A Robotic Camera Holder for Laparoscopy

Patrick A. Finlay

Armstrong Healthcare Ltd, High Wycombe HP13 7AG England

Abstract - **In minimally invasive surgery, a robotic telemanipulator can provide a valuable third hand for the operating surgeon. The robotic system holds the endoscopic camera and moves it in response to intuitive head movements of the surgeon. This gives full personal control over the image position, eliminates problems of camera shake and releases a qualified assistant for more effective clinical duties.**

INTRODUCTION

Endoscopic minimally invasive surgery was first introduced in the 1920's for gynaecological procedures. The subsequent development of minimally invasive surgery for abdominal laparoscopic procedures in the 1980's has led to a rapid growth in the demand for this technique for gall bladder and hernia operations in particular. In urology, an increasing interest in laparoscopic procedures is developing.

The principle advantages of endoscopic minimally invasive surgery are well known: a substantial reduction in post-operative recovery time, less damage to surrounding tissues, reduced post-operative pain and the absence of post-operative scarring. Against this must be set the fact that endoscopic procedures take longer and require more training for the surgeon and support staff. In addition endoscopic techniques require extra manpower to assist with the additional instrumentation. The use of robotics in laparoscopic surgery is able to reduce the supernumerary staff required, and give the surgeon improved personal control over the conduct of the operation.

ENDOSCOPIC SURGERY

In endoscopic, as opposed to conventional open surgery, the surgeon makes a small hole or port in the patient. A 10mm diameter tube know as a cannula is inserted into the port, having a seal arrangement. The patient's abdominal cavity is then inflated by admitting carbon dioxide gas through a tap in the cannula. This distends the abdomen and provides the surgeon with room in which to work.

A laparoscope is then inserted through this first port. The laparoscope consists of a telescope about 300mm long and 10mm diameter. A rod lens arrangement conveys the view at the tip of the instrument to a camera mounted at the proximal end, which remains outside the patient. High intensity light is fed down the telescope for illumination. The camera view is displayed on a colour monitor mounted above the patient, and it is this view which the surgeon uses when carrying out the operation.

Further ports are then created and fitted with cannulae, through which a variety of instruments are inserted. The surgeon then carries out the necessary dissection and repair activities, using diathermy to control bleeding.

One of the most notable features of laparoscopic surgery is the need for three hands: the surgeon requires two to manipulate instruments and a third to hold the laparoscope and camera assembly. The third hand in practice is usually provided by an assistant who holds and moves the laparoscope under oral instruction from the surgeon. This is an unsatisfactory arrangement: not only does it tie up an expensive assistant in a tedious and ergonomically uncomfortable task, but the communication between surgeon and assistant is not straightforward: for example an instruction from the surgeon to move the camera right must be interpreted as a move to the left by an assistant who is on the opposite side of the table. Frequently miscommunications result in the camera being pointed in the wrong spot, leading to frustration and stress.

ROBOTIC IMPROVEMENTS

This unsatisfactory arrangement led to the development[1] of a robotic camera holder for laparoscopy, now known as EndoAssist. EndoAssist holds the telescope, and moves it in response to movements of the surgeon's head. Technically, EndoAssist is a robotic telemanipulator with three normal degrees of freedom controlled by corresponding head gestures. The surgeon wears a headband fitted with multiple transmitters which communicate with a receiver unit mounted on the surgeon's monitor. As the surgeon turns his head, different signals are detected and used to infer direction. The EndoAssist controller converts these signals into movements of the camera in the logical direction. Thus to move the camera to view more to the left, the surgeon turns his head left; to move up, he looks up and so on. This can be accomplished by relatively small angles of head turn, so that the surgeon does not need to shift his gaze from the monitor, but merely looks towards the side of the screen where he wishes the view to move. The EndoAssist only responds to head movements when the surgeon is additionally pressing a footswitch, thus allowing him to make unhindered head movements when no camera motion is required.

Instead of a conventional robot geometry, EndoAssist is designed with an articulation and control method specifically intended for the needs of the laparoscopic surgeon. Kinematically the robot is a 3 degree of freedom cylindrical geometry manipulator, with an additional linkage added to make its movements goniometric - that is, all passing through a single point. The linkage is schematically illustrated in figure 1. The laparoscope is attached to the robot arm by a pin joint which can rotate freely. The goniometric locus is the vertical line defined by possible intersections of axis 2 with the laparoscope axis. The working envelope of the arm is optimised when the goniometric point is situated at the patient entry point, and when the robot is first introduced into the operating theatre, axis 1 is adjusted to this height.

There are four possible movements of the laparoscope, corresponding to the pan, tilt, zoom and swivel motions of its camera. The swivel motion is only required if an angled optic laparoscope is used. Pan and swivel motions are directly related to movements of the corresponding robot axes. Zoom and tilt are achieved by synchronous motion of the robot vertical and pitch axes

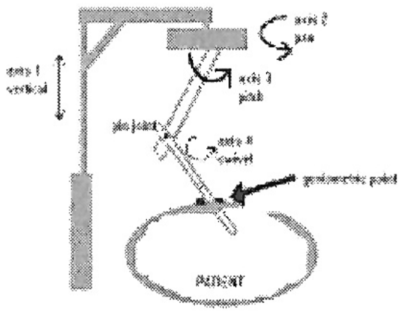

Fig 1: Schematic illustration of EndoAssist geometry

It will be appreciated that even if an axis drive were to fail, the movement of the laparoscope would still pass through the goniometric point. It is hence physically impossible, even in a fault condition, for the robot to move in a direction which would cause tearing of the patient's skin: this is an important safety consideration.

When the footswitch is pressed by the surgeon, the robot controller will read the sensor and provided a gesture has passed a pre-set threshold, will trigger movement of the appropriate robot axis. The robot can move the camera in the pan, tilt and zoom senses.

To stop a movement, the surgeon can either reverse the gesture or remove his foot from the footswitch. An emergency stop button is also provided, but has never been required. Safety has been designed into the EndoAssist, which uses stepper motors and supplementary redundant encoders to control and monitor position. There is also a force sensor which automatically stops movement if an excessive force is exerted on the telescope. In normal use the telescope is operating in the extended abdominal cavity, and therefore does not contact any organs: the force sensor is a precautionary guard against any inadvertent contact with organs or other instruments which might exceptionally occur.

CHANGES DURING DEVELOPMENT

As a result of early trials, a number of design changes were implemented to improve the ease of use of the system. One change was to make the robot a free standing unit, rather than clamping part of it to the operating table. This has the advantage that set up and removal are very simple: the unit is wheeled to a convenient position next to the table, and positioned so that its goniometric point lies at the laparoscope entry port. Two laser diode aiming lights are used to assist with this. The wheels are then braked, and the EndoAssist is ready for use.

Sterilisation was originally achieved using standard hospital drapes, but is now managed by covering the arm in a transparent sterile bag. An autoclavable clip is used for securing the laparoscope, and is designed to be easy to fit and remove. If it becomes necessary at any time to remove the robot, the clip is released and the EndoAssist is wheeled away.

One of the design concerns was to ensure that the EndoAssist mechanism did not intrude into the operating area. The surgeon needs to be able to move his laparoscopic instruments very freely, and a conventional arm would have prevented this. For this reason, after early trials the mechanism was mounted at a higher level, and the pivoting arm length was increased to compensate. This arrangement proved more satisfactory. However it was found that even the single pivoting arm could occasionally obstruct the surgeon's freedom of movement in some operations. For example in gall bladder surgery it was discovered that the when the camera was pointing at the cystic duct, the robot arm position prevented the surgeon from moving instruments across the mid-line of the patient. This was overcome by providing a curved pivotal arm as an alternative option. For many cases, such as hernias and fundoplications, the straight arm remains preferable.

The possibility of voice control was considered at an early stage, but was rejected due to the inconvenience of needing to pre-programme the robot with each user's voice profile, and the unacceptably high reject rate reported by users of other voice control systems. It was noted that users' voice profiles change significantly at times of high stress and tiredness, leading to a failure of the system to recognise commands at times when it is most important. By contrast, head control was found by the majority of users to be intuitive to learn and error free.

PERFORMANCE

EndoAssist has now been used for several thousand clinical procedures. Results show that users are able to master the basic control of the unit following ten minutes pre-operative practice using a phantom. Feedback from users has indicated another advantage of the system, which is its ability to maintain a steady image over a long period of time, as opposed to the shaky image resulting from hand tremor of a human assistant at the end of a 2 hour procedure.

A randomised trial[2] of 100 cases of laparoscopic cholecystectomy in which half the patients were treated using a manually held camera, and half with a camera held by EndoAssist showed that the use of EndoAssist reduced the time of the operation by an average of 8 minutes ($p<0.05$) allowing additional operations to be scheduled on the list. The variation in times of operations was also reduced, with the standard deviation of EndoAssist cases being 2/3 that of manual cases. This improved the hospital's ability to schedule cases and plan resources.

The use of head control was demonstrated to have a short learning curve effect: users were performing at fully-trained performance level after three cases.

The trial demonstrated that laparoscopic operations could be performed successfully using a robot instead of a human camera holder, who could then be deployed to more clinically useful tasks.

A number of users have reported the benefit of using EndoAssist in training junior surgeons. Conventionally, the instructor holds the camera for a trainee surgeon who holds the instruments. When the trainee needs help with the instruments, the instructor has to hand the camera over to the trainee. Using EndoAssist, both trainee and instructor have their free and the additional benefit of a constant steady image

FUTURE POSSIBILITIES

Some interest has been expressed in the use of EndoAssist for telepresence and telesurgery. In telepresence, the user wears a helmet mounted display consisting of two miniature colour monitors, one directed at each eye. Movement of the head correctly coupled to an EndoAssist would cause exactly corresponding shifts in the monitor images, and would give the user the sensation of being physically present in the surgical site, and able to look around. Trials have shown two types of difficulty with this arrangement. One concerns the inherent latency of the system.. The maximum tolerable motion delay to avoid intruding into conscious perception is around 300 milliseconds. Whilst a certain amount of hysteresis is inevitable with a mechanical system, it is possible for EndoAssist to achieve this level of latency with slow head movements . However the speed of EndoAssist is limited for safety reasons, and a rapid head movement results in the tracking system following at a slower speed leading to disorientation in the user and even motion sickness. A second difficulty relates to the tendency of the user to lose contact with reality when in a telepresence mode, thereby risking collisions with external objects in the real world. Telepresence is therefore unlikely to be of practical value for this type of technology in the near future.

In telesurgery, the surgeon is physically separated from the patient. The surgeon may be in an adjacent office (but not needing to scrub up) or may be in a different location altogether. In either case, the possibility exists for an experienced surgeon to assist a junior colleague who is physically with the patient. EndoAssist has successfully been used in telesurgery experiments, in which the distant surgeon is able to take control of the camera and move it to indicate different areas of interest to his local colleague. A major programme is currently underway supported by the European Union to demonstrate the potential for telesurgery using a specially modified EndoAssist. In this application[3] the robotic arm holds an ultrasound probe which is inserted into the patient in a manner similar to an endoscope, and is then manipulated by a remote ultrasonographer who liaises with the operating surgeon via a teleconferencing link. This enables an expert ultrasonographer to diffuse his skills more widely by assisting at a distant operation. It is one of a number of examples of telesurgery currently under investigation for future commercialisation.

CONCLUSION

EndoAssist has been shown to be a useful tool in minimally invasive surgery, reducing the time of procedures, giving the operating surgeon improved personal control and better image quality. More importantly it has been shown that the use of EndoAssist enables a skilled medical assistant or junior surgeon to be re-deployed for primary treatment of patients rather than acting as a tool-holding assistant. In these days of fixed hospital manpower but ever increasing waiting lists, this is an appropriate application of advanced technology to improve the delivery of healthcare.

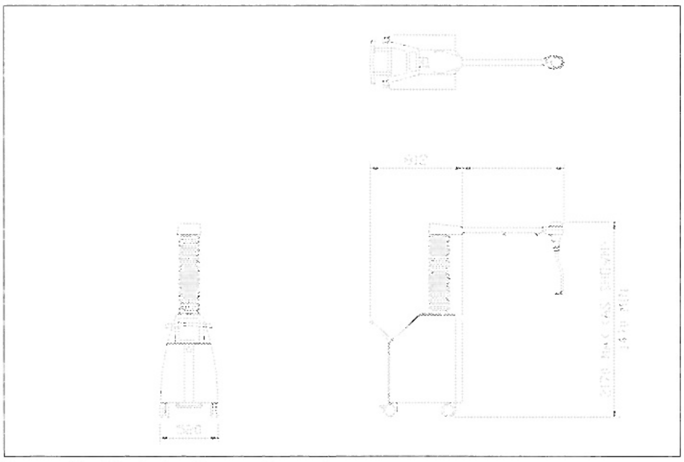

figure 2: EndoAssist outline views

REFERENCES

1. P.A. Finlay: Clinical Experience With A Goniometric Head-Controlled Laparoscope Manipulator *IARP Symposium on Medical Robotics, Vienna 1996*

2. S. Aiono, J. Gilbert, P.A. Finlay: *Proc SMIT conf, Boston Ma, Nov 1999*

3. L. Angelini, P. A. Finlay: MIDSTEP - A Telesurgery Demonstrator For Remote Ultrasound-Guided Interventions: *European Conference of Endoscopic Surgeons, Rome 1997*