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3D object data acquisition and processing for virtual reality applications

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The general concept of 3D data acquisition and processing system which enables us gathering information about shape, morphing, and movement of 3D object for virtual environment is presented. The methodology based on combined structured light, spatio-temporal phase analysis, and photogrametry is described. For virtual reality the concept of a virtual camera, as the mean for interactive object visualization is introduced. The exemplary initial results of implementation of such a system are presented.

Keywords: 3D shape measurement, digital fringe projection, spatio-temporal fringe pattern analysis, movement trajectories, virtual reality.

1. Introduction

Recently, one of the biggest challenges in multimedia technologies is to create fully interactive virtual reality (VR) systems [1]. This requires generating numerically or even better gathering real data about static or dynamic 3D objects and scenes and delivering them to virtual reality environment [2]. In VR, the observer can move around and select a vantage point from which to view the image. Currently, three different systems provide limited 3D interactive content [1], still object imagery, 3D freeze-and-rotate-effects, and true 3D video.

The still object imagery is based alternatively on a digital-image set or 3D polygonal models. The digital-image set method [3] captures a large set of digital images of a given object viewed from different viewpoints. The user intuitively selects between these views. View controls that include panning and rotation along the horizontal and vertical axes further the 3D illusion. However, this method is based on 2D images and in order to provide truly realistic 3D imaging the system requires numerous views and therefore the file size becomes unmanageably large. A second still object imagery method uses computer graphics algorithms [4] or experimental-optical data acquisition and numerical conversion methods [5] to build 3D polygonal models of 3D objects, then pastes texture maps onto these objects' surfaces. This 3D polygonal model can be rendered from arbitrary viewpoints and file size remains relatively small. However, the numerical models often look artificial or plastic because the texture maps and limiting lighting effects do not accurately represent the surface appearance from all angles. That is the reason why the experimental methods of gathering data about 3D objects in the form of cloud of co-ordinate points have become so popular [6].

Visualization of 3D still objects is not sufficient, yet. The real challenge is to create 3D video [1]. In movies and television shows it is usually realized by 3D-freeze-and-rotate method. At a particularly significant moment, the action freezes and the viewpoint rapidly rotates around the action's centerpiece. This can be performed by arranging many cameras, spaced at close intervals that are along the desired viewpoint trajectory. Playing back the images from each camera, one after another, creates a limited 3D effect. However, synthesizing interpolated images requires vast processing power and hours of human intervention. There are also attempts to produce a live 3D object monitoring by using multiple of robotic camera mounts slaved to track the motion of a single camera operator. Here, no image interpolation is performed in order to provide real-time visualization. Unfortunately, this method resulted in an image distorted by vertical motion, zoom-calibration errors and repeated a few degree jumps as the viewpoint is shifted to each successive camera.

The most recent attempts focus on creating true 3D video (presented e.g. by virtual viewpoint) in which a viewer can move through the captured scene in both time and space [1]. The essential constrain in such a scenario is that the foreground content is physically separated from the background which does not move and changes color or brightness. For this type of system the cameras are spaced around the capture space and calibrated precisely. Because the scene's 3D structure is known, the system can combine multiple live or pre-recorded 3D video streams in real time and insert them into computer graphics based virtual environment. The system can combine the video stream data with other virtual reality technology such as head-mounted display, CAVE automatic virtual environment system or

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teleimmersion [7], to insert humans or other 3D objects with real appearance into the virtual environment.

This concept of true 3D video reported above is based on capturing 2D images from multiple directions which in consequence creates a limited 3D effect. Much better solution is to capture 3D data representing the shape and texture of real 3D object and transferring them into virtual reality environment. The general concept of methodology and system realizing this task is presented in Section 2 of this paper. It describes also the roles of the main modules of the system including measurement, processing, and virtual environment modules. The method of gathering data about static and variable in time 3D object are presented in Sections 3 and 4. The initial experimental-numerical results of 3D data capture and transfer realized in the proposed set-up are presented in Section 5. Finally, the remarks (Section 6) on the further works required for creating fully interactive true 3D video combined with virtual reality environment are given.

2. General concept

The basic novelty of the proposed true 3D video relies on the usage of an optical 3D object measurement system based on active fringe projection method [5–7] supported by photogrametry [8]. Measurement system provides the sets of data including:

- cloud of co-ordinate points representing 3D static object seen from multiple directions (x,y,z),
- texture of 3D object (R,G,B),
- trajectory(ies) of the rigid body motion of the object or its parts (also trajectory of an arbitrary object point),
- 3D shape modifications (morphing) of an object or its actual shape in the form of cloud of co-ordinate points (x,y,z).

The general scheme of the true 3D video system is shown in Fig. 1. It has modular structure which includes:

- measurement module which consists of N sets with digital light projector (DLP) and two cameras. Each of sets captures original stereo-pair images of an object and a set of object images with fringes and Gray code projected by DLP as seen from single direction. N measurement sets cover full hemisphere field of view and enable us to capture the data from multiple directions,
- processing module which:
  - for static objects, converts the intensity images (original and with projected fringes) into the cloud of points with texture (x,y,z,R,G,B). The clouds of points gathered by sets from N directions are merged in order to provide true 3D data. Then, they are converted into triangle mesh with or without texture [9,10]. This true 3D object representation is loaded into virtual environment in which it can be visualized.
  - for objects, variable in time, the module calculates actual position of markers within the measured volume (from the stereo-pair images). These values form a movement trajectory of any marker located at the object. If the marker is situated at non-morphing part of an object, the rigid body motion is determined. Combining these data with spatio--temporal phase analysis concept enables us to monitor and calculate the actual shape and its variation of any morphing object [8,11].
  - virtual environment module which provides the VR scene and includes the virtual camera due to which the proper interactive visualization of 3D data is realized [12]. In order to provide interactions between the user and 3D objects placed in VR environment, the system includes the feedback loop between measurement and VR modules. It returns information about the position and offers parameters of virtual camera which are chosen by the interactive user of the system.

Modular structure of the system enables us the division of the data gathering, processing and visualization process into three main parts and provides an effective use of three computers stations connected by fast links. The variable streaming between processing module and VR module enables us visualization at different levels of quality (amount of processing data) depending on the computational resources of the outside (remote) user's computer and the type of object and its movement/morphing (rigid body motion only, morphing of whole or parts of an object).

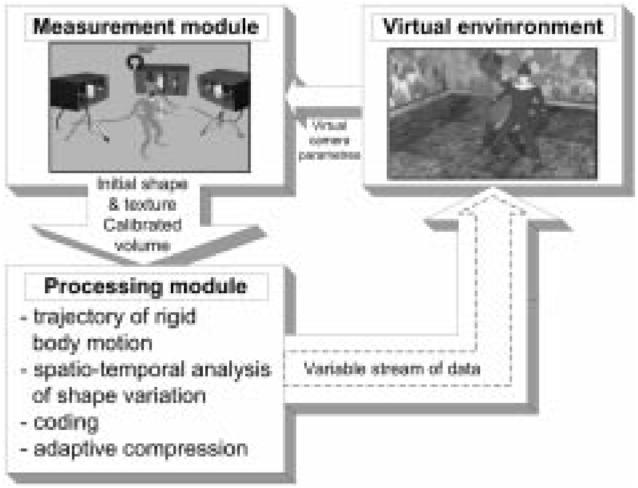


Fig. 1. General scheme of 3D data acquisition and processing system for virtual reality applications.

True 3D object measurement system provides enormous amount of data about object shape and texture. However, the information required for visualization in virtual environment at any moment t_i is limited to these data points which are seen from the chosen viewpoint. A virtual camera (VC), placed at this point is the essential element of the system presented. Data taken for real-time processing are limited to the points which are included in the solid angle determined by the virtual camera. Due to the key-role of the measure-

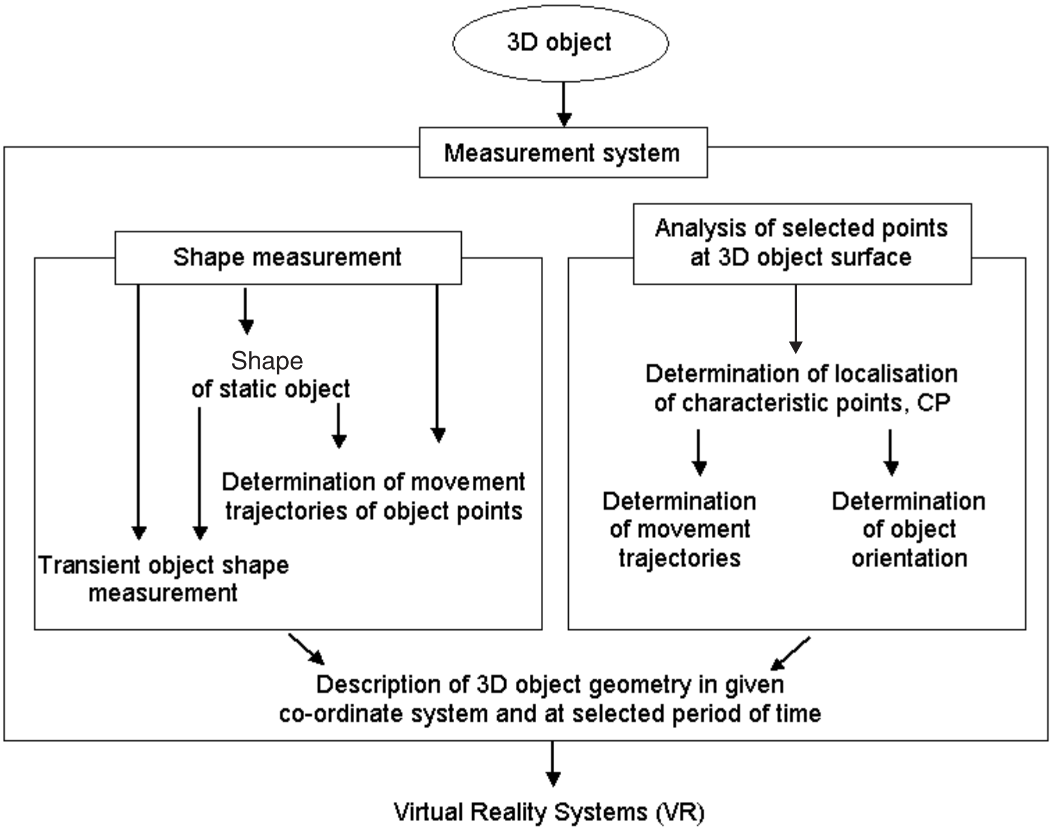


Fig. 2. Scheme of 3D object shape, morphing, and localization measurement process.

ment module, the special attention is paid to the methodology of 3D object analysis, its changes both object localization and its orientation. The general scheme of a measurement process, which includes the most possible measurement paths, is presented in Fig. 2. The below descriptions of the main modules, which rely on variety of measurements paths and the rules of their operation are presented together with the experimental-numerical results of 3D data capture, data processing and transfer realized in the proposed system.

3. True 3D shape measurement of static object

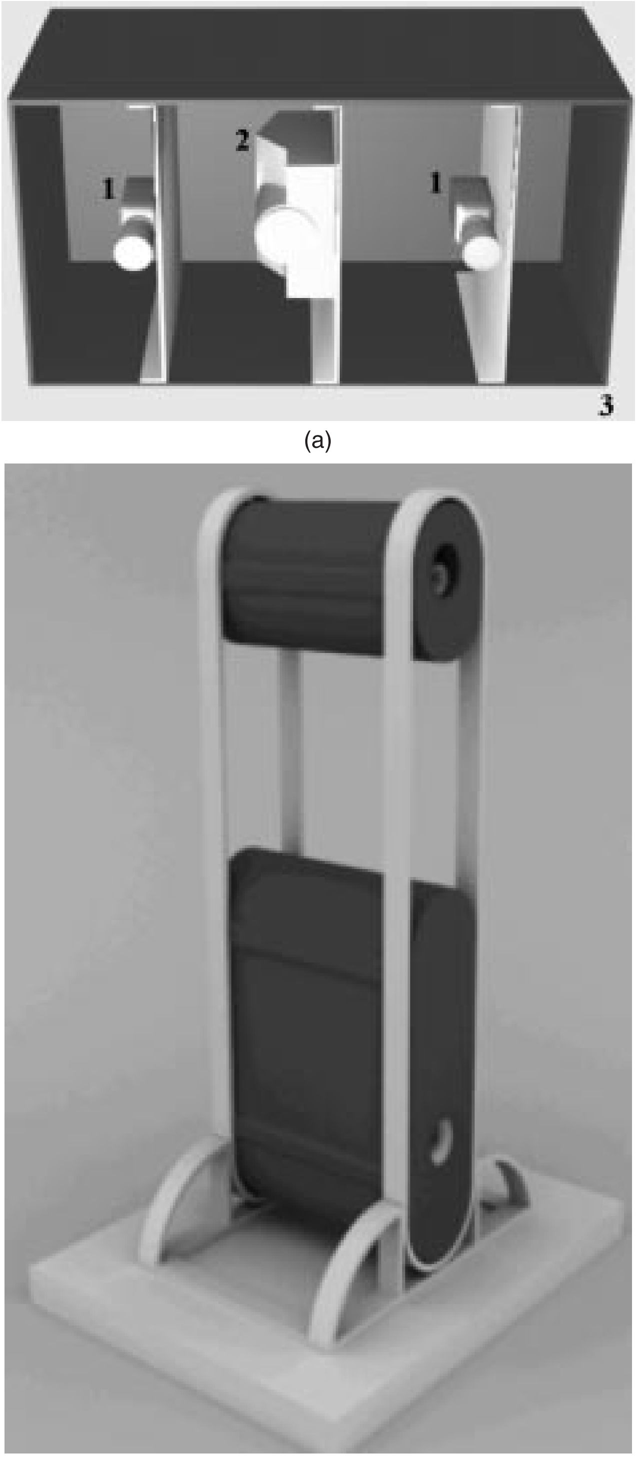
The true 3D measurement system is built with commercially available instrumentation. To realize full hemisphere measurement, N directional modules are situated around the measurement volume [9]. Each of them consists of digital light projector (DLP), two CCD cameras, and a fixing frame (see Fig. 3). Additionally, they are equipped with calibration and processing modules. The measurements are performed according to the main assumptions:

- phase measurement is based on fringe/Gray code projection method,
- (x,y,z,R,G,B) co-ordinates calculation is based on the pre-calibrated measurement volume,
- common co-ordinate system for all directional modules is determined experimentally,
- clouds of (x,y,z,R,G,B) points are converted into triangle mesh,
- the final triangle mesh of an 3D object (with or without texture) is fully transferred into VR environment and serves as the model for further modifications and visualization.

3.1. Directional 3D-measurement module

The DLP provides active projection of 2D patterns on the measured object. CCD camera is a common RGB camera with digital or analogue interface. The fixing ramp is constructed on the base of aluminium profiles. The actual geometrical configuration makes possible to work with measurement volumes up to $2\times2\times2$ m^3 (here for experiment the $1\times1\times1$ m^3 volume was calibrated). The knowledge about the parameters of the objectives in the DLP and CCD is not important and does not influence on the measurement accuracy.

Calibration module consists of a calibration model and its manipulator. Processing unit is an ordinary PC based computer with a set of several special cards, frame-grabber card (acquisition of CCD camera image), DLP pattern generator, and digital IO card (managing the manipulator of calibration model). The system works alternatively in the calibration and measurement modes. After each change in the geometrical camera-projector set-up, the system should be recalibrated. The system calculates the values of Cartesian co-ordinates (x,y,z) on the basis of calibration matrix which is generated in the calibration process.



(a)

(b)

Fig. 3. 3D shape measurement set-up for measurement from single direction: (a) the measurement set-up with 2 CCD cameras and (b) the photo of commercial version of system with single CCD camera.

The goal of the calibration is to create a calibration matrix on the basis of a measurement of the known geometrical model. Then, 3D co-ordinates can be easily calculated from the real object measurement by using the calibration matrix. The calibration process eliminates also the influence of aberrations coming from the camera and projector objectives.

The calibration matrix is a set of planes which are measured during the calibration process. Each of planes is the matrix represented by a set of points with six co-ordinates (i,j,Φ,x,y,z) calculated from fifteen images (5 phase-shifted line patterns with sinusoidal profiles, 9 Gray codes, 1 image of plane with markers) where:

- i,j are the pixel indices in a source image taken from CCD camera (i = 0,..., N; j = 0,...,M; $N{\times}M$ is the resolution of the CCD camera),
- Φ is the phase value calculated in (i,j) pixel,
- x,y,z are the Cartesian co-ordinates of (i,j,Φ) pixel, in the calibration matrix space.

The calibration is performed on the calibration model which is a plane with a set of identical markers located at a special translation stage. The central marker ($x = 0$, $y = 0$) is distinguished by size. The calibration process starts with placing the plane at the front of measurement volume. It represents the XY plane in the space of Cartesian co-ordinates of calibration matrix set for ($x,y,z = 0$). At the next step, the phase Φ is calculated (from sine patterns and Gray codes) for all pixels (i,j). Then, the image of calibration model is binarized and the positions of the markers' centers are determined. Next, the co-ordinates (x,y) for each pixel (i,j) are calculated using 3rd order polynomial interpolation between markers' centres. At the end, algorithm sets value z (position of calibration model) to all points in this virtual plane. The new calibration plane may be calculated and measurement volume grows. After saving a calibration matrix at a hard disk, the measurement volume is calibrated and new local set of co-ordinates is created. The (0,0,0) point in the real space is at the position of the ($x = 0$, $y = 0$, $z = 0$) point and it is stable as long as the geometry of the system is kept.

The goal of the measurement mode is to capture and calculate a shape of the object on the basis of a calibration matrix. The measurement mode includes the following stages:

- gathering data and calculating a cloud of the points (x,y,z),
- gathering data about (R,G,B) information.

At the first stage, the unwrapped phase Φ is calculated for each pixel (i,j) from a set of fourteen images including:

- 5 phase shifted deformed grid patterns with sinusoidal profile [Fig. 4(a)]; these images are used for determination of $\Phi(i,j)\mathrm{mod}(2\pi)$ by temporal phase shifting method [7],
- 9 Gray codes [Fig. 4(b)], these images provide data for hierarchical phase unwrapping procedure, i.e., $N(i,j)*2\pi$, where N is an integer value [2,10],
- 1 full white image for texture generation [Fig. 4(c)].

Then, the co-ordinates (x,y,z) are calculated for each pixel (i,j,Φ) according to the formula

(a) (b) (c)

Fig. 4. Set of sample images needed for calculation of a cloud of points: (a) sample sine pattern, (b) sample Gray code image, and (c) measurement object – Michael face.

$$(i, j, \Phi) \to (x, y, z), \quad z = Z(\Phi, i, j), \;\; x = X(z, i, j), \;\; y = Y(z, i, j), \tag{1}$$

where Z(Φ,i,j) is the best RMS fitted 5th order polynomial $z = f(\Phi)$ calculated from a calibration matrix for the pixel (i,j), $X(z,i,j)$ is the best RMS fitted linear function $x = f(z)$ calculated from calibration matrix for (i,j) pixel, $Y(z,i,j)$ is the best RMS fitted linear function and $y = f(z)$ calculated from calibration matrix for (i,j) pixel.

Figures 5(a), 5(b), and 5(c) show the exemplary clouds of the points (x,y,z) captured from various directions around the object with additional (R,G,B) information.

3.2. Full-hemisphere measurement system

The clouds of points presented in Fig. 5 are gathered by directional modules which are positioned in their own co-ordinate spaces. To merge these clouds, additional calibration of the directional modules, in respect to a model object, is required. This model is created from three spheres rigidly connected each other [Fig. 6(a)]. Each directional module measures the model and the centres of the spheres are calculated in the local co-ordinates. Next, the transformation matrixes are calculated to fit the centres measured from different views. Applying these transformation matrixes to the data captured in local co-ordinate system allow transforming them into a common co-ordinate space. Figure 6(b) presents the result of merging the local clouds of points into one resultant cloud of points with global co-ordinates.

To export the measured data of 3D object into virtual reality or computer graphics systems, a cloud of measurement points must be transformed into any format accepted by these systems. One of the most popular representations of 3D objects is a triangular mesh. In order to transfer the cloud of independent, not connected with others and not or-

(a) (b) (c)

Fig. 5. Exemplary clouds of points (x,y,z) captured from various directions around the object with additional (R,G,B) information.

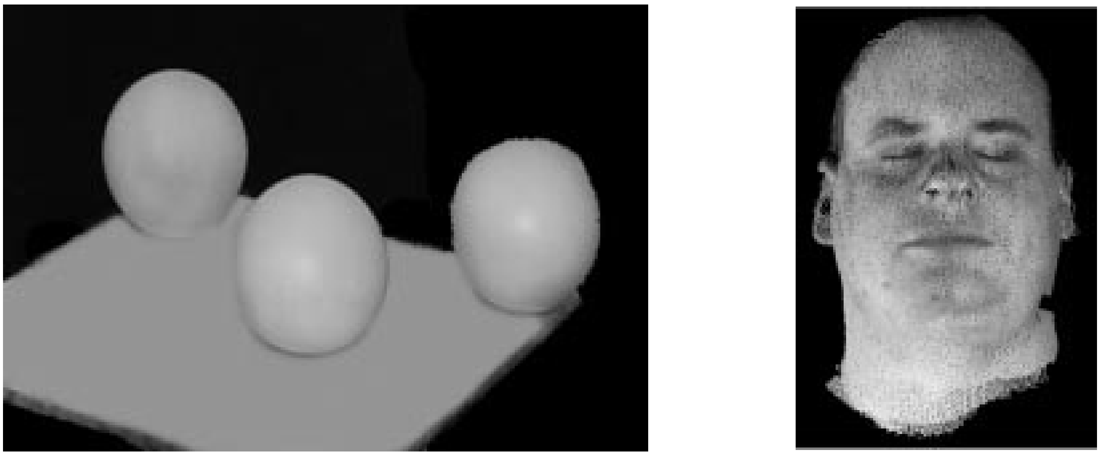


Fig. 6. Unification of the co-ordinates spaces of the directional modules: (a) calibration model and (b) merged cloud.

dered points (x,y,z) into a triangular mesh, the best fit algorithm based on the local least square method is applied. This algorithm requires setting some parameters which define the class of an object and the output mesh resolution. Values of these parameters may be modified by an end user and depend on an object, "a priori" knowledge about the accuracy of the measurement and an expected accuracy of the result.

These algorithm parameters are:
- size of the radius for experimental data interpolation (**SRI**),
- minimal number of points in a cloud indispensable to create one point of triangular mesh (**MN**).

The choice of parameters **SRI** and **MN** influence directly on the process of the reduction of measurement points and weight averaging of the values of the object co-ordinates.

For the measurement system, which allows to measure cloud of points with additional colour information there is a need to create a texture. Texture is a simple B/W or RGB image with only one requirement: the X and Y resolutions of the image must be a power of two. Texture has its own co-ordinates (u,v), each in the range (0,1) [11]. The result of triangulation procedure without and with added texture and performed on the cloud of points shown in Fig. 6(b) is presented in Figs. 7(a) and 7(b).

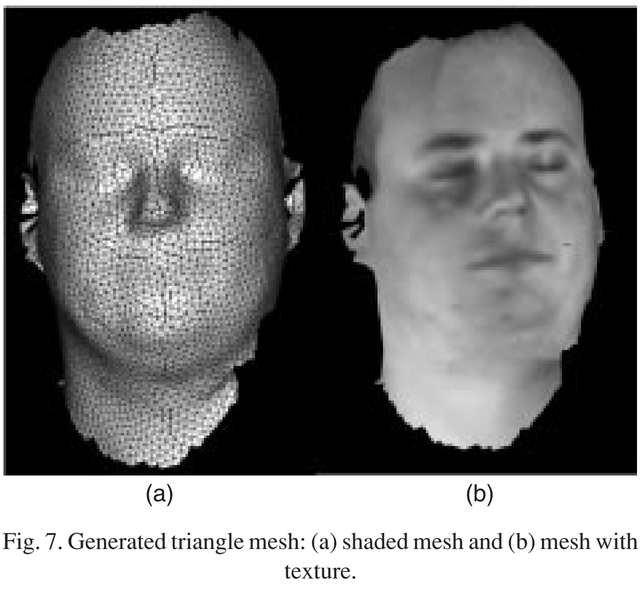


Fig. 7. Generated triangle mesh: (a) shaded mesh and (b) mesh with texture.

4. Analysis of variable in time objects

The system described in Section 3 (Figs. 1 and 2) is also used for monitoring and analysis of variable in time 3D objects. In order to optimise the stream of data used in VR environment, the system provides two types of data:
- movement trajectory of the markers placed at an object. If the markers are located at nonmorphing areas, they represent an object's rigid body motion,
- cloud of the points which represent the actual shape of an object seen from j-th direction and in t_i-moment of time. These clouds of points are compared with the static model (Section 2). Depending on the level of deformation, decision about visualization of modified or unmodified object representation is taken.

Below, the methodology of determination of movement trajectories is presented. Also two alternative methods of an actual shape determination are described including:
- colour fringe/Gray code projection [13] applied for an arbitrary 3D object,
- spatial heterodyning [8] applied for 3D objects with relatively low shape gradients.

The method, which should be implemented in the system, depends on a type of an object to be measured and actual hardware possibilities of the user. In general, the above methods provide measurements with lower accuracy when compared with a static object measurement (as described in Section 2). This is the reason why the static model is modified in the case of its variations in time only. If rigid body motion is detected, the static model is translated within the measurement volume according to the movement trajectories of at least three markers placed at the object.

The general equation of an image in CCD matrix plane analysed by spatial heterodyning and photogrametric methods is given by

$$I(x,y;t) = a(a,y) + b(x,y)\cos[2\pi f_0 x + \phi(x,y;t)] + \\ + \sum_{i=1}^{N} m(x - x_i, y - y_i; t) \qquad (2)$$

where $a(x,y)$ and $b(x,y)$ is a background and local fringe pattern modulation, respectively, f_0, is the spatial carrier frequency of the projected fringes, $\phi(x,y;t)$ is the phase directly connected with the object's coordinates at the given point, $m(x - x_i, y - y_i, t)$ is the intensity function of i-th marker located at an object.

As the fringe pattern is actively generated by the DLP projector, the spatial frequency of this pattern as well as its spectral content can be adjusted. This feature of measurement system is used for implementation of the measurement methodology selected.

4.1. Measurement of movement trajectories

The 3D co-ordinates of an object, treated as a rigid body, are calculated by photogrametric principles on the basis of the positions of markers (fiducial points) within the measurement volume of the system [8]. Markers are made of Schotchlite micro-prismatic material of highly directional reflectivity when properly illuminated. In the system (Fig. 2), each camera is equipped with a group of light emitting diodes that illuminates the markers. They are visible on the object surface as bright dots, regardless to the local intensity of the projected fringe pattern.

Determination of a movement trajectory of a rigid body motion requires monitoring of the position of at least three markers placed at an object before a measurement [8]. The use of three markers is necessary to calculate an orientation of an object within the measurement volume. If a trajectory of a selected point is required, it is sufficient to monitor a single point only.

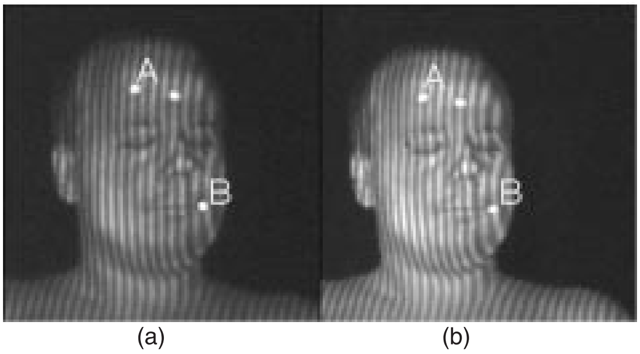


Fig. 8. Visualization of the detected fiducial points seen from two cameras: (a) left camera and (b) right camera view.

To calculate (x,y,z) co-ordinates of a marker, the images of an object are captured by two CCD cameras during a required time of measurement. Then, all saved images (Fig. 8) are searched for fiducial points. The regions that are recognized as fiducial point are flagged. The feature vector of an marker is defined by: region intensity, region size, intensity difference between the closest neighbourhood and the marked area, aspect ratio height to width and fill factor (height*width/number of points).

Each fiducial point recognized from the first saved frame is flagged with a unique identification number. The flagged regions are tracked in the sequential frames. Knowing the (x,y) position of a given marker at both camera planes and referring to the calibrated measurement volume of the system, (x,y,z) position of the given marker is determined.

The x and y co-ordinates of the markers A and B from Fig. 8 in sequentially saved frames are shown in Fig. 9. The A marker movement trajectory describes the rigid body (head) movement, while the path of B marker shows the movement of morphing point (mouth).

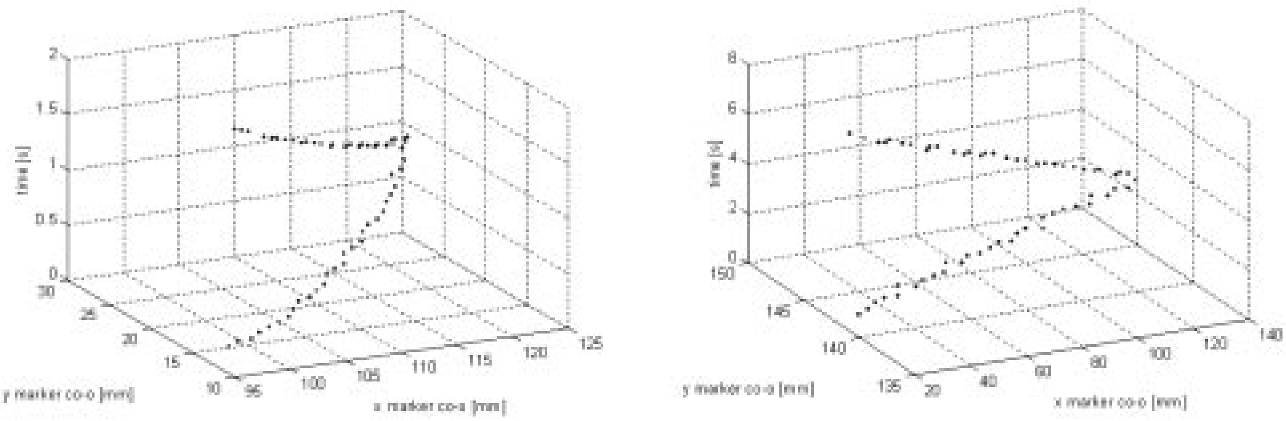


Fig. 9. Movement trajectory within the x,y plane in time of markers: (a) marker B and (b) marker A from Fig. 8.

4.2. Measurement of shape variations

4.2.1. Colour fringe/Gray code projection

The colour-encoded digital fringe and Gray code projection technique [13] presented in this section requires only one image to generate the 3D surface of an object with slowly varying slopes and three (or four) images to measure shape of an arbitrary 3D object.

The structured light requires capturing the multiply of images (often up to 15 images, see Section 3) to provide data for determination of non ambiguous (x,y,z) object co-ordinates. The redundancy of information, which until now was obtained by multiplicity of monocolour images, may be also introduced into spectral (colour) content of an image.

The principle measurement requires capturing of the following images:

- image with colour sine mask projection,
- images of colour Gray code masks projection,
- image of an object with uniform illumination,
- optionally, the image of an object with no illumination.

In the proposed procedure, the spatial phase shifting method SPSM [14] is implemented (Fig. 10). It uses three images algorithm based on the intensities captured simultaneously from the R, G, B channels of CCD colour camera. For the colour-encoded fringe pattern, three sine intensity distributions with $2/3\pi$ phase shifts are coded independently in RGB colour components. In such a case, each pixel (x,y) of CCD camera includes three intensity values. The colour sine pattern is created by summing R, G, B component of sine fringes. It follows that the single colour image includes three sine masks which are intensity distributions of colour components: red, green, and blue [Fig. 10(c)]. If the period of fringe pattern is represented by $3n$ pixels (where n is integer), the phase shift $2/3\pi$ is given exactly by n pixels and a phase is calculated accurately (no phase shift errors) by the formula

$$\phi(x,y) = \arctan\left(\frac{\sqrt{3}[I_B(x,y) - I_G(x,y)]}{2I_R(x,y) - I_G(x,y) - I_B(x,y)}\right)\text{s} \quad (3)$$

where $I_R(x,y)$, $I_G(x,y)$, and $I_B(x,y)$ are the intensity values of colour components R, G, B, respectively, in the current pixel (x,y).

In order to reduce the number of images, required to determine the continuous phase values and then the height (z-coordinate) of each object point, the colour-coded Gray codes are proposed. Any three Gray codes are recorded in one colour mask, i.e., each code is associated with different R, G, B colour component. This way of coding reduces the number of the projected images to 2. At first, the standard sequence of the modified Gray codes is formed and then the white colour is associated with one of colour components (RGB). Each colour is repeated for two sequential binary codes. Then, these three codes which have different colours are put together. In this way, two sequences of colour Gray codes arise. At the end, two colour images are created on the basis of these sequences. Finally, the colour Gray codes methodology makes possible to project six Gray codes in two masks [Fig. 10(d)]. The method with colour coded fringes seems to be best fitted to the requirements connected with measurements of variable in time 3D objects. However, the accuracy of shape determination is much lower and also the problems with analysis of colour objects occur [13].

4.2.2. Spatial heterodyning method

If the shape of an object does not include steep gradients or steps, it can be analysed by one of spatial heterodyning methods. Fourier transform (FT) or spatial

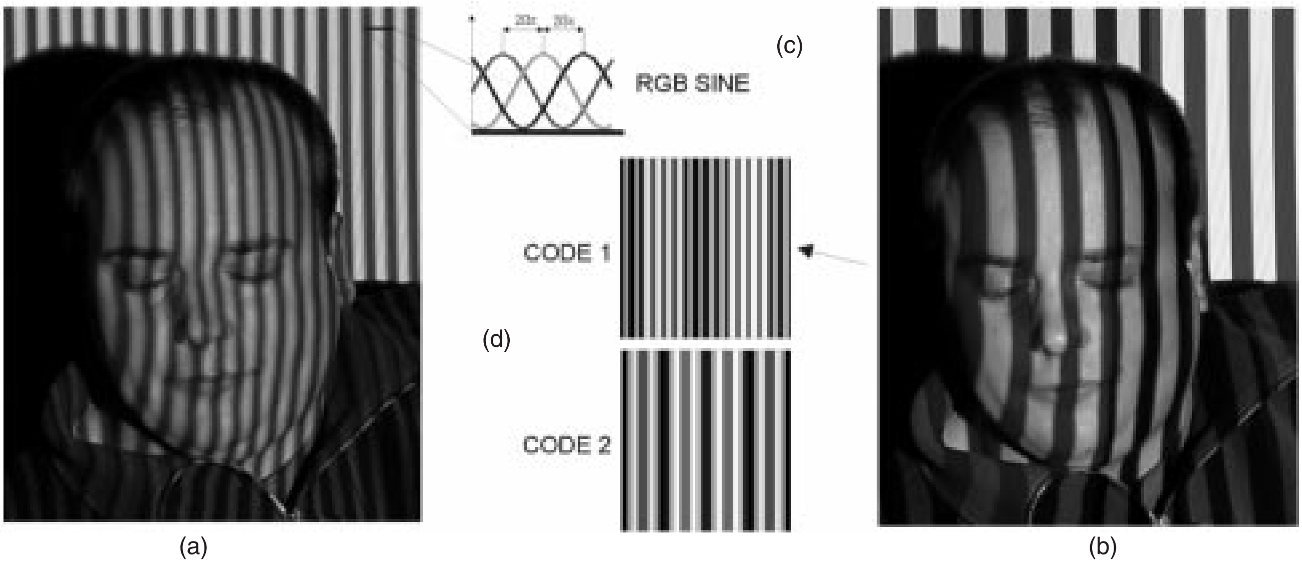


Fig. 10. Object with projected (a) colour sine fringes and (b) the first coloured Gray code. The additional figures show: (c) the mechanism of forming colour sine fringes and (d) two colour Gray codes.

carrier phase shifting (SCPS) techniques [14]. They require a single image for phase determination, so temporal variations of shape can be monitored in a video rate. The most suitable technique is SCPS, which is very simple, can be very easily automated and does not require significant computer power. The SCPS method delivers the relative phase map, which includes the information about the relations of height between object points. Such a phase is scaled by using the knowledge about the co-ordinates of fiducial points and basing on the calibrated measurement volume.

The shape calculation begins after a marker identification procedure. Then, a phase analysis of the fringe pattern images saved by CCD1 or/and CCD2 is performed by means of 5 point SCPS algorithm with the assumption of constant local derivative of phase [15]

$$\Phi(x,y) = \tan^{-1}\left(\frac{\sqrt{4[I(x-1,y)-I(x+1,y)]^2 - [I(x-2,y)-I(x+2,y)]^2}}{2I(x,y)-I(x-2,y)-I(x+2,y)}\right), \tag{4}$$

where $I(x,y)$ is the intensity at CCD camera co-ordinates (x,y), x, y defined in pixels.

With this algorithm, the higher phase gradients can be introduced and the higher accuracy results obtained. Due to the periodic properties of cosine function, the phase reconstructed from Eq. (4) is in the form of mod2π [Fig. 11(a)]. The phase map mod2π is later unwrapped by a modified quality-guided path following the algorithm [8]. The unwrapped phase requires subtracting the known linear phase term $2\pi f_o$ and a proper scaling. As a result, the relative shape map is obtained [Fig. 11(b)].

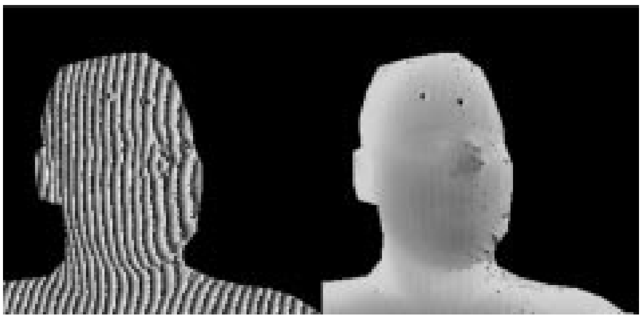

(a) (b)

Fig. 11. Main steps in a process of shape map calculation: (a) wrapped phase mod2π, and (b) resultant unwrapped phase map.

The spatial heterodyning fringe pattern analysis method is a very convenient tool for shape variations monitoring, however, it provides the co-ordinates with high noise and may suffer significant error when too big gradients of shape occur.

5. Visualisation of 3D object in VR environment

True 3D object measurement system (N sets) provides enormous amount of data about object shape and texture. However, the information required for visualization in virtual environment at any moment t_i is limited to these data points which can be seen from the chosen viewpoint. A virtual camera VC, placed at this point, is an essential element of the system presented. Data taken for real-time processing are limited to the points which are included in the solid angle determined by the virtual camera.

The information about VC position and parameters is distributed in form of matrix VC [Figs. 2 and 12(b)]. The matrix VC consists of co-ordinate of the camera point position **PP**, co-ordinate of the target point **TP**, the vector of view angle (α,β,γ), and the vector of rotation [Fig 12(b)].

The general concept of the system is based on the following rules:

- system visualize the essential information about an object's geometry,
- selection of data points is performed on the basis of information about the virtual camera location,
- constant interaction between a measurement system and virtual environment is required.

The true 3D video system requires vast data processing. It is realized through three main processing steps. The first one is responsible for controlling of measurements and a preliminary preparation of data and it was described in Sections 3 and 4. In the second step, the system selects the data seen by the virtual camera and performs their further reduction and coding. Significant reduction of transferred data is performed for the objects (or their parts) which are not subjected to deformation. In such a case, the movement trajectories of minimum three fiducial points are transferred only and the properly shifted and rotated model of static object is visualized. If a shape of an object has changed, the information about the modified cloud(s) of points has to be specifically coded and compressed [12] in order to allow real-time visualization of the modified object seen by the virtual camera. The general scheme of data processing required to visualize 3D data is shown in Fig. 12(a). Below, we present the initial capabilities of the system showing a role of virtual camera by visualization of an object seen from different view points (Fig. 13) and static model modification by implementation of data about variable segments of an object (Fig. 14).

6. Conclusions and future works

In the paper, we have proposed the general concept of true 3D video system based on capturing 3D clouds of points

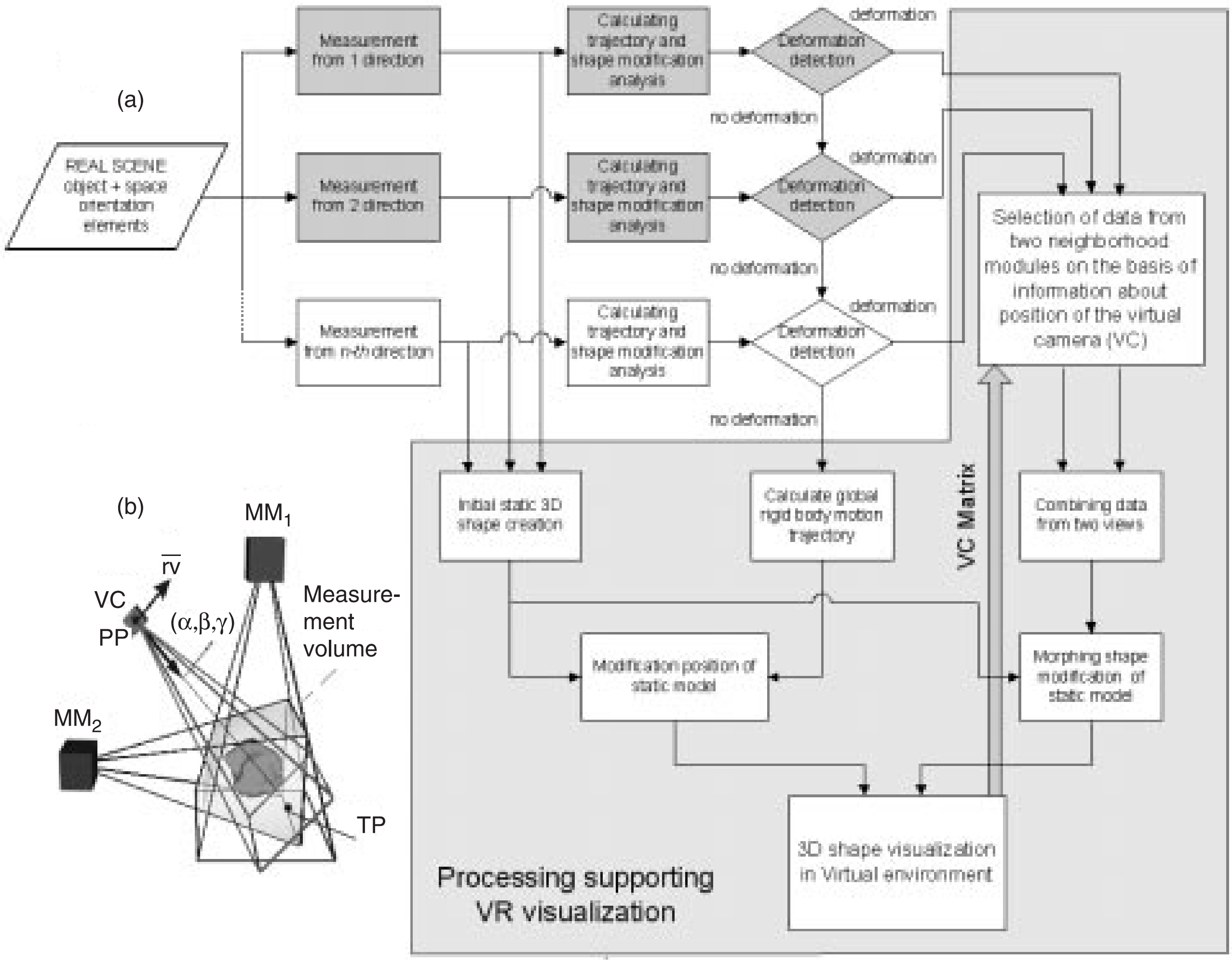


Fig. 12. Visualization of 3D object in VR environment, (a) the scheme of data processing required to visualize 3D data in virtual environment and (b) the scheme and parameters of virtual camera in reference to measurement set-ups. MM_i – measurement module, VC – virtual camera.

from *n*-directions and supported by monitoring of markers located at an object. In order to provide real-time processing, the data transferred for further visualization are limited

Fig. 13. Two visualizations of face as seen by the virtual camera in (a) first position and (b) second position.

to those which are seen by the virtual camera. The newly captured data are compared with the selected part of a static object model which is initially introduced into VR system. The comparison makes possible to vary the stream of the data transferred to VR in order to properly visualize the required part of an object.

The initial results prove the applicability of the concept presented, however, the experimental works were performed at a limited class of 3D objects and were based on a system consisting of two measurement sets-up only.

However, there are numerous issues which require proper solutions and improvements. They include:

- providing method for generating global texture at a static object model created on the basis of *n*-directional measurements,
- increasing accuracy of the data gathered for morphing objects,
- creating efficient criteria for quick recognition of morphing and non morphing areas,
- providing a method for generating of high-density mesh in real time.

Fig. 14. Static model modified with local shape variation calculated by spatial heterodyning method.

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