Getting Anesthesia Online: The smartOR Network

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***Abstract*—In this article, the concept of a future manufacturer-independent network standard for operating rooms is presented. On the basis of this standard, the realization of an integrated networked operating room is discussed using two workstations: One for the surgical and one for the anesthesia workplace displaying and controlling further networked components like patient bench, endoscope or tracking system respectively. As the main focus of this work the anesthesia workstation with an integrated system for telesupervision is presented. The workstation consolidates information from patient monitor, anesthesia machine and syringe pumps. Furthermore, information from surgical devices are requested to support the anesthesiologist. As a medical application the integration of an extended alarm concept is discussed followed by an outlook on options such a system can offer in near future.**

Keywords-telesupervision; anesthesiology; smart operating room; network; SOA; patient alarms

I. Introduction

Part of this work was previously published at the EMERGING 2011 in Lisbon [1]. The described materials and methods are part of a research project called smart operating room (smartOR). The project aims to develop a manufacturer independent standard for device connectivity in the operating room, the Open Surgical Communication Bus (OSCB). Therefore this article presents a motivation for the standard and a description of the state of the art and our vision. After that the protocol itself (OSCB) is described followed by the concepts.

A. Motivation

In Figure 1, a typical view of the anesthesiologist's workplace can be seen. Obviously there is a multitude of different medical devices like a patient monitor, an anesthesia machine, infusion pumps, operating room lights and surgical devices, like endoscopes and further instruments supporting the medical staff to treat the patient.

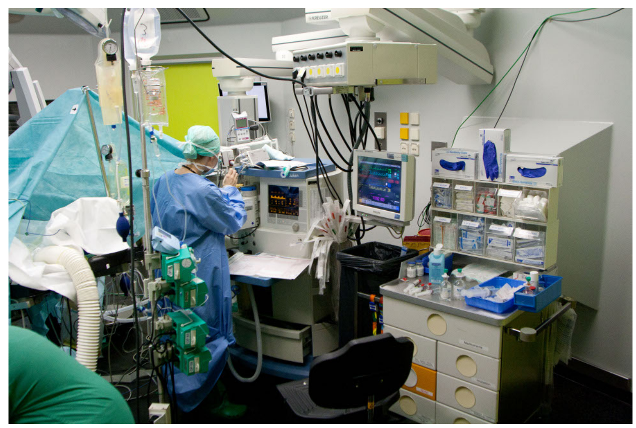

Figure 1. Typical scenario in an operating room [2]

All of these devices are necessary for a safe and successful process of the surgical intervention. However, the variety of devices, which are in most cases from different manufacturers, offer different risks for the patient and the operating staff. Each device has own operating panels and display concepts. Hence, information is presented to the user very individually and non-uniformly. For example, most infusion pumps have numeric displays with according numeric input. The patient monitor has a touch surface and the anesthesia machine is operated using a combination of setting valves and key input. Furthermore, in most cases there is a barrier between the anesthesiologist's workplace and the surgical workplace, due to hygienic reasons, which limits the interaction and information exchange between the anesthesia and surgical team. Nevertheless, despite of different tasks and focuses (performing surgery or controlling narcosis and patient's health state respectively), an interaction is required for optimal patient safety.

Currently, companies like for example Wolf [3] or Stryker [4], are building integrated operating room solutions presenting consolidated information from all devices in centralized displays. An example of such an integrated operating room can be seen in Figure 2. Consolidated displays can be

Figure 2. Operating room of the future. Example for consolidated data from various devices [3]

seen, which present optimized context-adapted information. Devices can be operated in a uniform way, so that usability concepts are clearly improved. Furthermore, several safety and assistance concepts can be integrated to support clinicians. Unfortunately, there are still drawbacks. Usually, integrated operating room systems are only built by one manufacturer or a limited range of partners. The operating rooms are optimized for only a certain type of interventions. Furthermore, these solutions are often based on proprietary protocols which do not allow a manufacturer-independent connection.

The aim of this manuscript is to enlighten these aspects in detail and to present our vision of the networked operating room of the future.

B. State of the Art

The situation presented in Figure 1 can be found in most hospitals, although the above mentioned integrated operating room solutions exist. A typical device set of the anesthesiologist's workplace consists of patient monitor, anesthesia machine, and syringe pumps. In still frequently used older equipment the only networked combination is the anesthesia machine and the patient monitor in order to display vital signs of the anesthesia machine at the patient monitor's display. Hence, the patient monitor only displays vital signs; the anesthesia machine provides a user interface to control the parameters for mechanical ventilation and anesthesia. New upcoming solutions for the anesthesiologist's workplace like the Draeger Smart Pilot View [5] [6] or the GE Healthcare Navigator Application Suite [7] are often expensive and, like the integrated operating room solutions, only connectable to a limited range of devices. The advanced integrated operating rooms present clearly arranged user machine interaction and support the staff during the intervention. The manufacturers of these integrated solutions are often developing devices for special purposes like endoscopy or brain surgery. Therefore the application of these rooms is often limited to a specific field of interventions. The described integrated operating room solutions are based on proprietary protocols. Therefore only manufacturer with an according license are able to integrate their own device into these operating rooms. Especially, smaller manufacturers with innovative products are handicapped without a license. Furthermore, more and more hospitals would combine different devices from different manufacturers to improve patient's treatment with best cost efficiency. A manufacturer independent standard would make possible every combination of devices regardless which manufacturer has produced it and which intervention type is performed.

But why does such a manufacturer-independent standard does not exist yet [8]?

In medical applications every device must be certified to comply with national and international medical standards like the ISO 60601 [9] for electrical operating safety and according to medical device acts. Furthermore, a risk analysis according to the ISO 14971 [10] or the ISO 80001 [11] must be performed. In case of connected devices this certification and risk analysis must be done for every device combination. This procedure is associated with much effort and costs. In case of a manufacturer independent standard the effort is much bigger, because the multitude of devices is larger and the risks are much more complex to assess. Due to the multitude of devices available on the market there must be developed new methods for the safety concepts and the risk management. Furthermore, the interest by the bigger manufacturer is low establishing a manufacturer independent standard. However, the request by clinicians for such a manufacturer independent standards becomes bigger and bigger.

C. The Vision

Our vision is to develop a standard for manufacturer-independent inter-device communication based on a service-oriented architecture (SOA) and on well-known internet technologies. The Open Surgical Communication Bus (OSCB) is the implementation of the standard. The use of a SOA has been previously proofed by different projects like the orthoMIT [12], the FUSION [13] or the Medical Device Plug and Play (MDPnP) [14] projects. During the design time of the standard, aspects like risk management and certifiability play an important rule. Concepts to integrate risk management into the protocol and mechanisms to ensure the safety and reliability of the network will be integrated into the standard.

Based on the defined standard new concepts for device operation and display concepts will be developed. Furthermore, the patients safety should be increased and medical staff should be supported by intelligent alarm systems. First in the following Section the basic concept with most important components of the smart operating room (smartOR) is presented [15]. In the Technical Realization in Section III the Open Surgical Communication Bus (OSCB) and underlying technologies are discussed. After that the implementation of an anesthesia workstation as a technical application is described in Section IV, followed by the medical application in Section V. Finally the most important results and future work is described in Section VI.

II. smartOR System Overview

The structure and the essential components of the smartOR concept are shown in Figure 3 and described in the following sections.

A. Open Surgical Communication Bus

As central component the OSCB is realized using standard hardware used in Local Area Networks (LAN). Every device in the operating room must be connected to the OSCB. Therefore, in principle, each device can communicate with each other. All devices are medical products and certified by according laws and standards. To ensure a flexible and reliable communication, each device has to implement a specific set of communication functions, which are described in Section III-B.

B. Surgical Workstation

The surgical workstation displayed in Figure 4 is the central display and control component of the surgeon's workplace. During surgical interventions the surgical workstation can be controlled by the surgeon itself using modern interface methods like gesture or speech input methods. Alternatively, the assistance personal can control the workstation. During the intervention the surgical workstation presents context-related information for the surgical team. This information consists of major vital signs, relevant alarms as well as the actual patient's health state in a compact form similar to a traffic light. Additional information like currently used devices and according functions can be easily used by the operator. Furthermore, the manufacturer of a device can deploy customized user interfaces.

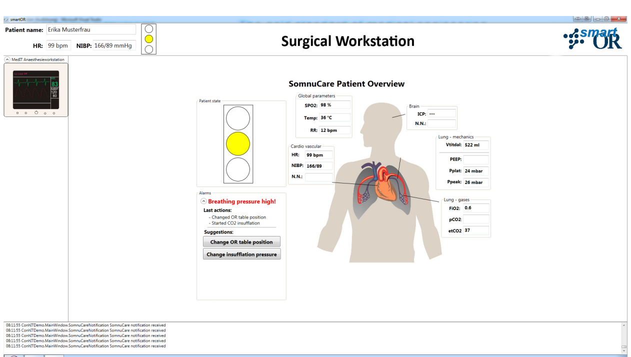

Figure 4. Very brief and consolidated information from the anesthesia workstation about the current patient's health state on the display of the surgical workstation

C. Anesthesia Workstation

The anesthesia workstation is the central information and control system of the anesthesiologist's workplace. Furthermore, it integrates the telesupervision system facilitating support opportunities by a "remote consultant" in critical situations or during teaching. The visualization of the concept can be seen in Figure 5. The anesthesia workstation retrieves the information from patient monitor, anesthesia machine and infusion / syringe pumps and displays vital signs, alarms and infused drugs on the central display of the anesthesiologist's workplace. Additionally all information that are available in the anesthesia workstation can also be displayed on a remote tablet PC. Hence, a supporting consultant has an overview of the current progress and state of the intervention. Furthermore, assistance systems like decision support facilities or evaluation algorithms of the patient's health state can also be provided for the anesthesiologist. In case of remote support, an additional video and audio connection can be established for consultation. The anesthesia workstation and the telesupervision system are the main focus of this work; they are described in Section IV more detailed as application of the smartOR network.

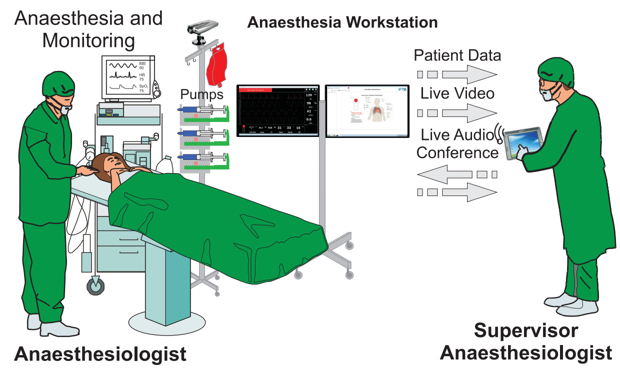

Figure 5. Anesthesiologist's workplace with telesupervision system modified after [1]

D. Medical Devices

There are many devices used by a surgeon. From a simple scalpel over an endoscope to a specialized navigation system for brain surgery. Whether the scalpel itself is a device, which is not be networked it could be tracked by a navigation system. The navigation system, for example, supports the surgeon during brain surgery allocating a tumor. The endoscope is used in combination with endoscopic lights and an insufflation device, which pumps CO2 into the abdominal region. All these devices need to be operated by a surgeon or an assistant. Connecting these devices together allows the surgical workstation to operate them from one central control unit in an efficient and uniform way. Therefore several industrial partners from the smartOR

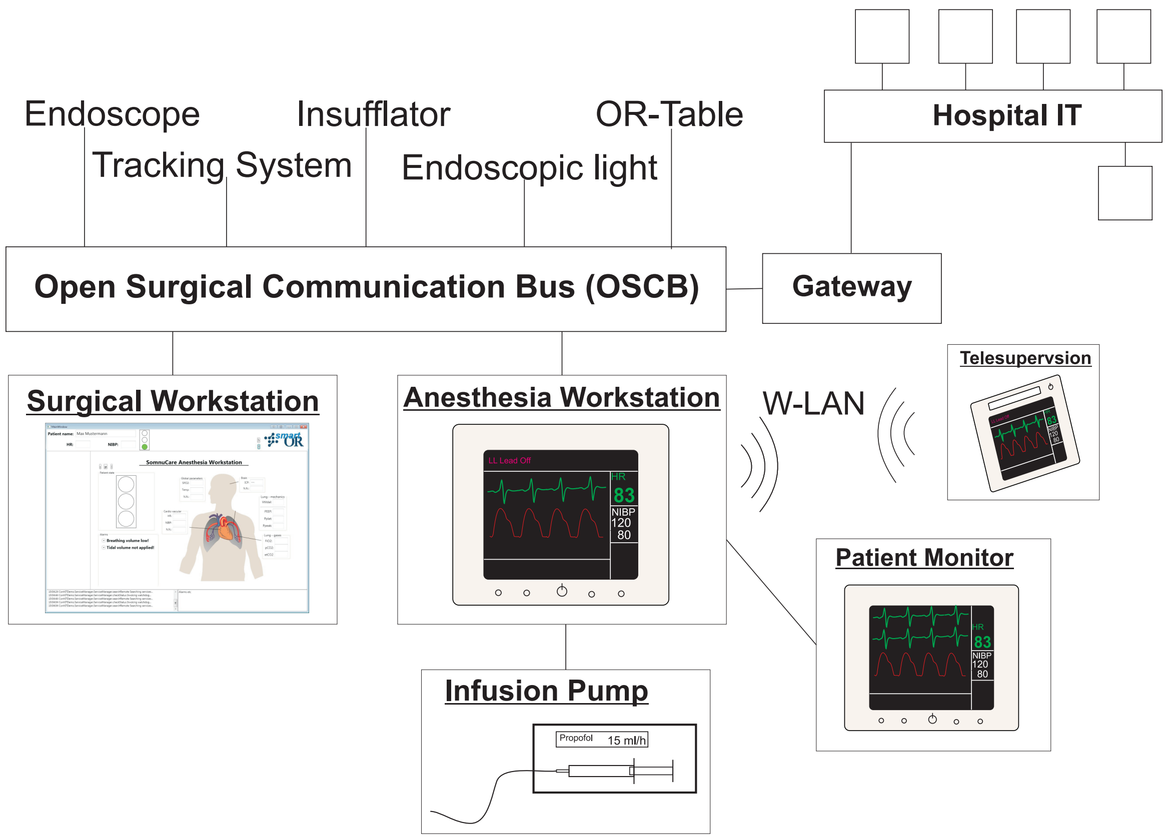

Figure 3. smartOR network overview modified after [1]

project participate in developing new standards and integrate their devices by using the already mentioned OSCB bus.

Figure 3 shows the anesthesia devices, which are currently not directly connected to the OSCB. A high amount of time critical data has to be transmitted from the device to the workstation, for example multiple waveforms like the electrocardiogram (ECG) or the photoplethysmogram (PPG). In most cases these data are not relevant for devices used by the surgeon in a non-consolidated form. Furthermore, at this time, these devices cannot be directly connected to the OSCB, because the software and interfaces on those device has to be adopted. Therefore, the anesthesia workstation is used as a protocol converter, which can forward relevant and requested data to the OSCB.

E. Gateway

For security and performance reasons, the OSCB of each operating room is an isolated network. Interaction between other ORs and the hospital IT network is realized by a gateway, which filters the traffic from the hospital IT. Additionally sensitive data from the OSCB is filtered. On the other hand patient data from the Hospital Information System or images from radiology (e.g. DICOM [16] format) can be transferred from the hospital IT through the gateway to the OR. Furthermore, updated patient records from anesthesiology and surgery can be returned to the hospital information system.

F. Results

The above mentioned devices and methods are the basis for the smartOR network, which is realized using components and protocols described in Section III. In the smartOR the anesthesia and surgical workstations are the new display and control instruments and represent central components. The surgical and anesthesia devices can be controlled by the workstations. All components can be substituted by components from other manufacturer as long as these are using the OSCB standard.

III. Technical Realization

In this Section, the technical principles of the OSCB are described. Since the standard is still in development, the current state of development is presented.

A. Internet Technologies Used

The communication layers are represented by the OSCB, which is described according to the ISO reference model in Figure 6. The physical and data link layer of the OSCB is based on the Ethernet standard IEE802.3. Ethernet is a commonly used standard and has already been approved in many medical applications like in the Medical Device Plug and Play MDPNP protocol [14][17] and Draeger Infinity network [18]. Moreover, Wi-Fi is used according to IEEE802.11 [19], to integrate mobile systems like the tablet PC for the telesupervision system. Finally the used physical layer does not matter, as long as used devices are conform to the ISO60601 [9] and according to medical device acts. Relevant for communication and for the protocol implementation are network and upper layers.

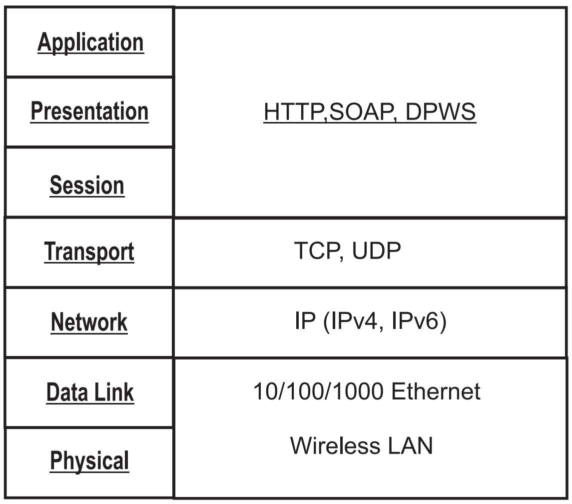

Figure 6. Modified ISO / OSI reference model for the OSCB

The IP based TCP and UDP protocols are commonly used in the internet and local networks. Hence our network and transport layer is based on these protocols as well. The performance and transmitting characteristics (CSMA/CD) are sufficient as we have not to match real-time criteria with the OSCB. The OSCB is only defined for device identification, device management, exchange of parameters, alarms and commands with no hard real-time demands. Large amounts of data and real-time data, like high resolution video must be transmitted using other protocols. Additionally there can be other communication channels used, like a M2IO switch (comparable to a KVM switch with matrix functionality) or additional communication channels.

In the upper layers we use web service technology according to the Device Profile for Web Services (DPWS) [20] [21] standard. The DPWS standard combines SOAP [22] technology with functions for device discovery. Every device in the smartOR network implements methods for discovery, registration and deregistration. Therefore all devices in the operating room can be easily managed by a central management component, as a new device on the OSCB registers itself by the management component. Other devices can retrieve a list of all devices from the management component. If the central management component fails, devices can manage themselves using the integrated DPWS device discovery functionality . The web services and exchanged messages are described in the following section in detail.

B. The Open Surgical Communication Bus

As described above, DPWS [20] [21] is used as the upper communication layers and builds the basis functionality in the OSCB. The OSCB defines the description of a DPWS device, web services hosted by a device and the messages exchanged by the web services.

Every device in the OSCB must implement three web services according to Figure 7:

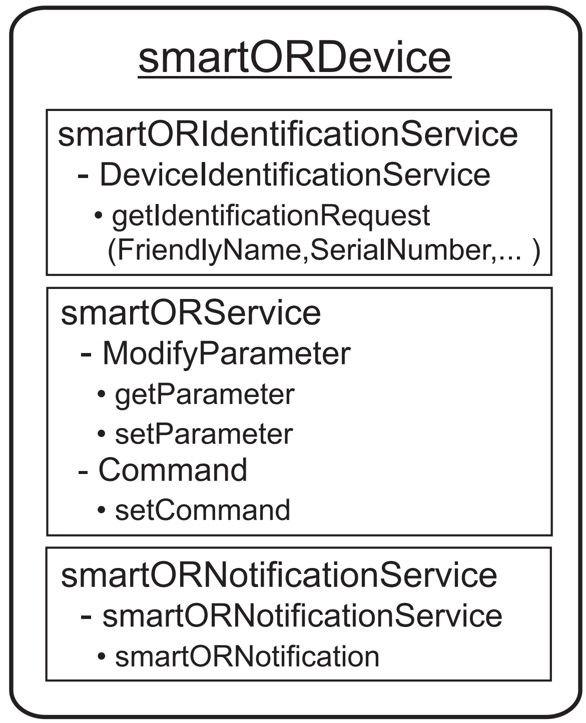

Figure 7. Web Services

- The *smartORIdentificationService* is used for device identification. It submits information about the device like hardware revision, software version and available parameters and commands.
- The *smartORWebService* is used for parameter exchange and command exchange. With the functions *getParameter* and *setParameter* various parameters like vital signs or device parameter can be read and set.
- The *smartORNotificationService* implements a notification service, which can be subscribed by clients. After subscribing the notification service every subscriber will be informed by the service about parameter changes or alarms.

Every device parameter, command and event has its own identification according to the ISO11073 [23]. The identifier is build using specified rules, which can be found in the standard. For example the designation of an insufflator device would be MDC_DEV_INSUFFLATOR. Where 'MDC' is the global identifier for parameters according to this standard and stands for medical device component. The second part specifies if it is a device (DEV), a command (CMD) or an event (EVT). Parameters are named using the device name as second part. For example 'MDC_ECG_HEART_RATE' means the heart rate derived from the ECG.

C. Results

Some parts of the OSCB are not specified yet; therefore even not all parts are realized in the software protocol. The usability of the SOA has been still proved [24] [25]. Currently just the WS4D-JMEDS framework in Java is used for the implementation of the OSCB. Therefore there is no comparison available between the WS4D-JMEDS framework and other framework's like WS4D-gSOAP or the .NET Micro framework DPWS implementation. Hence the WS4D-JMEDS framework is written in Java and offers much functionality a state of the art PC is necessary for implementation. The direct implementation in Java based medical devices is easy. Unfortunately, using this library in medical devices based on special embedded systems, still need effort or writing software interface for adaption.

IV. Implementation of the Anesthesia Workstation

The anesthesia workstation is one of the central components of the smartOR and develops its full capabilities in combination with other components in the network. However, the workstation can be used standalone. For example the software has been tested in different studies connected only to a patient monitor, an anesthesia machine and syringe pumps. During the studies patient data were recorded during surgery in order to develop new alarm concepts, for example the one described in Section V.

The anesthesia workstation consists of a special medical PC, which is equipped with hardware interfaces like RS232 and Ethernet for medical device connection. Up to two screens can be used for visualization. The functionality is implemented in a software called SomnuCare, which is primary developed in C++ using the Qt [26] library. For easy development and integration of new components the software is separated into different modules.

The most important modules of the SomnuCare software can be seen in Figure 8. The central and most important component is the memory mapped file (MMF) engine. It stores and caches all data from the interfaces, where each MMF represents a single data stream from an interface. Such a data stream can be a waveform like an ECG, numeric vital signs like heart rate or alarms from a medical device. Data acquisition is performed by the interfaces itself as described in Section IV-B. All interfaces in SomnuCare have a uniform API, which is described later in Section IV-B. This concept enables the programmer to add further interfaces for data acquisition without change of other parts of SomnuCare.

The telesupervision system is such a module and integral component of the SomnuCare software. This system consists of the anesthesia workstation as server component and a tablet-PC as remote component for the supervisor. The remote side is realized running an additional instance of the SomnuCare software, which is connected to the anesthesia workstation in the operating room using Wi-Fi.

The telesupervision server emulates an interface for the supervisors tablet PC and mirrors all data stored in the MMF engine to a special interface on the tablet PC.

A. Integration into smartOR Network

Currently only the Java based WS4D-JEMEDS framework is used for the OSCB protocol, as mentioned above. SomnuCare itself is written in C++. Therefore an additional module is used to integrate the web service functionality in SomnuCare. The program translates the web service requests to serialized strings, which are forwarded to the counterpart in SomnuCare using an IPC socket. The web service module makes use of the MMF engine to retrieve the requested data and sends them back to the Java program. Finally the Java program answers the request of the client.

B. Interfaces for Data Acquisition

As mentioned above the SomnuCare interfaces are used to read data from devices using different hardware interfaces and software protocols. For example a patient monitor can be connected via Ethernet to the workstation using an UDP multicast based protocol and an anesthesia machine using Draeger Medibus [27] protocol via an RS232 interface. The communication with the connected device is performed by the interface, so independently from the physical connection each device can be integrated in SomnuCare. The interface only has to implement the API functions shown in Figure 9 for configuring, starting and stopping the interface. Every interface holds an internal state machine, which is controlled by these functions. This enables SomnuCare to automatically handle different types of connected devices using a uniform API. The interfaces in SomnuCare are controlled by a manager module described in Section IV-D, which configures, starts and stops the interfaces and handles possible changes of state, for example caused by a disconnection. Received data is directly written by the interface to the memory mapped file engine.

C. Memory Mapped File Engine

The memory mapped file engine makes use of the operating system's memory mapped file API and supports reading and writing data to multiple segmented memory

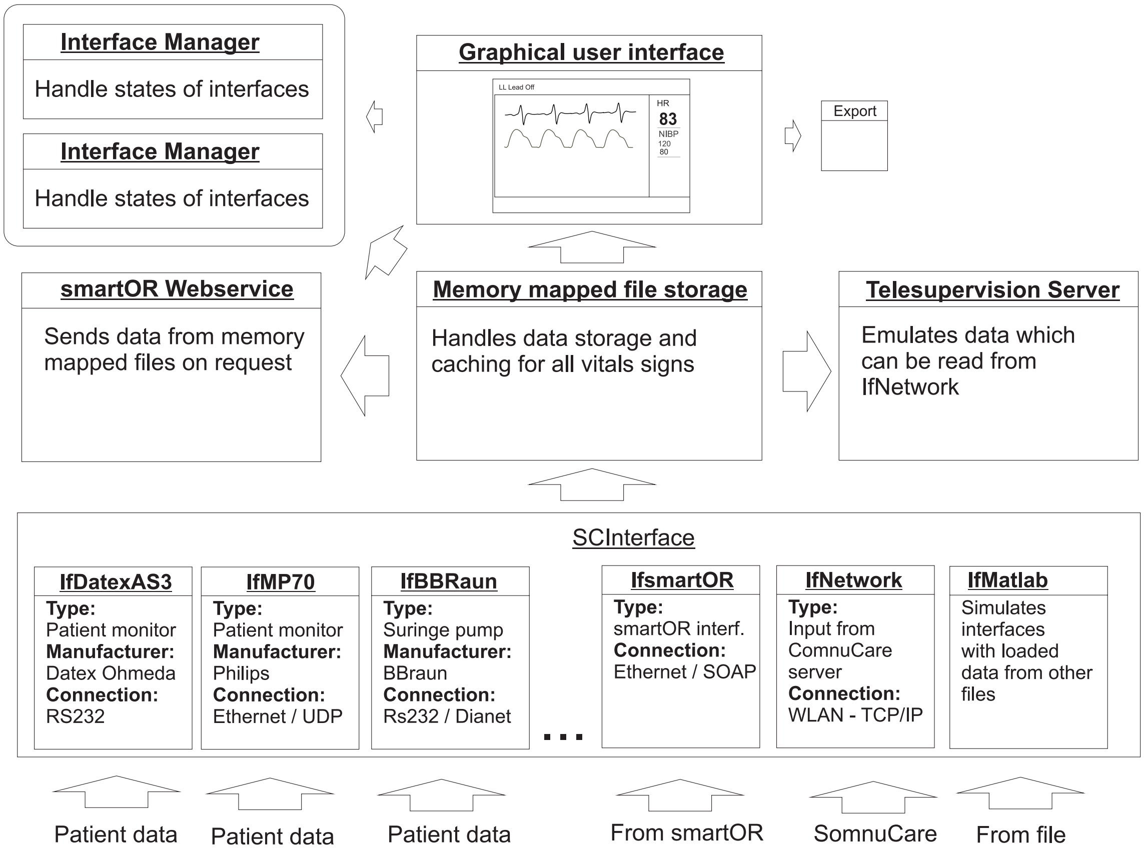

Figure 8. Structure of the SomnuCare software modified after [1]

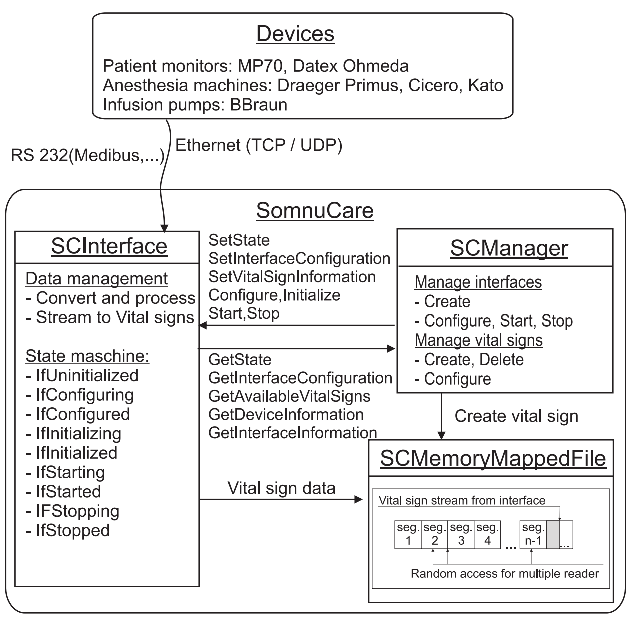

Figure 9. The SomnuCare interface

mapped files. Writing and reading data is performed by operating system functions. The memory mapped file technology allows data written to the memory mapped file being accessible like data in the RAM and stored to the hard disk like a log file at the same time. Hence only interfaces are used to write data to multiple memory mapped files, the engine supports only one writer for each memory mapped file, which can append data. Because all data should be logged and be available for other algorithms, functions for erasing or sorting data are not implemented. Reading is allowed by multiple instances as shown in Figure 10. This is necessary because the data from the interfaces is needed in different modules of the software. For example, the GUI as viewing element needs access to the last appended data, the telesupervision server must send the last incoming data, which have not already been send, to the client and the web services need to send specific data on request. During long interventions there can be a large amount of data stored in the MMF engine. For example during a 5 hour intervention with up to 50 recorded vital signs 500 MB data accumulate. To save memory not the whole file is mapped into memory. Therefore only the last segment is allocated. If the last segment is full, the file will be expanded with the segments size and this new segment will be allocated.

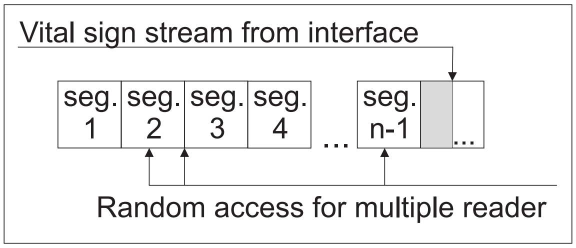

Figure 10. The SomnuCare interface

The reading function is able to randomly access segments. To improve the performance of multiple readers, they can register their instance for reading only appended data, which are tagged during insertion. In order to control all of these functions a special control segment is implemented in a separate memory mapped file. It stores information about segment handling and tagging new data for every reader instance. Furthermore, individual information like sample rate or data type can be stored in the control segment. This enables other programs to open the memory mapped file and use the contents for further evaluation.

Vital signs stored in the MMF engine and interfaces are controlled by a manager component, which is described in the following Section.

D. Manager Components

As mentioned above, the interfaces and vital signs are controlled by manager modules. The manager modules consists of hash lists, which can be stored to a database for persistence. During the runtime of SomnuCare the manager walks periodically through the lists in order to control the state and configuration of every interface or vital sign. Via the user interface the manager can be configured.

E. Telesupervision Server

The telesupervision server mirrors new appended data in all memory mapped files over the wireless network to the remote instance. Since the data in the memory mapped files is stored in a binary format, a binary protocol is used for data transmission. On the client side the counterpart is implemented as a standard SomnuCare interface. Therefore there is no modification needed on the client instance, except activating the according interface and setting the IP address of the server. Like all other interfaces the supervision interface must implement the state machine. This enables the network interface to automatically reconnect after a WLAN disconnect or any other failure. After a disconnect the interface tries to reconnect and load missing data in order to proceed with its normal operation. Due to the data tagging functionality and the consistency of the memory mapped files, no data will be lost, so an additional resynchronization is not necessary.

F. The Graphical User Interface

The graphical user interface of SomnuCare is designed to match the view of a standard patient monitor (Figure 11), because the patient monitor style has been proven for years. In order to test new features, alarm concepts and algorithms

Figure 11. SomnuCare user interface [1]

the layout of the GUI can be modified. Furthermore, new elements can be inserted, for example a traffic light in order to visualize the state of a vital sign, as described later in Section V.

G. The Simulation Mode

Normally SomnuCare is used in an operating room scenario for interfacing other devices and supporting the anesthesiologist. Additionally SomnuCare can be used stand alone in studies with simulated or previously recorded data. Therefore a special interface (IfMatlab) is integrated, in order to load Matlab [28] workspaces and playback these data. Since IfMatlab acts as a standard interface and all data going through this interface are fed back into the MMF engine, allowing new algorithms to be evaluated.

H. Processors

A processor reads data from the memory mapped file engine and applies customized algorithms. The output of a SCProcessor is feed back into the memory mapped file system and therefore the computed output is available for different modules in SomnuCare.

For example a special SCProcessor instance is used to plot waveforms like ECG or real time blood pressure with a specific data rate. This is necessary because physicians are trained to make diagnosis based on standardized signals. Unfortunately, devices of different manufacturers transmit vital signs using different sample rates and block sizes. Therefore the processor must resample these signals and insert a time delay for uniform plotting.

I. Results

The SomnuCare software is a modular C++/Qt software, which is easily extensible with new features. It stores all data from connected devices in a memory mapped file engine and makes these data available for live and post-hoc processing. The workstation aims the look and feel of a patient monitor. However, it is not limited to the display of the patient monitor signals only, but is able to view data from patient monitor, anesthesia machine and syringe / infusion pumps. Furthermore, it is able to visualize new concepts like for example the display of the vital signs state.

SomnuCare itself has been used in different studies in die operating room recording data from patient monitors, anesthesia machines and syringe pumps from different manufacturers. The software will be permanently improved and extended in order to integrate new devices and try new concepts. The current realization of the OSCB integration is only a transitional solution.

The IPC communication between C++ and Java is afflicted with much overhead. Furthermore, receiving data from the OSCB using a web service client is not working. As long the SomnuCare software interfaces needed devices directly this is no drawback.

The performance of the Wi-Fi connection is sufficient to transmit all data processed in the workstation to the supervisor. However, there are still problems with the video/audio link between the operating room and the remote station. Especially transmitting patient data and establishing the audio link needs a good Wi-Fi infrastructure, because the bandwidth is not sufficient if the connection is week.

V. Medical Application

As mentioned in the introduction the vision of the smartOR network is to support the staff in the operating room. The presented smartOR concept and standard sets the base for the following presented medical application. In this Section a first approach to such a decision support and intelligent alarm system is described.

The data collected during the study described in the following Section are the basis for the presented alarm concepts. At the time the study took place, the SomnuCare software was not completed, therefore a special software module was developed to capture the data exclusively from the Datex Ohmeda AS/3 and BBraun perfusor serial interfaces and store them as comma separated text files. Relevant anesthesia and intervention-related events and milestones respectively were recorded by the same software. Thus, post-hoc synchronization was not required. Furthermore, the patients' sex, weight, age, size and the type of intervention were recorded.

A second study based on the SomnuCare software was carried out with a Philips MP70 patient monitor and BBraun syringe pumps. The setup was comparable to the described study, which will be explained in the following Section more deeply.

A. Data Acquisition During Surgery

The data collected during the described studies are the base of the alarm system integrated in SomnuCare. The original study with a limited device combination has been previously published in [1].

In order to improve comparability of the collected data, similar surgical interventions, most of them gynecologic laparoscopic, were selected for recording. Anonymous data acquisition took place at the University Hospital Aachen after approval by the local ethics committee. Generally, the most important steps were pointed out as milestones:

- Start of presence of the anesthesiologist
- Start of anesthetization
- Approval for surgery
- Start of surgical preparation
- Start of surgical intervention
- End of surgical intervention
- End of surgical wrap-up
- End of anesthesia
- End of presence of the anesthesiologist

Furthermore, following events were recorded:

- Anesthetic events like intubation or inserting of a stomach tube
- Surgical events like skin incision, intra-operative relocation
- Intravenous drug injection

All vital signs and information from the following devices were recorded:

- Datex Ohmeda AS/3 or MP70 patient monitor
- Draeger Cicero, Cato, Primus anesthetic machine connected via Datex Ohmeda monitor
- Up to four BBraun perfusor infusion pumps

The above listed devices represent the standard setup in the University Hospital Aachen for these surgical interventions and resulted in the following recorded vital signs:

- Heart rate, non-invasive and/or invasive blood pressure, oxygen saturation
- Respiratory rate, tidal volumes, pressures, fractions of end-tidal $CO2$, $O2$ and anesthetic gases
- Anesthesia agents via syringe pumps and/or anesthetic gas concentration via the anesthetic machine

In total, data from 17 surgical interventions were recorded (8 female, 9 male patients). A balanced anesthesia with anesthetic gases (Isoflurane, Sevoflurane) was carried out in 8 cases; the remaining 9 received a total intravenous anesthesia using Propofol and Remifentanil.

B. Anesthesia Alarm Concept

Generally, patient alarms are generated if a vital sign, for example the blood pressure, exceeds previously set limits.

In the operating room this concept is reasonable, since every exceeding can be critical. But, after critical situation, it is not necessary to repeat this alarm every 2 minutes, after the alarm has been confirmed and the underlying problem is already solved. As a solution for this problem, the following state machine was implemented for every important vital sign, for example like heart rate, non-invasive blood pressure and oxygen saturation: Compared to conventional alarms, which are triggered by exceeding pre-configured but fix limits, the state machine reconsiders the change of the vital sign after limit exceeding. So, initially the concept of classical limits is kept, but supplemented with the state machine algorithm.

Concretely, the alarm is rated into four conditions, similar to a traffic light.

- RED for a serious danger for the patient
- ORANGE for a situation with a potential danger for the patient
- YELLOW for the phase after a RED or ORANGE alarm is cleared
- GREEN for no alarm

The resulting state machine and flow diagram can be seen in 12.

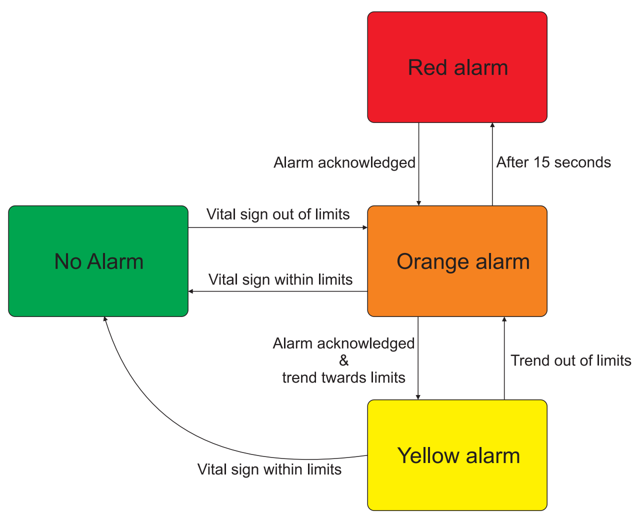

Figure 12. Resulting state maschine [1]

C. Results

The described traffic light alarm system is useful to avoid unnecessary alarms after critical situations. An example of such a situation can be seen in Figure 13. After a markedly increase of the blood pressure an orange alarm will be raised. If the alarm is acknowledged and the vital signs trend is targeting in-between the limits, the alarm turns into a yellow alarm. The yellow alarm still gives fair warning to the anesthesiologist, but the intrusive periodic acoustic warning is suppressed. If the trend is going worse, the alarm will return to the orange or red state.

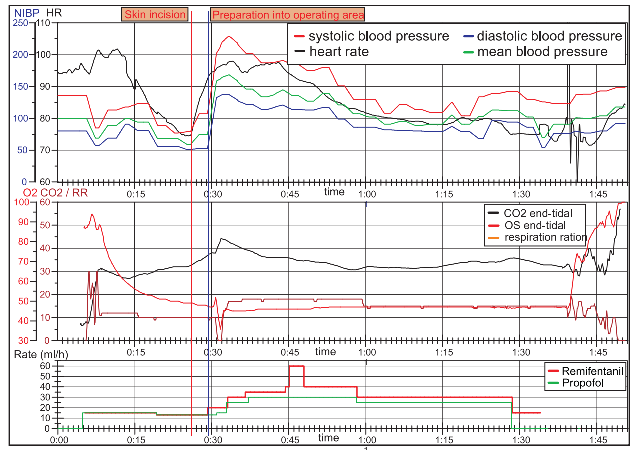

Figure 13. Example of an recorded surgical intervention [1]

VI. Conclusion and Future Work

With regard to develop a manufacturer-independent protocol and interface standard for the operating room, first advances of the smartOR concept were described. In particular, the Open Surgical Communication Bus as well as approaches to realize workstations, which are custom-designed for anesthesia and surgery respectively were presented. First clinical data were already collected via already existing hardware interfaces and software modules and used for the development of novel anesthesia alarm concepts. Nevertheless the system is not fully developed yet but in progress.

A. smartOR System Overview

All devices in the smartOR are managed by a central device. Currently the device manager is integrated in the surgical workstation and lists all available devices in the user interface. However, the device manager should manage the access between the devices and manage the risk a new device or data exchange between devices can bring. Therefore additionally the device manager should integrate the risk and security management for the network.

Furthermore, fall back strategies must be planned in order to handle a failure of this component. Of course the network should be still functional even whether in a function limited mode. For example if the device manager fails, the network could keep its current state and ignore new devices, which risk and security aspects cannot be assessed by the manager.

The gateway is included in the concept, but not been implemented yet. It should consist of a powerful PC, which is able to run a stateful firewall, in order to filter unsecure traffic from the hospital IT, while forwarding relevant data, like DICOM images from the radiology or patient information from a hospital information system.

B. Technical Realization

The described components and protocols used in the lower layers of the OSI reference model, like Ethernet, TCP and UDP are used in many applications. Even in medical applications the used technologies are state of the art. Since there are no hard real time criteria to match, Ethernet with 100Mbit/s or 1GBit/s is fast enough for the OSCB.

A comparison between different DPWS frameworks is still missing. The currently used WS4D-JEMEDS framework is a flexible tool, but not optimized for the OSCB. In future we will implement the OSCB protocol using different frameworks, like the in C++ written WS4D-gSOAP or the .NET Compact Framework, which covers the C# world. Additionally the consortium is developing an optimized framework in C++, with less dependencies to other libraries. This helps integrating the OSCB to medical devices, which are based on limited embedded hardware. The SomnuCare software will be modified to use the new C++ framework.

Another point is the cross operating room communication with the telesupervision client. As already mentioned the smartOR gateway filters all possible risky and unnecessary traffic and isolates each operating room. Implementing a cross operating room operation for the telesupervision system, the gateway must allow the traffic for the telesupervision system and forward it to the hospital IT or a WiFi infrastructure.

C. Implementation of the Anesthesia Workstation

The anesthesia workstation is a modular software, which integrates devices like patient monitor, anesthesia machine and syringe pumps into the OSCB. Furthermore, the software is capable of performing real time computations on the signals received from the interfaces. The concept has been approved in practical use in studies and in the demonstration environment, according to Figure 3.

One of the most important following steps is the direct integration of a DPWS framework, without external processes running, in order to reduce overhead and additional interface logic, which is not conform to the standard SomnuCare interface logic, described in Section IV-B. One possible solution would be the integration of the self-developed framework or the WS4D-gSOAP framework. Furthermore, work has to be done equipping syringe pumps and anesthesia machines with a control mode, so that parameters of connected devices can be changed by the workstation. This would help in situations where the anesthesiologist has to act near the patient and is not able to setup new dose rates or parameters on the devices. Realizing such functions needs an extension to the described concepts, mainly extensions in the risk management. The workstation must ensure the correct setting of dose. Furthermore, the user must be present in the operating room in order to supervise the new setup.

D. Medical Application

Several medical applications and advances can be achieved using the approach to reduce unnecessary but intrusive alarms is meaningful for practical and safety reasons. The conventional min/max alarms have been approved for many years and will therefore be kept and extended with technologies, which use the information from other devices in the smartOR network. For example the system can correlate possible blood pressure variability with the setting of the OR table. Than a workflow engine can analyze the actions of every device in the OR and determine possible future steps of the intervention in order to adopt alarm limits or to give advices for the next steps. Furthermore, dependent on the next steps of the intervention, the system can recommend, for example, to increase depth of anesthesia in advance of skin incision or a pending painful procedure.

ACKNOWLEDGEMENT

The described work is supported by the German Ministry of Economics and Technology. The smartOR project has the support code 01MMA09041A. The responsibility of this publication is by the authors. The authors would thank the following smartOR project partners for the efficient collaborative work:

- Innovation Center for Computer Assisted Surgery (ICCAS) der Universitt Leipzig
- LOCALITE GmbH
- Richard Wolf GmbH
- SurgiTAIX AG
- Synagon Gmbh
- VDE/DGBMT

Furthermore, the project is supported by clinics of different branches.

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