Research Article

INFLUENCE OF MARKER ARRANGEMENT ON POSITIONING ACCURACY OF OBJECTS IN A VIRTUAL ENVIRONMENT

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Abstract

The paper presents results of studies undertaken by the authors, aimed at determination of character of influence of marker arrangement on real-time measurement of position and orientation of an object, using an exemplary optical tracking system PST-55. Such a system can be used for interaction in immersive Virtual Reality applications. To ensure better immersion of a user in a virtual environment, it is necessary to directly translate its actions into 3D image presented by the VR application. It is possible, among other things, by the application of systems for tracking user's movements. During the presented studies, an object with infrared-reflective markers deployed on its surface was placed in the center of a rotary table, then it was measured by the tracking system to determine the influence of the object angular position on the accuracy of determination of its position and orientation by the examined device. The measurements were performed for several different arrangements of markers, to formulate guidelines for their deployment on objects used for work in a virtual environment.

Keywords: marker arrangement, positioning, virtual environment.

INTRODUCTION

Along with an increase of the computing power of computer processors and the performance of the graphical processing units, there is a huge development occurring in the branches of computer graphics, visualization and simulation using Virtual Reality. Because of very high costs of highly effective computer equipment in terms of performance, the simulators have been mostly used for military purposes in the early years. As the technology was developed, the hardware prices were gradually dropping and the simulations aided by VR have started to be widely used for entertainment, professional trainings (especially concerning medicine [1]), in some industry branches [2], specialized education and foreign language teaching [3].

The studies performed on an early stage of development of the Virtual Reality systems prove, that immersion of a user in an artificially prepared reality allows subconscious acquiring of certain competences [4]. This phenomenon is used, among other things, for curing phobias, including arachnophobia [5] or in trainings with application of Virtual Reality, especially in design and prototyping of new workplaces [6]. To achieve a state of immersion, it is necessary to engage as many senses of a user in interaction with the virtual environment as possible.

Sight is a fundamental sense for humans and it is used as a base for all immersive applications. Visual stimuli are usually supplemented with the aural and tactile sensations. The effect of immersion in the Virtual Reality is easier to achieve, if the image perceived by the user is affected by movement of the user's head or other limbs in space, in real time. The studies performed worldwide indicate that allowing a user to interact with the virtually created environment and accurate

representation of his real movements directly affects effectiveness of the conducted training [7]. Systems for tracking user's movements allow the tracking of selected points (markers) on a human body or an object used by a human to interact with the virtual environment. The tracking information is usually composed of position and orientation data. More realistically tracked objects are present in the virtual environment, the higher immersion level can be achieved.

The aim of the presented studies was to examine the accuracy of a selected tracking system. During the studies, the authors made an attempt at determination of character of influence of marker arrangement on a tracked object on a real-time measurement of position and orientation of an object, using an exemplary optical tracking system PST-55.

THEORETICAL INFORMATION

Classification of tracking systems

There are many available tracking systems and they are very much diversified if it comes to operational parameters and purchase costs. It is possible to divide the tracking systems regarding the principle of their operation. The following systems can be distinguished:

1) Mechanical tracking systems – they usually use sensors arranged in a kinematic structure [8]. The mechanical tracking systems include accelerometers and gyroscopes. An example of a mechanical tracking system is the InertiaCube2, a system based on a professional accelerometer. Another example is a prototype of a device for tracking user's shoulder and elbow joints in real time, built in Laboratory of Virtual Design of Chair of Management and Production Engineering of Poznan University of Technology [9]. It reads basic movements of the arm and additionally it is equipped in buttons and a joystick allowing more advanced communication with the Virtual Reality software applications. In such devices, angular measurement is of main focus – it can be realized using various converters, such as potentiometers, optical, magnetic or capacitive encoders or resolvers. The advantage of these systems is their independence on any base – they usually do not have a limited work area.

2) Acoustic tracking systems – the acoustic systems work on the basis of the detection of sonic waves. All the acoustic systems available on the market emit ultrasonic impulses, which allow to determine the tracked object position thanks to known velocity of sonic wave propagation in a given medium. Calculations of time needed for the ultrasounds to travel to the sensors are performed in real time and the position is determined. In most cases, the sensors are installed in a certain points of the measurement space, while the ultrasound wave emitter is put on a tracked object [10].

3) Electromagnetic tracking systems – they measure a local magnetic field vector using a magnetometer, or they are based on changes of current induced in an electromagnetic coil during a change of magnetic field through the winding. Three magnetic sensors perpendicular to each other, placed in one frame can be used to generate a 3D vector indicating orientation of the sensor regarding the field emitter. It is possible to use both the magnetic field generated by Earth and active source of the magnetic field, consisting of many coils. Thanks to the induction of field on particular coils in a strictly defined order, it is possible to determine a position and orientation of the tracked object in relation to the source [10]. The ferromagnetic materials and conducting materials in the environment can influence the shape of the magnetic field. The eddy currents caused by a changing magnetic field can lead to improper determination of position and orientation of an object. This problem can be eliminated by the removal of elements that can influence the system operation. An example of a magnetic tracking system is the Polhemus Liberty, which allows to track an object in six degrees of freedom. It is composed of a main unit (a converter), four (or more) signal receptors connected to the main unit and active source of the magnetic field – a marker. A disadvantage of this system is its high susceptibility on disturbances caused by metal objects present in the work area, the weight and size of markers installed on or inside the tracked objects. An advantage of this type of tracking systems is no need of visual contact between markers and receptors – a user equipped with a marker can be even behind a wall, as long as he is inside the receptor's field of detection and no metal objects are present between him and the receptor.

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4) Optical tracking systems – they are based on visual object recognition, usually on base of an image from two or more cameras. This type of tracking system was used in the studies presented in the paper. Optical systems can make use of markers (active or passive / retroactive) or be markerless – recognize the object or the user on the basis of some more complex algorithms. An example of a tracking system working without markers is the Kinect system made by the Microsoft company. In this device, both the infrared light, bouncing from the tracked object (a human body) and the visible light recorded by a standard camera is used. The digital camera detects the user's posture, while the infrared detector helps to calculate the distance from the device. The optical systems tracking positions of an object on the basis of light emitted by a single diode or reflected by the marker are able to track only the position of the object, without determination of its orientation (angular position) regarding the assumed coordinate system. In case of application of two or more markers (or detected points) together, it becomes possible to detect also the angular position of the whole set (arrangement), provided that the mutual positions of the markers do not change during the whole tracking period. It allows tracking both the position in XYZ axes and the rotation around these axes. The more markers put together in a fixed arrangement, the more stable and accurate is the real-time measurement. The markers, especially the passive ones, usually have small weight and size, thanks to this they do not cause discomfort during use.

For the studies, an optical tracking system was selected with possibility of tracking both the single markers and the whole arrangements, put together in any defined set of positions. This allowed to determine if the placement of the markers on an object and shape of the object has an influence on its recognition by the tracking system and the accuracy of measurement of its linear and angular position.

Characteristics of the selected tracking system

During the studies, an optical tracking system PST-55 was used, from the PS-Tech company. The device is equipped with two infrared cameras and diodes emitting the infrared light. The diodes enlighten the scene, allowing tracking objects which reflect the infrared rays, even if other light sources are not present in the tracking area. The system is connected with a computer with a proper software installed via a RJ-45 network cable. The device allows tracking objects in a space of a pyramid shape (Fig. 1), which can be increased using several devices at once [11]. The dimensions of the tracking area can be changed by using a different lens size – in the device used in the studies, a lens of 4.5 mm was used.

The PS-Tracking software supplied by the device manufacturer is used for exchange of data between the device and a computer. The software allows, among other things, a preview of the camera image, which ensures the possibility of evaluation of visibility of markers (and whole objects) placed inside the camera detection area. If the markers are too close to each other, they are not
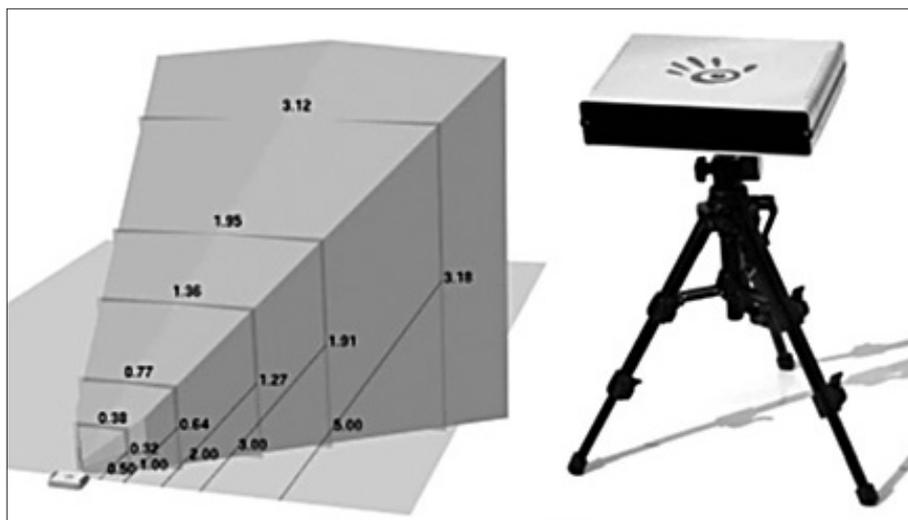
Fig. 1. Shape and size of tracking area of the PST device used in studies and the device view [11]

properly detected by the system, even if they do not physically contact each other. If possible, the markers should be placed on planar surfaces.

To make it possible to track the position of a selected physical object, it is necessary to arrange a set of markers on it. The markers are supplied by the producer in a form of round elements cut out of the infrared-retroactive tape. Their bottom side is covered with a self-adhesive. At least four markers must be placed on a selected object to allow the recognition of its position and orientation by the device. The arrangement must be recorded in the system and given a specific ID. The recording is realized by placing the object with markers in the work space of the tracking systems' cameras and then fluent rotation of the object to record all the markers. The process of implementation of an object to the system is simple and it can be performed quickly, if the markers are properly located. If the markers are placed incorrectly or the object is rotated too quickly, the tracking system will be not able to determine a relation between the newly recorded points and the points recorded in a previous step.

After implementing a marker arrangement to the system (Fig. 2), an ID (a unique name) needs to be assigned to the tracked object, as well as its ordinal number. After the recording (calibration) procedure, it is possible to correct the stored arrangement by the removal of improperly recognized markers.

It is necessary to make at least four markers visible to the device (both during recording and further use), if this condition is not fulfilled, the relation between the markers cannot be determined and the process of object recognition is immediately stopped.

STUDY DESCRIPTION

Tracked object characteristics

The presented studies are a part of the broader study, aimed at selection of the best software and hardware solutions for the medical Virtual Reality training application – simulation of the ultrasonic examination procedure. For the described studies, a modified version of the ultrasound examination device head was used. The real head was digitized using the technology of 3D optical scanning. The optical scanner Atos I from the GOM company was used for this process, of measurement area size of 125×125×125 mm.

The 3D scanning process applied to obtain a digital model of the real ultrasonic examination head is based on a structural light projected on a measured object. The light in form of stripes is deformed on a measured object, the deformation image is recorded by two (or more) cameras. The data are analyzed by the 3D scanner software and in a short time, a point cloud is generated out of each scan. Such a method of obtaining data is sufficient from the viewpoint of required dimensional and shape accuracy [13], but would be not available for use in the real time tracking due to complexity of calculation algorithms. A result of the measurement was a digital model in a form of a triangular mesh (generated automatically on the basis of the point cloud). On the basis of the mesh model, a solid model was prepared in a CAD system. Additional geometry was added to the original shape of the head, to allow the placement of additional markers for better recognition by the PST-55 system.

The digital model of the ultrasonic examination head was manufactured using the additive
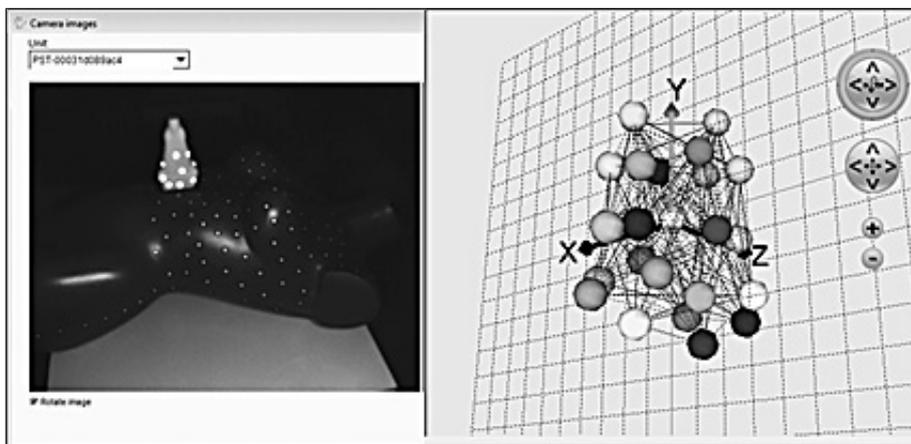
Fig. 2. View from the camera of the PST-55 system and recognized markers, seen in the system as points in space [12]

manufacturing technology of Three-Dimensional Printing (3DP). The model was manufactured in a layered manner, out of ceramic powder grains joined together by a liquid binding agent. The binding agent is deposed on the powder to form a specific section of the 3D model and the process is repeated until the model is finished. The obtained shape was then subjected to post-processing, in a 3-form of cleaning, manual grinding and infiltration using a polyurethane resin. The two parts of the head (the base and the additional marker surface) were manufactured separately and they were assembled together using a threaded connection. This modular structure allowed testing of different marker surfaces. The whole device was supplemented by installation of a button activated by the contact of the head with the surface of body examined during the simulated medical procedure. The device is presented in the Figure 3.

Methodology of the studies

The object was covered with the maximal possible number of markers, deposed in an experimental way (randomly), then the arrangement was implemented in the software and given a specific ID. The head was then placed on a rotary table, allowing rotation to an exact angular position, with accuracy of ±1°. The measurement system PST-55 was placed on a tripod in a distance of 1 m from the center of the rotary table. After setting a table in a specific angular position, the PST-55 system recorded the position and orientation of the measured object – the head. Total 5 measuring series for 12 positions were performed (each time the table was rotated by 30° clockwise). In each position, the data was recorded for two seconds

Fig. 3. Physical model of a modified ultrasound examination head, with the additional object – a surface for additional markers. Retroactive markers of the PST-55 system arranged on the basic and additional geometry

(the software allows a timestamp at each measurement, so the accuracy of time measurement was assured by the device itself), with frequency of the measurement set to 50 Hz.

For the reference, the measurements were also performed on a model object, supplied by the device manufacturer with the device. This object is a regular dodecahedron, with three markers present on each surface (Fig. 4). According to the producer, the markers on each surface are placed in unique sets of arrangements, not to confuse the system when recognizing particular surfaces and to increase precision of position and rotation tracking. The studies were performed in the same conditions.

To determine the influence of the distance to the measurement system on the measurement (tracking) results, the PST-55 system was placed in a distance of 2.2 m from the rotary table and the measurement procedure was performed again for both objects.

RESULTS

The results of measurements for each position were averaged. Then, on the basis of the gathered data, repeatability of measurements for each position was determined, with distance 1 m from the measurement system. The results – ranges (differences between maximum and minimum measurement deviation for a given angular position) are presented in Tables 1 and 2. Absolute measurements are not presented, as they are not important for the main purpose of the studies, which was to determine how different objects, with different marker arrangements are recognized by the system in varying positions and distances. The coordinate system consists of standard XYZ axes and Euler rotations defined in a standard way (heading, pitch, roll).

Fig. 4. A reference object – regular dodecahedron with the optical system markers, supplied by the PST-55 device manufacturer

Table 1. Range of results of measurement of the head object, measuring system 1 m from the object

Position	X range [mm]	Y range [mm]	Z range [mm]	Heading range [°]	Pitch range [°]	Roll range [°]
1	0.07	0.34	1.02	0.11	0.20	0.31
2	1.21	0.63	0.71	0.60	2.27	0.19
3	0.40	0.50	1.18	0.11	1.22	0.46
4	0.34	0.88	0.17	1.74	0.68	1.27
5	0.37	0.31	0.66	0.10	1.73	0.79
6	0	0	0	0	0	0
7	0.12	0.45	0.97	0.29	0.22	0.81
8	0.23	0.36	0.72	0.03	0.45	0.30
9	0.13	0.36	0.64	0.03	0.23	0.11
10	0.15	0.19	1.07	0.23	0.43	0.24
11	0.25	0.32	0.69	0.13	0.30	0.37
12	1.11	0.37	0.49	1.95	0.77	4.82

Table 2. Range of results of measurement of the model object (dodecahedron), measuring system 1 m from the object

Position	X range [mm]	Y range [mm]	Z range [mm]	Heading range [°]	Pitch range [°]	Roll range [°]
1	7.69	14.12	7.93	42.56	20.61	133.00
2	6.45	7.49	1.48	30.25	87.60	138.40
3	3.81	4.73	2.73	102.91	35.75	112.23
4	6.20	5.99	3.21	127.33	5.29	66.96
5	0.13	0.03	0.11	0.03	0.16	0.11
6	1.42	5.51	2.25	83.33	18.91	89.21
7	1.58	2.40	1.68	21.75	74.20	89.86
8	5.26	6.61	2.74	43.74	57.54	136.03
9	0	0	0	0	0	0
10	3.81	2.20	1.20	42.04	32.12	132.33
11	10.40	8.06	5.81	72.12	68.54	122.56
12	4.78	3.90	1.72	72.34	47.61	174.36

A range of zero (recorded in certain cases in the Table) means that with a given angular position, position and orientation of the object was not recognized by the system. Such a situation happened for the ultrasonic examination head after rotation of 180° to the original position, for the model object – after rotation of 270° to the original position. Observed differences in the measurement repeatability both for position and orientation of both objects are significant. The model object supplied by the device manufacturer is recognized in a far worse manner than the object built by the authors for the purpose of the study.

The measurements were repeated after moving the tracking system to a 2,2 m distance from the measured objects. The results, in the same form as for the 1 m distance, are presented in Tables 3 and 4. The measurement results are in-conclusive – in case of the head, the measurement repeatability improvement is clearly visible, but for two angular positions the system was not able to recognize the marker arrangement. Detection and repeatability for the dodecahedron generally improved in comparison with the 1 m measurement distance (the object was recognized at all positions), but it is still much below the acceptable range of values.

CONCLUSIONS

The study results are much different than general expectations. The single PST-55 device is not able to correctly recognize all positions and orientations of a single object in space. It can result with an incorrect determination of position of an object in a virtual space, which could lead to

Table 3. Range of results of measurement of the head object, measuring system 2.2 m from the object

Position	X range [mm]	Y range [mm]	Z range [mm]	Heading range [°]	Pitch range [°]	Roll range [°]
1	0.05	0.04	0.07	0.05	0.04	0.07
2	0.12	0.08	0.12	0.12	0.08	0.12
3	0.23	0.26	0.20	0.23	0.26	0.20
4	0.05	0.25	0.05	0.05	0.25	0.05
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0.02	0.07	0.11	0.02	0.07	0.11
8	0.05	0.08	0.02	0.05	0.08	0.02
9	0.31	0.11	0.26	0.31	0.11	0.26
10	0.05	0.04	0.11	0.05	0.04	0.11
11	0.04	0.02	0.09	0.04	0.02	0.09
12	0.06	0.07	0.05	0.06	0.07	0.05

Table 4. Range of results of measurement of the model object (dodecahedron), measuring system 2.2 m from the object

Position	X range [mm]	Y range [mm]	Z range [mm]	Heading range [°]	Pitch range [°]	Roll range [°]
1	7.86	7.35	4.90	79.37	68.41	176.08
2	3.69	2.82	1.08	107.13	37.86	173.57
3	12.01	5.00	6.48	71.01	42.28	131.33
4	9.35	4.85	6.25	73.10	69.16	152.79
5	2.00	8.16	5.11	80.41	13.19	98.89
6	3.94	7.09	3.48	16.69	81.05	93.03
7	3.70	2.52	3.73	23.30	105.32	136.31
8	10.9	7.37	9.71	53.13	24.73	98.28
9	6.80	10.87	2.27	44.19	7.10	107.49
10	3.75	4.782	3.32	61.67	58.64	111.65
11	4.98	1.60	4.10	24.20	71.52	120.90
12	5.59	1.70	2.41	99.94	1.94	22.32

negative sensations of a user and decrease in the immersion effect. This problem could probably be solved by using additional devices to track the same object and synchronize the positions of the tracked points.

For the object prepared by the authors, with a random arrangement of markers, the measurement accuracy and repeatability is good. Most recorded deviations do not exceed 1°, which is generally an acceptable value for the immersive Virtual Reality simulations and for this class of devices (the PST-55 system is generally considered as a low-cost device). However, for the model object (originally supplied by the device manufacturer), the recognition is far below an acceptable level. The angular position deviations as high as 176° allow concluding that the measurement system was not able to detect the marker arrangement properly and that the whole object was

recognized as flipped by 180° (dodecahedron is symmetrical, so this is possible). The same situation happened for most of the recorded positions. It is probably caused by the marker arrangements on the side surfaces of the dodecahedron not being unique, which leads to the system recognizing the wrong surfaces and determining the position of the whole object in a wrong way. Increase of distance from the measurement system helped to recognize the model object in all the positions, but it did not improve the measurement repeatability, as opposed to the head object, where the repeatability was improved after increasing the measurement distance.

The whole study allowed concluding that an effective methodology of arranging optical markers on objects needs to be prepared, to obtain proper detection of the arrangement and repeatable and accurate measurement of position and

orientation of the tracked object. Further studies are planned in this topic by the authors, including both measurements and practical use of different shapes and marker arrangements.

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