(x1, y1)$

$\overline{V2}=(x2, y2)$

$(a1,b1,-f)$
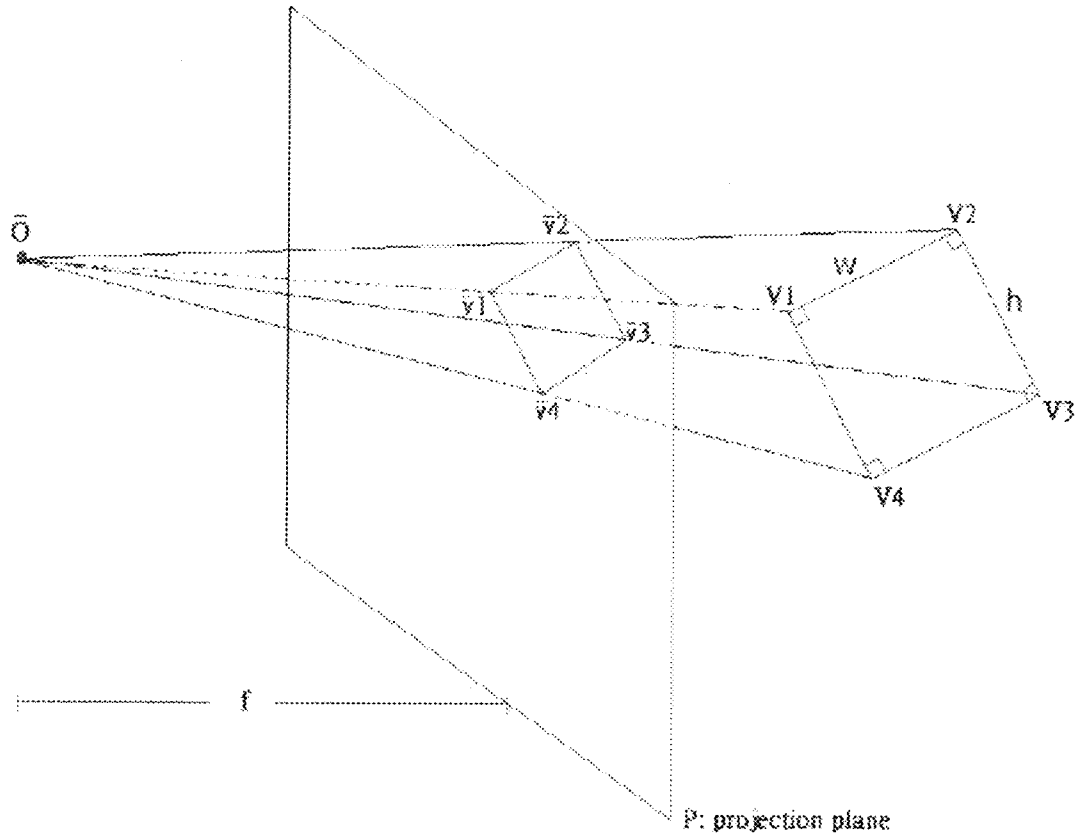
F1

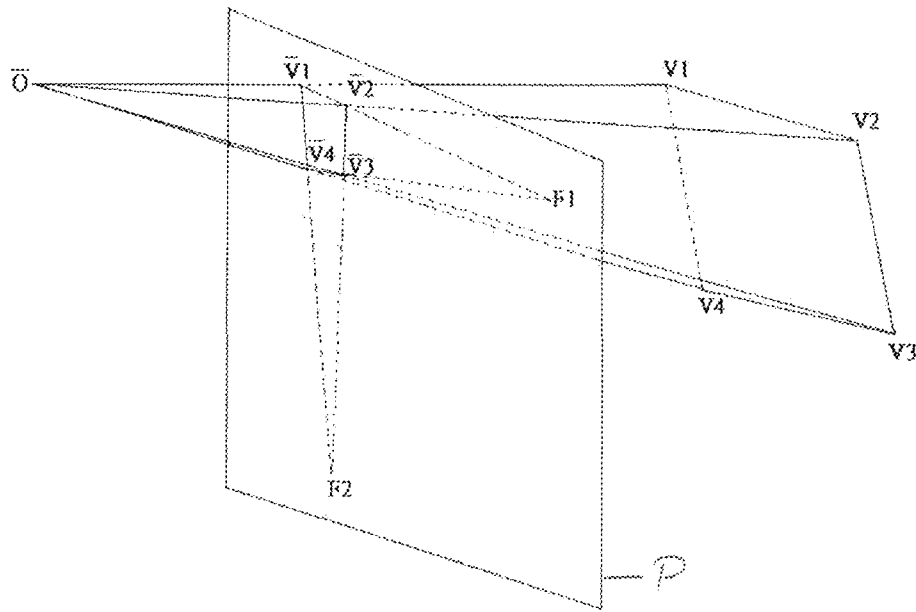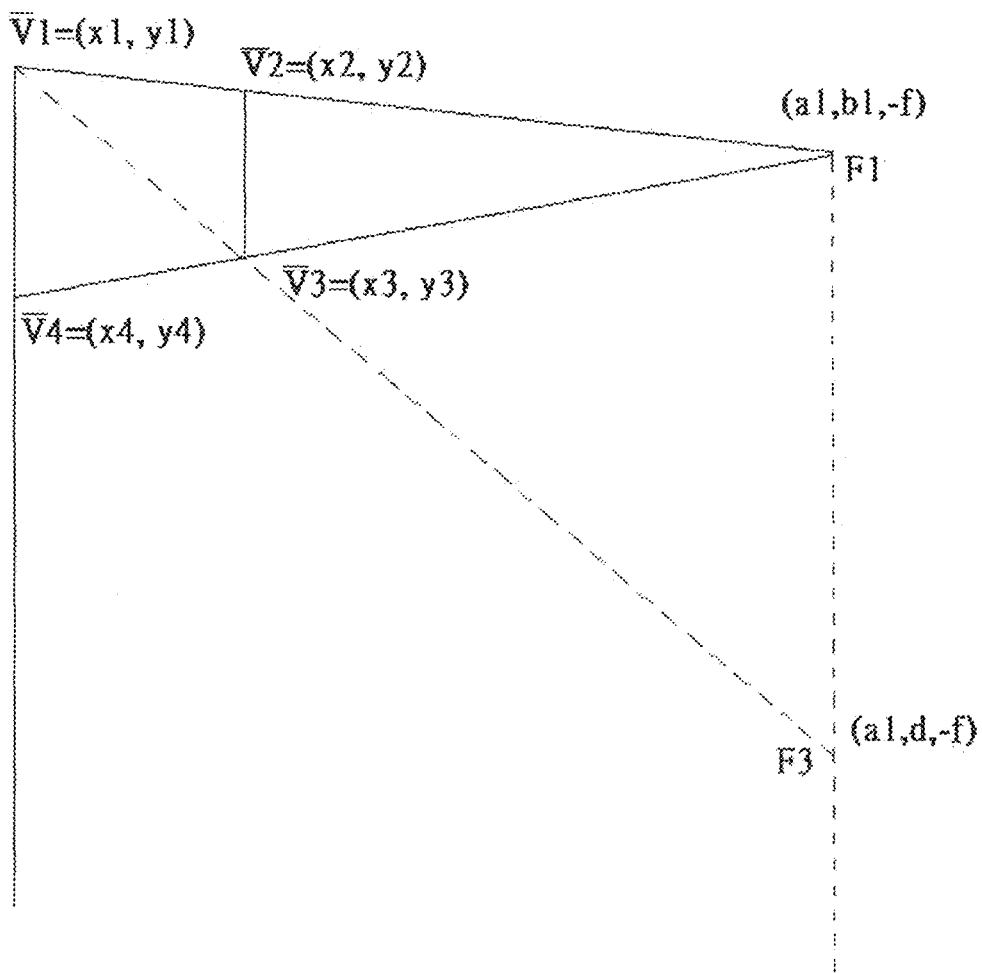$\overline{V3}=(x3, y3)$

$\overline{V4}=(x4, y4)$

$(a1,d,-f)$

F3

Fig. 12

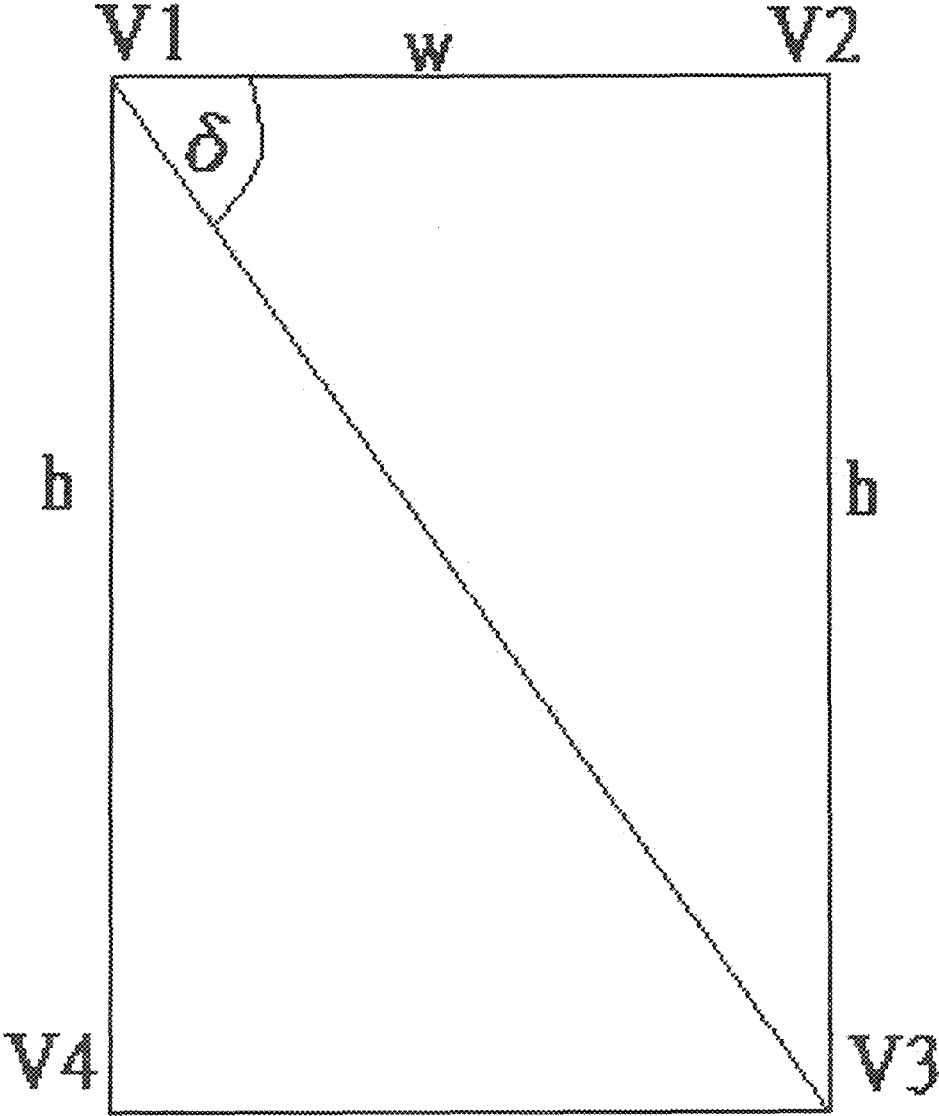Fig. 13

2D AND 3D POINTING DEVICE BASED ON A PASSIVE LIGHTS DETECTION OPERATION METHOD USING ONE CAMERA

This utility patent application claims the benefit of priority in U.S. Provisional Patent Application Ser. No. 61/857,290 filed on Jul. 23, 2013, the entirety of the disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to human-computer interaction systems. More specifically, this disclosure pertains to methods and systems for use of a conventional video recorder such as a webcam for two-dimensional (2D) and three-dimensional (3D) pointing and command inputs in a computing system relying on passive light detection for both 2D and 3D modes. Embodiments of a pointing/input device for use in the methods and systems are disclosed.

BACKGROUND OF THE INVENTION

The operation of a conventional mechanical or optical pointing or input device such as a mechanical or optical computer mouse is well known in the art. By use of these devices, a user can select files, programs, or actions from lists, groups of icons, etc., and can "gesturally" move files, programs, etc. issue commands or map to specific actions, for example in drawing programs.

As examples, a mechanical computer mouse relies on one or more wheels and/or balls to track movement or displacement information relative to forward-backward and left-to-right movement of the computer mouse, for example by interrupting infrared beams of light directed at light sensors to create pulses representative of wheel or ball movement. Simple logic circuits interpret the relative timing of the pulses to indicate which direction the wheel(s) or ball(s) is moving, which is then converted by driver software into motion of a visual indicator such as a pointer, cursor, or cross-hair along X and Y axes of a computing device display screen.

An optical computer mouse replaces the mechanical mouse wheels or balls with one or more visible or invisible light sources such as light-emitting diodes (LEDs), laser diodes, infra-red light, etc. to detect movement of the mouse relative to an underlying surface such as a mouse pad. The inertial/gyroscopic computer mouse uses a tuning fork or other accelerometer to detect rotary movement for every axis supported, most commonly using 2 degrees of rotational freedom and being insensitive to spatial translation. The user need only perform small wrist rotations to move a pointer or cursor on a display screen.

Almost all modern 2D pointing devices utilize an active approach for detecting movement of the device. The underlying technology of modern surface-independent (meaning that a specific surface type is not required, although some type of surface is) 2D pointing/input devices such as optical mice (see FIG. 1) is known as digital image correlation. The mouse includes a shell or housing and a variety of input means such as left and right buttons, a scroll wheel, etc. A displacement detection LED disposed on a bottom surface of the mouse is used to detect movement of the mouse over a surface. An optical or optoelectronic mouse uses an optoelectronic sensor (essentially, a tiny low-resolution video camera) to image a naturally occurring texture of an underlying surface made of materials such as wood, cloth, mouse pad materials and Formica, using light reflected from the

surface. These surfaces, when lit at a grazing angle by the displacement detection LED, cast distinct shadows that resemble a hilly terrain lit at sunset. Images of these surfaces are captured in continuous succession as the mouse is translated over the surface, often at a speed of more than one thousand frames per second. Depending on the speed with which the mouse is moved, each image will be offset from the previous image by a fraction of a pixel or as many as several pixels. By using cross correlation to calculate how much each successive image is offset from the previous image, a displacement processor can determine the distance the mouse has moved from image data captured by the sensor. The movement of the mouse can then be translated or converted into a corresponding movement of a visible marker such as a cursor on a graphical user interface such as a computer screen.

Even though a special surface such as a mouse-pad is not needed by a modern optical mouse, operation of the mouse still requires a surface on which to rest and over which to travel. If a suitable operating surface is not available and an alternative such as a touchpad or trackball is also not available, a conventional optical mouse cannot be used. In turn, certain tasks often done with pointing/input devices such as a computer mouse are difficult to impossible to accomplish with alternative pointing/input devices such as touchpads or trackballs. For example, use of drawing programs without a computer mouse can be difficult if not impossible. Likewise, tasks such as two-dimensional (2D) or 3D sculpturing or drawing, "flying" in multi-dimensional space (for example, three-dimensional space defined by X, Y, and Z axes) such as during gaming, etc. would be difficult to accomplish using a conventional touchpad, trackball, etc. Still more, personal computers (PCs) are not merely tools for surfing the internet and sending e-mail in the modern world. Increasingly, PCs serve as digital media centers to view photos, listen to music, and watch video clips, films and TV shows. Indeed, notebook, laptop, and desktop computers are rapidly becoming accepted accessories or supplements to (and in certain situations replacing) the home entertainment center.

Likewise, the modern television is no longer just a TV, offering integrated Internet capabilities and set-top boxes that offer more advanced computing ability and connectivity than a contemporary basic TV set. The modern "smart" TV can deliver content from computers or network attached storage devices, such as photos, movies and music. These devices also provide access to Internet-based services including traditional broadcast TV channels, pre-recorded programs, video-on-demand, electronic program guides, interactive advertising, personalization, voting, games, social networking, and other multimedia applications. All of these require a remote control-like device that can provide cursor control, i.e. a pointing/input device as is known for computing devices. Unfortunately, traditional television remote controls cannot conveniently provide such functionality. As noted above, a conventional pointing/input device such as a computer mouse requires a desk or other hard surface to function.

For this reason, attempts have been made to adapt the familiar computer mouse to operate in the air or "on the fly," to avoid the need for a surface over which to translate the mouse for operation. Indeed, 3D pointing has long been a desired feature in human-computer interaction to allow tasks that are not possible with a 2D pointing device, such as 3D sculpturing or space navigating. However, 3D pointing technology has not reached a stage that is considered both reasonably affordable and manipulative.

3

For 3D pointing, it is necessary to identify the location of the pointing device with respect to a reference point in a 3D space. Unlike 2D pointing which mainly uses an active approach, 3D pointing has been attempted using both active and passive approaches. The approach taken depends on whether the pointing device includes a displacement detection system that works in 3D space. The optical displacement detection system of an optical mouse can only work on a surface due to the operating mechanism summarized above; it cannot work if suspended in 3D space.

In the active approach, typically an imager such as an IR camera is integrated into the pointing device to detect lights from an IR emitter of a console such as the console of a gaming device, and calculate spatial coordinates for the pointing device accordingly. The Wii® Remote marketed by Nintendo® falls within that category. A problem with this approach is that the pointing device spatial coordinates can only be calculated when its imager has a direct line of sight to a sensor bar associated with the gaming device console.

Another active type of 3D mouse uses a tuning fork or other accelerometer to detect rotary movement for every axis supported. Logitech® and Gyration's inertial mice (also called gyroscopic mice) fall in this category. The most common models work using 2 degrees of rotational freedom. An operator uses wrist rotations to move the cursor. The inertial mouse is insensitive to spatial translations. More recently, an inertial mouse was developed, equipped with g-sensors (pairs of accelerometers extended over a region of space) to calculate the mouse position, orientation and velocity; hence such a mouse can provide at least 9 spatial parameters for pointing purposes. However, the price of such an inertial mouse is quite high; usually 10 times more than the price of a typical optical mouse.

For pointing devices that do not include a distance measuring component, a passive approach has been evaluated requiring a separate component to measure the distance between the pointing device and, for example, a gaming device or base station, or to identify the location of the pointing device with respect to the gaming device or base station. All gesture-based pointing device approaches, such as the Kinect® device marketed by Microsoft®, belong to this latter category. In this case, the fingers or the hands of a user play the role of a pointing device and a special imaging device is required to identify the locations of the fingers or hands of the user. Three-dimensional mice such as 3Dconnexion/Logitech's® SpaceMouse® in the early 1990s and Kantek's® 3D RingMouse® in the late 1990s, also known as bats, flying mice or wands, also fall in this category. As an example, the RingMouse® was tracked by a base station through ultrasound. This approach has been found to provide insufficient resolution.

Still other attempts have been made to implement passive detection of a pointing device location by combining pointing and imaging functionalities in a single device. In one such device, a digital camera mounted into the housing of a computer mouse includes a mode selection system to switch the device between a 2D mouse function and a digital camera function (see FIG. 1). The device could not be used for 3D pointing. In another attempt, three one-dimensional imaging devices were used to track a point light source, to recognize and execute gestures input by the operator. The problem with this approach is that a holding time is required before each operation such as a click or drag can be performed.

To date, the present inventors are unaware of any attempts to use a single-lens imaging device to capture the motion and

4

clicking activities of an "on the fly" pointing device for 2D and 3D pointing in a 3D human-computer interaction system.

SUMMARY OF THE INVENTION

To solve the foregoing problems and address the identified need in the art, the present disclosure provides devices, and methods and computing systems incorporating the devices, for accomplishing two-dimensional and three-dimensional pointing/command input operations in "air mode," i.e. without requiring translating a pointing device over a surface and measuring a distance displacement thereof. In the disclosure are described such devices, methods, and systems using a passive detection method, which advantageously can be accomplished using a conventional imaging device such as a common web cam.

In one aspect, a pointing/input device for two-dimensional and three-dimensional pointing/command input is described. In one embodiment, a pointing/input device for effecting two-dimensional and three-dimensional pointing and/or command input by way of a single imaging device operatively connected to a computing device is provided. The device includes a first set of actuable light sources disposed on a first surface of the device housing. At least one light source of the first set emits a first color light. A second set of actuable light sources is disposed on the first surface of the housing, the second set emitting a second color light that is different from the first color. In an embodiment, the first color may be blue and the second color may be red. A third set of actuable light sources is disposed on a second surface of the housing. The third set of light sources emits a color light that may be the same as or different from the first or second color.

One or more actuators are provided for differently activating one or more of the light sources of the first, second, and third sets of light sources. The activated first set and second set of light sources are visible to and detectable by the imaging device when either of the first surface of the housing or the second surface of the housing are facing a field of view of the imaging device.

In another aspect, a method for two-dimensional and three-dimensional pointing/command input is described which uses passive light detection and requires only a single conventional imaging device. In an embodiment, the method comprises providing at least one pointing/input device as described above, and holding and/or moving the at least one pointing/input device within a field of view of the imaging device. The imaging device captures a plurality of sequential image frames each including a view of the at least one pointing/input device having at least one light source of the first set, the second set, and/or the third set of light sources activated to emit light.

Next, from one or more views of at least one of the first set, the second set, and/or the third set of light sources in the captured plurality of sequential image frames, a two-dimensional or a three-dimensional position and/or motion and/or orientation of the at least one pointing/input device is calculated. A visual marker can then be rendered on a graphical user interface, the visual marker corresponding to the calculated position and/or motion and/or orientation of the at least one pointing/input device. Activation patterns of the first set and/or the second set and/or the third set of light sources may be mapped to a predetermined pointing and/or input command, and to a three-dimensional position and/or motion and/or orientation of the at least one pointing/input device.

In yet another aspect, a computing system for two-dimensional and three-dimensional pointing/command input is described which uses passive light detection and requires only a single conventional imaging device. In an embodiment, the computing system comprises a computing device having at least one processor, at least one memory, and at least one graphical user interface, at least one pointing/input device as described above, an imaging device operably linked to the computing device and configured for capturing a plurality of sequential image frames, and at least one computer program product operable on the computing device processor.

The computer program product includes executable instructions for determining at least a two-dimensional or three-dimensional position and/or a motion and/or an orientation of the at least one pointing/input device from digital data of the plurality of sequential image frames providing views of at least one activated light source of the first set, the second set, and the third set of light sources held and/or moved within a field of view of the imaging device, and for rendering on the graphical user interface a visual marker corresponding to the determined position and/or the motion and/or the orientation of the at least one pointing/input device. The imaging device may be a conventional web cam. Computer-executable instructions of the computer program product map an activation pattern of one or more light sources of the first, second, and third sets of light sources to predetermined pointing and input commands, and to a three-dimensional position and/or motion of the pointing/input device.

These and other embodiments, aspects, advantages, and features of the present invention will be set forth in the description which follows, and in part will become apparent to those of ordinary skill in the art by reference to the following description of the invention and referenced drawings or by practice of the invention. The aspects, advantages, and features of the invention are realized and attained by means of the instrumentalities, procedures, and combinations particularly pointed out in the appended claims. Unless otherwise indicated, any patent and/or non-patent citations discussed herein are specifically incorporated by reference in their entirety into the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings incorporated in and forming a part of the specification, illustrate several aspects of the present invention, and together with the description serve to explain the principles of the invention. In the drawings:

FIG. 1 shows a side view of a prior art optoelectronic mouse including an integrated digital camera;

FIG. 2 depicts a human-computer interaction system according to the present disclosure using a stand-alone webcam as an imaging device;

FIG. 3 depicts a human-computer interaction system according to the present disclosure using an embedded webcam as an imaging device;

FIG. 4 shows a front perspective view of a pointing/input device according to the present disclosure;

FIG. 5 shows a bottom perspective view of the pointing/input device of FIG. 4;

FIG. 6 shows an enlarged view of the pointing/input device of FIG. 5;

FIG. 7 depicts schematically a top view of a control mechanism for the pointing/input device of FIG. 4;

FIG. 8 shows a user holding the pointing/input device of FIG. 4 in a field of view of the imaging device of the

human-computer interaction system of FIG. 3, for accomplishing a two-dimensional pointing/command input operation;

FIG. 9 shows the pointing/input device of FIG. 4 in a field of view of the imaging device of the human-computer interaction system of FIG. 3, for accomplishing a three-dimensional pointing/command input operation;

FIG. 10 depicts a perspective projection of a rectangle on a projection plane P;

FIG. 11 graphically depicts a perspective view of a projection of four vertices $V_1V_2V_3V_4$ of the rectangle of FIG. 10 on projection plane P ($\overline{V}_1$, $\overline{V}_2$, $\overline{V}_3$, and $\overline{V}_4$) wherein none of the edges of the rectangle defined by $V_1V_2V_3V_4$ are parallel to the projection plane P, used to calculate a position and/or orientation of the pointing/input device of FIG. 4;

FIG. 12 graphically depicts a perspective view of a projection of four vertices $V_1V_2V_3V_4$ of the rectangle of FIG. 10 on projection plane P ($\overline{V}_1$, $\overline{V}_2$, $\overline{V}_3$, and $\overline{V}_4$) wherein V_2V_3 and V_1V_4 are parallel to the projection plane P but V_1V_2 and V_3V_4 are not, used to calculate a position and/or orientation of the pointing/input device of FIG. 4; and

FIG. 13 schematically depicts an angle δ between $\overline{OF}_1$ and $\overline{OF}_3$, which is the same as the angle between V_1V_2 and V_1V_3.

DETAILED DESCRIPTION OF THE
INVENTION

In the following detailed description of the illustrated embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration, specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Also, it is to be understood that other embodiments may be utilized and that process, reagent, materials, software, and/or other changes may be made without departing from the scope of the present invention.

The present disclosure relates to a human-computer interaction system 10 that allows 2D and 3D pointing operations in air mode, i.e. without any requirement for translating a pointing device over a surface and measuring a distance displacement thereof. The system 10 comprises a specialized pointing/input device 14, an imaging device 12, and at least one light tracking computer program. The imaging device 12 may be connected as a separate peripheral to a computing device 16 by wired means such as universal serial bus (USB) cables 17 (see FIG. 2), or by wireless means such as a USB receiver that receives a signal sent by a wireless imaging device 12 (not shown). Alternatively, the imaging device 12 may be provided as an embedded or integrated attachment to a computing device 16 (see FIG. 3). The computing device 16 includes a graphical user interface 18, such as a conventional 2D or 3D screen, and an input means such as a keyboard 20.

The imaging device 12 is typically a single lens imager such as a conventional webcam, although use of multi-view imaging devices is contemplated. The imaging device 12 includes a digital video recorder operatively coupled to an image sensor which encodes images for later decoding by the computing device 16. Any suitable video recorder which is or can be configured for use with computing devices 16 is contemplated, such as a conventional webcam or other recorder or recorder configuration for providing digital data representative of captured image frames showing a particular view. A number of suitable image sensors are known in the art and are contemplated for inclusion in the present

input device **14** are facing the imaging device **12** and the pointing/input device **14** is within the horizontal and vertical fields of view of the imaging device **12**. When the operator moves the pointing/input device **14** in the air, the images taken by the imaging device **12** will be processed by one or more computer program products to determine a location of the LED **30**. That information is then used to determine the location of a cursor (not shown) displayed on graphical user interface **18**.

Computer program product(s) and calculations for performing this tracking job for 2D pointing are described in detail in co-pending U.S. utility patent application Ser. No. 14/089,881 for "Algorithms, software, and an interaction system that support the operation of an on the fly mouse," the entirety of which is incorporated herein by reference. Briefly, one or more computer program products include executable instructions for calculating a position of activated blue LED **30** in a captured image including a view of the pointing/input device **14**, and mapping that LED **30** position to a corresponding visual marker position in a graphical user interface **18**. Acquired digital image frames are converted to digital data by an imaging device **12** sensor, and analyzed to determine regions of increased color intensity corresponding to a position of the LED **30** in the image frame. The data may be subjected to one or more filtering steps to remove areas of lesser color intensity, and to remove areas displaying a color that is other than the predetermined blue color of LED **30**. Data representative of a location of the LED **30** are scaled in a non-linear fashion to render a visual marker such as a cursor on the graphical user interface **18**, corresponding to a calculated position and/or motion of the LED **30** moved in three-dimensional space.

The use of the pointing/input device **14** for left click, right click, drag, etc. operations will now be described. For a left click operation, actuating left button **26** of pointing/input device **14** actuates left switch **40** which in turn actuates a left LED **32**b of the second set of light sources **32**, which as noted above in the depicted embodiment emits a red light. The left LED **32**b will remain in an "on" status as long as the left button **26** is not released. Therefore, by processing the corresponding images including an activated blue LED **30** and an activated red left LED **32**b, the pointing computer programs interpret the combination of activated point light sources and the length of time of activation of left LED **32**b as a left click command, a double click command, or a drag command. Right click functions are performed and processed similarly, except that operator O actuates right button **24** to activate right (red) LED **32**a.

It will be appreciated that the two red LEDs **32**a, **32**b are not activated simultaneously, therefore the software differentiates left click and right click commands by the position (in a captured image) of the activated red LED relative to the activated blue LED **30**. Thus, activation of the left-side (relative to the blue LED **30**) red LED **32**b is interpreted as a left click command, and activation of the right side LED **32**a is interpreted as a right click command. To execute a double click command, it is required only to detect a "click," i.e. a separate event of activating a point light source, twice within a constant predetermined time period, for example 100 ms. In an embodiment, the following actions are interpreted as a drag command: (a) activate left (red) LED **32**a; (b) track the activated left (red) LED **32**a; and (c) inactivate left (red) LED **32**a. The process of tracking an activated red light source is substantially as described supra for tracking the blue LED **30**. Hence, all familiar pointing functions of a computer mouse can be performed by the pointing/input

device **14** in 2D mode except these functions are performed in the air, instead of requiring a surface over which the device **14** is translated.

For operation of the pointing/input device in 3D mode, in the depicted embodiment operator O places the pointing/input device **14** in 3D mode using button **28**. This action deactivates first light set **30** and activates third light source set **33**, which in the depicted embodiment emit light having a red color. Operator O then holds pointing/input device **14** with the second surface (in the depicted embodiment, the bottom surface) in which third light source set **33** is disposed facing a field of view of the imaging device **12** (see FIG. 9). The computer program products of the system **10** can now analyze sequential image frames captured and converted to digital data by the imaging device **12** to compute a 3D depth of the pointing/input device **14** and from that information also an angle of the pointing device (with respect to an xz-plane) in each captured image frame. Therefore, by moving the pointing/input device **14** in three-dimensional space, information regarding the depth and angle of the pointing/input device **14** can be input to the computing device **16** and interpreted to control, for instance, the dimension of a window or a drawing, or the orientation of an object or a photo, as rendered on a graphical user interface **18**. The process of computing a 3D depth and/or angle of pointing/input device **14** including aligned point light sources is described in detail below.

When in 3D mode, the above-summarized 2D "click," "double click," and "drag" commands are interpreted similarly because second light source set **32** is visible to the imaging device **12** through slots **35** and so can detect activation of one or more of the light sources of second light source set **32**. Left/right click and drag commands are still performed by pushing and holding the left button **26** or right button **24**, respectively, of the pointing/input device **14**. However, many additional three-dimensional operations are possible because eighteen attribute parameters are provided to the computing device **16**. When pointing/input device **14** is in 3D mode, a position of the pointing/input device **14** (and therefore a location of a screen cursor; not shown) is not determined by light source set **30** as is the case for 2D mode, since light source **30** is deactivated. Instead, a position of the pointing/input device **14** (and therefore a location of a screen cursor; not shown) is determined by one of the light sources of third light source set **33**, in the depicted embodiment light source **33**a (see FIG. 6).

Exemplary calculations used by the one or more computer program products for using captured images showing the variously actuated point light sources of the first, second, and third sets **30**, **32**, **33** of light sources will now be described. For this process, one assumption is that a pinhole of the imaging device **12** ($\overline{O}$) is the center of perspective projection (see FIG. 10); P, a sensor plane of the imaging device **12**, is the projection plane; $V_i = (X_i, Y_i, Z_i)$, i=1, 2, 3, 4 are the to-be-determined coordinates of the third set **33** of light sources **33**a, **33**b, **33**c, **33**d; $\overline{V}_i = (x_i, y_i, z_i)$, i=1, 2, 3, 4 are the known projections of $V_i = (X_i, Z_i)$, i=1, 2, 3, 4 on the projection plane. The computation process is shown below.

Certain variables in the calculations are as follows: Given:

$\overline{O} = (0,0,0)$: center of projection

$V_1 V_2 V_3 V_4$: a rectangle with vertices $V_i = (x_i, y_i, z_i)$, i=1, 2, 3, 4. The width and height of the rectangle are w and h, respectively.

P: projection plane. The distance between $\overline{O}$ and P is f. Here we assume $\overline{O}$ is the origin of a three-dimensional

coordinate system and the projection plane is perpendicular to the z-axis of the coordinate system at the point (0, 0, −f).

∇_i: projection of V_i on the projection plane P; $\nabla_i=(\overline{x}_i, \overline{y}_i, -f)$.

To calculate V_i from ∇_i, i=1, 2, 3, 4 (see FIG. **11** for an illustration of the given condition), in one case an assumption is made that none of the edges of the rectangle $V_1 V_2 V_3 V_4$ are parallel to the projection plane P. Without loss of generality, we assume V_1 is closer to the projection plane than the other three vertices of the rectangle. In this case, if we extend $\nabla_1 \nabla_2$ and $\nabla_3 \nabla_4$ to the right, the lines would intersect. Let the intersection point be $F_1=(a_1, b_1, -f)$. F_1 is called a vanishing point. Since ∇_1, ∇_2, ∇_3 and ∇_4 are known to us, a_1 and b_1 are computable. That $V_1 V_2 V_3$ is not parallel to perpendicular to the projection plane P means that ∇_1, ∇_2 and ∇_3 are not coinciding, i.e., $\nabla_1 \neq \nabla_2 \neq \nabla_3$. Since ∇_1, ∇_2 and ∇_3 are known, the distance between ∇_1 and ∇_2, and the distance between ∇_2 and ∇_3 can be computed.

Similarly, extending $\nabla_1 \nabla_4$ and $\nabla_2 \nabla_3$, the lines would intersect at a point at the bottom (see FIG. **11**). Let the intersection point be named $F_2=(a_2, b_2, -f)$. F_2 is also a vanishing point and the coordinates a_2 and b_2 are computable.

Since the line $\overline{OF}_1$ is parallel to $V_1 V_2$ and the line $\overline{OF}_2$ is parallel to $V_1 V_4$, the angle between $\overline{OF}_1$ and $\overline{OF}_2$ is 90°, consequently, we have

$$\overline{OF}_1 \cdot \overline{OF}_2 = a_1 a_2 + b_1 b_2 + f^2 = 0 \qquad (1)$$

What this means is, the distance between $\overline{O}$ and the projection plane does not have to be given to us, because f can be computed from (1) as follows:

$$f = \sqrt{-a_1 a_2 - b_1 b_2} \qquad (2)$$

With the information on F_1, F_2 and f, we can compute V_1, V_2, V_3 and V_4 now. First, we know that

$$V_1 = t_1 * \overline{OV}_1 \qquad (3)$$

for some positive parameter t_1. Since $\overline{OF}_1$ is parallel to $V_1 V_2$, V_2 can be expressed as

$$V_2 = V_1 + w \frac{\overline{OF}_1}{|\overline{OF}_1|} \qquad (4)$$

where w is the width of the rectangle $V_1 V_2 V_3 V_4$ and $|\overline{OF}_1|$ is the norm of the vector $\overline{OF}_1$. On the other hand, V_2 must be a point on the ray defined by $\overline{O}$ and ∇_2, i.e.,

$$V_2 = t_2 * \overline{OV}_2 \qquad (5)$$

for some positive parameter t_2. Hence, from (3), (4) and (5), we have

$$t_1 * \overline{OV}_1 + w * \frac{\overline{OF}_1}{|\overline{OF}_1|} = t_2 * \overline{OV}_2 \text{ or}$$

$$t_1 x_1 + \frac{a_1 w}{\sqrt{a_1^2 + b_1^2 + f^2}} = t_2 x_2 \qquad (6)$$

$$t_1 y_1 + \frac{b_1 w}{\sqrt{a_1^2 + b_1^2 + f^2}} = t_2 y_2 \qquad (7)$$

$$t_1 f + \frac{fw}{\sqrt{a_1^2 + b_1^2 + f^2}} = t_2 f \qquad (8)$$

By substituting the expression for t_2 in (8) into (6), we get

$$t_1 x_1 + \frac{a_1 w}{\sqrt{a_1^2 + b_1^2 + f^2}} = \left(t_1 + \frac{w}{\sqrt{a_1^2 + b_1^2 + f^2}}\right) x_2$$

If $x_1 \neq x_2$, we get

$$t_1 = \frac{(x_2 - a_1)w}{(x_1 - x_2)\sqrt{a_1^2 + b_1^2 + f^2}} \text{ and} \qquad (9)$$

$$t_2 = \frac{(x_1 - a_1)w}{(x_1 - x_2)\sqrt{a_1^2 + b_1^2 + f^2}} \qquad (10)$$

Consequently, we can use (3) to get V_1, (4) or (5) to get V_2. Once we have V_1, we can use the following equations to get V_3 and then V_4:

$$V_3 = V_1 + \frac{\overline{OF}_2}{|\overline{OF}_2|} h \qquad (11)$$

$$V_4 = V_3 + \frac{\overline{OF}_1}{|\overline{OF}_1|} w \qquad (12)$$

So locations of all four vertices of the rectangle are known to us now.

In a second case, $\nabla_1 \nabla_2$ is not parallel to $\nabla_4 \nabla_3$, but $\nabla_1 \nabla_4$ is parallel to $\nabla_2 \nabla_3$ (see FIG. **12**). This case means $V_2 V_3$ and $V_1 V_4$ are parallel to the projection plane but $V_1 V_2$ and $V_3 V_4$ are not. Without loss of generality, we assume that $V_2 V_3$ and $V_1 V_4$ are also parallel to the y-axis. In this case, like the previous case, if we extend $\nabla_1 \nabla_2$ and $\nabla_4 \nabla_3$, we get a vanishing point $F_1=(a_1, b_1, -f)$, the intersection point of ∇_1 ∇_2 and $\nabla_4 \nabla_3$, but we don't get an intersection point for ∇_1 ∇_4 and $\nabla_2 \nabla_3$. However, in this case, if we connect ∇_1 and ∇_3 with a line and extend this line, it would intersect the vertical line that passes through F_1 (see FIG. **14**). The intersection point is also a vanishing point. We will call this vanishing point F_3. It is obvious that $F_3=(a_1, d, -f)$ where d is to be determined. Note that

$$\frac{y_3 - y_1}{x_3 - x_1} = \frac{d - y_1}{a_1 - x_1}$$

Hence, we have

$$d = y_1 + (a_1 - x_1)\frac{y_3 - y_1}{x_3 - x_1} \qquad (13)$$

On the other hand, since $\overline{OF}_1$ is parallel to $V_1 V_2$ and $\overline{OF}_3$ is parallel to $V_1 V_3$, the angle between $\overline{OF}_1$ and $\overline{OF}_3$ is the same as the angle between $V_1 V_2$ and $V_1 V_3$ which is δ (see FIG. **13**), therefore, the inner product of $\overline{OF}_1$ and $\overline{OF}_3$ satisfies the following equation $a_1^2 + b_1 d + f^2 = \sqrt{a_1^2 + b_1^2 + f^2} * \sqrt{a_1^2 + d^2 + f^2} * \cos \delta$

or

$$(a_1^2 + b_1 d + f^2) = (a_1^2 + b_1^2 + f^2)(a_1^2 + d^2 + f^2)\cos^2 \delta$$

This equation is equivalent to

$$(a_1^4 \sin^2\delta + b_1^2 \sin^2\delta + 2a_1^2 b_1^2 d - a_1^2 d^2 \cos^2\delta - a_1^2 b_1^2$$
$$\cos^2\delta) + (2a_1^2 \sin^2\delta + 2b_1^2 d - b_1^2 \cos^2\delta - d^2 \cos^2\delta)f^2 +$$
$$\sin^2\delta \cdot f^4 = 0$$

Let

$$t = f^2$$

$$A = \sin^2\delta$$

$$B = 2a_1^2 \sin^2\delta + 2b_1^2 d - b_1^2 \cos^2\delta - d^2 \cos^2\delta$$

$$C = a_1^2 \sin^2\delta + b_1^2 d^2 \sin^2\delta + 2a_1^2 b_1^2 d - a_1^2 d^2 \cos^2\delta - a_1^2 b_1^2 \cos^2\delta$$

Then (14) can be written as

$$At^2 + Bt + C = 0$$

Solving the above equation provides:

$$f^2 = t = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

Take the positive root and then take its square root to get f. Once we have information on F_1, F_3 and f, we can compute V_1, V_2, V_3 and V_4 using an approach similar to the one used in Case 1.

In a third case, $\nabla_1 \nabla_2$ is parallel to $\nabla_4 \nabla_3$ and $\nabla_1 \nabla_4$ is parallel to $\nabla_2 \nabla_3$. In this case, the problem is unsolvable. One needs to perturb the rectangle $V_1 V_2 V_3 V_4$ a little bit to get into either Case 1 or Case 2, and then proceed.

Thus, by use of digital data rendered from captured images including the activated light sources variously of first light source set 30, second light source set 32, and third light source set 33, a depth and/or orientation of pointing/input device 14 in 3D space may be calculated as described and rendered as a cursor on a graphical user interface 18. Particular combinations of activated light sources of second set 32 are interpreted as particular pointing or command inputs of the pointing/input device 14 as described, and rendered on a graphical user interface 18 of a computing device 16.

Summarizing, the present disclosure provides a pointing/input system including an input or pointing device 14 which allows pointing and command input in 2D and 3D mode, without requiring a direct connection to a computing device 16 or a surface over which pointing/input device 14 must be translated. All standard functions of the pointing/input device 14 such as left click, right click, drag and drop, etc. are performed using buttons and actions corresponding to those with which a user of a conventional computer mouse is familiar. The pointing/input device 14 is inexpensive and simple, requiring only sets of aligned visible point light sources and simple circuitry. Advantageously, the disclosed system 10 is likewise economical and simple, and many elements of the system are likely already available in many homes but for the pointing/input device 14 and software. But for the pointing/input device 14 and software, for additional hardware the system 10 requires only a computing device 16 and a conventional imaging device 12 such as a standard webcam, and has no requirement for any specific wired or wireless connection (such as wiring or cabling, or a specialized IR or other signal) between the pointing/input device 14 and the imaging device 12. Exemplary advantages of the disclosed system include allowing an operator to point and/or input gesture commands to a computing device, a

"smart" television, and the like in either 2D or 3D mode, transitioning between these modes by simple switch actuations. Still further, the system of the present disclosure can be readily retrofitted to existing computing devices as long as the devices support operation of an integrated or peripheral imaging device such as a webcam.

One of ordinary skill in the art will recognize that additional embodiments of the invention are also possible without departing from the teachings herein. Thus, the foregoing description is presented for purposes of illustration and description of the various aspects of the invention, and one of ordinary skill in the art will recognize that additional embodiments of the invention are possible without departing from the teachings herein. This detailed description, and particularly the specific details of the exemplary embodiments, is given primarily for clarity of understanding, and no unnecessary limitations are to be imported, for modifications will become obvious to those skilled in the art upon reading this disclosure and may be made without departing from the spirit or scope of the invention. Relatively apparent modifications, of course, include combining the various features of one or more figures with the features of one or more of other figures. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally and equitably entitled.

What is claimed is:

1. A pointing/input device for effecting two-dimensional and three-dimensional pointing and/or command input using a single imaging device operatively connected to a computing device having at least one processor and at least one memory, comprising:

a housing;

a first set of light sources disposed on a first surface of the housing, at least one light source of the first set emitting a first light color when activated;

a second set of light sources disposed on the first surface of the housing, the second set emitting a second light color when activated that is different from the first color;

a third set of light sources disposed on a second surface of the housing, the third set emitting a light color when activated that may be the same as or different from the first or second color; and

one or more actuators for differently activating one or more of the light sources of the first, second, and third sets of light sources to provide a plurality of light source activation patterns corresponding to a plurality of pointing and/or input commands.

2. The pointing/input device of claim 1, wherein the first color is blue and the second color is red.

3. The pointing/input device of claim 1, including an actuator for activating the first set of light sources.

4. The pointing/input device of claim 1, including an actuator for activating the second set of light sources.

5. The pointing/input device of claim 1, including an actuator for activating the third set of light sources that may be the same as or different from the actuator for activating the first set of light sources.

6. The pointing/input device of claim 1, wherein light emitted by the first set and second set of light sources is visible to an imaging device when either of the first surface of the housing or the second surface of the housing is facing a field of view of the imaging device.

7. In a computing system environment, a method for two-dimensional and three-dimensional pointing and/or command input, comprising:

providing at least one pointing/input device including a first set of light sources emitting a first light color when activated, a second set of light sources emitting a second light color when activated that is different from the first color, and a third set of light sources emitting a light color that may be the same as or different from the first or second color, the pointing/input device further including one or more actuators for differently activating one or more of the light sources of the first, second, and third sets of light sources to provide a plurality of light source activation patterns corresponding to a plurality of pointing and/or input commands;

while actuating the one or more actuators to provide the plurality of light source activation patterns, holding and/or moving the at least one pointing/input device within a field of view of an imaging device operably connected to a computing device having at least one processor, at least one memory, and at least one graphical user interface;

by the imaging device, capturing a plurality of sequential image frames each including a view of the at least one pointing/input device having at least one light source of the first set, the second set, and/or the third set of light sources activated to emit light;

from one or more views of at least one of the first set, the second set, and/or the third set of light sources in the captured plurality of sequential image frames, calculating a two-dimensional or a three-dimensional position and/or motion and/or orientation of the at least one pointing/input device; and

rendering a visual marker on the graphical user interface corresponding to the calculated position and/or motion and/or orientation of the at least one pointing/input device.

8. The method of claim 7, further including mapping an activation pattern of the first set and/or the second set and/or the third set of light sources to a predetermined pointing and/or input command.

9. The method of claim 7, including mapping and displaying in the graphical user interface a three-dimensional position and/or motion and/or orientation of the at least one pointing/input device, comprising:

determining a three-dimensional coordinate of each activated light source of the third set of light sources in each of said plurality of sequential image frames;

converting the determined three-dimensional coordinate into a three-dimensional position of the visual marker in the graphical user interface; and

displaying the three-dimensional position of the visual marker in the graphical user interface.

10. The method of claim 9, further including determining the three-dimensional coordinate by:

calculating a depth of each activated light source of the third set of light sources with respect to a pre-determined origin of a three-dimensional coordinate system;

calculating an angle of a light beam emitted by each activated light source of the third set of light sources with respect to a projection plane defining a plane perpendicular to a z-axis of the three-dimensional coordinate system; and

determining a three-dimensional coordinate and orientation of the at least one pointing/input device from said calculated depth and angle.

11. The method of claim 7, including calculating from the captured plurality of sequential image frames at least a spatial and a velocity parameter of the at least one pointing/input device when moved through three-dimensional space and rendering on the graphical user interface a visual marker corresponding to the calculated spatial and velocity parameter of the at least one pointing/input device.

12. The method of claim 11, including providing at least one computer program product comprising executable instructions operable on the computing device, for calculating from the captured image frames at least the spatial and velocity parameters of the at least one pointing/input device.

13. A computing system for tracking a motion and/or an orientation of a pointing/input device, comprising:

a computing device having at least one processor, at least one memory, and at least one graphical user interface;

at least one pointing/input device according to claim 1;

an imaging device operably linked to the computing device and configured for capturing a plurality of sequential image frames; and

at least one computer program product operable on the computing device processor, the at least one computer program product including executable instructions for determining at least a two-dimensional or three-dimensional position and/or a motion and/or an orientation of the at least one pointing/input device from digital data of the plurality of sequential image frames providing views of at least one activated light source of the first set, the second set, and the third set of light sources held and/or moved within a field of view of the imaging device, and for rendering on the graphical user interface a visual marker corresponding to the determined position and/or the motion and/or the orientation of the at least one pointing/input device.

14. The system of claim 13, wherein the imaging device is a web cam.

15. The system of claim 13, wherein the at least one computer program product includes executable instructions for mapping an activation pattern of at least one light source of the first set and/or the second set and/or the third set of light sources to a predetermined pointing and/or input command.

16. The system of claim 15, wherein the at least one computer program product further includes executable instructions for mapping and displaying in the graphical user interface a three-dimensional position and/or motion of the at least one pointing/input device, comprising:

determining a three-dimensional coordinate of each activated light source of the third set of light sources in each of said plurality of sequential image frames;

converting the determined three-dimensional coordinate into a three-dimensional position of the visual marker in the graphical user interface; and

displaying the three-dimensional position of the visual marker in the graphical user interface.

17. The system of claim 16, wherein the at least one computer program product includes executable instructions for determining the three-dimensional coordinate in each of said plurality of sequential image frames by:

calculating a depth of each activated light source of the third set of light sources with respect to a pre-determined origin of a three-dimensional coordinate system;

calculating an angle of a light beam emitted by each activated light source of the third set of light sources with respect to a projection plane defining a plane perpendicular to a z-axis of the three-dimensional coordinate system; and

determining a three-dimensional coordinate and orientation of the at least one pointing/input device from said calculated depth and angle.

* * * * *