Stereoscopic image transfer of information in minimally invasive surgery

Vladimir Jehlicka

***Abstract*—**In current medical practice, in addition to traditional minimally invasive surgery carried out operations that are represented by laparoscopic and robotic assisted operations. In the present article is the process operation is understood as the activity of a closed control loop, in which information is transmitted as the input, ie, action, and output signals. Attention is focused on monitoring the output signals, i.e. the transmission of visual information from the operating field to the surgeon. When laparoscopic surgery is a picture of two-dimensional and does not allow the surgeon to obtain good spatial idea. While the robot-assisted surgery is a stereoscopic image information transmission, which allows to implement operating procedures with the greatest possible accuracy when good spatial orientation of the surgeon. The article, among other things deals with stereoscopic vision and imaging, and its subsequent effect on increasing the quality of surgical operations.

***Keywords*—**Transfer of information, closed regulated circuit, feedback, stereoscopic vision, stereoscopic projection, minimally invasive surgery.

I. Introduction

THE term minimally invasive operations we mean the laparoscopy or robotic assisted surgery, which brings benefits to both patients and surgeons. Conventional surgical procedures generally require a large surgical wounds that are necessary to make the operated part of the patient's body accessible. Consequently, there is a number of subsequent problems which is mainly related to a long convalescence. In mininimally invasive surgery is less trauma to the patient's body, lower blood loss, smaller scars, minimizes the risk of infection, shortens hospital stay and faster recovery and return to normal life. Surgeons bring the benefits mainly robotic surgeries. The doctor is not exposed to long physical exertion because he operates sitting supported wrists of both hands. Therefore not subject to fatigue, which is associated with traditional operating procedures and manifested primarily back pain, shaking hands, etc.

Minimally invasive surgery is used primarily for performances in the soft tissues of the abdominal cavity and thoracic cavity. They are used particularly in the field of general surgery, urology, gynecology, cardiac and thoracic surgery [1].

In economic terms, it is more expensive procedures than conventional surgery, but thanks to shorten hospitalization and minimize subsequent health problems, to bring a significant economic effect in reducing the cost of the drugs, stay in a hospital bed costs and the overall convalescent [1].

The quality of minimally invasive surgery always depends primarily on the human factor, i.e. the quality of the operator. From a technical perspective, the quality of the surgery depends on the quality of information transmission from the surgeon to movement the operating instruments on one side and on the quality of the transmitted image information from the surgery field back to the operating surgeon.

II. Minimally invasive surgery like closed regulated circuit

From a purely technical point of view, the process of minimally invasive surgery is closed circuit, which is regulated by a system of individual surgical operating instruments, the regulator is a surgeon, the action signals are transferred movements of the surgeon's fingers and feedback is closed by image transmission of the surgery field. More information about the feedback regulated systems can be found e.g. in [2], [3] or [4].

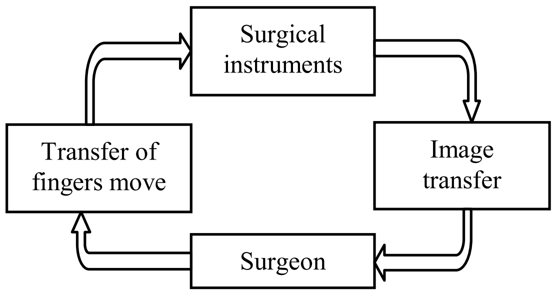

Fig. 1: Diagram of a closed regulation loop with feedback during minimally invasive surgery

A. Laparoscopic surgery

In laparoscopic surgery the surgeon standing over the operating table, the fingers controls the movement of laparoscopic instruments that are inserted into the patient's body and the screen monitors the activities performed in the operating field. The advantage of conventional laparoscopic instruments is simply solved their mechanical operation. But considerable disadvantage is their limited mobility. The work of the surgeon is very physically demanding, because it works in an ergonomically awkward position, and control instruments are unnatural and counterintuitive. Image of the operative field is scanned by a miniature camera, which is part of the endoscope. The image is not stereoscopic, but it is transmitted in a 2D format on the monitor. The surgeon is not mediated by a three-dimensional view of the surgical field, which is used for the classic carried out operations.

B. Assist robotic surgery

The development of digital technology made it possible to implement fundamental changes in the transmission of action signals and in the implementation of feedback. Gradually, robotic systems are designed that immediately separated from the patient's surgeon. One of them is the da Vinci system, which can be described as tele-manipulator [5], [6]. Surgical process is controlled by surgeon, who sits at the control console and its own operating procedures are implemented through the operating console. Standard operating room layout is shown in Figure 2. The relevant action signals that transmits the surgeon, are digitized and transmitted to the stand with computer technology and with control monitor. Action signals are then transmitted to the operating console, which provides movement of operating instruments.

Fig. 2: The spatial arrangement of daVinci [6]

C. Transfer of action signals

Transferring of action signals is in minimally invasive surgery mean the transfer of information from the surgeon to surgical instruments, i.e. the transfer of hand and finger movements of the surgeon to the surgical instruments and performance parts. The laparoscopic surgery is the transfer implemented purely mechanically.

The robot-assisted surgery is the surgeon's finger movements captured by sensors, whose outputs is digitally processed to computer and the necessary information are transmitted to the surgery console. To understand this process it is necessary to address the description of the motion of bodies in three-dimensional space.

III. Position and Movement in Three Dimensions

A. Position of bodies in three-dimensional space

If we want to describe the position and movement of bodies in three-dimensional space, then you must first define frame of reference, to which we apply to the position of the reference body. Reference frame is a body or group of bodies, which for present purposes we consider static objects without motion. Body dimensions that define the reference frame the order of magnitude larger than the dimensions of the body, whose position and movement are monitored. We can explore such as the position and movement of cars due to the defined road network, or room location and movement of aircraft models due to the hall in which we fly with these models, etc.

In the mathematical description of the position and motion of bodies three mutually perpendicular coordinate axes are defined, known as the axis x, y and z which intersect at the beginning of the coordinate system with the designation O - see Figure 3. A pair of axes defines the coordinate planes xy, xz and yz. Location of a particular point in three-dimensional space is uniquely determined by the coordinates of point (x, y, z), see Figure 3 Location-dimensional body is defined by body location of significant points, e.g. position of the block can be defined by specifying coordinates of any three vertices of this block.

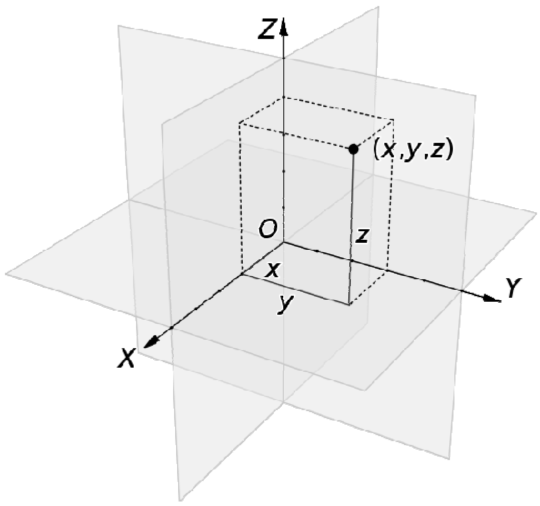

Fig. 3: Coordinate system in three-dimensional space [7]

The coordinate system is always defined so that it is firmly connected to the reference body, or a to set of reference bodies. When describing the position and motion of bodies in the laboratory scale we can define the coordinate system so that the xy plane is given by the plane of worktops and x and y axes are given by table edges.

B. The movement of bodies in three-dimensional space

The shape of the trajectory of a moving body can be divided into sliding movement or the translational, rotational and general.

In the simplest case, consider a linear movement, which is a special case of translational motion. The body moves along a trajectory in the shape of the line. It is obvious that all of the defined body landmarks move on straight lines parallel to each other. In general translational motion trajectory of the moving body in the shape is curve and all points of the body are moving along trajectories that have the same shape of the curve.

In the case of rotary motion, all landmarks bodies move in circles with different radii in general, but with the same center of rotation.

The general movement of the body is composed of translational and rotational motion. If we want to describe the motion of a body, then we must find a vector function, which describe the position dependence of three significant points on the body over time.

The movement of solids is often defined by the number of degrees of freedom. It follows that the translational motion can move the body due to the three coordinate axes, so that translational motion has three degrees of freedom. During rotary motion body can rotate in all three coordinate axes, so that rotational movement again has three degrees of freedom. In general body movement can move and rotate to all three coordinate axes so that the general movement of the body has six degrees of freedom [7], see Figure 4.

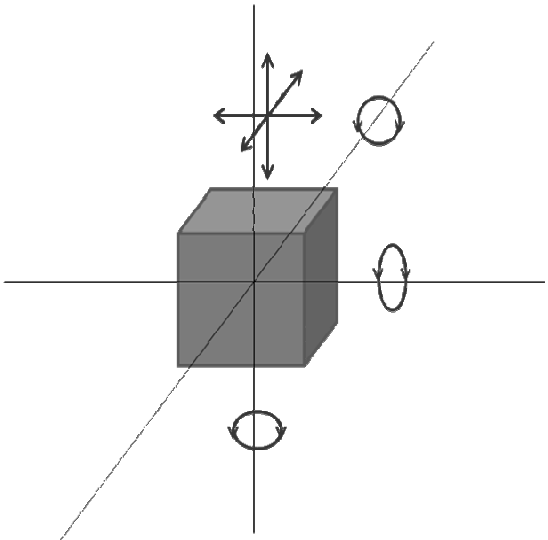

Fig. 4: Six degrees of freedom in general body movement in three-dimensional space [7]

In minimally invasive surgery is mentioned that laparoscopic surgical tools show seven degrees of freedom. This seventh degree is end-stage movement of the surgical instruments, i.e. the movement of the jaw scissors, pliers, etc., which can in any position opens up, and squeeze.

IV. Transfer of signals the robot-assisted surgery

A. Transfer of action signals

In this case it is the transmission of movements of the surgeon's hand and finger to movements on the part of powerful operational instruments. From a technical point of view it is necessary to define two three dimensional coordinate systems with three-dimensional transformation equations for converting coordinates of moving objects from one system to another and thus define the transmission of relevant information.

The first coordinate system is a real space in which the surgeon works with his hands and fingers of the hands. Finger movements are sensed by special sensors, in which fingers of the surgeon are firmly fixed, see Figure 5.

The second coordinate system represents the operating space of a patient's body, in which surgical instruments move, see Figure 6.

Fig. 5 Fixing the surgeon's fingers to sensors of position [6]

Fig. 6: Surgical Instruments in the patient’s body [6]

Both coordinate systems have to be identically oriented. This means that when the surgeon's hand movement is top-right also in this direction must move the surgical instruments. It is also necessary to ensure the conversion of coordinates due to the size of the movement of fingers of the surgeon and the size of movement of parts of operational tools. It should be noted that the diameters of operational tools are 8 mm, exceptionally 5 mm. If we compare the images shown in Figure 5 and 6, then it is clear that the surgeon can perform finger movements in the range of tens of mm, while the tail end of the surgical instruments perform movements only to the extent the units mm. It follows that the movement of powerful operational tools is part of the order of ten times smaller than the movement of the surgeon's fingers. This also significantly increases the quality of the transmitted information, since the end of the operational tools because of these conversions are ten times more sensitively controlled by the surgeon's fingers, than if the surgeon is held in the hand.

All transfers between the two coordinate systems are implemented through the control computer. That among other things, allows detection of unwanted shaking fingers of the surgeon, which can be caused by fatigue or other health ailments. Tremor software is removed and the resulting trajectory is smoothed operational tools and optimized.

Transfers all digital signals are transmitted via an optical cable which connects to the control console with control computer and the operating console.

B. Operating console

Patient part of the whole robot system consists of the operating console, which ensures the stability of shoulders with operational tools and an endoscope with a camera by its solidity. Optical digital stereoscopic camera is controlled by surgeon on pedals of the control console. Check monitor screen is usually placed on a rotating arm of the operating console, see Figure 7.

Fig. 7: Operating console [6]

The basic setting positions of arms are done by hand and are fixed using the brakes. This setting performs staff assisting the surgeon. A detailed look at one of the arms with the surgical instruments is shown in Figure 8.

Fig. 8: Shoulder surgical instrument [6]

For robotic assisted surgery was developed a number of different surgical instruments. There is shown on the Figure 9 detail of the working arm of one of a series of surgical tools.

Fig. 9: Detail of the working parts of the surgical instrument [3]

V. FEEDBACK DURING MINIMALLY INVASIVE SURGERY

Feedback is done by a video transmission of operating area in an optimal form so that the surgeon was right and if possible the most accurate information on position of surgical instruments and of current events in the patient's body.

During standard laparoscopic surgery is a single hole into the patient inserted a digital camera that captures images from the operating area. Captured image can be increased as needed and is transmitted to a monitor that monitors surgeon. The digital camera is a single chip and the resulting image is 2D. For good visual perception of the surgeon, it is necessary to realize stereoscopic images in 3D.

A. Stereoscopic vision

The term stereoscopic vision understand the spatial vision, which allows us to perceive three-dimensionality of objects, their distance and depth in space. Stereoscopic vision is allowed eye position on the retina fall two slightly different images of the observed image. These are then subsequently processed in the brain resulting in spatial perception.

Angle to each other form an axis of both eyes when viewing objects is called stereoscopic parallax. With the increasing distance of the observed object from the observer, this angle decreases, while also decreasing the resulting spatial perception. Limits of stereoscopic vision, then we understand the smallest value of stereoscopic parallax, in which there is still a stereoscopic vision. This limit is called the radius of stereoscopic vision is influenced by the quality and vision of the observer.

Distance eyes in humans ranges from 56 to 72 mm. As the mean distance is considered a = 65 mm. While observing the subject at a distance d from the observer, then the true stereoscopic parallax relationship:

$$\mathrm{tg}\,\alpha = \frac{a}{d}\,. \tag{1}$$

Given that this is a small value of angles α, to the extent of tens of arc minutes, it is possible to linearize non-linear function tg(x) and replace the first polynomial degree

$$\mathrm{tg}\,x \doteq x\,. \tag{2}$$

Then the value of stereoscopic parallax can be calculated approximately from the relation

$$\alpha \doteq \frac{a}{d}, \tag{3}$$

where angle α is expressed in degree arc in radians. Observe simultaneously the two subjects that are different from the eyes of the observer distance, then these objects are observed corresponding to different sizes and stereoscopic parallaxes α_1 and α_2. If the observer to distinguish the different distances of objects observed, it is necessary that the difference between the two stereoscopic parallaxes:

$$\alpha_1 - \alpha_2 \geq \alpha_0 \tag{4}$$

was greater than or equal to the stereoscopic vision α_0. Its value is influenced by the quality of a particular observer's eye and really sharp, high-quality stereoscopic vision is located approximately in the range

$$\alpha_0 \in \langle 10'; 30' \rangle. \tag{5}$$

In practice this means that the best stereoscopic impression we get when observing objects that are at a distance of tens of centimeters to tens of meters. In extremely favorable situations, the human organism can perceive the spatial layout of objects up to a distance of 1 km.

The spatial arrangement of objects it can be seen in the distance, which we call the radius of stereoscopic vision, distance d_0 to the size of this relationship is valid

$$\alpha_0 = \frac{a}{d_0}, \tag{6}$$

from which follows

$$d_0 = \frac{a}{\alpha_0}. \tag{7}$$

The radius of stereoscopic vision can be increased with additional optical systems. Base and observation a, which is given by the distance eye of the observer, it is possible to extend the use of prisms or mirrors. The value limit of stereoscopic vision α_0 can be reduced by a suitable optical system.

B. Stereoscopic projection

We live in a three-dimensional space in which we are able to perceive the spatial arrangement of individual elements and their mutual movement by our vision. Three-dimensional projection of the space is very difficult. For example, there exists the display cubes in which object is displayed - see Figure 10. On the walls of the cube is located 5 LCD displays that mediate view of a display object from different viewing angle. 6th a base wall, which is not equipped with any LCD display. Rotating the cube, then we can simulate the circumvention of an object within a three-dimensional space [8].

Fig. 10: Rotating cube [8]

The opposite effect occurs when the viewer is placed in the projection space so that the image is projected around him with a viewing angle of 180 ° - see fig. 11. The viewer has the feeling that it is located inside the three-dimensional space [9].

Fig. 11: Hemispheric projection [9]

A similar impression a viewer gets during the current projection on three screens, which surrounded him [10] – see fig. 12.

Fig. 12: current projection on three screens [10]

In principle, however, it is necessary to distinguish three-dimensional perception of the real world and its stereoscopic projection [11].

Often we encounter the terms 3D cinema, 3D TV, 3D monitors, but in reality is always a stereoscopic display of three-dimensional space. Stereo-camera can simultaneously create two laterally shifted images, which are projected separately for left and right eye of the viewer - see Figure 13.

Fig. 13: Stereo-camera [12]

In order to achieve high-quality spatial effects even for large scenes shots of distant objects, it is necessary to enlarge the distance between the lens stereoscopic camera. In relation (7), thus increasing the value a, thereby to increase the radius of stereoscopic vision d_0. Figure 14 shows the stereoscopic camera that allows you to change the distance between its lenses.

Fig. 14: Stereoscopic camera with adjustable distance between objectives [13]

Transferring of stereoscopic taken images to the viewer's eyes are realized using different technologies that differ by the principles of decoding of the images for the left and right eyes [14].

The oldest technology is anaglyph. The observer is deployed usually blue or red-green-blue glasses that will filter out the different color images for the left, respectively. right eye. The resulting sensation is not too good, because there is a significant color distortion [14].

3D Active technologies are applied to both 3D projectors, 3D and 3D monitors or TVs. The principle consists in alternating projection images for the left and right eye, with a minimum frequency of 12 frames per s. The viewer has deployed 3D active glasses, which are controlled with a frequency corresponding to broadcast images to the right eye socket was opaque when it is shown image for the left eye and left eye socket was similarly opaque for posting the image to the right eye [14].

Passive 3D technology uses the properties of polarized light. Most screening is carried out two synchronized projectors, which are placed before the polarizing filters. Projectors and images reflected polarized in mutually perpendicular planes on a special screen that reflects light in the polarization plane. The reflected light falls on the passive polarized glasses the viewer, which allows the passage of polarizing filters in the light only to the eye socket, which is intended for the left, respectively right eye [14].

Active-passive-3D technology is based again on the polarization of light. The projection is a projector that is equipped with a polarization modulator. It is electronically synchronized with 3D projector so that the transmitted light alternately polarized in one plane or the other depending on whether it is currently projected image to the left or right eye [14].

Above mentioned systems that use different types of glasses, more or less unnatural way burden the mind of the viewer and some spectators cause health problems. The most natural transmission of information allowing such systems, in which the image acquired for the left eye is transmitted without any distortion or transformation in the left resp. right eye of the observer [11], [15].

Mikroma camera, which was equipped with two lenses, allowing simultaneously capture two images, which were determined separately for the left respectively. right eye of the viewer, see Figure 15.

Fig. 15: Stereoscopic camera Microma [16]

Individual film boxes were inserted into stereoreels that it was possible to view a dedicated viewer. The eyes came full color undistorted image [15], [16].

C. Feedback in robot-assisted surgery

Feedback is represented by the transmission of color stereoscopic projection of the surgical area to eyepieces of the control console. The images are scanned by two-chip digital camera with a diameter of 12 or 8 mm see Figure 16.

Fig. 16: Stereoscopic camera [6]

The image is processed by a central computer and transmitted to the control console eyepieces Figure 17.

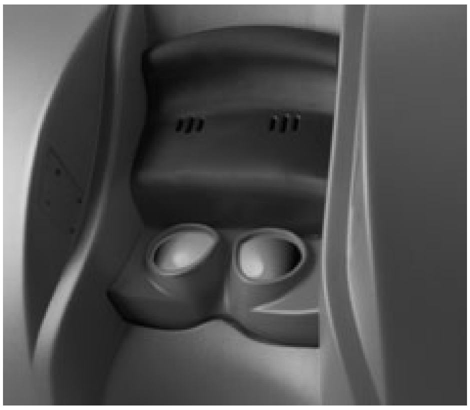

Fig. 17: Eyepieces in surgeon control console [6]

It is necessary before the surgery to adjust the camera and eyepieces so that the resulting image was good, well-focused and has not been duplicated. This setting is done manually from the surgeon control console. During the operation can change the camera settings to your specific needs, including zooming. The images in both eyes of the surgeon are thus transmitted without any distortion and the resulting visual perception is totally natural. Video information is transmitted in the highest possible quality.

In Chapter stereoscopic vision were discussed basic concepts and relationships associated with the perception of stereoscopic three-dimensional space, the average human eye distance of the eye a = 65 mm . If double-chips camera, which is shown in Figure 16, has a diameter of 12 or 8 mm, then it can be assumed that the axial distance between the two camera chips is approximately 5-7 mm. That is ten times smaller than the range of human eyes. This corresponds to the radius of stereoscopic vision, which may be calculated from equation (7). It is obvious that this camera provides optimal spatial perception at a distance of tens of mm, which is to transfer image information from the operating field optimum.

VI. Conclusion

The results of any operations are dependent primarily on the quality of the surgeon, his experience and accuracy of work. From a purely technical perspective, the quality of operation significantly affected by transferring info across the control circuit.

On the one hand, a stereoscopic image information transfer from the operating field eyepieces to control console operator. While the standard laparoscopic surgery the surgeon has the possibility to perceive three-dimensional space the operating field, then the robot-assisted surgery is the spatial perception realized with the maximum quality possible. An important advantage is the fact that the captured images are transmitted to the eyepiece without any distortion that would be encumbered by the eye and brain surgeon with subsequent induction of excessive fatigue.

On the other hand, the action is the transmission of signals. This involves the transmission of moving hands and fingers of the surgeon to move the end part of the operational instruments. In the article it was shown that the transmission of digital information can filter out unwanted movements in the fingers of the surgeon, which are caused by shaking, and optimize the trajectory of individual instruments. At the same time increases the accuracy of individual interventions, because the end part of the motion graph operational tools requires that the surgeon performed the movement of fingers in the range of centimeters.

Stereoscopic video transmission information and transmission of digital signals action significantly contributes to improving the work of surgeons in minimally invasive surgery.

References

[1] *CSRCH* [online]. 2011 [cit. 2011-07-21]. „DaVinci Systém“. Available: WWW: <http://www.csrch.cz/davinci-system.html>.

[2] Rotter M., Trhlík M., Hubálovský Š., Srnka A., Dupák J., Ota J., PariP. Nuclear orientation faculity at Charles University in Prague. *Czech Journal of Physics*. 2000, č. 50, 0011-4626.

[3] Milková, E., Hubálovský, Š., Pražák, P. Modeling of a Real Situation as a Method of the Algorithmic Thinking Development and Recursively Given Sequences. *WSEAS transactions on information science and applications*. 2010, roč. 7, č. 8, s. 1090-1100. 1790-0832.

[4] Hubalovsky, S., Mixing of two different temperature water flows as feedback controlled system mathematically modeled and simulated in MS Excel spreadsheet. In: *WSEAS International Conference on System Theory and Scientific Computation (ISTASC'11)*, Florence, WSEAS Press, 2011, ISBN 978-1-61804-027-5.

[5] *Hospimed : Technologie moderní medicíny* [online]. 2010 [cit. 2011-07-21]. „Da Vinci“. Available: WWW: <http://www.hospimed.cz/divize/divize-hi-tech/produkty/hi-tech/da-vinci/>.

[6] *Stargen-eu* [online]. 2011 [cit. 2011-07-21]. „Da Vinci“. Available: WWW: <http://www.stargen-eu.cz/produkty/da-vinci/>.

[7] K. Volenec, et al. „*Robotika a technická kybernetika*“. Hradec Králové : Univerzita Hradec Králové, 2010. Robotika, pp. 47-59.

[8] *Týden.cz : Věda, Technologie* [online]. 2010 [cit. 2011-07-21]. „Zařízení pCubee zvládne 3D zobrazení i bez brýlí“. Available: WWW: <http://www.tyden.cz/rubriky/veda-a-technika/technologie/zarizeni-pcubee-zvladne-3d-zobrazeni-i-bez-bryli_164141.html>.

[9] E. Pavelka. *Svět hardware* [online]. 2000 [cit. 2011-07-21]. „Jak na 3D zobrazení?“. Available: WWW: <http://www.svethardware.cz/art_doc-AFC4E54C7C307D42C125698300262790.html>.

[10] *Institut intermédií* [online]. 2008 [cit. 2011-07-21]. „Virtuální realita a vizualizace“. Available: WWW: <http://www2.iim.cz//?id=69>.

[11] Š. Hubálovský, A. Hubálovský. „Využití ICT při tvorbě a modelování stereoskopického obrazu“. *Media4u Magazine : Čtvrtletní časopis pro podporu vzdělávání* [online]. 2010, 7, 1, [cit. 2011-07-21]. Dostupný z WWW: <http://www.media4u.cz/>. ISSN 1214-9187.

[12] *Recenze okamžitě* [online]. 2010 [cit. 2011-07-21]. „3D tv a možné zdravotní problémy“. Available: WWW: <http://www.recenze.okamzite.eu/articles/3d-tv-a-mozne-zdravotni-problemy/>.

[13] *Medieninformatik HTW Dresden* [online]. 2008 [cit. 2011-10-23]. Zweikamerasystem für 3D-Videomaterial. Available z WWW: < http://wwwmi.informatik.htw-dresden.de/index.php?id=143&projectID=14>.

[14] *Gali-3D* [online]. 2011 [cit. 2011-07-21]. „Co je 3D stereoskopie“. Available: WWW: <http://cs.gali-3d.com/stereoskopie-princip-3d/>.

[15] „*Stereokotoučky*“ [online]. 2010 [cit. 2011-07-21]. Návod k fotoaparátu Stereomikroma II. Available: WWW: <http://www.stereokotoucky.cz/cz/man_stereomikroma2_cz.html>.

[16] *Československé* fotoaparáty [online]. 2011 [cit. 2011-10-23]. Meopta Přerov. Available: WWW: <http://www.kostikidis.estranky.cz/fotoalbum/meopta-prerov/-meopta-prerov/084-stereo-mikroma-a__resize.jpg.html>.

Vladimír Jehlička was born in Pardubice, Czech Republic in 1951. In 1975 he received degree Ing. in the Processes, equipment and automation of chemical processes at the University of Pardubice, in 1981 he received degree Ph.D. in the Technical cybernetics at the University of Pardubice, in 1998 he became associate professor in the Automation of machines and technological equipment at the Technical University in Ostrava.

Since 1975 he worked as an assistant professor at the University of Pardubice, since 1998 worked as a associate professor at the University of Hradec Kralove, where since 2005 he is Dean of the Faculty of Education.

Doc. Ing. Vladimír Jehlička, CSc. is a member of the Department of informatics, Faculty of Science, University of Hradec Kralove, where he focuses on programming, modeling and simulations of real systems.