Advanced Technique for Tele-operated Surgery Using an Intelligent Head-mount Display System

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***Abstract*— Recent medical-robotic developments have enabled tele-surgery to become a powerful treatment option when a surgeon is not available locally. But, even though tele-surgery has greatly improved, certain developments regarding the interaction between a surgeon and the remote surgical room is still in need of improvement, especially image display and camera movement. First, the use of two-dimensional imaging during tele-surgery causes a loss in depth perception, orientation and hand-eye disassociation. Likewise, the use of stationary screens can cause neck-strain to a surgeon. Also, the quality of data transmission during the real-time video streaming of a tele-surgery is a high priority issue.**

To approach these issues, we propose a new head-mounted device that provides a more ergonomic and intuitive feeling to tele-operational surgeons. This device allows them to naturally control the view of the camera via head movement, hence providing a three-dimensional view. And by enabling the head-mount display to provide the remote surgical camera with orientation information, our application-level Quality of Service framework can adjust image quality to prevent excess delay and jitter during robotic tele-surgical video. Thus, our device can provide high quality video, as well as a more natural and ergonomic feeling to performing tele-operated surgery.

I. Introduction

Replantation is the process of reattaching a limb that has been completely severed from the body. This is distinguished from the process of revascularization where the limb has not been completely amputated and thus, a portion of the tissue remains [1]. One of the key parts during the reattachment of a limb is to first restore blood flow to the limb by reconnecting the arteries, ultra-small vessels and neural structures through micro-vascular anastomoses [1]. Although micro-vascular anastomoses is very common now days, technology has yet to improve this procedure.

To become proficient at micro-vascular anastomoses, a surgeon must become completely familiar with the operative microscope; doing so will minimize the struggle to achieve optimal visualization [2]. This includes positioning the microscope in such a way to prevent fatigue and tension in the neck and arms, which can amplify the risk of tremors. An alternative approach is robot-assisted surgery through the use of systems like the “da Vinci” System (intuitive Surgical). But, despite the great advantages of this system, such as its fully articulating micro-instruments, and 3-D visualization [3] this surgical system remains expensive and cumbersome. And their approach towards the control and visualization of the surgical region doesn’t provide a surgeon with an intuitive control system; forcing the surgeon to use a stationary monitor and a tele-manipulator for camera movement and image magnification [4].

In this paper we provide an ergonomic yet efficient solution for the control of a surgical camera during tele-operated and microvascular surgeries.

II. State of Art

Various methods for visualization during micro-vascular anastomoses exist, including the use of an operating microscope, magnifying loupes, remote micro-vascular tele-manipulators [5], and the use of robotic systems like the da Vinci Surgical System.

One of the challenges of microsurgery is training and the breakdown of the operative technique. Even though, the recent approaches towards the visualization of ongoing microsurgeries are innovative, systems like the “da Vinci” still require surgeons to go through arduous training to become familiar with hand manipulators to control the surgical instruments and camera. There is yet to be a more ergonomic vision control system, which will enable the surgeon to control the camera by natural head movements.

III. Architecture

A. Major Components

The architecture of our system is composed of two sections, a command center and a patient-side remote center. The command center is made up of two devices: (1) the smart head-mount, which provides the surgeon with 3-D view, and captures head motions. (2) The command center-processing unit; a computer that serves as a bi-directional point of data transfer. It receives the data from the smart-head mount display, filters unwanted motion, and transfers the data to the patient-side control unit. It also receives the video stream sent by the patient-side processing unit.

The patient-side remote center is also composed of two devices: (1) the smart camera unit; a HD Camera equipped with a pan and tilt mechanism. (2) The patient side processing unit; a computer that also serves as a bi-directional point of data transfer, equipped with our image preprocessing software. This computer receives the head-mount’s motion data and sends it to the camera. Upon receiving the video stream, it optimizes it by degrading the image quality from the area outside the surgeon’s region of interest. This will ensure that high-quality video can be provided even during limited or reduced bandwidth.

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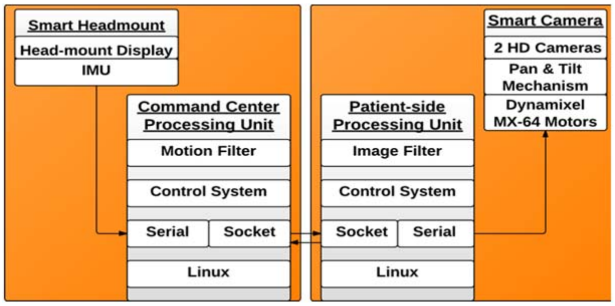

Figure 1. Architecture

B. Procedure

Once our system is initialized, the head motion data is sent via a serial connection to our command center-processing unit, which will filter unwanted motion. Next, both processing units will synchronize. Once the command and the patient-side remote center are synchronized the Smart Camera's pan and tilt mechanism will await head motion data and the HD camera will begin capturing live video. The video stream that is captured by the HD camera is then sent to the patient-side processing unit, which will optimize the quality of the image according to the motion of the head mount and the available bandwidth. This video stream will then be sent to the head-mount display depicted by Fig. 1.

IV. Implementation and Prototyping

At this moment we are in the early stage of implementation, mainly focusing on the motion control of the smart camera. The use of a synchronized head-mount display would give the surgeon and ergonomic and intuitive feeling of the operation by allowing the remote camera to follow head movements in any direction.

A. Implementation Plan

- First phase: Motion Control – Head motion and camera synchronization, vibrations and sudden tilt filtering.
- Second phase: Image Control – Adjust image resolution to allow a faster refresh rate, minimize pixel trailing, motion blur and reduce delay.
- Third phase: Video Quality Optimization-Preprocessing algorithm to improve the performance of video codec.
- Fourth phase: 3-Dimensional Video Implementation – Use two cameras and an image fusion algorithm.
- Fifth phase: Perform integrated test and tuning

B. Prototype

In this paper, to prove the concept of our architecture, our prototype is focused on motion control. The smart head-mount display is composed of the following: a Sony HMZ-T1, and a 3D-Robotics ArduIMU (Ardu-Inertia Measurement Unit). The control-processing unit is composed of a computer equipped with an Intel i7 processor, 4 GB of memory, the Ubuntu operating system, and our motion filtering software. The patient-side remote control station has the same specifications except that it is equipped with our image preprocessing software. The smart-camera is composed of a Logitech QuickCam Pro 5000 camera, and two Dynamixel MX-64 servomotors as depicted by Fig. 2.

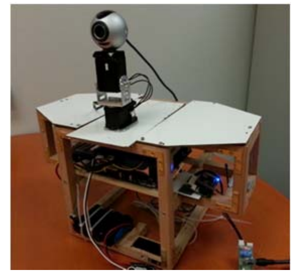

Figure 2. Patient-side Processing Unit

We have successfully tested our phase one prototype as depicted by Fig. 3, and achieved synchronization and an ergonomic control system.

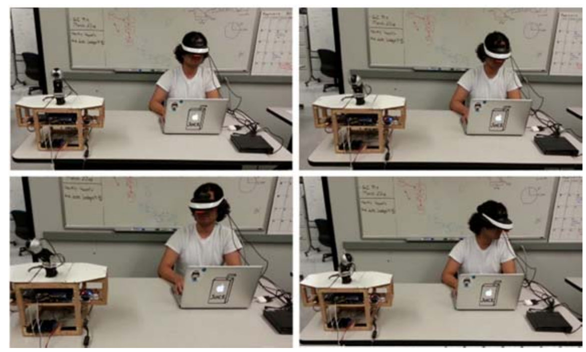

Figure 3. Testing synchronization

V. Conclusion

In this paper we proposed an architecture to improve the process of tele-surgery through the implementation of an intelligent head-mount display control system. We successfully implemented the motion synchronization phase and proved the concept of intuitive camera motion control. However, we still need to improve upon our results and follow through with our implementation plan.

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