M-CASEngine: A Collaborative Environment for Computer-Assisted Surgery

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Abstract. Most computer-assisted surgery systems are an isolated standalone system in the operation room with obtrusive and cumbersome wired connections. Surgery data preparation, registration, segmentation, planning, etc. have to be running at one place. Dynamic data acquisition and cooperation during the surgical procedure is not currently possible. We develop the M-CASEngine system which provides a distributed collaborative environment for computer-assisted surgery. It enables the doctors to access and plan the surgery, and actively participate in remote surgeries, share patient information and exchange opinions in real time from anywhere at any time. By utilizing cutting-edge network technologies, the system greatly improves the overall performance of computer-assisted surgery.

Keywords: Gateway, Communication optimization, Adaptive encryption, Access control, Segmentation, Registration

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1. Introduction

Most computer-assisted surgery (CAS) systems are an isolated system in the operating room with obtrusive and cumbersome wired connections which are not conducive to portable displays, or interactive surgical navigation and comparison with pre-surgical plans. Surgery data preparation, registration, segmentation, planning, and related operations have to run and display at one physical site which reduces the potential for collaborative interaction. There is a need for a more functional system that would enable doctors at remote locations to access and plan the surgery, and actively participate in remote surgeries, share patient information and exchange opinions in real time before, during and after the surgery. M-CASEngine meets these requirements.

The goal of this project is to significantly improve the efficiency and success rates of surgery while helping to decrease surgery duration and improve outcome by applying collaborative tools which may help lower various in-theatre and pre-planning risks, to surgical processes with high risk factors. In the last three years, with the support of Michigan Economic Development Corporation (MEDC), the researchers at Wayne State University have successfully developed a CAS Engine CASMIL [1]. CASMIL is a comprehensive Image-guided Neurosurgery System with extensive novel features. It is an integration of various modules like rigid and non-rigid body co-registration (image-image, image-atlas, and image-patient), automated 3D segmentation, brain shift predictor, knowledge based query tools, intelligent planning, and augmented reality.

2. System Structure

In the collaborative environment of M-CASEngine, distributed role members need to connect to the M-CASEngine from different places using diverse devices as shown in Fig. 1. Each role member has their own device and network connections. For example, the role member 1 uses dialup network to connect their laptop to the system. Within the local area network where the M-CASEngine resides, gateways may be deployed. Gateways play important role in the implementation of the system. At each stage, from the pre-surgery to the post-surgery, there is large computation to be done in a prompt and secure way. It is impractical for M-CASEngine to perform the entire work load by itself. Gateways act as offload processing assistants to share the work load of requested tasks, such as secure and real time communications between M-CASEngine and remote role members. With the support from adjacent gateways, M-CASEngine can focus on the surgery related computing as if the information from the remote role members is provided locally.

This gateway is an extension of the proxy in our preliminary work [4]. As we can see in Fig. 1, gateways deployed around the M-CASEngine provide these methods. We implement several modules in the gateway based on its functionalities in the collaboration session as shown in Fig. 2. Its functions includes: 1) Discover the remote devices of the role members. 2) Negotiate communication optimization algorithms, in other words, protocols and the client side programs with the devices of the role members. 3) Deliver protocol modules and programs to the devices. 4) Monitor the procedure of the collaboration sessions. 5) Provide QoS such as delay time. 6) Provide security and privacy. In order to finish these functions, a gateway needs to know some peer side information, such as network bandwidth, application data format and so on. A gateway has four modules including a negotiator, a distributor, a session monitor, and a proxy as shown in Fig. 2. Due to limited space, we omit details of each module that can be found in related work [2].

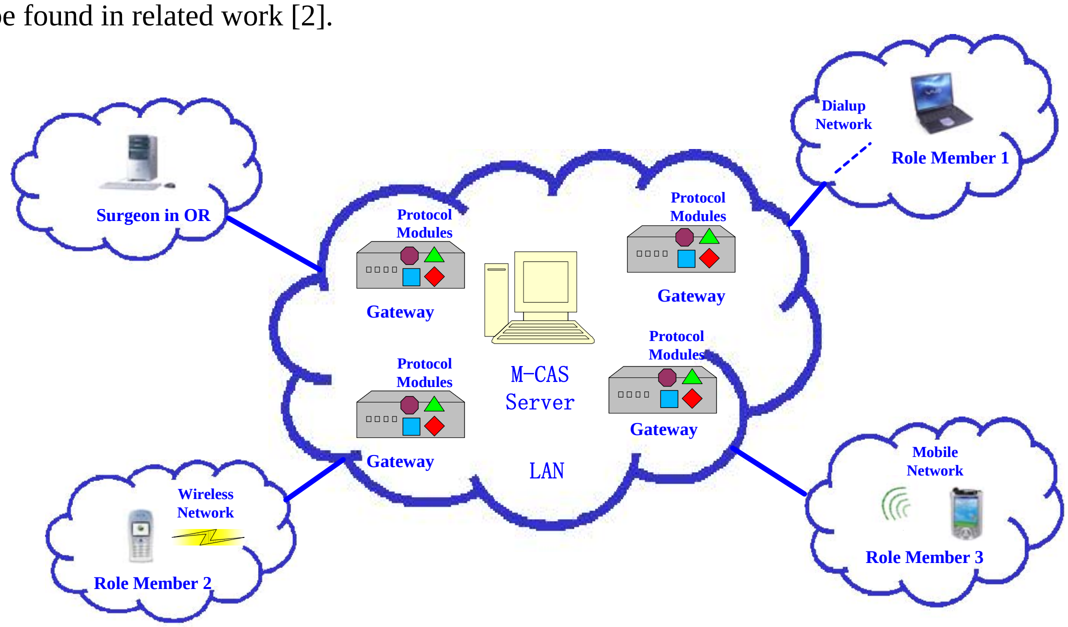

Fig. 1. The structure of the system.

3. Functions of the System

3.1 Implementing real time communications between collaborative doctors

Real time communication is an important metric of the cooperation environment for computer-assisted surgery. Collaborative message should be received promptly. Any long delay could influence the surgery output. Two approaches, an adaptive communication optimization [3, 4] and adaptation across domains [2] have been developed to support the real-time requirement.

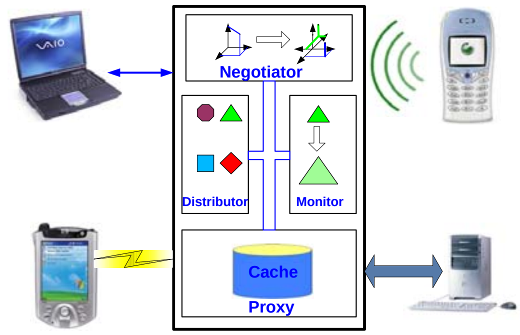

Fig. 2. The structure of gateway.

For communication optimization, there are some differencing algorithms proposed to minimize the communication delay for different data types. In our previous work [2, 3], several document formats are evaluated under some specific differencing algorithms to achieve the smallest possible total delay across some network types by finding the tradeoffs between the two major components of total response delay, the communication delay and the computing delay. The smaller the total delay is, the faster the real time nature of communication would appear.

Communication optimization can optimize the communication between two ends across one network situation, like dialup, wireless. But in our collaborative environment, it is very likely that a collaboration session is across multiple network domains. For example, in the system structure Fig. 1, if role member 1 and 2 collaborate together to provide consultation to the surgery, this session will cross both the dialup and wireless network. According to the different configurations of end clients, gateways deployed around the M-CASEngine use protocol modules to adapt the optimization algorithms across multiple domains. Furthermore, proxy-based service replication will be leveraged to support real-time communication across wide-area networks.

3.2 Enforcing secure and access control in the cooperation procedure

Patients' information should be transmitted in a secure way according to the HIPAA [5] standard. On the other hand, different doctors should have dissimilar views of the same data set, which is protected by the access control model. Novel location-based access control mechanism and an adaptive encryption protocol [6] are designed and implemented in this project.

In terms of adaptive encryption protocol, there are lots of encryption algorithms, such as DES, AES and RC4 [7] that have been proposed in the literature. However, it is impossible to have a one-size-fits-all algorithm that can be used in all scenarios and devices, because of the mismatch between diverse characteristics of those algorithms, heterogeneous devices, and applications requirements. For example, DES is only supported by legacy application. Applications developed since 2004 typically adopt AES as the standard. Similar to the adaptation across different domains, encryption protocols also need the adaptation. Generally speaking, different encryption protocol should be selected based on diverse configurations and application requirements.

For location-based access control, a novel access control mechanism different from traditional approaches like access control list or role-based access control is required. Different kinds of role members pay attention to different aspects of the data. The radiologist may only take care of the diagnosis of patient's X-ray images instead of patient's profile. A basic security requirement is that users should be enforced with a view of the data corresponding to their security level. Security administration of such large system is complex. On the other hand, as a ubiquitous computing environment, M-CASEngine is accessed by different role members from different locations using diverse devices asynchronously. In order to strengthen the patient privacy we should control not only the permissions of each role but also the location, calendar, and device of the user who is in the role when he tries to access the data.

3.3 Developing user-friendly user interface for doctors using different devices

Various functions and devices demand particular user interfaces (UI). For example, PocketPC and smartphones are both limited by memory/computing/power capacity. So, we should put only simple display and user-input tasks on those devices. The complicated backend processing should be supported by the central server or proxies. For PocketPC and smartphone, the display screen is small; whereas the desktop and laptop have large screens. Thus, we should provide different UI for different devices. The CAS server in Operation Room has a large screen, the display screen is divided into four parts, and each part provides a different angle of the patient's brain, 2D or 3D, as shown in Fig. 3. On the contrary, the screen of PocetPC and smart phone is much smaller; we need to do content-adaptation to these devices by shrinking or filtering the content, as exemplified in Fig. 4.

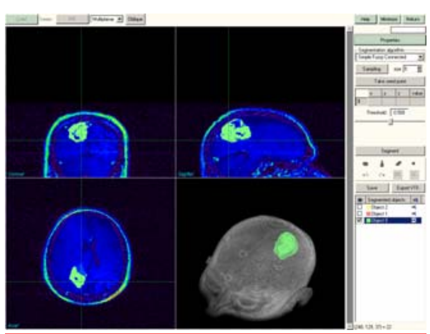

Fig. 3. The CAS interface on desktop.

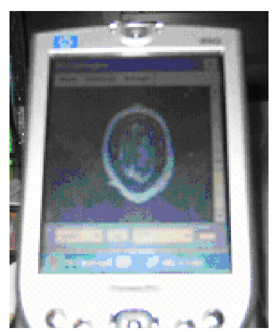

Fig. 4. A DICOM image on PDA.

As an example, assume doctor A has to be on travel but has access to his smart phone. Radiologist B is attending a conference using PDA with wireless network. Neuro-specialist C is at home using a laptop. When the surgeon in the Operating Room viewing the DICOM images on CAS Server (shown as Fig. 2) needs the advice from doctor A, for example, at the beginning of the surgery, he will use VoIP to call in doctor A and start a conversation in real-time. After a while the surgeon wants the radiologist B to have a look at several DICOM images. He can immediately notify B via VoIP and send the images to the PDA device, as shown in Fig. 4. Furthermore, they can dynamically mark the comments on the image and the change will be reflected on the other side immediately. During the surgery, the surgeon may need to change the planning according to some emergency situation, he can easily invoke doctor C who is at home. Using the client side UI (which is similar with the CAS Server's UI) doctor C can cooperate with the surgeon on the same data set to do the planning remotely. Simultaneously, the remote doctor can use the handheld device to interact each other. As Fig. 5 shows, doctor X can choose another doctor from the contact list or SIM card by just saying that person's name he/she wants to call or dial a number directly. Fig. 6 shows that doctors can interact with each other using instant messaging.

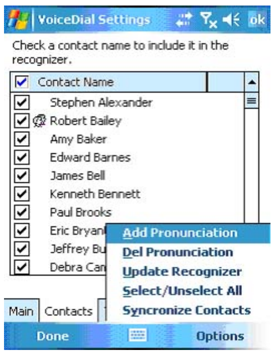

Fig. 5. A snapshot of contact list.

Fig. 6. A snapshot of instant messaging.

4. Conclusion

The computer-assisted radiology and surgery system involves many research fields, such as image processing, UI, wide area PACS and teleradiology, expert systems, etc. Currently, most of the existing CARS systems are isolated standalone systems in a centralized place. Pre-surgery preparation, registration, segmentation, planning, etc., have to be running at one place. Dynamic data acquisition and cooperation in the surgery procedure is not possible. Such inconveniences seriously impede the implementation of IHE (Integrating the Healthcare Enterprise) and telemedicine. M-CASEngine provides a collaborative environment for computer-assisted surgery that alleviates the above drawbacks..

References

[1] G. Kaur, et al. CASMIL: A Comprehensive Software/toolkit for Image-Guided Neurosurgeries, Neurosurgery edition of IJMRCAS (International Journal of Medical Robotics + Computer Assisted Surgery) 2006.

[2] H. Lufei and W. Shi, Energy-aware QoS for Application Sessions Across Protocol Domains, Technical Report MIST-TR-2005-009, October 2005. Submitted for publication.

[3] H. Lufei, W. Shi, and Lucia Zamorano, Communication Optimization for Image Transmission in Computer-Assisted Surgery, Technical Report MIST-TR-2004-007, March 2004. poster presented in the 2004 Congress of Neurological Surgeons Annual Meeting (abstract), Oct 2004. San Francisco.

[4] H. Lufei and W. Shi, Fractal: A Mobile Code Based Framework for Dynamic Application Protocol Adaptation in Pervasive Computing, in 19th IEEE International Parallel and Distributed Processing Symposium, Denver, CO, April 2005. The Best Paper Award.

[5] HIPAA, Health Insurance Portability and Accountability Act http://www.cms.hhs.gov/HIPAAGenInfo/

[6] H. Lufei and W. Shi, An Adaptive Encryption Protocol in Mobile Computing, book chapter of Mobile/Wireless Network Security, edited by Y. Xiao, S. Sheng, and D. Zhu, Springer 2006.

[7] W. Stalling, Cryptography and Network Security, Prentice Hall, 2003