METHOD AND SYSTEM FOR DISPLAYING THREE-DIMENSIONAL OBJECTS

Field of the Invention

The invention generally relates to a multi-user means for displaying realistic three-dimensional objects and, it may relate to a means based on monocular and binocular mechanisms of spatial visual perception using a visualization means for providing an image on a screen surface.

Prior Art

Means for displaying three-dimensional objects are used in various virtual reality systems for scientific, industrial, educational, game purposes, etc. When a traditional visualization means (i.e., a means for forming an image on a screen surface, not in a volume of a medium) are used, e.g., means based on substantially flat panels like liquid crystal displays (LCD), plasma panels, projection screens, it is expedient to use methods that utilize as much spatial visual perception mechanisms as possible.

Visual perception mechanisms are classified into monocular and binocular mechanisms and into physiological and psychological ones. Monocular mechanisms include occlusion, recognizability of known object dimensions, motion parallax, linear perspective, texture gradient, shading, and accommodation. Binocular mechanisms include convergence and binocular retinal disparity. Physiological mechanisms include those mechanisms, which may be defined by conceptual and formulaic means in mathematics and physics (motion parallax, accommodation, convergence, and binocular retinal disparity), while psychological mechanisms include those mechanisms, that are based on human perception experience (all other mechanisms). Generally, the physiological spatial perception mechanisms prevail during spatial visualization, while the psychological ones are supplemental.

Occlusion (also known as interposition) is a mechanism ensuring depth perception in a situation when one object obstructs view of another object.

Motion parallax is an effect of displacement of image parts relative to each other with an angular velocity being proportional to a difference of distances between the image parts and the viewer, when the mutual position of the viewer and the object under observation changes. This effect is most distinct for moving objects positioned close to the viewer in a motionless environment relative to the viewer.

Recognizability of dimensions is based on a notion of object size in human perception experience, which allows using information of visible size of an object for understanding how far the object is located relative to the viewer.

Thus, realistic representation of three-dimensional objects for one or more viewers may be provided by using visualization means forming an image on a screen surface and utilizing at least two main psychological visual mechanisms of spatial perception of images, binocular parallax and motion parallax, so as to provide a degree of realism not less than degree of realism in a hypothetical MP3D system having an overall delay within 5 ms, providing a high degree of geometric correctness of the view, when the viewer moves at a speed in a range of 0 m/s to 3 m/s and an acceleration in a range of 0 m/s^2 to 10 m/s^2, and using manipulators for control of virtual objects, wherein orientation and spatial position of the manipulators are tracked substantially in the same way as position of the viewer's eyes.

Summary of the Invention

The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

A method of creating a 3D effect of an image formed on a display device surface may be provided, the method simultaneously providing at least effects of binocular parallax and motion parallax and including the following steps:

- using a system comprising
    - at least one display device;
    - at least one pair of glasses for stereoscopic separation of images, the glasses comprising at least two optical shutters and at least two markers;
    - at least two optical sensor arrays;
    - at least two reading and processing devices;
    - a marker 3D coordinates calculation device;
    - at least one marker coordinates prediction device;
    - a 3D scene formation device;
    - at least one image output device,
- obtaining pictures from the optical sensor arrays, detecting the markers in these pictures, and determining 2D coordinates of the markers;
- determining 3D coordinates of the markers based on 2D coordinates of the markers;
- extrapolating coordinates of the markers so that effective overall delay does not exceed 5 ms;
- performing formation of a 3D scene considering the 3D coordinates of the markers;
- outputting the 3D scene image on the at least one display device, wherein images of the 3D scene intended for each eye of a viewer are outputted alternately.

In such a method, the markers may be light emitting markers.

Such a method may further include a step of controlling a tracing window, wherein the system may further comprise at least one tracing window control device.

A system for creating a voluminosity effect of an image formed on a display device surface may be provided, the system simultaneously providing at least effects of binocular parallax and motion parallax and comprising:

- at least one display device configured to display a sequence of images;

- at least one pair of glasses configured to provide stereoscopic separation of images, the glasses comprising at least two optical shutters and at least two markers disposed in a predetermined way;

- at least two optical sensor arrays configured to obtain pictures of the markers and disposed in a predetermined way;

- at least two reading and processing devices configured to read data from the optical sensor array and to determine 2D coordinates of the markers;

- a marker 3D coordinates calculation device configured to calculate 3D coordinates of the markers based on 2D coordinates of the markers;

- at least one marker coordinates prediction device configured to extrapolate coordinates of the markers so that effective overall delay does not exceed 5 ms;

- a 3D scene formation device configured to form a 3D scene considering the 3D coordinates of the markers;

- at least one image output device configured to output the 3D scene image to the at least one display device.

In such a system, the markers may be light emitting markers.

Such a system may further comprise at least one tracing window control device configured to determine an area of the optical sensor array for reading data therefrom, depending on position of a picture of at least one of the markers, wherein size of the area of the optical sensor array is less than size of the entire frame of the optical sensor array.

Such a system may be further configured to calibrate viewer tracking means comprising the markers, the optical sensor arrays, the reading and processing devices and the marker 3D coordinates calculation device.

Such a system may be further configured to automatically detect interfering emission sources and to exclude effect thereof on detection of the markers.

Such a system may further comprise a synchronization device configured to provide synchronization of the optical sensor arrays with each other or with each other and with the markers.

Such a system may further comprise at least one communication device, wherein the glasses may also comprise at least one communication device, and the system may be configured to selectively switch the markers on and off.

communication device for determination of 3D coordinates of the markers, when determination of the markers by the optical sensor arrays is impossible.

Such a system may further comprise at least one radio communication device and at least one tracing window control device configured to determine an area of the optical sensor array for reading data therefrom, and it may be configured to use data obtained from the orientation device of the manipulator via the radio communication device for determination of size and position of the tracing window.

Such a system may further comprise at least one radio communication device, wherein the manipulator may also comprise at least one radio communication device, and the system may be configured to selectively switch the markers on and off.

Such a system may be further configured to generate a luminosity map when the markers are switched off, in order to automatically detect interfering emission sources and exclude effect thereof on detection of the markers.

In such a system, the markers may be configured to emit IR light.

In such a system, the markers and/or the optical sensor arrays may be equipped with narrow-band optical filters.

Short Description of Drawings

Fig. 1A and Fig. 1B show a rendering method of prior art, in which the frame rendering time exceeds the time of displaying the frame on the screen.

Fig. 2A shows a rendering method of prior art, in which the frame rendering time does not exceed the time of displaying the frame on the screen.

Fig. 2B shows an ALAP rendering method, in which the frame rendering time does not exceed the time of displaying the frame on the screen.

Fig. 3 shows a general view of an LCMP3D system in one embodiment disclosed herein.

Fig. 4 shows a functional diagram of an LCMP3D system in one embodiment disclosed herein.

Fig. 5 shows a method of calculation of 3D coordinates of markers in one embodiment disclosed herein.

Fig. 6 shows a general view of a smart camera in one embodiment disclosed herein.

Fig. 7A shows a general view of glasses in one embodiment disclosed herein.

Fig. 7B shows a general view of a marker with partially removed shell in one embodiment disclosed herein.

Fig. 8 shows a general view of an LCMP3D system in another embodiment disclosed herein.

Fig. 9 shows a general view of an LCMP3D system in still another embodiment disclosed herein.

Fig. 10 shows a general view of glasses in another embodiment disclosed herein.

Fig. 11 shows a general view of an LCMP3D system in one more embodiment disclosed herein.

Fig. 12 shows a process of displaying three-dimensional objects, the process implemented in an LCMP3D system in one embodiment disclosed herein.

Fig. 13 shows a process of finding markers and determination of their 2D coordinates, the process implemented in an LCMP3D system in one embodiment disclosed herein.

Fig. 14 shows a process of controlling a tracing window of a smart camera in an LCMP3D system in one embodiment disclosed herein.

Detailed Description of the Invention

The basic criteria of quality of MP3D systems relate to realism of perception of a virtual world, which depends on quality of stereoscopic separation, quality of rendering and geometric correctness of the view.

Quality of stereoscopic separation is degraded due to ghosting, a phenomenon, when each eye perceives the image intended for the other eye, besides the image intended for this exact eye. Ghosting may be caused by various factors like residual phosphorous glow in plasma screens or incomplete coincidence of polarization direction, when polarization stereoscopic separation is used. Currently, a combination of a DLP (Digital Light Processing) projector and shutter glasses provides the best quality of stereoscopic separation.

Generally, quality of rendering is not a critical factor in modern MP3D systems, however more detailed rendering and using special effects additionally allow enabling psychological mechanisms of spatial perception like texture gradient, shading, etc., which facilitates increasing realism of perception.

Geometric correctness of a 3D scene projection is the most important quality indicator of an MP3D system. If an image is formed for viewing from a first position, but is displayed to a viewer located in a second position, then the viewer sees a distorted object, i.e., the viewer receives the wrong information on the object shape and proportions. These distortions become noticeable when the position error (the distance between the first position and the second position) is about 5% of the distance between the viewer and the screen (i.e., less than 5 mm for the most of virtual reality systems).

Geometric correctness of a view is affected by precision of tracking position of the viewer and by the time period between the start instant of determination of the viewer’s position and the instant of output of the image on the screen. The precision of tracking directly affects the

particular, vertical elements of objects look deviated from the vertical (i.e., inclined), whereas horizontal elements look as they have wrong proportions.

Consequently, a viewer may feel a dissonance between data acquired by visual perception channels and data obtained from vestibular system. This dissonance causes onset of naupathia symptoms (nausea, vertigo, cephalalgia). This phenomenon is called virtual reality motion sickness or VR-sickness.

Moreover, the impact of the overall delay on image geometric distortions observed by a viewer differs for cases of uniform motion of the viewer and accelerated motion of the viewer. In particular, it has been found experimentally by the inventor, that human perceptive system accepts image geometric distortions rather indifferently, when the viewer moves uniformly, especially in uniform rectilinear motion. In this case distortions exist, but their nature does not change. For instance, a cubical object is perceived by a viewer as a parallelepiped, but the parameters of the parallelepiped will be unchanged so long as the viewer moves uniformly, and a vertically oriented object looks inclined, but stable. During accelerated motion, especially when direction of movement is changed sharply, distortions become highly noticeable and very unpleasant to the viewer, like oscillation of vertically oriented objects from side to side, which provokes naupathia. This additionally indicates the importance of minimization of the overall delay in game MP3D systems, which are characterized by a high motion activity of viewers.

According to the inventor's estimate, the overall delay should not exceed 5 ms so as to reduce image geometric distortions down to perceptibility threshold and ensure visual comfort to the viewer. Implementation of an MP3D system for several viewers (multi-user mode) imposes even more tight constraints on the system. It is obvious that achievement of such a value of the overall delay is impossible by trivial optimization of software algorithms and hardware improvement of existing MP3D systems.

The above-indicated value of the overall delay is valid both for systems with no prediction of the viewer's position and for systems with prediction of the viewer's position, i.e., for systems using time extrapolation of the viewer's coordinates. In the latter, the effective overall delay is the period of time between the start instant of determination of the viewer's position and the instant of output of the image on the screen with due account for the delay compensation; and the main quality criterion of such a virtual reality system is reliability of prediction of the viewer's position, which reliability largely depends on the overall delay value prior to compensation.

The techniques disclosed herein may be achieved owing to implementation of an LCMP3D (Lag Compensated MP3D) system. One of the technical solutions of the LCMP3D

system may be prediction of the viewer’s position for the moment of prospective output of image on the screen.

This allows compensating the physically existing overall delay to ensure realism of representation of three-dimensional objects in the LCMP3D system not worse than realism of a hypothetic MP3D system without compensation, wherein the overall delay does not exceed 5 ms. It should be noted that the fact of using overall delay compensation in an MP3D system does not guarantee realism of representation of three-dimensional objects, since prediction of the viewer's position is stochastic in its nature and thus constitutes an additional distorter. For example, compensation of the overall delay amounting to 80–120 ms, which is typical for tracking systems based on optical recognition of the viewer's face, is unable to provide realism of representation of three-dimensional objects due to low accuracy of extrapolation of the viewer coordinates for such a long-time interval.

A set of original solutions regarding design, technology and algorithm was developed to provide parameters of the LCMP3D system, which solutions facilitate predicting viewer's position and compensating the overall delay. Combination of these solutions allows ensuring a high degree of realism of spatial image perception in a virtual reality system.

It is clear that realism of representation of three-dimensional objects in a system with prediction of the viewer's position directly depends on accuracy of the prediction. It is also known that outcome of extrapolation algorithms is very sensitive to quantity and quality of input data. In particular, the following factors affect the prediction accuracy:

(a) age of data; the prediction accuracy falls dramatically in a nonlinear manner, when the data age increases;

(b) size of the sample, based on which the extrapolation is performed; the prediction accuracy rises, as the sample size increases, however if the sampling rate is static, increase in the sample size over some critical value causes decrease in the prediction accuracy due to obsolescence of data in the heading part of the sample;

(c) noisiness of data; the prediction accuracy drops, when the level of noise increases;

(d) horizon of extrapolation; the prediction accuracy falls dramatically in a nonlinear manner, when the extrapolation horizon widens.

The inventor has found experimentally that in an LCMP3D system, the extrapolation horizon should not exceed 30 ms to provide good reliability of the viewer's position extrapolation and it should not exceed 50 ms in order to provide satisfactory reliability of the extrapolation.

Since the extrapolation horizon is conditional on the overall physical delay, high accuracy of extrapolation may be ensured by the other three parameters, namely, a smallest possible input data age, optimal sample size, and decreased noisiness of input data.

Fig. 3 shows a general view of an embodiment disclosed herein in a form of a demo desk for three-dimensional presentations. An LCMP3D system (10) comprises a supporting framework (16), a display (18), four smart tracking cameras (17), a computer (19), one or more pairs of glasses (12), and one or more manipulators (13) for the viewers. A viewer may see a three-dimensional image on the display (18) through the glasses (12), while the image is correctly modified according to position of eyes of each viewer upon the viewer's movement nearby the desk in the upper semi-sphere above the surface of the display screen.

Fig. 4 shows a functional diagram of an LCMP3D system in an embodiment of Fig. 3. In order to facilitate understanding, Fig. 4 shows just those devices, which are specific for this exact implementation of the LCMP3D system (10). The display (18), the four smart tracking cameras (17), and the computer (19) are mounted in the supporting framework (16). Moreover, at least one pair of glasses (12) is included in the LCMP3D system (10). At least one manipulator (13) may be used for control of virtual objects. It should be noted that the LCMP3D system (10) also comprises other components needed for functioning the system. In particular, the glasses, the manipulators, the computer and the smart cameras comprise, when necessary, power sources, indication and control means, interfaces, data transmission lines, supporting and enclosing frameworks, as well as other components ensuring fulfilment of technical, ergonomical, and aesthetical requirements.

The display (18) is a so-called plasma panel with a 1268 mm screen (diagonal) providing a picture size of 1280×720 pixels at 120 frames per second, a dynamic contrast of 5000000:1, and an internal delay of about 30 ms, for example, TH-50PF50E (Panasonic, http://www.panasonic.com/). Besides plasma panels, other types of displays providing the same or better parameters may be used.

It should be noted, that a display having the above-stated parameters provides good quality of a stereoscopic image for one viewer (with frame refresh rate of 60 Hz and on-off ratio of 2 for each eye of the viewer). Commercial availability of enhanced displays and image transfer interfaces will allow increasing the number of users of the LCMP3D system (10) with no substantial improvement of the architecture and operational principles of the system. In particular, using a HD (High Definition) display with image output rate of 240 frames per second will provide good quality of a stereoscopic image for two viewers, whereas 360 frames per second will be fine for three viewers.

The computer (19) is a general-purpose computer having traditional architecture and it comprises, *inter alia*, some specialized software of the LCMP3D system. Functions of the devices within the computer (19) shown in Fig. 4 are implemented by a combination of hardware

(both general purpose and customized), general purpose software (when applicable), and application-specific software of the LCMP3D system (10).

A radio communication device (191) is intended for providing communication between the computer (19) at one side and the glasses (12) and the manipulator (13) at the other side. In one embodiment disclosed herein, a radio channel (14) operates in the range of 2.4 GHz with GFSK modulation and provides stable communication coverage of about 10 m; it is implemented based on radio channel controller nRF24L01 and Enhanced ShockBurst protocol (Nordic Semiconductor, http://www.nordicsemi.com/). The radio channel (14) may also be implemented based on other similar technical solutions.

A marker 2D coordinate prediction device (194) predicts positions of marker pictures in the frame of each tracking camera, based on data obtained from the tracking cameras, for a certain moment in the future, thus implementing compensation of the overall delay. It should be noted that using the prediction imparts stochastic nature to the determination of the viewer's position.

A marker 3D coordinates calculation device (196) calculates coordinates of markers in the three-dimensional space. The calculation concept is illustrated in Fig. 5. The marker 3D coordinate calculation is performed based on marker 2D coordinates obtained using data regarding the reference point position, and based on the lens function and the value of angular misalignment of each camera. The reference point is a point of intersection of the principal optic axis of the lens and the working face of the optical sensor array in a tracking camera. The lens function represents the dependence of position of a point on the working face of the optical sensor array in a tracking camera on an angle between a ray passing the center of the working face of the optical sensor array and a point of tentative center of a marker, and a normal to the working face of the optical sensor array. Generally, the lens function is non-linear and asymmetrical and it depends on optical parameters of the tracking camera lens and on adjustment of the lens relative to the optical sensor array. The angular misalignment is a complex parameter including an angular deviation of actual position of the principal optic axis of the camera lens from the axis position defined in the camera setup, and an angle of rotation of the camera optical sensor array relative to the position defined in the camera setup.

For each tracking camera (in this case four cameras #1, #2, #3, #4), a direction to the marker center point is determined based on the marker 2D coordinates, the lens function, and the angular misalignment values. In an ideal system, all rays corresponding to these directions should cross in the marker center point. In a real system, even considering calibration, these rays may pass close enough to each other in a space area near the marker center point without

rigid structure necessary for ensuring a high tolerance of the LCMP3D system to vibration and shock load. The smart camera (17) also comprises the reading and processing device (172) and the tracing window control device (173). Moreover, the smart cameras (17) may be equipped with narrow-band light filters to decrease effect of interfering light sources on the tracking means. The tracing window control device (173) also contains means for transmission information via a communication line connecting the smart cameras (17) to each other and to the computer (19).

Glasses (12) are intended for time separation of a stereoscopic image for left and right eyes of the viewer. Fig. 7 shows one implementation example of the glasses (12) comprising stereoscopic glasses (120) and markers (121). The stereoscopic glasses (120) contain optical shutters and control means for the optical shutters. The stereoscopic glasses (120) themselves are well-known in the art, so a detailed description thereof is omitted.

In this embodiment, the glasses (12) are implemented based on stereoscopic glasses (120) XPAND Universal 3D Glasses (X6D Ltd, http://www.xpand.me/), which are additionally equipped with two markers (121). In this case, the stereoscopic glasses (120) are controlled via IR control signal, i.e., synchronization of the glasses optical shutters with the display (18) is done by an IR signal emitted by an IR light source (11) (see Fig. 3). The glasses (12) may be implemented based on other stereoscopic glasses of similar design and performance, like 3D Vision 2 Wireless Glasses (NVIDIA Corp., http://www.nvidia.com/), controlled by an IR-channel or a radio channel (e.g., using Bluetooth).

The marker (121) comprises a control circuit (125), at least one emitter (123), at least one power source (124), at least one radio communication device (122), at least one marker operation mode indicator (126), at least one marker operation control button (127), and at least one electric connector (128). Additionally, the marker (121) may comprise an orientation device (129). The emitters (123) may be equipped with narrow-band light filters to decrease effect of interfering light sources on the tracking means.

The glasses and markers may be manufactured as an integral device and may have shared control channels (e.g., a radio channel), a shared power source and a shared charge connector. In another embodiment disclosed herein, the glasses may be provided without the charge connector; in this case the power source may be charged using induction. The glasses may be provided without any control buttons and may go into in a standby or sleep mode, when not used; in this case the marker light on and optical shutter switch orders are transmitted via the control channel. Additionally, the glasses may contain other devices like acoustic emitters, vibration sources, and augmented reality displays furnishing the user with additional information in some numerical, text, or pictorial form.

concepts for the orientation device (139) of the manipulator are substantially valid for the orientation device (129) of the glasses.

Fig. 8 shows a general view of another embodiment disclosed herein, in a form of a single-user desktop system intended for scientific, engineering, educational or entertaining purpose. An LCMP3D system (20) comprises a supporting framework (26), a projector (24), three smart cameras (27), a computer (29), glasses (22), and one or more manipulators (23) for a viewer, as well as an IR signal source (21) for synchronization of optical shutters of the glasses (22). The viewer may see a three-dimensional image on the projection screen (28) located on the desk working surface through the glasses (22), while the image is correctly modified according to position of eyes of the viewer upon the viewer's movement nearby the desk in the upper semi-sphere above the surface of the screen. A DLP projector providing a picture size of 1280×720 pixels at 120 frames per second, dynamic contrast of 3000:1, and average response time of about 8.5 ms, e.g., WD720U (Mitsubishi, http://www.mitsubishi.com/), may be used as the projector (24). Instead of the optical front projection system, a rear optical projection system may be used, wherein the projector (24) is located under the desk working surface, into which a rear projection screen (28) is integrated. Instead of synchronization of optical shutters of the glasses via an IR channel, synchronization via a radio channel may be used.

Using three smart cameras (27) in the LCMP3D system (20) of Fig. 8 provides a high reliability of tracking the viewer's position, however, the LCMP3D system (20) of Fig. 8 maintains its operational integrity when just two smart cameras (27) are used, as hiding markers of the glasses (22) from the smart cameras (27) by any articles is unlikely in such a system.

Fig. 9 shows a general view of still another embodiment disclosed herein, in a form of a single-user or multi-user floor-level game system. Generally, an LCMP3D system (30) is structurally and functionally similar to the system of Fig. 8, but differs by its form-factor, i.e., it comprises a bigger screen (38), which may be a front or rear projection panel disposed on the floor surface or integrated into the floor or deck; it also may be a plasma or LCD panel (or several seamlessly tailored panels) integrated into the floor or deck. In particular, Fig. 9 shows an LCMP3D system (30) using front projection from a projector (34). The LCMP3D system (30) also differs from the LCMP3D system (20) in the number of the tracking cameras (37) (at least four) and disposition of the cameras (above the game area, e.g., on the room ceiling or on masts, towers or any other supporting framework located inside or outside the premises). Another difference is using glasses (32) of different design (refer to Fig. 10), wherein markers (321) are located as to provide minimal shadowing (hiding) thereof by any other articles, when the viewer moves, and thus to provide maximal freedom of the viewer's movement and still ensure reliable

tracking position of the markers. One more difference is using a manipulator (33) comprising an orientation device like the above-mentioned orientation device (139).

Fig. 11 shows a general view of one more embodiment disclosed herein, in a form of a multi-user floor-level game system. Generally, an LCMP3D system (40) is structurally and functionally similar to the system of Fig. 9, but differs by that tracking position of markers of glasses (42) and at least one manipulator (43) of each of the viewers (in this case players) allows fairly accurate tracking the change of spatial position and posture of at least one body portion of each player in order to provide playback on a screen (48) in a form of a related game character changing its spatial position and posture, correspondingly. It should be noted that compensation of the overall delay in the LCMP3D system (40) provides an absence of noticeable geometric image distortions, and also ensures synchronism of movements of a player and the related game character.

The embodiments disclosed herein, represented in the above in the form of LCMP3D systems (10, 20, 30, 40) having one display or several displays disposed in one plane may also be implemented in the form of LCMP3D systems (10, 20, 30, 40) having one display or several displays disposed in different planes, e.g., in a form of CAVE (Cave Automatic Virtual Environment) rooms, etc., as well as having one display or several displays with nonplanar displays, e.g., displays forming a semispherical screen in order to provide IVR (Immersive VR) systems.

A method of displaying three-dimensional objects in an LCMP3D system is illustrated by a flowchart diagram in Fig. 12.

In step (50), switching on and initializing tracking cameras are performed.

In step (51), generation of a luminosity map is performed when all markers are switched off. This is necessary for determination of interfering irrelevant IR light sources and for excluding (or at least decreasing) their effect on marker tracking accuracy. Filtering the irrelevant IR light sources is done by subtraction of a picture obtained from tracking cameras, when the markers are switched off, from a picture obtained from tracking cameras, when the markers are switched on. In order to increase reliability of the filtering, generation of a luminosity map is performed under increased exposure relative to the working exposure.

In step (52), switching markers on is performed by an order from a computer, transmitted via a radio communication device of the computer.

In step (53), synchronization of tracking cameras is performed by a command from a computer, transmitted via the synchronization device. If a user is moving and the tracking cameras operate asynchronously, they capture marker positions in different moments and, correspondingly, in different places. Therefore, reliability of marker 2D coordinates calculated in

step (55) deteriorates, which leads to decrease of accuracy of extrapolation of the marker 2D coordinates; in turn, this causes “blurring” the marker 3D coordinates calculated in step (58), which results in decrease of accuracy of tracking the viewer’s position, thus degrading the realism of a three-dimensional image. Providing universal time for all smart cameras, glasses, markers and the computer may be a condition for maintaining synchronization.

When operation of the NMP3D system is synchronized, commands for reading frames and switching a corresponding marker or corresponding markers are sent in advance. This command may be sent by one tracking camera, which is a master for other tracking cameras; otherwise this command may be sent by a synchronization device.

In step (54), calibration of tracking means is performed. The calibration results in data regarding the reference point position, the lens function and the angular misalignment values for each camera. Further, the reference point position data is transferred to the corresponding smart cameras, and the lens function and the angular misalignment values for each camera are transferred to the computer.

In step (55), detection of markers in pictures obtained from optical sensor arrays of the tracking cameras is performed; further, marker 2D coordinates are determined, i.e., their positions in the coordinate grid of corresponding frames of the tracking cameras are calculated. The marker detection and 2D coordinates determination process are further discussed in detail with reference to Fig. 13.

In step (56), elimination of false markers is performed. False markers are irrelevant IR light sources, pictures of which in the frame are similar to the real marker pictures, so they are not discarded in the process shown in Fig. 14. In order to eliminate false markers, pictures of frames without predetermined markers are used, the markers switched off for a while by command from a marker identification device. The pictures of such special frames, in which predetermined markers are absent, while interference signals are present, are used for excluding (or at least decreasing) effect of the irrelevant IR light sources, e.g., by way of subtracting pictures thereof from pictures of regular working frames. In order to decrease use of resources, it is preferable to read pictures of these special frames only within the tracing window.

In step (57), control of the tracing window is performed. The tracing window control process is further discussed in detail with reference to Fig. 14.

In step (58), extrapolation of the marker 2D coordinates is performed in order to provide compensation of the overall delay. As a simplified approach, extrapolation of the marker 2D coordinates is a linear extrapolation. As a more complicated approach, a non-linear extrapolation may be used, e.g., cubic extrapolation, bicubic extrapolation, spline extrapolation, etc. The extrapolation algorithm may be selected automatically depending on expected movement manner

of the viewers and the computer workload in a certain configuration of the LCMP3D system. Dependence of the extrapolation algorithm on expected movement manner of the viewers is determined by the fact, that accelerated motion is less predictable than uniform motion. The extrapolation horizon is defined by the overall delay value in a certain configuration of an LCMP3D system, and it is selected so as the effective overall delay in an LCMP3D system using extrapolation would not exceed 5 ms. For example, in one embodiment of the LCMP3D system (10), the non-compensated overall delay is about 50.6 ms, including 4 ms for tracking means operation, 8.3 ms for formation of three-dimensional scene, 38.3 ms for representation of the image on a display, therefore, the extrapolation horizon in such a system is about 45.6 ms.

In step (59), determination of the marker 3D coordinates is performed, i.e., their position in the three-dimensional space is calculated. The marker 3D coordinates are calculated based on extrapolated marker 2D coordinates determined for each of the tracking cameras. The calculation is performed in the computer using the calibration results, namely lens function and the angular misalignment values.

It should be noted that in one embodiment disclosed herein, extrapolation of the marker 3D coordinates may be used instead of extrapolation of the marker 2D coordinates, i.e., current 2D coordinates of markers may be transferred to the computer, where 3D coordinates of markers may be determined based on the 2D coordinates, so the 3D coordinates may further be extrapolated in a marker 3D coordinates prediction device (not shown in Fig. 4). In another embodiment disclosed herein, extrapolation of 2D coordinates of the markers may be performed in smart cameras (in this case the cameras comprise marker 2D coordinates prediction devices not shown in Fig. 4), and extrapolation of the marker 3D coordinates may be performed in the computer, wherein different algorithms and/or different extrapolation horizons may be used for extrapolation of 2D coordinates and 3D coordinates of the markers. In one more embodiment disclosed herein, extrapolation of 3D coordinates of the markers may be totally or partially performed in smart cameras. Selection of the extrapolation mode (2D/3D) and the extrapolation algorithm (linear/non-linear) may be done automatically depending on expected movement manner of the viewers and the workload of processors of the smart cameras and/or the computer in a certain configuration of the LCMP3D system.

In step (60), identification of markers is performed. Identification of markers is not mandatory in the LCMP3D systems (10) and (20) in the single-user mode without using manipulators equipped with markers. In other cases identification of markers is required. In the single-user mode of the LCMP3D systems (10) and (20), it is assumed that the left marker is always located on the left of the viewer’s eyes, and the right marker is always located on the right of the viewer’s eyes, i.e., the glasses are not turned upside down. In the LCMP3D systems

(10) and (20) in the multi-user mode, and in the LCMP3D systems (30) and (40) turning the glasses upside down may occur, which is caused by necessity of providing freedom of movements of players, according to the game story, and/or by possible appearance of the player's excitement. In these systems, overturn of the manipulators upside down may also occur, including those equipped with more than one marker. Identification of markers is done by the marker identification device. In particular, a pause in light emission of a marker is used for initial identification of markers, which is provided at a predetermined moment and lasts for a predetermined time (e.g., the marker may stay switched off during one interval of regular working thereof), which allows determining a marker that was lost and subsequently appeared again. Further, identification of markers is performed by tracing the marker shift within the frame. When necessary, recurrent identification of markers may be done in a similar way to the initial identification of markers, as disclosed in the above.

In another embodiment disclosed herein, identification of the markers may be performed by collation of previously known information regarding mutual spatial position of markers belonging to a certain device (glasses or manipulator) with calculated 3D coordinates of the markers, while each device may comprise more than two markers. In this embodiment, each device is characterized by a unique arrangement of the markers. This option may be used, e.g., when marker identification by tracing marker movements within the frame is not reliable due to high motion activity of the viewers, and frequent using recurrent identification of markers by pausing light emission of a marker is undesirable.

In step (61), formation of a 3D scene, i.e., generation of images for each eye of each viewer is performed. A special software (a so-called 3D engine) is responsible for formation of a 3D scene, e.g., using the Unity 3D engine (Unity Technologies, http://unity3d.com/) is enough for the LCMP3D systems (10) and (20), whereas a customized 3D engine supporting several GPUs (preferably with open source code) is expedient to be used in LCMP3D systems having composite screens (so-called multiscreen), which customized 3D engine may be designed in-house or outsourced.

In step (62), output of images to a display is performed. Images for each eye of each viewer are outputted in a proper order, while synchronization of the stereoscopic glasses is provided.

Fig. 13 shows a process of detecting markers and determining 2D coordinates thereof. This process is performed in each smart camera independently, and it yields data regarding each marker, namely, coordinates of the weighted center of the marker outline in the frame of the tracking camera, the outline size, and an integral parameter of the marker picture brightness, which data is transferred to the computer for further processing.

square of tracing windows of all tracking cameras is minimized and it constitutes a condition of approximate equality of squares of the tracing windows of all cameras. The second criterion relates to the situation, when different cameras may have unequal working conditions while tracking certain markers, which directly affect reliability of tracking those markers.

Moreover, the second criterion characterizes a misbalance of computational loads of the smart cameras. If the limitation regarding the square difference of the tracing windows of all cameras is rather soft (which may be typical for a multi-user LCMP3D system), then the misbalance of computational loads of the smart cameras may be significant. In this case the smart cameras may redistribute among themselves the computational loads related to processing pictures of frames, calculating data regarding each marker, and determining parameters of each tracing window. This possibility is provided by a communication line between all smart cameras (not shown in Fig. 4), a corresponding data exchange protocol, and an embedded software of the smart cameras. Such communication lines and data exchange protocols are well-known in the art, so their detailed description is omitted. After completion of step (604), the tracing window parameters are transferred to a corresponding process and the algorithm of Fig. 14 is finished.

In step (603), an area is determined, where a marker missing in a picture taken by a certain tracking camera may be located. Determination of this area is performed by way of comparison of current data (and former data, if necessary) obtained from this tracking camera and other tracking cameras.

Step (605) is substantially similar to step (604). After completion of step (605), the process returns to step (601).

It should be noted that, in order to facilitate comprehension, Fig. 12 shows only those steps of the above-mentioned method, which are substantial for understanding thereof; however, the method may include other steps ensuring operation of the system. Necessity of such steps is clear to a person skilled in the art and implementation thereof is known to an artisan, so their description is omitted.

A technical result may be providing realistic representation of three-dimensional objects for one or more viewers by using visualization means forming an image on a screen surface and by utilizing at least two main psychological visual mechanisms of spatial perception of images, binocular parallax and motion parallax, at a speed of viewer's motion in the range of 0 m/s to 3 m/s and at an acceleration of viewer's motion in the range of 0 m/s^2 to 10 m/s^2. The technical result is attained owing to providing effective overall delay within 5 ms for the viewer, which is ensured by prediction of the viewer's position, i.e., by time extrapolation of 2D coordinates or 3D coordinates of markers. Extrapolation accuracy is defined by parameters of input data used for extrapolation, namely quantity (sample volume), quality (precision and

Claims

1. A method of creating a 3D effect of an image formed on a display device surface, the method simultaneously providing at least effects of binocular parallax and motion parallax and including the following steps:

- using a system comprising:

at least one display device;

at least one pair of glasses for stereoscopic separation of images, the glasses comprising at least two optical shutters and at least two markers;

at least two optical sensor arrays;

at least two reading and processing devices;

a marker 3D coordinates calculation device;

at least one marker coordinates prediction device;

a 3D scene formation device;

at least one image output device,

- obtaining pictures from the at least two optical sensor arrays, detecting the markers in the pictures, and determining 2D coordinates of the markers;

- determining 3D coordinates of the markers based on the 2D coordinates of the markers;

- extrapolating coordinates of the markers so that an effective overall delay does not exceed 5 ms;

- forming a 3D scene considering the 3D coordinates of the markers;

- outputting images of the 3D scene on the at least one display device, wherein the images of the 3D scene intended for each eye of a viewer are outputted alternately.

2. The method of claim 1, wherein the markers are light emitting markers.

3. The method of claim 1, further including a step of controlling a tracing window, wherein the system further comprises at least one tracing window control device.

4. The method of claim 1, further including a step of calibrating means for tracking viewer's position, wherein these means comprise the markers, the optical sensor arrays, the reading and processing devices and the marker 3D coordinates calculation device.

5. The method of claim 1, further including a step of detecting interfering emission sources and excluding effect thereof on detecting the markers.

6. The method of claim 1, further including a step of synchronizing the optical sensor arrays with each other, prior to the step of obtaining pictures from the optical sensor arrays.

7. The method of claim 2, further including a step of synchronizing the optical sensor arrays with each other and with the markers, prior to the step of obtaining pictures from the optical sensor arrays.

8. The method of claim 2, further including a step of selective switching the markers on and off, wherein the system further comprises at least one first radio communication device, and the glasses of the system also comprise at least one second radio communication device.

9. The method of claim 8, further including a step of generating a luminosity map when the markers are switched off, in order to automatically detect interfering emission sources and exclude effect thereof on detection of the markers, prior to the step of detecting the markers.

10. The method of claim 1 or claim 8, further including a step of identifying the markers after the step of determining the 2D coordinates of the markers, wherein the system further comprises a marker identification device.

11. The method of claim 1, wherein the step of extrapolating coordinates of the markers is a step of extrapolating the 2D coordinates of the markers performed prior to the step of determining the 3D coordinates of the markers.

12. The method of claim 1, wherein the step of extrapolating coordinates of the markers is a step of extrapolating the 3D coordinates of the markers performed after the step of determining the 3D coordinates of the markers.

13. The method of claim 1, wherein the system comprises at least three optical sensor arrays, at least three reading and processing devices and at least three tracing window control devices.

14. The method of claim 1, wherein displaying the image for each eye of the viewer is performed for more than one viewer.

15. The method of claim 1, wherein processing data obtained from the optical sensor array starts before reading a frame is finished.

16. The method of claim 1, wherein processing data obtained from the optical sensor array is performed in the at least two reading and processing devices in a distributed manner.

17. The method of claim 1, wherein determining 2D coordinates of the markers is performed with subpixel accuracy.

18. The method of claim 1, wherein the system further comprises at least one first radio communication device, and the glasses of the system also comprise at least one second radio communication device and an orientation device, and wherein data obtained from the orientation device of the glasses via the first and second radio communication devices is used for determining 3D coordinates of the markers disposed on the glasses, when determination of the markers by the optical sensor arrays is not possible.

19. The method of claim 1, wherein the system further comprises at least one first radio communication device and at least one manipulator comprising at least one second radio communication device and an orientation device, and wherein data obtained from the orientation device of the manipulator via the first and second radio communication devices is used for determining 3D coordinates of the markers disposed on the manipulator, when determination of the markers by the optical sensor arrays is impossible.

20. The method of claim 3, wherein the system further comprises at least one first radio communication device and the glasses of the system also comprise at least one second radio communication device and an orientation device, and wherein data obtained from the orientation device of the glasses via the first and second radio communication devices is used for determining size and position of the tracing window.

21. The method of claim 3, wherein the system further comprises at least one first radio communication device, and at least one manipulator comprising at least one second radio communication device and an orientation device, and wherein data obtained from the orientation device of the manipulator via the first and second radio communication devices is used for determining size and position of the tracing window.

22. The method of claim 1 or claim 3, wherein the step of detecting the markers and determining 2D coordinates of the markers includes the following steps:

- selecting lines of the optical sensor array for reading;
- reading a selected line of the optical sensor array;
- checking if a signal intensity of each pixel in the selected line exceeds a threshold value;
- if the pixel signal intensity exceeds the threshold value, detecting the marker picture outline and then passing to a step of calculating size of the marker picture outline; if the pixel signal intensity does not exceed the threshold value, returning to the step of reading a selected line of the optical sensor array;
- calculating size of the marker picture outline;
- checking size of the marker picture outline;
- if the size of the marker picture outline is within predetermined limits, passing to a step of calculating geometric center of the marker picture outline; if the size of the marker picture outline is not within predetermined limits, passing to a step of excluding the marker picture outline;
- calculating geometric center of the marker picture outline;
- calculating maximal and minimal radii of the marker picture outline;
- checking ratio of the maximal and minimal radii of the marker picture outline;

- if the ratio of the maximal and minimal radii of the marker picture outline is within predetermined limits, passing to a step of checking brightness uniformity, if the ratio of the maximal and minimal radii of the marker picture outline is not within predetermined limits, passing to a step of excluding the marker picture outline;

- checking brightness uniformity of the area within the marker picture outline;

- if the brightness uniformity of the area within the marker picture outline is within predetermined limits, passing to a step of calculating coordinates of weighted center of the marker picture outline, if the brightness uniformity of the area within the marker picture outline is not within predetermined limits, passing to a step of excluding the marker picture outline;

- excluding the marker picture outline from further consideration and passing to a step of labelling the marker picture outline;

- calculating coordinates of weighted center of the marker picture outline, transferring for a corresponding step at least one of the following: the coordinates of the weighted center of the marker picture outline, the marker picture outline size, and the ratio of the maximal and minimal radii of the marker picture outline, and then passing to a step of labelling the marker picture outline;

- labelling the marker picture outline and excluding the marker picture outline from further analysis of the picture obtained from the optical sensor array.

23. The method of claim 3, wherein the step of controlling the tracing window includes the following steps:

- checking if all markers are present in a picture obtained from the optical sensor array;

- if all markers are present in the picture obtained from the optical sensor array, passing to a step of checking necessity of adjustment of the tracing window parameters; if not all markers are present in the picture obtained from the optical sensor array, determining an area, where the marker missing in the picture may be located, then determining size and position of the tracing window, and transferring the size and the position of the tracing window for a corresponding step;

- checking if adjustment of the tracing window is necessary;

- if adjustment of the tracing window is necessary, determining size and position of the tracing window, and transferring the size and the position of the tracing window for a corresponding step.

24. A system for creating a 3D effect of an image formed on a display device surface, the system simultaneously providing at least effects of binocular parallax and motion parallax and comprising:

- at least one display device configured to display a sequence of images;

- at least one pair of glasses configured to provide stereoscopic separation of images, the glasses comprising at least two optical shutters and at least two markers disposed in a predetermined way;

- at least two optical sensor arrays configured to obtain pictures of the markers and disposed in a predetermined way;

- at least two reading and processing devices configured to read data from the optical sensor array and to determine 2D coordinates of the markers;

- a marker 3D coordinates calculation device configured to calculate 3D coordinates of the markers based on the 2D coordinates of the markers;

- at least one marker coordinates prediction device configured to extrapolate coordinates of the markers so that effective overall delay does not exceed 5 ms;

- a 3D scene formation device configured to form a 3D scene considering the 3D coordinates of the markers;

- at least one image output device configured to output the 3D scene image to the at least one display device.

25. The system of claim 24, wherein the markers are light emitting markers.

26. The system of claim 24, further comprising at least one tracing window control device configured to determine an area of the optical sensor array for reading data therefrom, depending on position of a picture of at least one of the markers, wherein size of the area of the optical sensor array is less than size of the entire frame of the optical sensor array.

27. The system of claim 24, further configured to calibrate viewer tracking means comprising the markers, the optical sensor arrays, the reading and processing devices and the marker 3D coordinates calculation device.

28. The system of claim 24, further configured to automatically detect interfering emission sources and to exclude effect thereof on detection of the markers.

29. The system of claim 24, further comprising a synchronization device configured to provide synchronization of the optical sensor arrays with each other.

30. The system of claim 25, further comprising a synchronization device configured to provide synchronization of the optical sensor arrays with each other and with the markers.

31. The system of claim 25, further comprising at least one first communication device, wherein the glasses also comprise at least one second communication device, the system configured to selectively switch the markers on and off.

32. The system of claim 24 or claim 31, further comprising a marker identification device configured to determine if a marker belongs to a certain device, based on data obtained from the at least two optical sensor arrays.

33. The system of claim 24, wherein the marker coordinates prediction device is configured to extrapolate the 2D coordinates of the markers.

34. The system of claim 24, wherein the marker coordinates prediction device is configured to extrapolate the 3D coordinates of the markers.

35. The system of claim 24, comprising at least three optical sensor arrays, at least three reading and processing devices and at least three tracing window control devices.

36. The system of claim 24, further configured to display three-dimensional objects for more than one viewer.

37. The system of claim 24, further configured to start processing data obtained from the optical sensor array before reading a frame is finished.

38. The system of claim 24, further configured to process data obtained from the optical sensor array in the at least two reading and processing devices in a distributed manner.

39. The system of claim 24, wherein the at least two reading and processing devices are configured to determine 2D coordinates of the markers with subpixel accuracy.

40. The system of claim 24, wherein the glasses comprise at least one second radio communication device.

41. The system of claim 40, wherein the glasses comprise at least one orientation device comprising at least one of the following devices: an accelerometer, a magnetometer, a gyroscope.

42. The system of claim 41, further comprising at least one first radio communication device and configured to use data obtained from the orientation device of the glasses via the first and second radio communication devices for determination of the 3D coordinates of the markers, when determination of the markers by the optical sensor arrays is impossible.

43. The system of claim 41, further comprising at least one first radio communication device and at least one tracing window control device configured to determine an area of the optical sensor array for reading data therefrom, wherein size of the area of the optical sensor array is less than size of the entire frame of the optical sensor array, and configured to use data obtained from the orientation device of the glasses via the first and second radio communication devices for determination of a size and position of the tracing window.

44. The system of claim 24, further comprising at least one manipulator.

45. The system of claim 44, wherein the manipulator comprises at least one marker.

46. The system of claim 25, further comprising at least one first radio communication device and at least one manipulator.

47. The system of claim 46, wherein the manipulator comprises at least one marker.

48. The system of claim 47, wherein the manipulator comprises at least one second radio communication device.

49. The system of claim 48, further configured to selectively switch the markers on and off.

50. The system of claim 48, wherein the manipulator comprises at least one orientation device comprising at least one of the following devices: an accelerometer, a magnetometer, a gyroscope.

51. The system of claim 50, configured to use data obtained from the orientation device of the manipulator for determination of 3D coordinates of the markers, when determination of the markers by the optical sensor arrays is not possible.

52. The system of claim 50, further comprising at least one tracing window control device configured to determine an area of the optical sensor array for reading data therefrom, wherein a size of the area of the optical sensor array is smaller than a size of the entire frame of the optical sensor array, and configured to use data obtained from the orientation device of the manipulator for determination of a size and position of the tracing window.

53. The system of claim 25, wherein the markers are configured to emit IR light.

54. The system of any of claims 24, 25, 45, 47, wherein the optical sensor arrays are equipped with narrow-band optical filters.

55. The system of any of claims 24, 25, 45, 47, wherein the markers are equipped with narrow-band optical filters.

56. The system of claim 31 or 49, further configured to generate a luminosity map when the markers are switched off, in order to automatically detect interfering emission sources and to exclude effect thereof on detection of the markers.