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Technical Report

3-D Telestration: A Teaching Tool for Robotic Surgery

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ABSTRACT

Background: **Telestration is an important teaching tool in minimally invasive surgery (MIS). While robotic surgery offers the added benefit of three-dimensional (3-D) visualization, telestration technology does not currently exist for this modality. This project aimed to develop a video algorithm to accurately translate a mentor's two-dimensional (2-D) telestration into a 3-D telestration in the da Vinci visual field.**

Materials and Methods: **A prototype 3-D telestration system was constructed to translate 2-D telestration from a mentor station into 3-D graphics for the trainee at the robotic console. This system uses fast image correlation algorithms to allow 2-D images to be placed over the same anatomic location in the two separate video channels of the stereoscopic robotic visualization system. Three subjects of varying surgical backgrounds, blinded to the mode of telestration (2-D vs. 3-D), were tested in the laboratory, using a simulated robotic task.**

Results: **There were few technologic errors (2), only one of which resulted in a task error, in 99 total trials. Only the experienced MIS staff surgeon had a significantly faster task time in 2-D than in 3-D ($P < 0.05$). The MIS fellow recorded the fastest task times in 2-D and 3-D ($P < 0.05$). There were nine task errors, six of which were committed by the MIS fellow. The nonsurgeon trainee had the least number of errors but also had the slowest times.**

Conclusions: **Robotic telestration in 3-D is feasible and does not negatively impact performance in laboratory tasks. We plan to refine the prototype and investigate its use *in vivo*.**

INTRODUCTION

Robotic surgery is an evolving field within minimally invasive surgery (MIS). Robotic surgical technology has allowed the movements of a surgeon's hands to be safely and precisely transmitted from a remote control console to robotic arms at the operative field. This approach has been successfully applied to a number of surgical procedures.[1–5]

In a previous work, we identified a number of clinical advantages and limitations to the utilization of surgical robots to perform the laparoscopic gastric bypass[1] and the laparoscopic cholecystectomy.[6] Other investigators have also described a number of limitations to robotic

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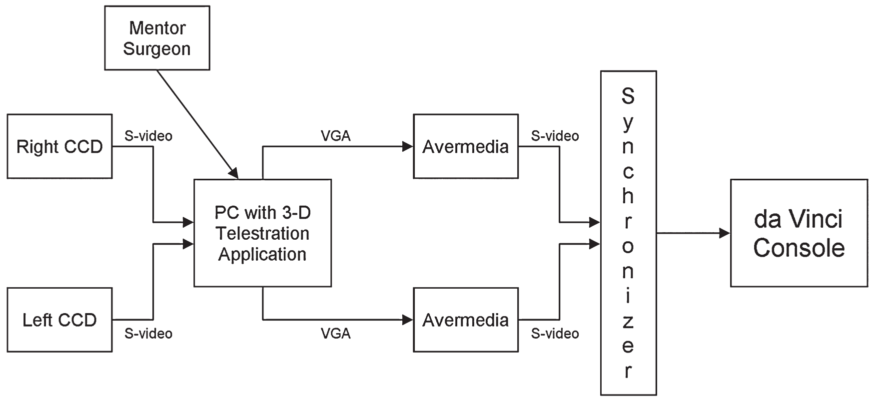

FIG. 1. Architecture of telestration system. CCD, charge-coupled device; PC, personal computer; 3-D, three-dimensional; VGA, video graphics array.

surgery, including difficulty in transferring robotic surgical skills form mentors to trainees.[7,8]

A major benefit to robotic surgery is true three-dimensional (3-D) visualization. While standard laparoscopy employs a two-dimensional (2-D) image, the da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA) utilizes a laparoscope with two separate visual channels powered by separate light sources. The image from each visual channel on the laparoscope is detected by an individual camera and displayed onto two separate monitors within the da Vinci surgeon console. Since each of the surgeon's eyes sees a unique image, this visualization system replicates human binocular vision and produces a true 3-D surgical field of view.

Similar to robotic surgery, telemedicine has become widespread in clinical practice.[3,9,10] Application of this technology has ranged from patient interview by video conference to remote surgery using a surgical robot.[10–13] Telestration has been a valuable tool in telemedicine.[13,14] This technology allows the remote mentor to participate within the trainee's environment by placing instructive markings onto a video image. This education paradigm has been successfully applied to surgical education.[9,11,13]

While telestration holds promise as a teaching tool in robotic surgery, a robotic telemedicine platform does not currently exist. To date, strategies that have been devised to teach robotic surgery have primarily involved hands-on training without the capability of placing instructive illustrations onto the robotic visual field.[15] The implementation of telestration to the da Vinci system poses a significant technologic challenge. Three options exist for telestration with the da Vinci system. The simplest method is to use 2-D visualization and 2-D telestration. This technique is easily implemented but eliminates the advantages of 3-D visualization. A second option would be to use a 2-D telestration system with a 3-D laparoscope. Such a system would only be capable of producing telestration in one channel of a stereoscopic camera. The graphic would be confusing and inaccurate. The best solution would be a telestration system that places a graphic to overlay the same position in both optical channels of a 3-D laparoscope and construct a true 3-D telestration.

The da Vinci visualization system utilizes two separate video channels to construct a true 3-D image. While robotic surgery offers the added benefit of 3-D visualization,[16] telestration technology does not exist for this modality, as current telestration systems are two-dimensional (2-D). These systems overlay telestration graphics onto a background image without any regard for depth. However, in order to accurately mark a target in the robotic 3-D visual space, the telestration graphic must appear in the same location to both the right eye and the left eye. This would require a compensation for the horizontal shift in human binocular vision, as replication of a telestrated graphic from the visual field of one eye to

FIG. 2. Mentor surgeon at a two-dimensional telestration station.

the exact same coordinates in the visual field of the other eye would produce an asynchronous image that would be unsafe in the clinical setting.

A 3-D robotic telestration system would improve the communication between the mentor and the operating surgeon at the robotic console by providing precise visual cues that will enhance the operating surgeon's understanding of the mentoring surgeon's directions. Such an interaction should enhance the educational experience and ensure patient safety. This project aimed to develop a prototype that would allow a mentor surgeon to telestrate on a live 2-D image of the surgical scene and display that telestration in the da Vinci console in such a way that the operating surgeon perceives that the telestration marks were made directly on the tissue. In this paper, we report our experience with a new 3-D robotic surgery telestration technology and results of the initial laboratory testing.

MATERIALS AND METHODS

3-D telestration technology

The 3-D telestration prototype consists of the da Vinci system (including video tower), a Windows XP (Microsoft Corporation, Seattle, WA) personal computing workstation with dual capture card and a multioutput display graphics card, and two Avermedia (Chung-Ho City, Taiwan) Micro-key devices (for converting the RGB video signal to s-video). The architecture of this system is illustrated in Figure 1.

Since the (x, y) position of a marked point in the right eye image does not correspond to the same (x, y) position in the left eye when viewing stereo images, a spatial correlation is required to place a mark made in the right eye image in its corresponding location in the left eye image and produce an accurate 3-D view. 3-D telestration is accomplished by having the mentor surgeon mark points in the right eye image of the surgical scene. A software algorithm then takes the 2-D location of each point in the right eye image, along with the left/right image pair of the surgical scene, and determines the corresponding (x, y) position of each point in the left eye image. Once a mark is placed in the right eye image, the video algorithm searches the left image for the feature that matches the marked location in the right eye. Based on the physical construction of the endoscope, the location of the feature in the left eye image can be sought within a defined search window. The algorithm then performs a disparity calculation throughout the search window (at a resolution defined by the correlation window) to determine the region that best matches the feature selected in the right eye image. The two images (i.e., the right eye and left eye), with their respective overlaying of telestration graphics, are combined into the 3-D da Vinci visual field. This results in a single telestration mark that appears to overlay the correct anatomy and at the correct depth in the surgeon's 3-D field. Without this compensation, there would be two separate telestration graphics in the 3-D field, which would be confusing and unsafe.

FIG. 3. Robotic trainee at the da Vinci control console, which is connected to the mentor station.

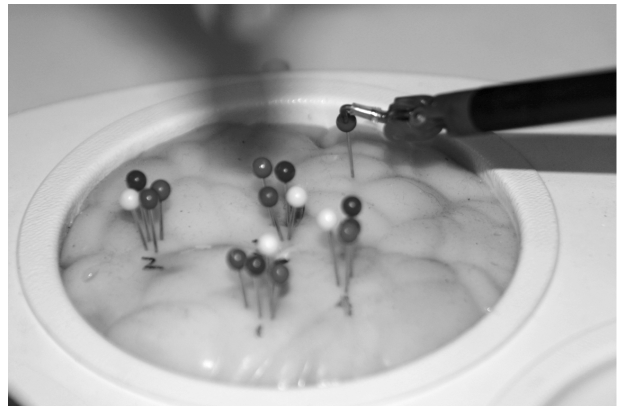

FIG. 4. Training model with four pin clusters (targets). The robotic instrument is in the ready position at the start pin.

The telestration image can be any free-form graphic (i.e., shape or writing) drawn by the mentor. The transfer of the image from the mentor station to the da Vinci visual field is essentially immediate.

Laboratory testing

A working prototype was tested in the laboratory. The prototype consisted of a 2-D mentor computer station (Fig. 2), which was connected to the da Vinci surgical robotic system (Fig. 3), as described above. The mentor could not differentiate depth at the 2-D mentor station. The mentor, in all cases, was an attending surgeon with extensive experience in minimally invasive and robotic surgery. The training model was constructed by using

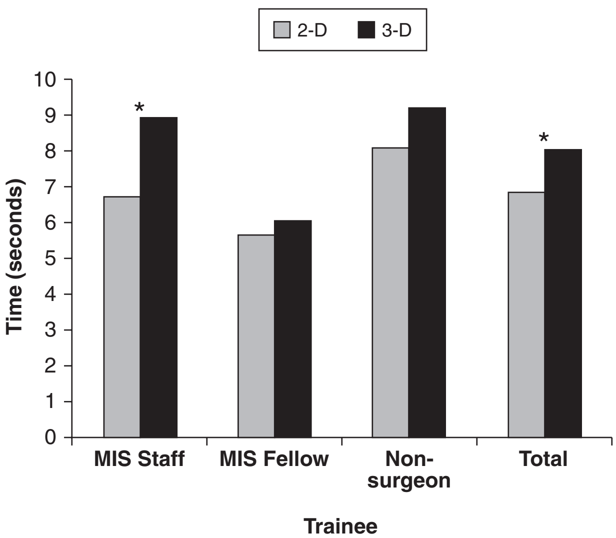

FIG. 5. Comparison of individual mean task completion times. 2-D, two-dimensional; 3-D, three-dimensional; MIS, minimally invasive surgery.

four clusters of four pins (Fig. 4). Pins in each cluster were in close proximity and placed at varying depths (Fig. 4). Each trial began with the robotic instrument touching the same starting point. The mentor would then randomly choose to use 2-D or 3-D telestration at the mentor console and place a mark on a single pin. The time to touch the target and any committed errors were then collected by a direct observer of the training model.

Three trainees of varying surgical expertise were tested: (1) an experienced surgery faculty member with fellowship training in MIS, (2) an MIS fellow with some laparoscopic experience, and (3) a psychiatrist without any MIS experience. Each trainee was allowed 33 repetitions, as described above.

Data collection and analysis

Data were collected for each attempt by each trainee (99 total trials). The telestrated target, telestration mode, time to target acquisition, and trainee errors were recorded. Data were analyzed by using the Fisher's exact test for comparison of discrete variables and the Student's *t*-test for paired comparisons of continuous variables. Statistical analysis of multiple continuous variables was accomplished via analysis of variance with the Bonferroni post-test. Statistical significance was set at the $\alpha = 0.05$ level for all analyses.

RESULTS

The telestration prototype functioned correctly throughout the study period. Of the 99 trials (33 per each of the 3 subjects), there were only 2 (2.02%) incidents in which the video algorithm did not perfectly correlate the 2-D telestration graphics into 3-D. In these situations, the mentee reported seeing two separate images, because the correlation algorithm did not completely superimpose the images. Only one of these incidents resulted in an error; the subject touched another pin within the same cluster.

Overall, the amount of time required to reach the designated target was significantly longer for 3-D telestration, compared to its 2-D counterpart ($P < 0.05$; Fig. 5). In an analysis of individual trainees, however, only the MIS staff was significantly faster in 2-D than 3-D ($P < 0.05$), while the MIS fellow and the nonsurgeon subject achieved similar times in both modalities (Fig. 5). The MIS fellow recorded the fastest time in both modalities (Fig. 5). This was significantly faster than both of the other subjects in 3-D ($P < 0.05$) and faster than the nonsurgeon subject only in 2-D ($P < 0.05$; Fig. 5).

In terms of accuracy, there were relatively few errors during the trials (Table 1). The MIS faculty committed only two errors, one error in 2-D and the other in 3-D (Table 1). The nonsurgeon trainee only committed one error, which was in 2-D (Table 1). He also reported an asynchronous telestration image, which did not result in an error, during one trial. The MIS fellow committed six errors, one of which occurred during a trial in which the telestration image was asynchronous (Table 1). The overall error rate was 9.1% (9 errors in 99 trials). There was no statistically significant difference in the overall number of errors between visualization modes (three errors in 2-D and six errors in 3-D). Similarly, there was no statistically

TABLE 1. DETAILS OF ERRORS COMMITTED BY EACH TRAINEE

	MIS staff		*MIS fellow*		*Nonsurgeon*		*Total*	
Visualization mode	*2-D*	*3-D*	*2-D*	*3-D*	*2-D*	*3-D*	*2-D*	*3-D*
Errors								
Touched different pin, same group	0	0	1	2	1	0	2	2
Touched different pin, different group	1	1	0	2	0	0	1	3
Failed to acquire target	0	0	0	1	0	0	0	1
Total	1	1	1	5	1	0	3	6

MIS, minimally invasive surgery; 2-D, two-dimensional; 3-D, three-dimensional.

significant effect of the visualization mode on the number of errors committed by each individual (Table 1).

DISCUSSION

This work represents the initial report of a novel technology designed to enhance the transfer of knowledge in robotic surgery. While telestration has been widely used in industry and education, the teaching capabilities of this technology has not been fully explored in surgery. When it has been utilized in clinical surgical education, telestration has been limited to 2-D applications. In this paper, we report our experience with a functional prototype of a 3-D telestration system that integrates into the stereoscopic imaging system of the da Vinci surgical robot. Further, this system allows the mentor to use simple 2-D telestration technology and algorithmically translates the instructions into 3-D telestration graphics in the robotic visual field.

We sought to answer a number of questions with this initial investigation. First, it was imperative to demonstrate that the technology was feasible. The system would have to be user-friendly to the mentor and easy to setup. This study clearly demonstrates that it is possible to construct a 2-D to 3-D surgical telestration system and to overcome the technologic challenges outlined earlier. Further, the prototype functioned reliably, with only 2 incidents of asynchronous 3-D image overlay in 99 trials.

It was also important to show that surgeons could easily adopt the system into clinical practice. The 3 subjects in this study ranged in MIS experience from none (nonsurgeon trainee) to extensive (MIS faculty). Yet, all trainees were able to understand the mentor's nonverbal communication and operate the robot accordingly. In fact, the least experienced subject (the nonsurgeon trainee) made the fewest errors but had the slowest task time. On the other hand, the MIS fellow performed the robotic tasks faster than the other trainees but committed the most errors.

The overall number of errors was low, and there was no statistically significant correlation between the mode of telestration (2-D versus 3-D) and the occurrence of errors. However, the safety of this technology cannot be clearly established from this limited initial report. As for the mentor interface, the technology was easy to use. The mentor reported a clear image of the operative field on the mentor display. The telestration software was technically intuitive and responsive to the mentor's controls.

CONCLUSIONS

This study demonstrates that 3-D telestration is possible and can be applied to robotic surgical education and clinical mentoring. The prototype device proved to be usable, reliable, and accurate. Most important, the 3-D image correlation algorithm did not significantly diminish performance in terms of task times and error rates, when compared with unadjusted standard 2-D telestration imaging. Our preliminary results were collected by using an inanimate model in the laboratory. The effectiveness of this system in the setting of actual tissue remains to be investigated. This technology warrants further investigation to refine the image correlation algorithm and the mentor interface, as well as to determine the feasibility of *in vivo* applications.

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