MIR: A Low Cost Digital Operating Room

ABSTRACT

This paper presents a low cost solution for Digital Operating Rooms called MIR (Multimedia Integrated Room). This solution offers a wider variety of useful features compared to other available digital rooms. MIR is capable of real time transmission and recording of endoscopic procedures using multiple HD cameras, integration with the hospital systems and also can be easily controlled by a wireless mobile device, like a cellphone or a tablet. The developed system main application areas are: a) remote medical students to follow the surgical procedure with high quality images; b) the specialist preceptor to help new surgeons remotely with audio and video; c) the surgical team to better visualize the surgery through the multiple camera views; d) facilitate the training of surgeons in minimally invasive surgeries.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life and Medical Sciences – *health, medical information systems.*

General Terms

Human Factors.

Keywords

Operating Room, Telemedicine, Minimally Invasive Surgery.

1. INTRODUCTION

Since the widespread use of personal computers that began in the 80´s, there is an explosive development of endoscopic surgery and many technological innovations derived from lightweight cameras, improved lens systems, better images, better equipments and telepresence systems. Parallel to that, two other areas are developing rapidly: diagnostic imaging systems like ultrasound, MRI and CAT scans, and integrated management of the hospital with major management systems.

The development of these three different areas occurred independently and separately. Some years ago the areas began to integrate, and every piece of information in the hospitals is being digitalized.

Minimally invasive surgery began to be held in the 80's. These surgeries are characterized by the utilization of cameras introduced in the abdominal and pelvic cavity through small incisions. The advantages brought by minimally invasive procedures are: a) aesthetic advantage, due to the size of incisions that leave smaller scars; b) lower risk of infection; c) less pain; d) less bleeding; e) less hospitalization and faster recovery time compared to conventional surgery.

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With the technological advances of computer science, terms such as telemedicine and digital or integrated operating room are becoming increasingly common in scientific articles, indicating a growing concern with the area [11] and popularizing the use of information allied to medicine. The advances in telemedicine had facilitated the training of surgeons in minimally invasive surgery. There are several different solutions for building a digital operating room, also known as integrated operating room, because it integrates with other equipment and systems in a surgical environment and in the hospital.

One of the features of a Digital Operating Room much used in training and education is video transmission and high definition videoconference with recording of the procedure. In general, what they do is to capture and display images on multiple screens, transmitting images and audio bidirectionally at conferences and classes, help to train residents at distance and allow the video documentation of surgical procedures [8]. Large companies such as Cisco [4] with its HealthPresence, Stryker [20] with its iSuite and Polycom [15] with their solutions for video collaboration, also invest in commercial telemedicine products.

However, according to Marcos Dias Ferreira M.D., the use of minimally invasive surgery is still not widespread, mainly because the lack of surgeons trained to perform this type of procedure and the lack of courses for the training of new surgeons.

The present paper introduces a low cost solution for operating rooms called MIR (Multimedia Integrated Room). The paper also performs an analysis of the existing solutions for digital operating rooms and compares the features with our proposed solution. MIR is already being used in minimally invasive surgeries and endoscopic exams conducted at the Santa Casa hospital in Porto Alegre, Brazil.

This paper is organized in the following way: section 2 presents the main features existing in Digital Operation Rooms. Section 3 discusses related works regarding applications of DORs to improve remotely the education of surgeons through high definition videoconference. Section 4 presents the main features of our solution, MIR. Section 5 compares our solution with other related works, and section 6 brings the final remarks.

2. DIGITAL OPERATING ROOM

Surgical rooms aggregated minimally invasive surgery with integration with the hospital PACS (Picture Archiving and Communication System) and also the hospital management system. Besides that, many surgical rooms allow the procedure transmission in real time through videoconference, generating a new way to teach and revolutionizing medical education. The acronym DOR (Digital Operation Room) in this paper refers to all this evolution in the surgical room already mentioned in the introduction.

So, in this paper, a digital operating room (DOR) differs from conventional operating rooms in the following aspects: a) use of

digital equipment, such as the endoscope; b) use of multiple monitors to display different views of the procedure, patient data and medical image; c) communication with remote locations; d) integration with PACS; e) integration with the hospital management system.

Quick access to surgical environment's information is a key feature of the DOR. Hospitals everywhere are taking advantage of the increased speed and flexibility of the technology, such as wireless, to improve healthcare. Tablets, for example, allow more interaction than the traditional paper records and can access real-time information [12]. During lectures or even during a surgery is possible to have the cooperation of the medical community. However, many people believe that wireless devices can cause interference with medical equipment, putting lives at risk. Indeed, the real risk of interference is very low if respected the limit of 1m away from medical equipment as pointed out by a survey on the use of communication devices in the operating room [17].

Among the possibilities offered by the DOR in education and second medical opinion, the transmission of multimedia and communication with remote places is the main feature [8] and is one branch of telemedicine. It allows an experienced surgeon, from a distant location, guide a team of resident surgeons with communication by voice and image in real time, even providing gains by allowing the tutor to guide more than one surgery at the same time, multiplying the orientation time. At a laparoscopic surgery, for example, the operating room enables the digital transmission of the procedure to other training centers, allowing other surgeons give their opinions.

In addition, operation rooms with real time transmission are a powerful tool for training new surgeons in new technologies, particularly in regions with lack of trained professionals. It's a way of democratizing access to new features and technologies in medicine, not only for physicians, but for thousands of patients that are still operated by procedures that may pose greater risks due to lack of trained surgeons in new technologies.

According to a survey conducted by Nocco among surgeons and instrumentalists nurses [14], the DOR, besides all aspects of communication and integration, can reduce the surgical risk of patients, improve the quality of surgery, perform surgical procedures less stressful and reduce operating time.

3. Related work

There are some works in surgical rooms involving the use of IT to capture, transmit and store data related to health, allowing the exchange of medical knowledge in situations such as during a live surgery [6]. These remote conferences are able to replace face to face contact reducing costs without losing the quality and shortening distances [3].

A study on telesurgery [2] observes that the cost of real time transmission can be relatively low, but for some applications, such as dermatology, the transmission quality must be excellent, with the best resolution possible and no losses, leading to environments that can become complex related to infrastructure. The study concludes that telesurgery brings many advantages, as to have an expert opinion to small communities and teaching of physician residents.

Technologies, systems and architectures used in remote communication may vary according to the partners involved, and the existing IT infrastructure is an important factor to take into account at the technological point of view when creating a new surgical operation room with remote capabilities [9]. One key aspect regarding infrastructure is the available bandwidth.

Rafig [16] conducted a study about the feasibility of remote surgical consultation and telementoring procedures in real time using two multimedia stations communicating over a LAN. Images were captured using a laparoscope in a procedure of thyroidectomy, and transmitted to an audience of medical students and trainees. A Polycom station was used to transmit images of the endoscope through the intranet. The audio between the operating room and the audience was also transmitted, enabling interaction. The remote audience was able to identify the relevant anatomical markings set established, supporting the viability of the study. One of the great advantages indicated was that the system reduced the number of observers in the operating room.

In a study conducted by the Pontifical Catholic University of Rio Grande do Sul (PUCRS) [18], classes were transmitted directly from the operating room to a conference hall using coaxial cables. The camera was positioned at 80 cm from the field of surgery, transmitting the images point to point via signal modularization. To show the image of the participants were used webcams. In the conference hall were placed two image projectors: one for the video of the surgery and other to display the audience. For transmission to other countries they used the Skype software. The audio between the operating room and the conference room was transmitted through a wireless microphone.

Researchers at Virginia Commonwealth University (VCU) devised a way to record surgical procedures [5]. In their approach, four cameras were placed in the operating room: one capturing images of the laparoscope, two filming the operating table and another recording anesthetic data. Three of the four cameras captured, in addition to video, audio. The films were edited and combined into a single split screen display. The result, approved by reviewers, may be used in addition to surgery documentation as material for lectures, events and classes.

A low-cost infrastructure tool for video conferencing in healthcare and based on open technologies was presented by a Brazilian research group of the Federal University of Paraíba (UFPB) [19][21]. In their approach, inside the operating room were captured two multimedia streams and displayed in a telemedicine room, but only one at a time according to the needs of the audience. The audio and video of the remote room was also captured, transmitted and displayed at the operating room, enabling interaction between the two environments. Their system also performs re-encoding to lower resolutions, allowing streaming to the Internet. The presented tool is able to coordinate and manage real-time multimedia streams using only computers, cameras and image projectors. Current versions of the tool support the display of 4K resolution with a dedicated fiber optics link.

A framework for surgical video streams was proposed by the Innovation Center Computer Assisted Surgery (ICCAS), a German medical school [22]. The solution also uses the network infrastructure of the building as a way to decrease costs. The client-server architecture achieves the capture and coding of the videos on the server side and decoding and displaying on the client side. The results showed acceptable performance for streams in the network of the operating room, with a resolution of 720 × 576 and an average frame rate of 25 fps.

4. MIR (Multimedia Integrated Room)

The MIR was designed to provide greater insight into the surgical theater during minimally invasive surgeries, without the need for sophisticated equipment or drastic changes in the hospital facilities.The main features of MIR are:

a) High-definition: up to 1920x1080p / 60 fps video capture, display and transmission over LAN and Internet. MIR is also capable of capturing the video streams from several different endoscopic equipments. The video streams then can be displayed in monitors in the surgery room, giving the medics a wider and more detailed view of the surgical field. Also the video streams can be transmitted for a nearby conference room or classroom, using LAN, or even to a distant one, over the internet. All the video streams are independently configured, and the same video stream can be displayed in several monitors at once.

b) Recording. The recording control is independent for each video stream, and the room has a dedicated recording server.

c) Integration with PACs (Picture and Archiving Systems), allowing the retrieval of the patient´s images, like CTs and MRI.

d) Integration with the hospital management system, which allows the retrieval of patients' data and exams. One of the TVs on the room can show information about the procedure, like laterality, name, and so on. Besides, the room can feed the system with the procedure duration, which can be useful in statistical terms to have the average duration of specific procedures.

e) It is an All-IP solution, allowing the transmission of video, audio and data through the hospital network and, when available, the system uses multicast to improve the transmission efficiency.

f) Easy control through a mobile device like a tablet. This is one of the key differentials of MIR in relation to the other studied rooms and will be detailed in a specific section.

g) A remote room which has one or more TVs, a computer, a microphone and a camera It is called the preceptor room and the schematic is shown in Figure 1. This environment is used for a second medical opinion, classes (surgeon operating and explaining the details to students in remote locations), tele mentoring, among others.

Figure 1. Preceptor room.

h) Modularity: the system allows many different configurations, according to the hospital needs. The current setup used in Santa Casa hospital consists of four capture equipments (regular computers), each one connected to a video source: one connected to a camera filming the surgical field, another connected to a camera that films the patient's abdomen, one linked to a video laparoscope and another connected to a remote room. These computers act as redundancy in case of fail, because the system can work with fewer computers.

Figure 2 shows the main elements of the room, which are: (1) the ceiling pendants, used to hold monitors, spotlights and medical equipment, making the environment more flexible and hiding cables; (2) and (3) auxiliary endoscopic monitors; (4) the light spots, which are steerable and flexible; (5) the high definition cameras, that capture the desirable angles of the surgery field; (6) the televisions, which show all angles of surgery for all surgical team along the entire procedure; (7) the endoscopic equipment.

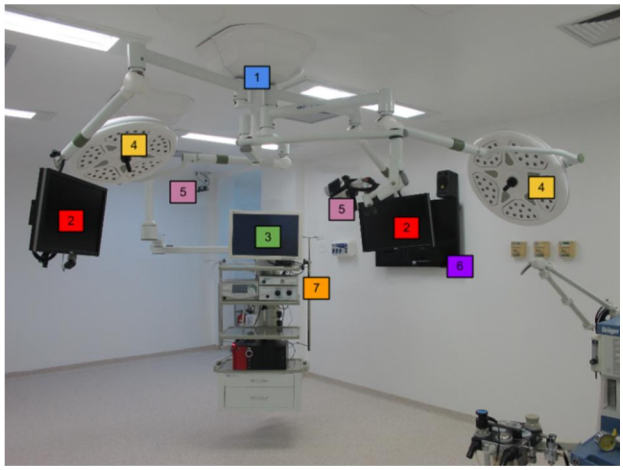

Figure 2. MIR elements in the room.

The bidirectional communication between the surgeon and a remote location is complete with a lapel or headset microphone. To configure and control the multimedia aspects of the environment there is a tablet with the surgical team.

An important attribute is that the MIR system is integrated. This enables real-time visualization of patient information. Communication with the medical images server and patient's Electronic Health Record enables the physicians and nurses to search, view and immediate handle the examinations performed by the patient throughout his life. This gives more freedom to the surgeon, eliminating red tape, delays and printings, generating environmental benefits. If used the tablet-PC, the access to patient information will be in the palm of the hand. Within the DOR the surgeon can visualize, for example, a radiograph at one of the monitors while the anesthetist observes patient data such as allergies and chronic disease through the tablet.

MIR uses, among other tools, a software for transmitting multimedia streams via LAN also developed by the MIR team. The MIR software is, in short, a tool that allows you to capture and send audio and video streams, supporting multiple views on a single monitor via split screen.

4.1 Software

The software of MIR is designed to run on regular computers and be able to communicate with other computers. An instance is able to capture, transmit and receive audio and video streams in real time, supporting, in the current version, up to eight streams per monitor. The transmission of streams is via IP and may be both unicast and multicast. This is important because it enables the transmission of streams with more efficiency when the network allows.

In addition, the software have operations such as recording, exchanging video positions at runtime, full screen, multiple views, screenshot, pause, and also allows pointing on the images remotely.

The video recordings can be stored on the machine that is making the capture or recorded on a dedicated server. For longer surgeries the software can even record the file into slices of determined sizes, making easier the copy and storage of files.

To encode and transmit a video it is necessary a camera connected to the computer (or a capture card for high resolution). The video capture process uses DirectShow library (an API for the Windows operating system that performs capture and processing of video streams). A conversion of format to YUV is performed to facilitate the video compression. When decoded, the video frame is applied as a texture on an OpenGL surface. The frames are encoded and transmitted via UDP sockets and, if requested, written to an mp4 file. All instances of the software communicate with each other by exchanging messages via sockets UDP.

The video encoding is made in H.264 using an internal library which allows recording, converting and streaming. The encoding parameters can be modified according to the machine capacity and bandwidth availability.

The core of the software is based on two queues. The first one contains raw frames in YUV 4:2:0 and the other one contains encoded frames, which are consumed simultaneously by different threads created accordingly to the origin of the stream. When the video is local (captured by a camera connected to the machine) the threads are capture, display, encode, transmission and record. When the video is remote (video being received by the network), the threads are receive, decode, display and record. A software instance can open up to eight modules of local or network video simultaneously.

4.2 Room control using mobile devices

A tablet-PC, smartphone, or even a computer can be used to control the MIR functionalities. This is possible thanks to the solution adopted which uses Web Services and messages via UDP and web sockets. Figure 3 shows on the right the tab “Control” of the interface, which is controlling two televisions with four streams each. The other tabs, seen on the left of the figure, shows the other possibilities of the interface: a) Agenda: integration with the hospital management system to get the room schedule; b) PACS; integration with the hospital PACS to get the patient´s images; c) Music: allows ambient music; d) Recordings: allows the choice of where to put recordings; e) Configurations: general tab to set destinations of the video, among other things; f) Turn on and off the room. The interface is very easy to use and even untrained nurses can control the room.

With this wireless control module is possible to execute simple video operations on the streams captured by the cameras, such as pause, stop, play, record and change positions. Besides, it is possible to activate and configure idle devices (previously connected) starting a new multimedia stream, control medical images and consult patient information’s, such as allergies and chronic diseases. The interface also allows transmitting surgical procedures to remote locations just informing the destinations IPs.

The graphic interface uses javascript. For communication with the MIR software we used NodeJs, a platform for scalable network applications. When a button is touched on the handheld device, a message is sent to the NodeJs via web sockets and it is forwarded to the UDP multicast group of the MIR software.

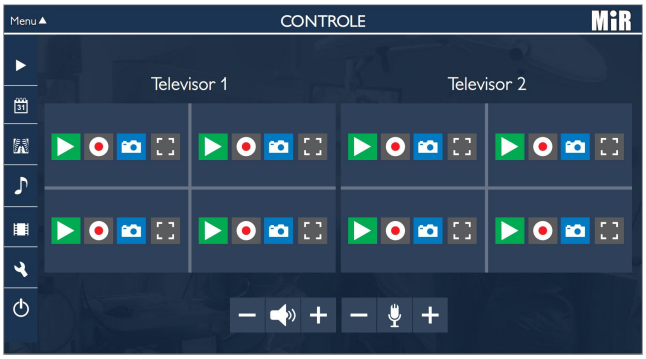

Figure 3. Tablet interface.

Web Services are used to inform the current configurations of MIR. The recording folders, the video resolutions, the codecs used, the machines of room, the devices connected to each machine, in short, all aspects of the environment are stored and updated by Web Services. When a configuration changes, the control module sends a message to the MIR software, and vice-versa if the configuration was changed by the computer software, keeping both synchronized.

Mobile devices integrated with the operating room make easier the configuration and retrieval of information inside the operating theater [13]. Also mobile devices can be easily covered with sterilized plastic, allowing even the surgeons to operate them without interfering in the sterilized environment. The graphical interfaces of MIR wireless controller are easy to use and require no additional training for the nurses or physicians. Figure 4 shows a nurse configuring the streams of MIR monitors. The TV on the left shows the Full-HD endoscopic image of a patient. The TV on the right shows an image retrieved of the hospital PACS.

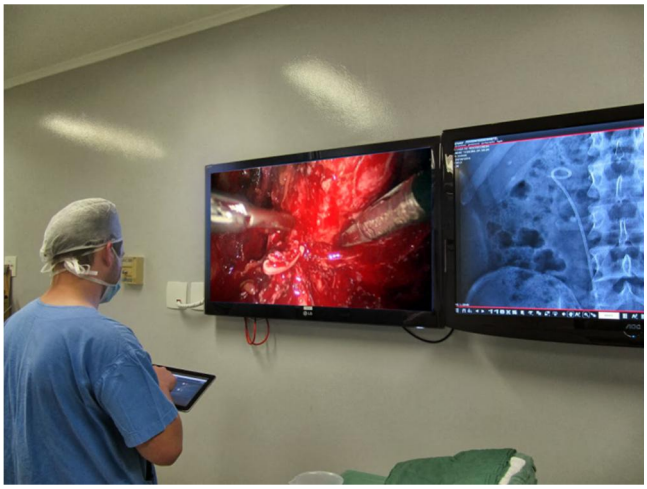

Figure 4. A nurse configuring the MIR using the tablet.

4.3 Results

The best way to evaluate a telemedicine system quality is using it on a real situation [1]. A MIR is already in use as a working prototype since April 2012 in Santa Casa Hospital. The hospital cooperates with the development of the project by participating in technical meetings with the development team, evaluating quality, interface and suggesting new features. Before the implementation

onto Santa Casa Hospital, the project was approved and validated by a local team of physicians.

The system was utilized in the transmission of the surgical environment to amphitheaters in many national real-time live surgery events with success. In an endourology symposium, for example, three images were captured inside the operating room: surgical field, patient abdomen and laparoscope. The sound of the operating room was captured by a wireless head microphone. The images were transmitted to an amphitheater outside the surgical theater in the local network by unicast. The amphitheater had an HD camera, an HD projector and microphones, so the audience could interact with the surgeon. The projector was able to show any image from the operating room, separately or simultaneously.

The projection at the amphitheater can be seen in Figure 5. In the superior left is possible to see the video laparoscope stream. In the inferior left and superior right we can see two angles of the DOR: abdomen camera and environment camera respectively. In the inferior right we can see the audience from the amphitheater. When necessary a particular video was set to full screen to show more details. In addition to the transmission is possible to see a REC signal in the three surgical videos, indicating that the surgery was recorded and documented.

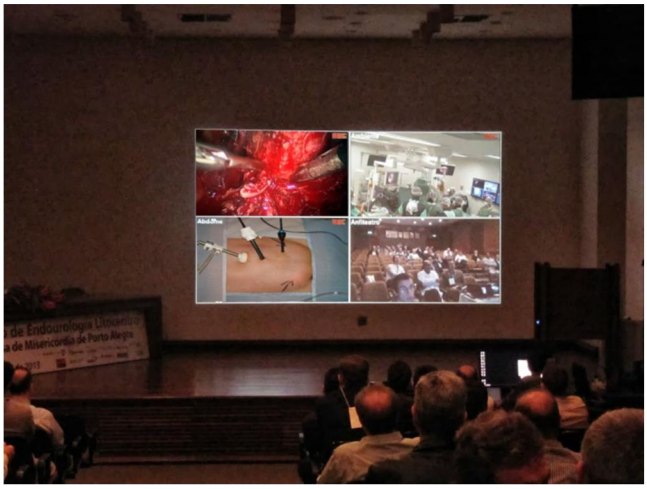

Figure 5. Projection on the amphitheater wall.

Figure 6 shows some of the monitors in the operating room showing the video laparoscope in full-screen. The TV on the left shows all captured angles of the operating room plus the audience in the amphitheater. There are two more TVs on the other wall of the room.

According to a renowned surgeon who used the MIR, the solution optimizes the time of the highly trained surgeon and speeds the training capacity of the surgeon on new technologies. The real time communication with the surgical team of residents' physicians, during the realization of laparoscopic surgical procedures in the MIR, allows the orientation of the team in a precise manner, not only in the positioning in the surgery but also on the correct position of the incisions. The surgeon position, incision point and manner of introduction of equipments in the patients are easily recognizable and oriented using the MIR, besides the endoscopic procedure.

Figure 6. MIR during the endourological symposium.

5. Comparison With Other Solutions

Table 1 presents a comparison between MIR and other solutions presented in the section "Related Works". As can be seen, MIR is the only one that has all the features. Besides, MIR is the only one with room control via tablet and integration with the Hospital management system. Related to number of images in the monitor, MIR supports up to 8 and VCU only up to 4. LAN transmission allows a great flexibility to the room, because an All-IP solution does not need fiber optics cables to connect remote places. In case of Internet transmission, only the MIR and UFPB solution allows streaming without third party softwares. Video recording is only allowed by the MIR and the VCU solution, in the others solutions or it wasn't said or requires additional third party equipment. Scalability (possibility to reach many remote places) and High definition are also qualities only of MIR and UFPB.

Considering the eight features of MIR, the solution that presents more similar features is the UFPB solution, however still with only half the features present in MIR.

Table 1. Comparison of features among different solutions.

Feature	PUCRS	VCU	UFPB	ICCAS	MIR
Multiple Streams per Monitor	No	Yes	No	N/A	Yes
Lan Transmission	No	No	Yes	Yes	Yes
Internet streaming Transmission	via Skype	No	Yes	No	Yes
Tablet Control	No	No	No	No	Yes
Video Recording	No	Yes	N/A	N/A	Yes
Integration with Hospital Systems	No	No	No	No	Yes
Scalability of Transmission	No	No	Yes	Yes	Yes
High Definition	No	No	Yes	No	Yes

6. Final Remarks

This paper presented MIR, a low cost complete surgical integrated room able to fulfill many of the technological requirements of a surgery transmission to use in education, allowing communication and recording of various high definition streams to a preceptor room or other points inside the hospital intranet. The room allows also transmission to the Internet through streaming in a reduced quality depending on the bandwidth. Integration with the hospital PACS and its management system was also implemented, allowing to the local and remote physicians a complete view of the patient´s records.

One key feature of the room is that it is All-IP, supporting unicast or multicast depending on the configuration and network possibilities.

The room control through mobile devices like a tablet is really a step forward in usability of surgical rooms.

All the MIR system is based on low-cost regular computers with redundancy, traditional High Definition PTZ cameras, tablets and regular low-cost TVs, among other small things. The major asset is the software that integrates everything. This makes the room cost at least half the price of similar ones.

The functional prototype installed in Santa Casa´s hospital has proved that the room is really useful. The hospital has about 5 educational national events for year, in different surgical specialties, and the room was used for transmission every time.

Comparing with other solutions in the literature, we found that the MIR room has at least twice the features of the others. Besides, MIR is a complete solution, with pendants, high definition video laparoscope, TVs, Cameras, and so on.

Future works include the software supporting 4K transmissions and 3D views of some streams. Still some work has to be done in terms of standards like HL7, DICOM and IHE [7].

7. ACKNOWLEDGMENTS

Our thanks are omitted from this version.

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