Autostereoscopic 3D Display in Laparoscopic Surgery

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Summary

An autostereoscopic 3D display can be viewed without the need for any special glasses or other headgear. This paper describes a multi-view autostereoscopic 3D display, developed at the University of Cambridge, and initial investigations into the feasibility of this device in laparoscopic surgery. The outcomes of these investigations are a plausible design for a 10mm diameter autostereoscopic laparoscope and a prototype of this design. The paper considers the challenges of this new technology as applied to laparoscopy, and assesses the benefits and costs of autostereoscopic 3D display with respect to conventional 2D TV display.

Autostereoscopic Display

An autostereoscopic 3D display can be viewed without the need for any special glasses or other headgear. A multi-view autostereoscopic display has the additional benefit that the observer can look around objects in the picture by moving his head from side to side, as in real life. Such a display will prove useful in laparoscopic surgery where it will give the surgeon much needed depth perception without the need to alter any other operating procedure. For example: the lack of a headset means that the surgeon retains vital eye contact with his immediate environment and his staff.

Various factors contribute to depth perception. Some of these are available in 2D images — for example occlusion. The two important missing factors are stereo parallax, seeing a different image with each eye, and movement parallax, seeing a different image when the head is moved. Two view stereoscopic displays, those which use glasses for example [1], provide only the first of these cues. A multi-view autostereoscopic display provides both: the viewer sees a different picture with each eye and can look around objects by moving his head side to side.

A multi-view autostereoscopic display has been developed at the University of Cambridge in a collaborative effort between the Computer Laboratory and the Department of Engineering [2, 3, 4, 5]. The current display can show up to six colour views, or sixteen monochromatic views. Several displays have been manufactured to the current specification and are in use in various research institutions. Negotiations are underway to manufacture a commercial large screen colour version of the display.

The display requires multiple laterally displaced views of a scene. These multiple views are displayed very rapidly on a cathode ray tube (TV screen). A directional

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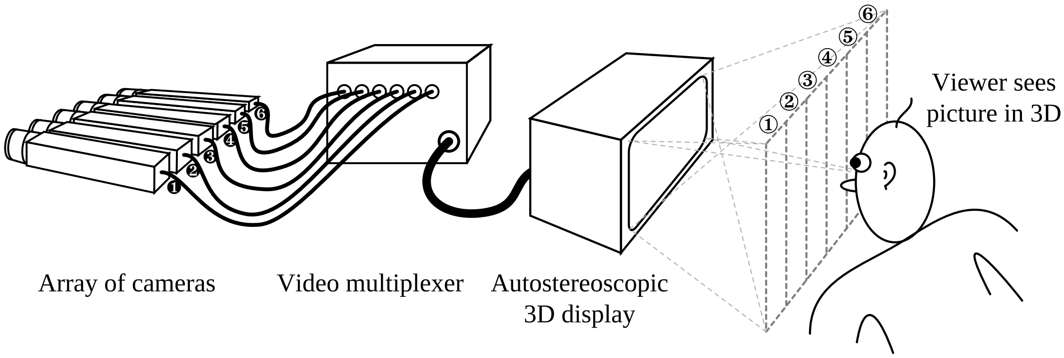

Figure 1: an autostereoscopic camera system. The six views captured by the six cameras are multiplexed onto the autostereoscopic display, allowing the viewer to see the scene in three dimensions.

modulator is placed in front of the cathode ray tube, still inside the display's cabinet. This is synchronised with the view display to ensure that each view is only visible in a distinct area in front of the screen. The result of this is that each eye sees a different view of the scene, providing stereo parallax; and the eye sees different views when the head is moved, providing movement parallax.

The research version of the display is 25cm diagonal, 6 view, 320×240 pixel full colour. The proposed large screen version is 640×480 pixel, full colour with at least 6 views. Current technology can easily provide for 6 views at over 800×600 pixel resolution.

The research display has been used in a variety of ways. A computer system has been developed which has allowed us to experiment with still images, interactive visualisation, and simulation. In addition to our in-house demonstration pictures, we have displayed still pictures provided by various interested parties, including a number of 3D medical visualisations. Interactive simulations have ranged from manipulation of CAD models to interaction with 3D data sets, notably with a set of MRI slices.

In addition to this general purpose computer system, specialised hardware has been constructed to take images from multiple cameras and multiplex these onto the display [6]. As many cameras are required as there are views on the display, and each camera provides the image for one view. The cameras must thus be equispaced laterally in the same way that the views are spaced laterally in front of the display (Figure 1). The current camera system operates at 640×480 resolution for 8 views in monochrome. At the time of writing a 6 view colour 320×240 camera system is under test.

Autostereoscopic Laparoscope

Investigation into the feasibility of using the autostereoscopic display in laparoscopic surgery began eighteen months before the first demonstration of live video input. A collaborative group was formed consisting of members of the Computer Laboratory, Department of Engineering, Department of Surgery and a manufacturer of microsurgical equipment. The outcome of these investigations are

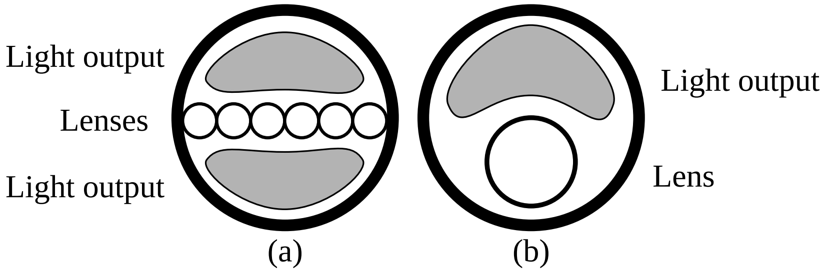

Figure 2: (a) the distal end of the autostereoscopic laparoscope, compared with (b) the distal end of a conventional 2D laparoscope.

described below.

An autostereoscopic laparoscope system is envisaged to consist of an autostereoscopic laparoscope connected to a video multiplexer which converts the video signals from the laparoscope into a video signal suitable for the autostereoscopic display, and a full colour autostereoscopic 3D display. The video multiplexer will also be able to output standard 2D video signals which can be used to drive conventional 2D TV monitors and video recorders. In theatre, we envisage the surgeon using the 3D monitor, while his assistant and staff view a number of conventional 2D monitors. A second 3D monitor could also be attached.

Given that both the autostereoscopic display and the video multiplexer can be built now, the main challenge is the production of a laparoscope capable of delivering a number of views of the scene. The main design decision here is the number of views required. Two views are all that is necessary for a stereo system with glasses, and at least three manufacturers, including Zeiss [1] and Olympus, have produced two view laparoscopes. Our autostereoscopic system requires a minimum of four views to be useful, and we have found that six views provides reasonable stereo and movement parallax. The more views displayed the smoother the 3D effect. Our decision was, therefore, to concentrate our effort on the design of a six view laparoscope.

The six views must be arranged laterally, requiring a laparoscope with either six lenses arranged laterally at its distal end or six views somehow multiplexed into a single light channel. Both approaches have been used in two view laparoscopes, and there is great promise in extending the latter approach to six views. However, the former approach requires less short-term research effort, and was thus chosen for the design of the prototype. It is desirable for the laparoscope to be compatible with existing cannulae. We therefore limit ourselves in our initial design to considering a circular cross-section with 10mm outside diameter. Other configurations could be used, such as a 15mm outside diameter circular tube, or an oval tube with area equal to a 10mm circular tube. These would provide a wider area for the lenses, but would require non-standard cannulae.

The proposed design consists of six lenses equispaced across the distal end of a 10mm outer diameter tube. With an inner diameter of 9mm, the centre to centre spacing of the lenses will be 1.5mm. An ideal set up for a 6 view autostereo display is for the viewers' two eyes to see views two apart. Thus the viewer is

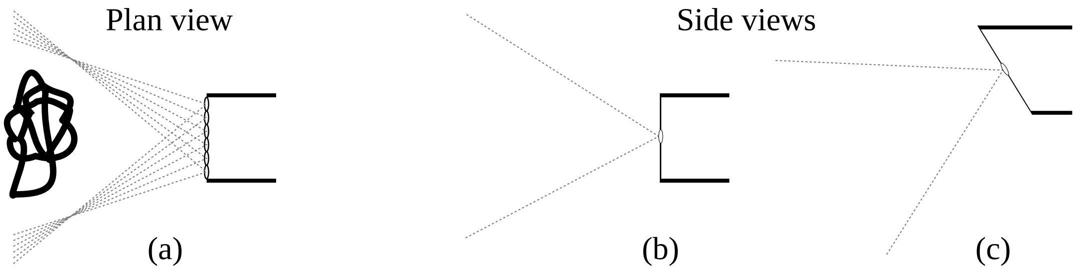

Figure 3: (a) the autostereoscopic laparoscope will be capable of a field of view of 60°. It will be possible to design it so as to view either straight ahead (b) or at, for example, 30° (c).

seeing views 1 and 3, or 2 and 4, or 3 and 5, or 4 and 6. This provides excellent stereo parallax, and sufficient movement parallax. A surgeon viewing a 3D picture through our laparoscope will thus see two views taken by cameras 3mm apart. For these parameters, a surgeon standing 1.5m from the screen will perceive a normal stereo image if the laparoscope is positioned 7cm from the objects under consideration. Closer than this, the surgeon's stereo perception will be enhanced, a situation which we have found improves depth perception.

The basic layout of the distal end of the autostereoscopic laparoscope is shown in Figure 2, compared with a conventional 10mm 2D laparoscope. The autostereoscopic laparoscope provides plenty of room for the optical fibres required to carry light into the abdomen, and light is piped into the proximal end of the laparoscope in the conventional manner. The laparoscope will be capable of a field of view of at least 60° (Figure 3). It is possible to design it so as to view either straight ahead or at the 30° angle favoured by Berci and Cuschieri [7].

Obviously no camera exists with a diameter of 1.5 mm, and so the images need to be carried in some way from the lenses at the distal end of the laparoscope to image capturing devices at the proximal end. We propose the use of rod lenses to transfer the images from end to end, as these retain the picture definition. At the proximal end the rod lenses will image onto CCD chips. Each rod lens can image onto one or three chips, the latter option providing higher colour definition. The housing for the CCD chips should be similar in size to the housing for existing 2D laparoscope cameras.

A laparoscope with rod lenses and in-built CCD chips requires considerable design effort, therefore a proof of concept model has been commissioned. This model utilises fibre optic bundles as image carriers, and these images are captured by the CCD chips in our existing autostereoscopic camera system. While having a lower image definition than rod lenses, this model will allow us to perform local trials in simulated conditions.

Challenges

There are several technological challenges involved in the construction of an autostereoscopic laparoscope. The image quality of the laparoscope must be similar to that of a conventional laparoscope in order for it to be acceptable as a surgical tool. In practice it will not be difficult to make an autostereoscopic display with sufficient resolution — 800 × 600 pixels is easily achievable using existing technology. The difficulties will be in the design of the lenses. These have small diameters and so transmit less light than the larger diameter lenses used in conventional laparoscopy. This is not an insurmountable problem and can be tackled with good lens design, high brightness light input, and sensitive CCD chips. An alternative solution has been proposed by Moore [8], where a fast CCD is placed near the distal end of the laparoscope, obviating the need for rod lenses. The fast CCD could alternatively be placed at the proximal end of the scope imaging from a large diameter rod lens, in a similar manner to Zeiss' two view system [1]. Should more than six views be desired, Moore's solution would prove even more useful because more views would otherwise require either smaller lenses or a larger tube.

A further challenge lies in the fact that the six cameras' views may need to be aligned with respect to each other in order that the surgeon sees a high quality three dimensional image. While the alignment can be performed optically, this may prove difficult. A simpler solution is to align the images digitally in the video multiplexer.

Benefits & Costs

The major benefit of the autostereoscopic laparoscope is that it provides depth perception without the need to change any other operating procedure. No headset or special glasses are required, allowing the laparoscopic surgeon to operate as with a conventional laparoscope. Dunn and Watson [9] comment a number of times on the difficulties posed by the lack of depth perception in conventional 2D laparoscopy, especially for beginners. Furthermore one of the author's (DCD) experience with a two view shuttered glasses system show that even an experienced laparoscopic surgeon can benefit greatly from depth perception. The use of an autostereoscopic display will allow laparoscopic surgeons to operate more quickly, yet more safely.

The autostereoscopic laparoscope system will, in mass production, be competitively priced relative to 2D laparoscope systems. It will also have as good definition as current systems. Perhaps the only real cost will be due to the fact that some viewers will find it tiring to view objects which appear to be far behind or far in front of the autostereoscopic display's screen. Such tiredness would be due to competition between the physiological cues of focus and convergence. The solution is to train the surgeon to place the laparoscope so that the objects of interest lie close to the plane of the display's screen. Thus the surgeon receives the benefit of depth perception at the cost of a little extra training in the correct use of the autostereoscopic laparoscope.

Conclusions

Autostereoscopic displays are coming out of the laboratory and into the commercial environment. An autostereoscopic laparoscope will benefit the laparoscopic surgeon, making his operations safer and faster. There are challenges yet to be overcome in making an autostereoscopic laparoscope, but the prototype model will give valuable information about how best to meet these challenges.

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