Cloud-super-computing virtual colonoscopy with motion-based navigation for colon cancer screening

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***Abstract*—A novel cloud-super-computing-based diagnostic system for colon cancer based on laxative-free virtual colonoscopy examination has been developed. The virtual colonoscopy images are post-processed by computationally intensive algorithms such as real-time computer-assisted bowel preparation for increased patient adherence to the screening program, and real-time computer-assisted detection for improved sensitivity in the detection of colonic polyps. A high-resolution mobile display system is connected to the cloud-super-computing virtual colonoscopy system to allow for visualization of the entire colonic lumens and diagnosis of colonic lesions at anytime, anywhere. The navigation through the colonic lumen is driven by a motion-based natural user interface based on a Kinect sensor for easy navigation and localization of colonic lesions. Preliminary results show that the cloud-super-computing-based virtual colonoscopy system with motion-based navigation improves the workflow and efficiency of the interpretation of virtual colonoscopy images for screening of colorectal cancers.**

***Index Terms*—Cloud computing, high-performance computing, motion-based navigation, virtual colonoscopy, cancer screening.**

I. Introduction

In clinical practice, there is an increasing demand for fast turn-around time in obtaining high quality, multi-dimensional images. Access to such images from anywhere at any time facilitates collaboration between clinicians and specialists and thus improves the quality and timeliness of care for patients. However, most high-quality diagnostic images are computationally intensive and require high-end resources such as dedicated three-dimensional (3D) workstations and advanced visualization software. In today's economic climate, investment in such high-end resources is often restricted, thus limiting broad adoption of improved imaging techniques and tools.

A. High-performance cloud computing

High-performance cloud computing (*HPCC*) [1] integrates high-performance computing (HPC) with cloud computing to provide an informatics infrastructure that delivers the supercomputing power needed for the processing and display of high quality, multidimensional diagnostic images on commodity desktop or mobile devices. Piloted by Amazon Elastic Computing Cloud (Amazon CABP; aws.amazon.com/ec2), HPCC holds significant potential for use in scientific supercomputing and computational imaging through the creation of a large cluster of HPC workstations that can be accessed by image interpreters (radiologists) through low-cost desktop and mobile display devices [1, 2]. Through HPCC, interpreters can review complex multi-dimensional images without the need for additional software or upgrades, and multiple interpreters can read the same data simultaneously for efficient, collaborative diagnosis.

B. Laxative-free Virtual Colonoscopy

The HPCC infrastructure can be used for advancing high-throughput cancer screening, such as *virtual colonoscopy* (*VC*). VC is considered a viable option for colorectal cancer screening, as detailed in the guideline by the American Cancer Society [3]. However, the perceived discomfort and inconvenience of the cathartic bowel preparation of VC have been identified as the primary causes of poor patient compliance in colon cancer screening [4, 5]. *Laxative-free VC* (*lf*VC) has emerged as an alternative colorectal examination that does not use cathartic agents [36-38]. Our recent prospective multi-center clinical trial [6] showed that *lf*VC is effective in improving patient adherence by eliminating patients' comfort concerns. The caveat is that *lf*VC introduces large quantities of solid stool that adhere to colonic mucosa and may take on various shapes, thus impairing interpretation of *lf*VC images [7]. The stool distracts and sometimes obstructs readers from focusing on subtle polyps, thereby reducing detection performance.

Confident interpretation of *lf*VC images can be realized by use of *computer-assisted bowel preparation* (*CABP*) and *computer-assisted detection* (*CADe*). The CABP removes oral-contrast-enhanced fecal materials. The CADe detects colorectal lesions automatically from *lf*VC data to offer a "second opinion" to improve readers' diagnostic performance [15] and to reduce interpretation errors [12-14].

These processes involve computationally intensive algorithms. Thus, we aimed to develop and validate the clinical benefits of a mobile HPCC virtual colonoscopy system that integrates novel high-performance CABP and CADe systems. The integrated system is expected to allow visualization of the

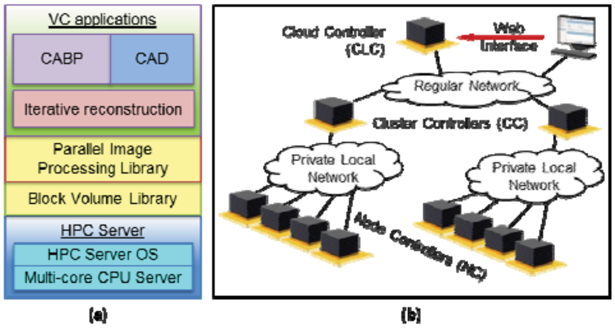

Figure 2. (a) Architecture of the prototype HPC platform for VC. (b) Network infrastructure of the cloud platform.

entire mucosal surface of the colon without artifact, and it will improve the quality of *lf*VC images while processing images much faster than conventional approaches. The system will also improve reader performance in the detection of colonic lesions in the images analyzed on mobile high-resolution display devices.

II. HPCC Virtual Colonoscopy System

A. Cloud infrastructure

We developed an HPCC informatics infrastructure [8] (Fig. 1a) that provides computationally intensive diagnostic imaging as a cloud service, such that high-quality diagnostic images can be generated in near-real time and delivered to clinical practice sites for efficient, accurate diagnoses and timely patient care, regardless of local computational capacity.

The HPCC infrastructure is implemented using OpenNebula (current version: 4.0 Eagle; opennebula.org) on the Linux Ubuntu Server Edition (current long-term version: 12.04) with the Kernel-Based Virtual Machine (KVM) hypervisor that allows computational nodes to run Windows and Linux images simultaneously on multiple virtual computers with private virtualized hardware (Fig. 1b). It implements private and public cloud networks by configuring Dynamic Host Configuration Protocol (DHCP) and Domain Name System (DNS) servers to provide virtual bridging for each running virtual machine image (VMI) with a unique virtual Media Access Control (MAC), and by providing a private network with pools of private Internet Protocol (IP) addresses and a public IP address for running VMIs. Users can form a hybrid cloud by grouping resources from internal private and external public Amazon Web Service-compatible clouds

B. Remote graphics cloud server

We employed a remote graphics cloud server (RGCS) for rendering 3D data sets of virtual colonoscopy at the HPCC infrastructure, so that only the final visualizations need to be transmitted through the cloud interfaces to remote users. The RGCS is implemented by use of the highly scalable ParaView multi-platform visualization software (www.paraview.org) for analysis and visualization of large multi-dimensional datasets at a distributed (and also shared-memory) computing

Figure 1. Illustration of HPCC virtual colonoscopy diagnosis system with high-resolution mobile devices and a motion-based navigation system.

environment that can make use of different numbers of CPUs on the HPCC infrastructure.

C. Mobile visualization client

The ParaView provides a thin-client model, where the visualization/rendering engine will run as a distributed parallel computation on the HPCC infrastructure, while an end-user client runs on remote computers and mobile devices.

Mobile devices with high-resolution displays, such as iPad with iOS and an Android tablet (Fig. 2), are used as a ParaView client for remote display of post-processed images, in particular, for easy navigation through high-quality rendering of the colonic lumen. Mobile devices receive series of 2D images of the final processed and rendered colon imaging data. We implemented the ParaView client on the mobile device by use of ParaViewWeb, where the web service component manages communication between remote visualization servers, called PWServer, and the client, called Web Client. The Web Client is being implemented by the JavaScript library of ParaViewWeb for web-based interactive colon visualization interface on mobile devices.

Preliminary evaluation of the performance showed that the platform was effective in substantially reducing the execution time of these computationally intensive processes [8]. Thus, the integration of CABP and CADe with HPCC makes it possible to display the colonic surface with CADe prompts of lesion candidates in near-real time on remote mobile high-resolution display devices [9].

III. Natural User Interface: Motion-based Navigation

Easy navigation through high-quality rendering of the colonic lumen helps trained radiologists make an accurate diagnosis more efficiently [10]. Virtual navigation is easier and more efficient with intuitive 3D Natural User Interface (NUI). For this purpose, we developed a motion-based 3D-NUI using commodity gaming device, Kinect motion sensing device (Microsoft Corporation, Washington, USA)(Fig. 2). The Kinect sensor has been configured to recognize a set of twohand motions, which triggers conventional navigation motions such as the fly-through of the colonic lumen to observe the entire mucosa, fly-around of a suspicious polyps for easier and more accurate visualization of the lesion morphology, and zoom in to a suspicious lesion to observe its surface morphology for efficient differentiation between polyps and residual stool.

Preliminary result showed that the use of the Kinect-based 3D-NUI can make the workflow of virtual colonoscopy examinations more efficient than that of conventional interface based on mouse and keyboard.

IV. Conclusion

A mobile HPCC-based virtual colonoscopy system has been developed for colon cancer screening. A high-resolution mobile device has been connected with the HPCC for visualization of post-processed colonic lumen and diagnosis of colorectal lesions on virtual colonoscopy images. The navigation through the colonic lumen is driven by a motion-based natural user interface based on a Kinect sensor. Preliminary results indicate that the HPCC-based VC system with natural user interface improves the workflow and efficiency of the interpretation of virtual colonoscopy images for screening colon cancer.

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