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A Haptic Augmented Reality Surgeon Console For a Laparoscopic Surgery Robot System

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Abstract: Robot surgery needs measures for safety and dexterous control of the surgical instrument for wider application, in spite of evident clinical efficacy in diverse surgery areas. Integration of the advanced human machine interface technologies including haptic rendering and augmented reality in surgeon console for robot-assisted laparoscopic surgery to provide enhanced safety and easier system control has been tried in this study. The surgeon console is composed of various hardware and software modules for endoscope video signal capture, image/vision signal processing, 3D deformable model handling, haptic and graphic rendering, and interface to displays and haptic devices. Intra-operative endoscopic video signal is processed to extract information for the tracking of “Object–Of–Interest (OOI)”s such as anatomic structure that needs cautious handling, bleeding site and the relative position of the surgical instruments, and displayed with overlaid image of 3D-reconstructed preoperative medical imaging data. Parts of the extracted or user-defined OOIs can be transformed into a deformable 3D model and interactively manipulated by the surgeon during the operation for intuitive information utilization. The haptic rendering provides virtual force field experience for the surgeon to have safer handling of the surgical instruments and dexterous execution of surgical task. The surgeon console framework has been implemented on a PC integrated in a laparoscopic surgery robot system under development. The system showed successfully the feasibility of the concept and further development for enhanced usability and graphical contents quality is underway.

Keywords: haptic, augmented reality, laparoscopic, robot surgery, safety

1. INTRODUCTION

Robot surgery has been becoming an established surgical method with evident clinical efficacy in diverse areas. In spite of rapid and enormous advancement in robot surgery, more technological improvement is still necessary in terms of safety and dexterous control of surgical instrument for wider application. The main factors related to safety and dexterity must be mechanical and control technologies such as robot manipulator structure, control algorithm and etc., which implement actual surgical task motion in the robot system. However, the development of novel robotic hardware requires relatively long development and evaluation time and it is deemed that augmenting intra-operatively provided medical information for surgeon in terms of safety enhancement as a form of interactive visualization system could also be a practical auxiliary solution for the purpose in the meanwhile. Numerous novel technologies for human machine interface or interaction have seen rapid advancement lately and can be utilized for the interactive information visualization including technologies such as haptic feedback rendering and augmented reality. The purpose of this development was to have an interactive haptic visualization system which integrates endoscopic vision with various medical image and physiological signal data obtained pre-operatively and/or intra-operatively. The system can be a framework tool for implementation of image-guidance in various endoscopy assisted surgery, which facilitates enhanced safety in surgical task.

2. METHOD

The system is composed of various hardware and software modules for endoscope video signal capture, image/vision signal processing, 3D deformable model handling, haptic and graphic rendering, and interface to displays and haptic devices. Basically it is a workstation computer on which image processing hardware modules are equipped and the system software runs. We utilized various available open source libraries for each specific functional module in the system software as depicted in Figure 1. The system software is composed of video signal preprocessing modules, haptic and graphic rendering modules, image processing computation modules, and peripheral device manager modules for display device, haptic interface device and etc. The diagram in Figure 2 shows the data flow and the structure of the system. The endoscope or laparoscope system is connected to the input of this system and the video signal is captured and processed for integration and augmentation of other medical information and finally displayed on a 3D graphic display device and haptic interface devices through graphic and haptic rendering, respectively.

Intra-operative endoscopic video signal is captured and converted into digital data and then processed to extract information for the tracking of “Object – Of –

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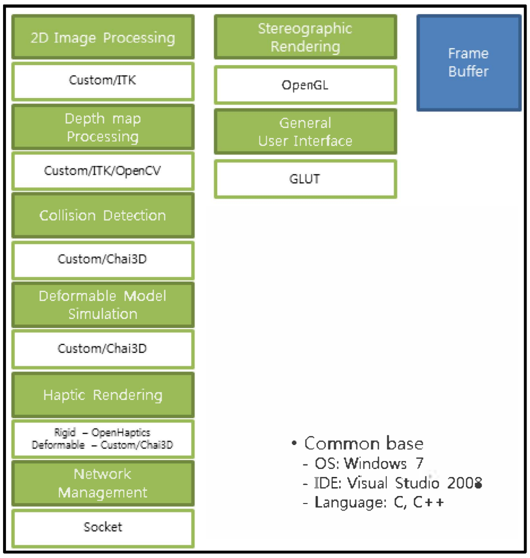

Figure 1. Block diagram of the software system composition

Interest (OOI)"s such as organ or anatomic structure that needs cautious handling, vascular/nerve structures and the relative position of the surgical instruments and possible registration to and overlaid display with preoperative medical imaging data. The OOIs are located by two common processes: feature extraction and tracking. Color and morphological information are used to segment the feature, and a Kalman filter is applied for robust tracking of the object locations with reduced error. Figure 3 shows the algorithm diagram. Parts of the extracted or user-defined OOIs can be transformed into a deformable 3D model and interactively manipulated by the surgeon during the operation for intuitive information utilization. The haptic rendering can provide virtual force field experience to the surgeon in various forms of augmented haptic feedback such as "virtual force sheath" to the surgical instrument and "virtual wall" around the OOIs, which can assist surgeon's better control of the safe handling of the surgical instruments and the dexterous execution of surgical task.

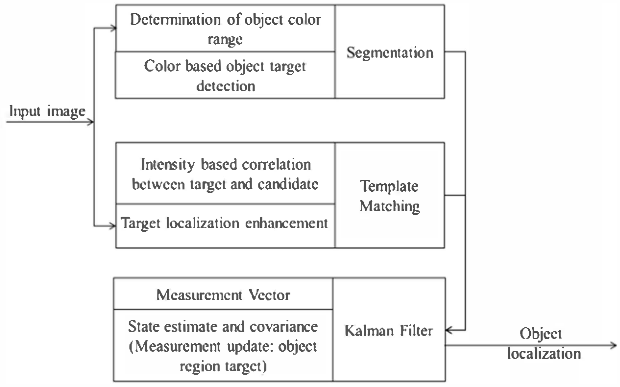

Figure 3. Image processing flow diagram

3. RESULT

In the graphic framework, the endoscopic video captured in real-time can be displayed with various graphics objects overlaid in augmented reality manner. Various concurrent processes run in real-time including full HD stereo display, haptic rendering computation thread with over 3 kHz of refresh rate depending on the scene complexity and deformable graphic simulation with approx. 10 ~ 120 Hz refresh rate depending on the contents complexity. Figure 4 shows the actual view of the graphics framework. Figure 4c shows preliminary results of the object tracking. The upper one shows instrument tracking and the lower one shows bleeding region tracking. User can interact with the graphic deformable model of 3D objects including haptic feedback through haptic interface devices. We used two of PHANToM Omni devices from sensible for left and right hand interaction. The haptic interaction can be with anatomical objects of which the model has been constructed from pre-op medical imaging data, or with arbitrarily set user designated region (as shown in Figure 4d as gray sphere mesh) in which the haptic

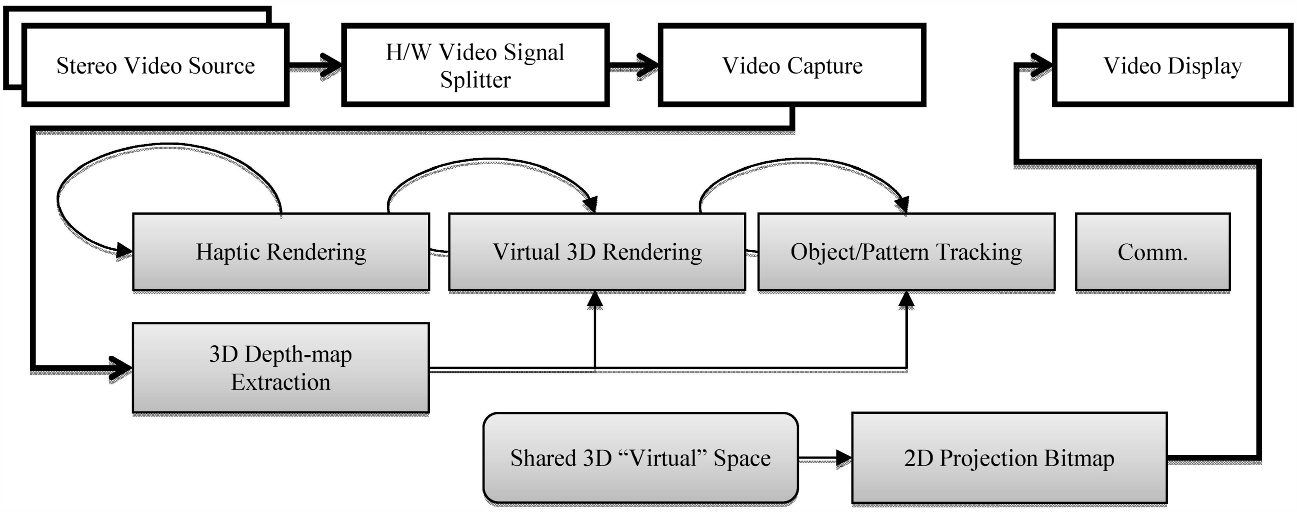

Figure 2. Block diagram of the surgeon console software functional structure

feedback is intentionally made tough or heavy to give the users a kind of caution for safer control of the instruments.

4. CONCLUSION

We believe that these kinds of auxiliary information can be meaningful help for surgeon to have better control of complex surgical operation. The implemented system showed successfully the feasibility of the proposed concept. And further developments are underway to incorporate modules for enhanced mathematical computation in the framework, and to integrate the console into a robot surgery system under development.

ACKNOWLEDGEMENT

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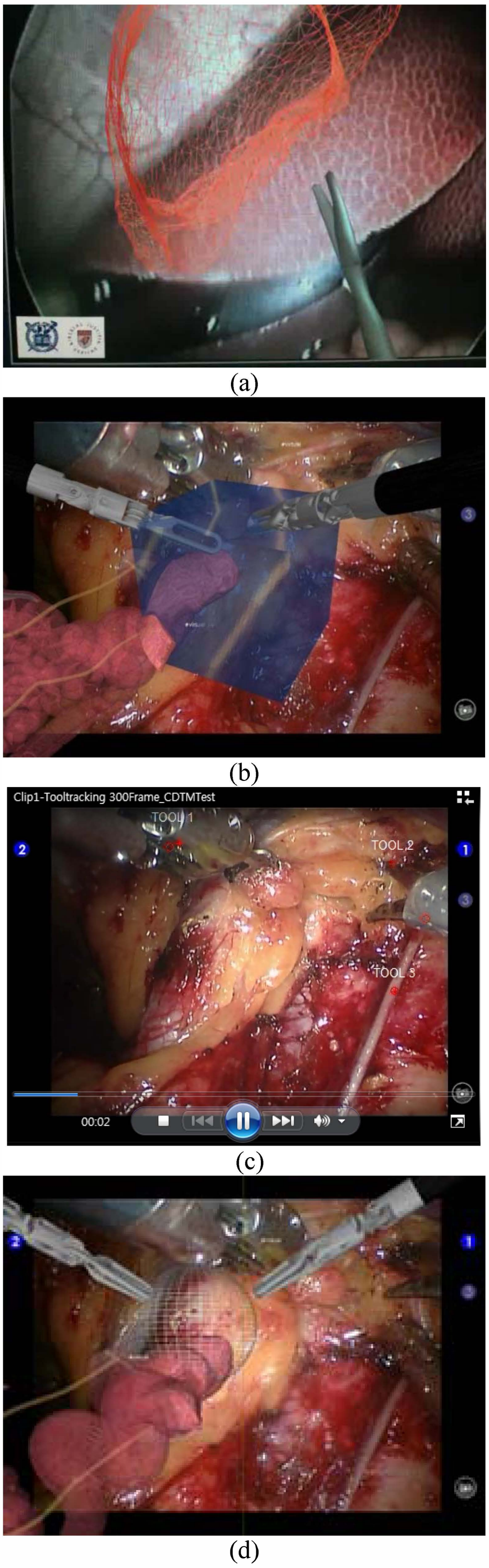

Figure 4. Display example: a) Early version with 640 x 480 resolution, b) Current version with 1024 x 768 resolution, c) the surgical instrument tracking result , d) “virtual wall” example with sphere shape limited region shown in gray mesh