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Single and twin optic 3D systems

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ABSTRACT

The clinical introduction of new technologies in surgical therapy has changed the traditional intraoperative procedures especially in terms of visual information available for the surgical team. The direct view on the operating site is more and more replaced by indirect visual information on the basis of optical systems and displays. Especially in endoscopic minimal access surgery the surgeon is decoupled from the operating site and a high quality and reliability of realistic visual spatial information is crucial. The use of stereoscopic systems could potentially provide an improved visual feedback for spatial manipulations, but the real impact of 3D-visualisation systems strongly depends on its implementation and boundary conditions within clinical applications. This paper discusses some aspects and potential bottlenecks of 2D and 3D visualization systems on the basis of experiences from laboratory investigations and clinical field studies in the area of laparoscopic surgery.

INTRODUCTION

In recent years surgical work and interaction with the operating site has been influenced significantly by the trend towards image guided minimal invasive surgery. More and more complex spatial manipulations have to be performed on the basis of two-dimensional images (endoscopic, x-ray projections, CT,...) and with very limited tactile or haptic feedback. As the visual information is the most important afferent parameter of sensumotoric 3D-manipulation performance, the introduction of new technologies such as computer assisted systems for image guided surgery, telesurgery or virtual environments has to be closely connected to the development and evaluation of adequate 3D-visualisation technology.

In this context, endoscopic surgery is the most prominent example. From the beginning of surgical endoscopy, the main problem has been to provide a sufficient view onto the intracorporal operating site. Endoscopic and even stereoendoscopic optics have been developed more than 100 years ago. Nevertheless, the breakthrough for surgical procedures guided by endoscopic images was initiated by the development of video endoscopic systems, enabling the surgeon and his team to perform interventions cooperatively. Moreover, the surgeons are not forced anymore into a bent posture over the ocular of the conventional endoscope. Thus unnecessary additional workload and the impairment of manual dexterity can be reduced.

However, monocular systems still display a two-dimensional flat image and do not provide binocular depth information. The surgeon has to derive the necessary spatial information from monocular depth cues supported by video-endoscopic system (Tab. 1). Especially in complex and critical situations the required mental substitution of the spatial information can lead to suboptimal performance.

3D-systems could potentially provide an improved visual information for spatial manipulations. Its use has been demonstrated in many non-medical as well as some medical applications.[4,6,13] However, its application in surgical work systems has been controversially discussed.[1,3,5,12,13,14,15] Therefore, its impact and interdependencies of technical as well as medical boundary conditions have to be evaluated in laboratory as well as in clinical field tests.

Table 1: Monocular and amending binocular depth cues

MONOCULAR DEPTH INFORMATION	BINOCULAR DEPTH INFORMATION
size*	
overlap	horizontal disparity
shading	
*motion parallax***	*convergency***
*accommodation***	
* only partially or ***not* supported by video-endoscopic systems	

Technical Principles of 3D-Systems

A stereoscopic visualization requires the acquisition of two slightly different images of a three-dimensional scene (horizontal disparity) producing the same retinal images that would be produced on the retina of the left and right eye under direct binocular viewing conditions. One common characteristic of all stereo-3D-display techniques is, that the corresponding images have to be displayed to the left and right eye separately, causing a spatial impression of the relating scene.

Basically two types of technical approaches can be distinguished:

- *Autostereoscopic Systems* (lenticular screens, holographic systems) display the binocular information without the need of an additional viewing device. Unfortunately these autostereoscopic systems are still in the stage of development and neither suitable nor available for clinical routine use. Apart from economic issues, the most critical points are the brightness, color and image resolution as well as the constraints concerning the position of the user in relation to the display.
- In contrast, there are different technical solution for 3D-visualisation *systems with viewing aids* commercially available:

– *Time parallel* systems (small head mounted displays (HMD), semitransparent mirror combined with polarised glasses or red-green glasses) display the information of both eyes optically separated for the left and right eye at a time.

– *Time multiplexed* systems display the information for the left and right eye alternately (LC-shutter glasses, passive polarized glasses combined with cross-polarized screen). These systems make use of the physiological phenomena of interocular suppression. While one eye perceives the corresponding full visual information the other eye must be provided with insufficient visual information (insufficient contrast) which will be suppressed by the visual apparatus.[7,10] This can be realised for instance by alternately occluding the left and right eye by means of LC-shutter glasses synchronized with a display presenting the corresponding information for the non-occluded eye each time. Flicker free images can be achieved if the images are displayed with at least 50 Hz for each eye.

For the surgical application, the systems have to fulfill some essential requirements:

The binocular image information must be provided on-line with high resolution, brightness, flicker free and in full color. The mobility should not be impeded, the surgeon should not be visually isolated from his or her environment (the team, patient, instruments, equipment,...) nor confused by different visually overlapping scenes. Last but not least the system should require a minimum of modifications concerning conventional surgical procedure and environment.

Most of the commercially available 3D-videoendoscopic systems are based on the active LC-shutter glasses technology as it actually seems to be the best solution available regarding most of the requirements mentioned above.[7]

What are the benefits and bottlenecks of these systems for endoscopic surgery or image guided therapy in general and what are the needs and challenges for further research and development ?

Impact on operators dexterity and subjective strain - laboratory investigations -

In initial laboratory investigations [5,12,13] we compared the manipulative performance measured by the time for the execution of standardized test cycles (defined grasping and removal of 100 pins on a test board with a laparoscopic forceps) under different viewing conditions such as direct view, monocular and binocular view through conventional mono- and stereoendoscopes as well as 2D- and 3D-videoendoscopic systems.
The use of a 3D video endoscopic systems improved the manipulative performance by 26% very significantly (p>99.5%) compared to the use of the traditional 2D-video systems (Fig. 1). In the very frequent unfavorable case of an incompatible arrangement for eye-hand-coordination with a camera viewing direction of about 90° in relation to the position and viewing direction of the surgeon, the improvement even was about 40% (p>99%).[13] Moreover, we registered a significant reduction of the subjective strain experienced by the test persons performing the given tasks under 3D-video endoscopic viewing conditions. [8,10]

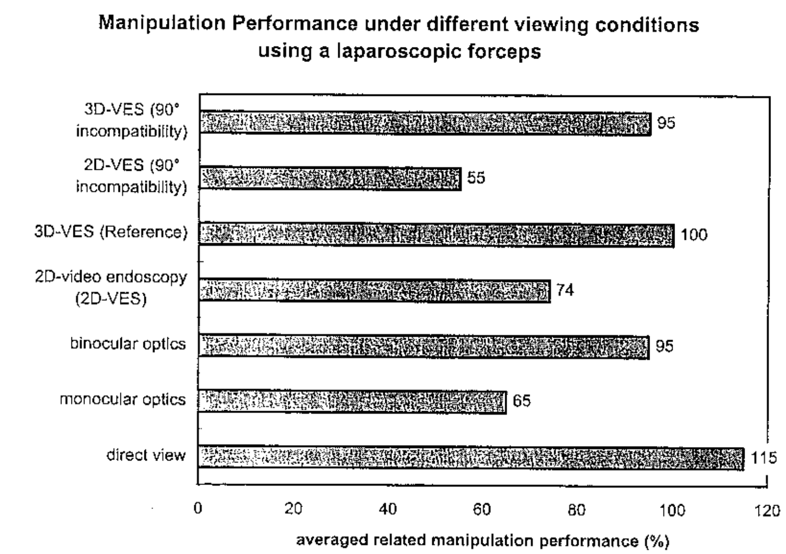

Figure 1: Results of laboratory investigations on the influence of monocular and binocular viewing conditions on the resulting manipulation performance [5,12,13]

Impact on spatial orientation and time of intervention in surgical routine

Although our initial studies pointed out a potential benefit of stereoscopic video systems, the evaluation of the „surgical reality benefit" of 3D visualization must be based on clinical field studies. [8,13] order to get more specific data under real clinical routine conditions we decided to analyze laparoscopic pelvic lymph node dissections.[6,8,9] type of intervention requires a high degree of ability of spatial orientation and manipulation. The interventions have been performed by one experienced surgeon (> 240 laparoscopic interventions) and one novice laparoscopic surgeon (< 25 lap.interventions). Apart from the duration of different phases of the intervention (e.g. opening of the peritoneal space, introduction of instruments, exposure of the iliac vessels, dissection and sampling of pelvic lymph nodes, control of the operating site,...), we also analysed the contribution of different typical task sequences and manipulations such as „cutting" or „ grasping". Moreover we discussed the interventions with the surgeons post-operatively on the basis of video documentations. The results of our field studies are discussed in more detail and can be summed up as follows: The experienced surgeon profits even more from stereo-3D-visualization than the non-experienced surgeon. The additional visual 3D-information enabled him to achieve the surgical goal - the dissection and sampling of lymph nodes - 38% faster compared to an improvement of about 15% for the novice surgeon (p>95%). 3D-video endoscopy enables the surgeon to fully apply his experience during intervention and to manage even critical situations which would be too complex or dangerous under 2D-video-endoscopic visual control.[9,10]

Investigations on basic phenomena of video-stereoscopy

The field studies confirmed in principlé the findings of our initial investigations. Therefore a more detailed assessment and optimization of these systems and its components seemed to be worthwhile. On one hand this concerns the fact that many surgeons still seem to prefer monoscopic systems and on the other hand apart from the observation of problems of headache or nausea, some people seem to have general problems in perceiving the displayed depth information

The first point is somewhat simple to explain: The monoscopic images are brighter and today mostly based on 3-chip camera technology delivering better images with higher resolutions compared to the 1-chip cameras used in stereoscopic systems. As we demonstrated in previous studies, a higher video resolution would also result in a higher resolution of depth perception.[10] Moreover the additional shutter glasses are necessary and seem to cause additional strain. Finally, the stereo-video-endoscopic systems are more expensive. At least the latter point is weakened by the fact, that the time of intervention can be reduced (charges for the operating theater, personnel , anaesthesia, ...), and in addition the spectrum of applications for laparoscopic surgery potentially could be widened.

The second problem is much more complex and difficult to analyse. In laboratory investigations we found in fact, that about *one third* of the test persons do have problems in perceiving the displayed depth information of stereoscopic *videobased* 3D-systems, although all of them have successfully passed all established conventional clinical stereovision tests (such as Random-Dot Test or 3-Bar Test).[10] We also investigated the influence of different technical parameters such as the characteristics of LC-shutters, color, contrast, resolution, distance „object-projection plane" and „user-monitor", parallax, base width and magnification of the endoscope, illumination of object and of the OR etc. on stereoscopic depth perception. We found, that user- and context-specific optimal setting can be found for many of these parameters.[7,10] Nevertheless, this does not solve the problem that there seems to be a population of about 30% without stereovideo vision.

Of course, these phenomena could be explained by the non-physiological viewing conditions: On one hand the visual information is not presented simultaneously to the left and right eye. On the other hand horizontal disparity of the two images, convergence and accommodation do not correlate compared to the case of natural depth perception.[2] But nevertheless the question remains unsolved, why this only concerns 30% of the subjects. Therefore we started further investigations on the interdependencies of individual visual information processing and technical vizualisation.

We analyzed for instance the behaviour of both test groups (with and without video-stereopsis) concerning their eye-movements with respect to the screen plane. For these

investigations we used a computer generated 3-bar Test and an eye-tracker device equipped with a LC-shutter system. The soft- and hardware environment developed in our lab allows for an adjustment of various parameters relevant for stereoscopic image processing (s. above).[7,10] Conventional 3-bar and Random-Dot-Tests have been used as control tests.

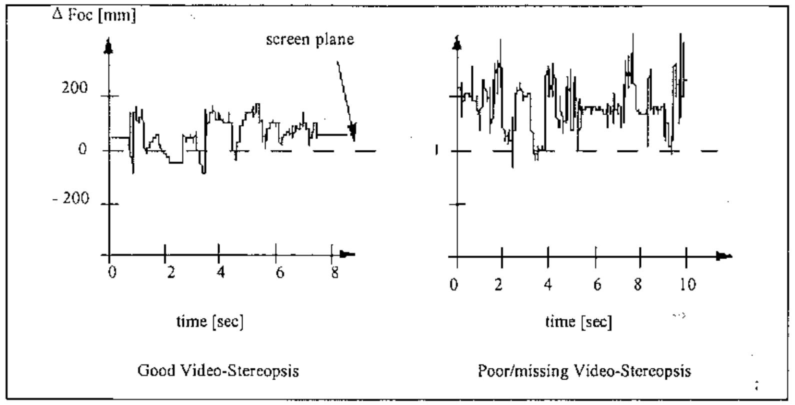

Figure 2: Typical course of the point of convergence in relation to the screen plane for test persons with (left) and without (right) video-stereopsis.[11]

Figure 2 shows one result of our initial study. Whereas the accommodation has to be adjusted to the screen plane in order to perceive a sharp image on the retina, the motor response of the eyes concerning convergence is decoupled in an unnatural way. One typical difference between the subjects with good (Fig. 2, left) and with poor/no video-stereopsis (Fig. 2, right), is a significantly different „depth scanning" behaviour. Whereas the first group shows a limited depth scanning more or less around the screen plane, the scanning of the second group is much deeper, noisy and decoupled from the screen plane. One hypothesis extracted from these findings is: - the more the convergence can be *decoupled from the parallax* and - the more it can be *coupled to the accommodation*, - the better is the capability for video-stereopsis. This hypothesis is one basis of our ongoing work.

CONCLUSIONS

The use of 3D-systems potentially could provide an improved visual information for spatial manipulations and its benefit has been shown in non-medical as well as some medical applications. Nevertheless, the discussion of the impact of 3D-visualisation systems in surgery is very controversial.[1,3,6,8,13,14,15] In fact the cost-to-benefit ratio of 3D-systems for clinical applications strongly depends on its technical realisation and boundary conditions of implementation.[10,13] Furthermore there is an obvious need for further research on basic phenomena of stereo-video-vision in order to ensure a safe and effective use to the benefit of both the patient and the surgeon. Last but not least the evaluation of its influence on the therapeutic outcome and analysis of related economic effects will have to justify a broader application of these new technologies.

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Concurrent three-dimensional endoscopy with head-mounted video display: a preliminary laboratory experience

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SUMMARY

Head-mounted virtual display systems have allowed improved visualization and operative efficiency during endoscopic procedures. Despite the improvement in display systems and development of new endoscopic tools, endoscopy is a technique which is known for its steep learning curve and difficulty when used in regions where local anatomy is distorted by disease processes. We describe a stereoscopic endoscope system mated to a head-mounted display which allows for more rapid appreciation of three dimensional anatomy as seen through the endoscope.

INTRODUCTION

Neuroendoscopy is a powerful means by which complex neurosurgical procedures may be accomplished through minimally invasive approaches. Endoscopic methods, however, are associated with steep learning curves, requiring great familiarity of the surgical anatomy as it appears through the endoscopic portal. A factor in this steep learning curve is the flat visual field of a monocular endoscopic image This limits the ability to appreciate distances between adjacent anatomical structures (Southard, 1997). The lack of stereopsis is a distinct disadvantage to surgeons familiar with microsurgical techniques where stereoscopic vision is possible.