A Concept on Cooperative Tele-Surgical System Based on Image-Guiding and Robotic Technology

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Abstract — **In our research group at the BART LAB, Mahidol University, Thailand, we have been conducting research on Computer-Integrated Surgery an/d Robot-Assisted Surgery for the past 8 years. The research involved several surgical applications, such as, laparoscopic surgery, percutaneous breast biopsy, neurosurgery, total-knee replacement and closed intramedullary of femur. Our experience included development of a novel 4-DOF wire-driven laparoscopic surgical robot, development of image-guided endoscopic robot, endoscopic tracking using electromagnetic field, development of total-knee replacement surgical planning and surgical robot, development of a robot-guiding system for closed intramedullary nailing of femur, development of a percutaneous ultrasound image-guided breast biopsy, development of a force-feedback haptic interface for surgical training, investigation on neurosurgical robot and investigation on intracranial pressure sensing system. This study is to develop a large-scale tele-surgical system which allows an expert-surgeon group to remotely work incorporate with a field-surgeon group based on image guiding and robotic technology. The tele-surgical system is separated into 3 sections: (1) Expert Site, (2) Surgical Site and (3) TeleCommunication for Surgery. The Expert Station is for the expert-surgeons to remotely control the surgical robots at the Surgical Station through a 3-D force-feedback haptic robot controller. The Expert Station is equipped with a set of monitors to display the real-time image from surgical site, the sensing data from the patients and the pre-operative medical images. The Surgical Station is for the field-surgeons which may have less experience than the expert-surgeons in Expert-Station. The field-surgeons are working on the surgical operation with the cooperative-typed surgical robots which are remotely-controlled by the expert-surgeons. The Surgical Station is also equipped with a surgical navigation system, surgeon tracking system and the sensing units. The communications between both stations are designed to perform redundancy based on multi-system which are; LANs, 3G, WiMAX and Satellite. The Cooperative Tele-Surgical System is designed and developed for the remote hospital and the field hospital.**

Keywords — **Tele-Surgery, Robot-Assisted Surgery, Computer-Integrated Surgery, Computer-Aided Surgery, Surgical Robot, Surgical Navigation, Surgery, Telemedicine.**

I. INTRODUCTION

Image-Guiding Surgery and Surgical Robotics Technology have become accepted by world-wide surgeons, and have been integrated into today surgical procedures. Example of Image-Guiding Surgical Systems currently use in the surgery, are such as, Medtronic Surgical Navigation in Total Knee Replacement Surgery [1], Materialize Surgical Navigation in Orthopedic Surgery [2], DenX System in Dental Implant Surgery [3] and Johnson and Johnson Navigation System in Neurosurgery [4]. The described systems have assisted the surgeon to perform their work easier, more accurate, more confident and more convenient than standard surgical procedures without navigation systems. Example of Surgical Robotic Systems currently utilize in the surgery, are such as, da Vinci system in laparoscopic surgery [5], RoboDoc in Hip Surgery [6], and AcroBot in Total Knee Replacement Surgery [7].

The ideas of tele-surgery have been introduced and discussed in the past a few decades [8-12]. Several tele-surgical systems are to demonstrate the Master-Slave robotic surgical scheme. Most systems are mainly concerned about the time-lag and the limitation of the systems.

However, the "Concept of Cooperative Tele-Surgical Systems" introduced in this study discusses about the possibilities of having skillful surgeon at the "Expert Site" located at the central areas or major cities. While the "Surgical Site" located in a remote-area or difficult-to-access area which also a less-skill healthcare personnels are available. In many countries around the world, most skillful surgeon, especially, some certain surgical procedures, are located in the major cities or country's central areas with a limited number of them. Therefore, the logistic problem on transferring the patients are growing since most severe surgical treatments only are able to perform in the main medical institutes. Whereas, the a number of remote medical treatment nodes which consists of systems with higher-technology, are able to set up scattering around the country. Therefore, we are focusing on the lack of skillful healthcare personnels which the problem can be solved based on the available image-guiding and robotic technology. Fig. 1 shows a diagram demonstrated the concept of "Cooperative Tele-Surgical System.

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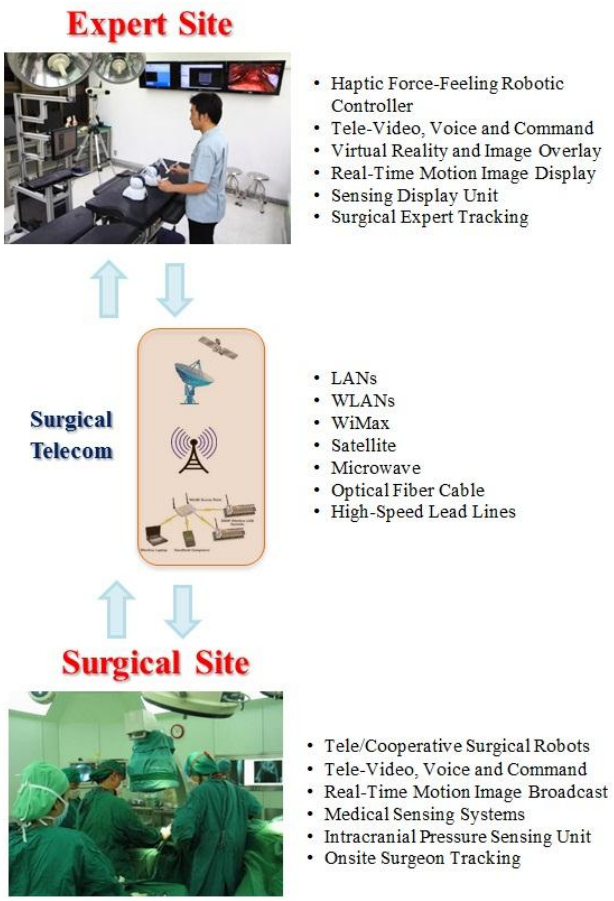

Fig. 1. The Concept of Cooperative Tele-Surgical System.

II. CONCEPT ON COOPERATIVE TELE-SURGICAL SYSTEM

The Concept on Cooperative Tele-Surgical System is based on the situation of non-uniform distributions of specialist or skillful surgeon for specific surgical procedures, such as, most specialists are located in the major cities or country's central areas. However, less-skillful healthcare personnels and image-guiding and surgical robotic technology are available to serve the patients' needs in the remote or difficult-to-access area.

The Cooperative Tele-Surgical System consists of 3 sections; (1) Expert Site, (2) Surgical Site and (3) TeleCommunication for Surgery. The "Expert Site" is intending to be at the central areas or major cities where the specialists and skillful surgeons are available. The Expert Site consists of the Surgical Robot Controller with Haptic Capability, Master-Surgical Robotic Control System equipped with Virtual Reality or Image-Overlay System on Surgical Model, Real-Time Surgical Information Display, Site-to-Site Communication Ports and Systems which include Video, Voice, Commands and Sensing Data. The "Surgical Site" is intending to be at remote or difficult-to access areas which can be multiple locations or mobile units. However, a group of trained healthcare personnels which could be un-specialists should be available at the "Surgical Site". Moreover, the "Surgical Site" should be equipped with Surgical Robots with Force Acquisition System, Slave-Surgical Robotic Control System based on Virtual Reality or Image Overlay System on the Patient, Real-Time Surgical Information Display, Site-to-Site Communication Ports and System which include Video, Voice, Commands and Sensing Data. The "TeleCommunication for Surgery" is a multi-modalities for transmitting and receiving Real-Time Surgical Information between Site-to-Site. The modalities are based on the redundant concept which include LANs, WLANs, 3G, WiMax, Satellite, MicroWave and Optical Lead Lines. The system may include a mobile unit to relay the signals between the sites.

The systems are based on available technology, such as, robot-assisted surgical systems, master-slave surgical robot control scheme, haptic force-feedback interface, object tracking based on optical tracking, mechanical tracking and electromagnetic tracking systems, virtual reality, surgical navigation and surgeon-system interface.

III. EXPERT SITE

Expert Site is a set up room for specialist or skillful surgeon located in the major cities or central areas where the experts are available. The available technology which should equipped in the Expert Site are including:

1) *Master-Surgical Robotic Controller with Haptic Feedback Interaction*: Master-slave robotic control scheme is currently the-state-of-the-art for sophisticated controlling procedure in tele-operated robotic system. The scheme allows the controller to duplicate the slave-liked structured controller (Master) to control the slave. Most surgical robot (Slave) equipped at the Surgical Site has a 4-DOF mechanism which the controller (Master) is designed in the similar motion. Adding Haptic interface into the Master allows the operator to feel the force feedback from the Slave robot at the surgical table. Together Master-Slave Scheme and Haptic Interaction give the necessary controlling/feeling information to the surgical operator at the Expert Site. Fig. 2 shows example of Master-Surgical Robotic Controller with Haptic Feedback Interaction.

2) *Virtual Augmented Reality*: In order to allow the specialist or surgeon at the Expert Site to interact with the surgical environment and patient from the surgical site, virtual augmented reality is the best solution for transmitting only key feature information through the telecommunication system then reconstruct the 3D virtual reality to make the expert surgeon to understand the situations from surgical

site. Fig. 3 illustrates example of 3D Virtual Reality developed at the BART LAB, Mahidol University.

3) *Real-Time Surgical Information Display:* During the surgery, a number of communicating information must be transferred back and forth between the Expert Site and Surgical Site through the telecommunication system. Important information is such as, Real-Time Video Streaming, Voice Communication, Patient Status Information, Master-Slave Commands, and other environmental information.

4) *Site-to-Site Communication Port and System:* The Communication Port and System is the transmitting/receiving system for all data and information between sites. Therefore, Site-to-site Communication port and system includes the Tx/Rx for each modality to be used in our system, such as, satellite dish, WiMax Tx/Rx, Optical Fiber port and 3G Tx/Rx.

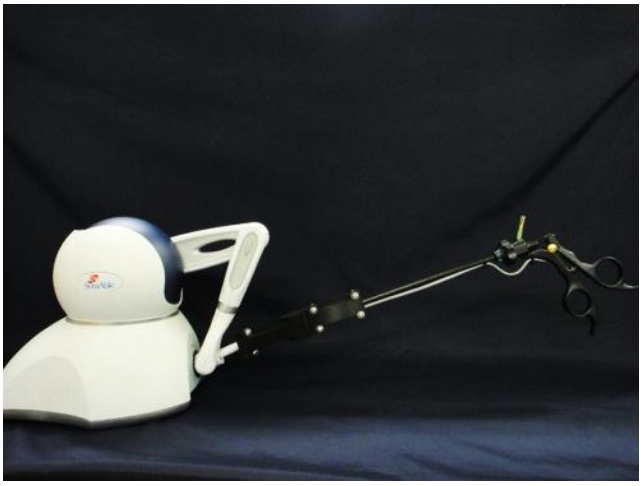

Fig. 2. Haptic Device for Master-Surgical Robotic Controlling [13].

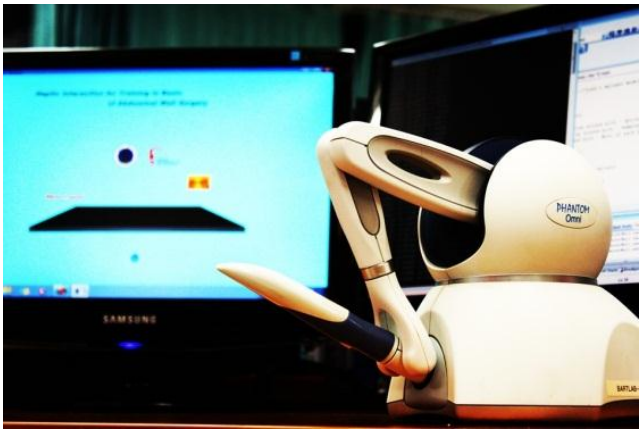

Fig. 3. Example 3D Virtual Reality on GUI for Expert Site [13].

IV. SURGICAL SITE

Surgical Site is a special operation room equipped with computer-integrated surgical system operated by a group of trained healthcare personnels whose may not be specialized in any specific surgery. The Surgical Site can be located in a remote or difficult-to-access areas. The Surgical Site can be a mobile unit. The available technology which should equipped in the Surgical Site are including:

1) *Surgical Robots with Force Acquisition System:* Force Acquisition System attached to the Surgical Robots play an important role to collect the force data streaming to feed through telecommunication system to haptic master controller. The system allows the expert surgeon at the Expert Site to perceive the force feedback during the surgical tool penetrate the patient's tissue at the Surgical Site. Therefore, the surgeon is able to feel in the similar way as in the real operation procedure. Fig. 4 shows example of a force acquisition system to collect the force feedback during the cutting procedure.

Fig. 4. Example of Force Acquisition System [13].

2) *Slave-Surgical Robotic System:* Master-Slave Robotic Control Scheme is normally used to control a tele-operated robot. In this situation, surgical robotic system employed at the Surgical Site is using the Master-Slave Robotic Control Scheme. Therefore, the surgical robotic system is a slave which remotely controls from the Master system at the Expert Site. Therefore, Surgical robotic system is designed to fit each specific surgical application. Example of a laparoscopic surgical robot is shown in Fig. 5, while example of a total knee replacement robot is shown in Fig. 6. The presented robots are cooperative robots with capabilities to remotely control though are able to override by the healthcare personnel at the Surgical Site for Safety purposes.

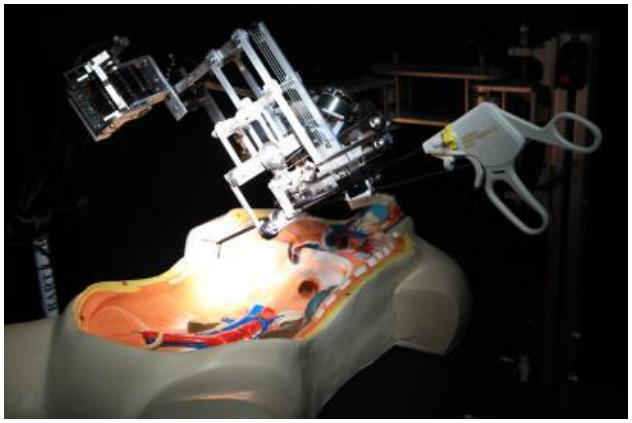

Fig. 5. Example of Laparoscopic Robot, MU-LapaRobot [14-16].

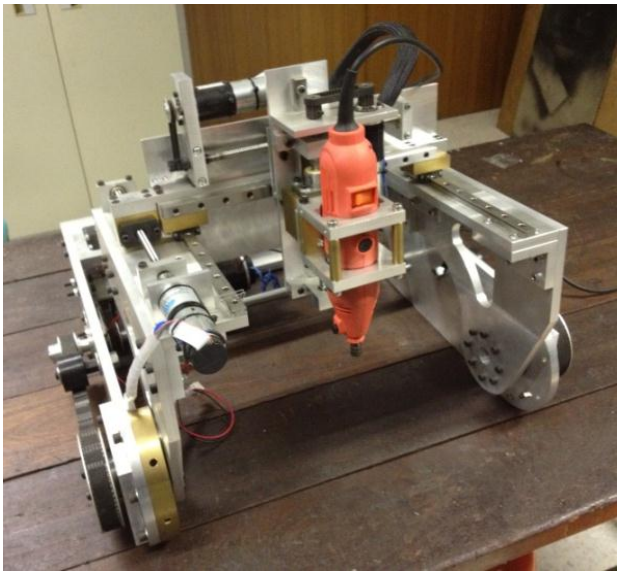

Fig. 6. Example of Total Knee Replacement Robot, MU-TKRobot [17].

3) *Real-Time Surgical Information Display:* In the similar way to Real-Time Surgical Information Display at the Expert Site, Surgical Display Center with the same information should be also located at the Surgical Site.

4) Surgical Navigation System is a system to guide the healthcare personnel at the Surgical Site to easily follow the surgical path and protocol based on the surgical planning and real-time tracking system. The surgical navigation allows less-skill surgeon or healthcare personnel at the Surgical Site to be able to assist the expert surgeon who is remotely operating the surgical robot from Expert Site. Fig. 7 shows an example of surgical navigation system based on the optical tracking system and markers.

5) *Site-to-Site Communication Ports and System:* STS Com Port and System is similar to the system at the Expert Site in order to transmit and receive data, information and command between sites.

V. TELECOMMUNICATION FOR SURGERY

In our concept, the communication system is based on multiple modalities, such as, LANs, WLANs, WiMax, Satellite, Optical Fiber and MicroWave. The reason of the communication system with multiple modalities is redundancy of communication for safety reason. Therefore, the STS Com Port and System should be able to handle multiple communication modalities.

VI. DISCUSSION

This paper describes a concept on cooperative tele-surgical system based on the problem of non-uniform distribution of surgical specialist which are normally located in the major cities or central areas. While the needs by specific healthcare treatments, especially, difficult surgical procedures are scattering around the world. Therefore, the concept of setting up the Expert Site, Surgical Site and TeleCommunication for Surgery is discussed based on available technologies and devices to allow the healthcare treatment remotely. Several technologies and devices are introduced to support the concept. Moreover, the healthcare personnels are being used in both Expert Site and Surgical Site. However, the specialists are assumed to join the system at Expert Site, while the less-skill healthcare personnels are assumed to join the system at the Surgical Site.

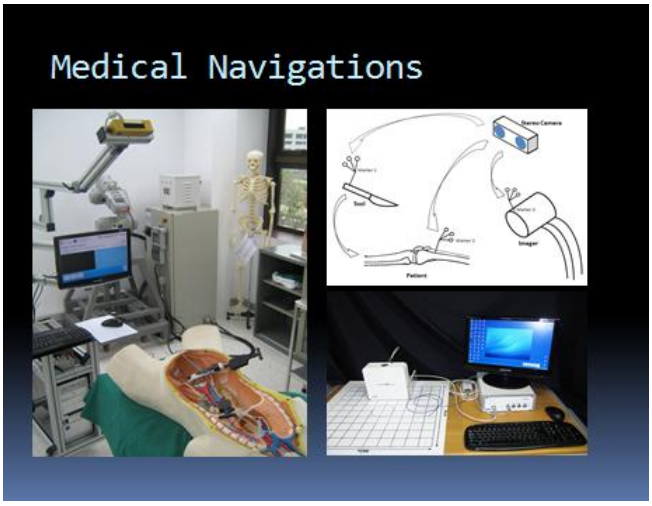

Fig. 7. Example of Surgical Navigations at BART LAB, Mahidol University. [18-20]

REFERENCES

[1] http://www.medtronics.com
[2] Hohl, S., "The Navigation System for Dental Implantology," Internet Reference at http://www.materialise.com.
[3] http://www.denx.com
[4] Hill, D.L., Maurer, C.R. Jr., Maciunas, R.J., Barwise, J.A., Fitzpatrick, J.M., and Wang, M.Y., "Measurement of Intraoperative Brain Surface Deformation Under a Craniotomy," *Neurosurgery*, 1998, 43(3): 514-526.
[5] http://www.havincisurgery.com
[6] Gueziec, A., Kazanzides, P., Williamson, B., and Taylor, R.H., "Anatomy-Based Registration of CT-Scan and Intraoperative X-Ray Images for Guiding a Surgical Robot," *IEEE Transactions on Medical imaging*, Vol. 17, Issue: 5, 1998, pp 715-728.
[7] Jakopec, M., Rodriguez y Baena, F., Harris, S.J., Gomes, P., Cobb, J., and Davies, B.L., "The Hands-On Orthopaedic Robot "Acrobot": Early Clinical Trials of Total Knee Replacement Surgery," *IEEE Transactions on Robotics and Automation*, Vol. 19, Issue: 5, 2003, pp 902-911.
[8] Butner, S.E., Ghodoussi, M., "Transforming anSurgical Robot for Human Telesurgery, " IEEE Transactions on Robotics and Automation, Vol. 19, Issue: 5, 2003, pp 818-824.
[9] Taylor, R.H., "A Perspective on Medical Robotics," *Proceedings on IEEE*, Vol. 94, Issue: 9, 2006, pp 1652-1664.
[10] Cavusoglu, M.C., Tendick, F., Cohn, M., and Sastry, S.S., "A Laparoscopic Telesurgical Workstation," *IEEE Transactions on Robotics and Automation*, Vol. 15, Issue: 4, 1999, pp 728-739.
[11] Rosen, J., and Hannaford, B., "Doc at a Distance, "*IEEE Spectrum*, Vol. 43, Issue: 10, 2006, pp 34-39."
[12] Chopra, N., Ferre, M., and Peer, A., "The Field of Telerobotics," *IEEE Robotics and Automation Magazine*, Vol. 15, Issue: 4, 2008, pp 9.
[13] Itsarachaiyot, Y., Pochanakorn, R., Nillahoot, N., and Suthakorn, J., "Force Acquisition on Surgical Instruments for Virtual Reality Surgical Training System," *Proceedings of the 2011 International Conference on Computer Control and Automation (ICCCA 2011)*, Jeju Island, South Korea, May 1-3, 2011, pp 173-176
[14] Direkwatana, C., and Suthakorn, J., "Development of Wire-Driven Laparoscopic Surgical Robotic System,"MU-LapaRobot"," *Proceedings of the 2011 IEEE International Conference on Robotics and Biomimetics (ROBIO 2011)*, Phuket, Thailand, December 7-11, 2011, pp 485-490.
[15] Direkwatana, C., and Suthakorn, J., "On The Design And Development of A Novel 4-DOF Wire-Driven Laparoscopic Surgical Robotic System, "MU-LAPAROBOT"," *Proceedings of The 7th Asian Conference on Computer-Aided Surgery (ACCAS 2011)*, Bangkok, Thailand, August 26-27, 2011.
[16] Direkwatana, C., Suthakorn, J., and Wilasrusmee, C., "MU-LapaRobot: A Novel 4-DOF Wire-Driven Laparoscopic Surgical Robot System for Cooperative and Tele-Operative Procedures," *Proceedings of the 34th Electrical Engineering Conference (EECON-34)*, Pattaya, Thailand, Nov 30 - Dec 2, 2011, Vol. 2, pp 1141-1144.
[17] Saensupho, W., Suthakorn, J., "A Novel Conceptual Design on Robotic Bone-Cutting Device Based on Kinematic Analysis: Toward Development of A Novel Robot-Assisted Total Knee Replacement Surgical System," *Proceedings of the 2011 International Conference on Computer Control and Automation (ICCCA 2011)*, Jeju Island, South Korea, May 01-03, 2011, pp 139-142.
[18] Lorsakul, A., U-Thainual, P., Mahaisaviriya, B., and Suthakorn, J., "Pose Recovery of Intramedullary Nail Distal Hole Using Neural Networks," *Proceedings of the 2008 International Society for Computer Assisted Orthopedic Surgery (CAOS2008)*, Hong Kong, June 4-7, 2008.
[19] Lorsakul, A., Sinthanayothin, C., and Suthakorn, J., "Point-Cloud-to-Point-Cloud Technique on Tool Calibration for Dental Implant Surgical Path Tracking," Proceedings of the SPIE Medical Imaging 2008 (SPIE2008), San Diego, California, USA, Feb 16-21, 2008.
[20] Suthakorn, J., and U- Thainual, P., "A New Algorithm for Recovering Distal Hole Pose in Intramedullary Nail," *Proceedings 5th World Congress on Biomechanics (WC Biomechanics 2006)*, Munich, Germany, July 29-August 4, 2006.,