Real-time Anaesthesia Diagnosis Display System with Multi-Modal Alarms

Ken Lee[1], Kyung Jean (Tyler) Yang[1], Beryl Plimmer[2] & Michael Harrison[3]
Dept of Electrical and Computer Engineering[1], Computer Science[2], Medical and Health[3]
The University of Auckland, New Zealand
leefecu@hotmail.com, yangkjean@gmail.com, beryl@cs.auckland.ac.nz, michael.harrison@auckland.ac.nz

ABSTRACT
Fatal errors during anaesthesia administration are usually preventable human mistakes. It is difficult for anaesthetists to keep monitoring every physiological change and to detect clinically critical events during anaesthesia. Intelligent patient monitoring systems to assist anaesthetists are under investigation. These systems require a distinctive and unique way of conveying alerts and diagnostic information to the anaesthetist in busy and noisy operating theatres. We present here a functional prototype of a multi-modal (audio & visual) alarm system, MMAS.

Categories and Subject Descriptors
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Human Factor, Reliability,

Keywords
Computerised diagnosis, Anaesthesia diagnosis system, Multi-modal alarm, Visualisation, Speech alarm, Auditory alarm

1. INTRODUCTION
With an overwhelming amount of data to analyse in a busy environment, anaesthetists are not in a position to diagnose and make decisions correctly and quickly all the time. In the operating theatre there are multiple monitors for the anaesthetist to repeatedly visually scan; many machines producing noises simultaneously, and many other simultaneous events that can distract the anaesthetist's attention. The aim of this project is to develop an effective interface for a decision support system to alert anaesthetists to critical conditions and provide them with appropriate intra-operative diagnostic information and protocols, and thus enhancing the anaesthetist's performance.

In the current system [4], data on a patient's condition such as heart rate, blood pressure and pulse volume are extracted from anaesthesia monitors in real-time. This data is analysed using statistical analysis and fuzzy logic computer algorithms to diagnose the status of patients. When a critical condition is detected the system generates an alert which needs to be conveyed to the anaesthetist with accompanying diagnostic data and treatment protocols.

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Our system MMAS runs quietly on a separate monitor from other monitoring systems receiving diagnostic information in real-time during surgery. When alerts are generated by the system MMAS notifies the anaesthetists by producing a distinctive multi-modal alarm and displays the diagnostic information with evidence and treatment protocols.

We took a user centred design approach to develop the user interface of MMAS including field trips to the operation theatre simulation room, reviewed the international standards for alarm sounds in operating theatres and in-depth discussions with Dr. Michael Harrison. Dr Harrison is an anaesthetist who specializes in computer supported diagnostic systems. He has taken the role of expert user in the project team. We developed low fidelity prototypes to use in tests and participatory design sessions. From these we have developed a functional prototype with two alternative interfaces that is ready for usability testing. The next section discusses the related work and system and user requirements for MMAS. We then discuss the development of MMAS and the issues involved. We conclude with our plans for usability testing of the prototype.

2. RELATED WORK
The area of computerised diagnosis for anaesthesia has been researched for over two decades with a goal of assisting anaesthetists to make correct decisions during operations. While problems with anaesthetics occur infrequently, they can be complex and extremely serious [3]. Computer support systems use complex artificial intelligence techniques to identify critical events for the anaesthetist, see [5] for a summary of work in this area. This project examines how, once identified, the alerts and accompanying information can be effectively presented to the anaesthetist in a busy, noisy and crowded operating theatre. The two output modalities available are audio and visual: while system input could be via keyboard/mouse, touch screen or voice. In this section we review the literature on these interaction modalities in the context of operating theatres to provide direction and guidelines in the development of MMAS.

A study [6] reveals that current auditory alarms have high false and frequency alarm rates. Only 3% of the 1455 alarm sounds examined were actual critical situations, which might have been life threatening to the patients. Due to this high rate of false alarms anaesthetists tend to disable the alarm function. Therefore, reducing the false alarm rate is crucial because it directly affects the reliability of the anaesthesia diagnostic system. This is outside the scope of this report, but is under investigation by one of the authors, Dr Michael Harrison.

Another study [7] compared the identification and learning ability of abstract alarms, speech and auditory icons. It showed that speech alarms provide the easiest output for anaesthetists to recognise urgency without learning or memorising. Furthermore,

the results show that auditory icons and speech alarms are easier to remember and participants responded more quickly compared to traditional abstract alarms.

When the number of alarm sounds running in operating rooms increased and varied significantly with automatic monitoring, the International Organization for Standardization (ISO) released ISO 9703-2 in 1994 [2]. These standards are to ensure that the auditory alarms are clear, identifiable and non-obtrusive to patients. Another standard, the International Electro technical Commission (IEC) [3] governs many areas of electrical medical equipment including alarm systems. This standard suggests limiting the number of alarms to eight and using a cautionary and an emergency version of alarms.

The use of effective graphical displays and user interfaces in anaesthesia has been extensively studied. Two studies [1, 6] compared time and accuracy of anaesthetists' performance on the then new graphical displays with a traditional cardiovascular display. The results clearly showed that there was statistically significant improvement in both time-performance and accuracy during unexpected critical situations.

Three input modalities are possible: keyboard and mouse, voice and touch screen. Keyboard and mouse present practical problems in operating theatres including physical space and cleaning, but these are not overwhelming. Voice recognition is not accurate enough for this life critical environment. Touch screens are therefore the input device of choice. There are particular interaction constraints for touch screens such as size of buttons which we must take into consideration during the design phase [8].

RT-SAAM [5] is a research project examining the use of an intelligent patient monitoring system during anaesthesia. RT-SAAM uses expert system techniques such as fuzzy logic, artificial neural networks, probabilistic alarms and logistic regression to diagnose anaesthesia related events. A new communication protocol was developed to acquire data from existing patient monitoring devices in real-time. RT-SAAM was tested through a series of offline and real-time testing in the operating theatre and is currently still under development at the Auckland City Hospital, in collaboration with Auckland University of Technology, with ethical approval from the local ethics committee. The focus of this project to-date has been to reduce the false alarm rate. The current system can only be used for diagnosing two events, AHV (Absolute Hypovolaemia) and FCO (Fall in Cardiac Output). Our project expands notification ability of RT-SAAM to six anaesthesia related events, AHV, FCO and four additional events.

Figure 1. RT-SAAM user interface[5]

3. USER-CENTRED DESIGN

MMAS has been developed using a strong user-centred approach to ensure that the prototype of MMAS implements features that can be effectively used by anaesthetists. For this reason, the over-arching methodology is to involve anaesthesiologists to formulate the user requirements from discussions and low-fidelity prototypes.

3.1 User Requirements

3.1.1 One-to-one interviews

The requirements gathering exercise started with a number of informal discussions with anaesthetists and the RT-SAAM team members. In these one-to-one interviews, we discussed the current research and the outputs from RT-SAAM to determine stages and processes for user activities. We also asked about the systems that they have used and identified limitations in current systems. Subsequent one-to-one interviews were structured, to determine specific requirements. These interviews uncovered details about the use of the system while keeping flexibility to look into unused provision or limits in previous research. The interviewees were from the departments of health and medicine at the University of Auckland and the Department of Biomedical Engineering at Auckland University of Technology. As a result, we achieved a degree of consistency and depth of understanding with regard to the interaction requirements.

3.1.2 Field Trips

Field trips to the University's Advanced Clinical Skills Centre, to the high fidelity simulation operating theatre, enabled us to understand the environment that the system will be running in at the usability testing stage of the project. In addition, conditions and requirements that need to be considered for verification of the system during the development process were identified during this phase.

3.1.3 Expert Consultation

Regular meetings between the members of the team including Dr. Harrison, an area expert, kept the user-centric methodology on track during the development process. The discussions with Dr Harrison, as the expert user, greatly influenced the project, in particular during user requirements gathering. The low fidelity prototypes and the project in process were evaluated during these team meetings.

3.1.4 Identifying and analysis of physiological data

The data collected from monitors includes a blood oxygen analyser (pulse-oximeter), electrocardiograph, blood pressure measuring devices, temperature monitor, carbon dioxide and volatile agent analyser. These values are considered basic data sets which are essential for the computerised diagnostic system. This physiological data is both digital and analogue. It is downloaded through the S5 Anaesthesia Monitor. This data is stored as an ASCII file that can then be imported into an Excel spreadsheet or can be converted into a text file at the development stage. These data will, however, be directly delivered to MMAS in real-time once its development is completed. The data is filtered, pre-processed and analysed to provide diagnostic information such as malignant hyperpyrexia, absolute hypovolaemia, fall in cardiac output, sympathetic activity, relative hypovolaemia and inadequate anaesthesia.

This data is processed by RT-SAAM and alerts generated. These alerts are available to MMAS.

The input for Multi-modal Anaesthetist System (MMAS) should be via touch-screen. Each interactive screen component must meet touch screen guidelines; 19mm buttons for 'fat fingered sailors' with 3mm gap [10]. Due to the low occurrence rate of alarms, most of the time the visual display should be minimal, it must however reassure the anaesthetist that the system is running and all is well. When an adverse state is detected by RT-SAAM our system must effectively notify the anaesthetist and provide them with supporting information, highlight the recent changes, provide reasoning for the diagnosis and provide a protocol for management.

3.1.5 Paper prototypes of visual display

The initial phase of paper prototyping started with brainstorming ways of visualizing individual elements required in the visual interface. Next we created a number of simple, rough paper prototypes to visualise the MMAS interface. This enabled analysis of the suitability of elements within each design. The third paper prototype included printed graphics from various image manipulation tools (figure 2 and 3). This paper prototype was a clear vision forward for the implementation with a solid foundation for the design.

At each phase the development team, including the area expert, discussed the designs, and used wizard of Oz techniques to refine the design ideas.

Figure 2. Paper Prototype of MMAS using movable UI elements - 1

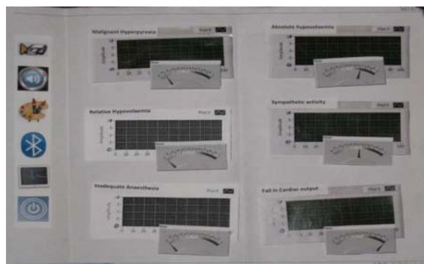

Figure 3. Paper Prototype of MMAS using movable UI elements - 2

3.1.6 Audio design with IEC Standards

The requirements analysis and literature suggested that audio output of alarms was a critical part of the system. We had several discussions on what and how we would support alarms. Clearly the alarms must meet the standards. That aside, we could consider auditory icons and speech output. The system must support multiple alerts and abnormal readings occurring at one moment in time. While it is simple to display multiple elements concurrently, sounds (particularly speech) need to be rendered serially. Acoustic or simple melody sounds have been found to have a low identification rate, speech alarms provide a higher identification rate without any learning or memorisation but are slower to render. We discussed a number of design possibilities that included blending auditory icons with speech indicating the six different diagnoses likely happen.

IEC standard [3] is used for medical equipment in many countries including the USA, the European Union and Japan. In particular, IEC 60601-1-8 (Table 1 below) describes the alarm sounds with three-tone melodies in details and sample sounds. Evaluation tests proved that these sounds are effective and higher identification rates can be achieved after training [3].

Table 1. IEC 60601-1-8; combined category and urgency encoding [3]

Common anaesthesia diagnosis	Melody
General	C4-C4-C4
Oxygen	C5-B4-A4 (OX-Y-GEN)
Ventilation	C4-A4-F4 (VEN-TI-LATE)
Cardiovascular	C4-E4-G4 (CAR-DI-AC)
Temperature	C4-E4-D4 (TEM-PRA-TURE)
Infusion	C5-D4-G4 (IN-FU-SION)
Perfusion	C4-F#4-C4 (PER-FU-SION)

Also, users are able to change each alarm sound for each anaesthesia event through the user settings.

3.1.7 Bluetooth headphone technology

Operating theatres are busy, noisy places and things tend to go smoothly or very wrong, very quickly. The normal environment includes multiple monitoring machines running with different visual and auditory sounds. To convey the alert sounds directly to the anaesthetist without interrupting the other surgical staff or disturbing the patients we decided to include a Bluetooth headset as a part of the standard system proposal. Bluetooth has the advantages of wireless connectivity that does not interfere with other medical and non-medical machines working in the operating rooms.

4. IMPLEMENTATION

So that MMAS would integrate easily with RT-SAAM and operating system monitoring equipment it has been implemented in LabVIEW 8.5[http://www.ni.com/labview/].

4.1 Visual Alarm

MMAS receives a stream of diagnostic data every 10 seconds from RT-SAAM. The data is displayed in a time-series graph in six categories of symptom (figure 4). When there is no adverse problem with a patient's condition, nothing will be displayed on the screen except the side menu (figure 4) and a colour indication of status (green or red). Corresponding graph(s) will show up on the screen if MMAS is notified of significant changes on patient's condition by RT-SAAM. It then displays appropriate pages of protocols for the particular event (figure 5).

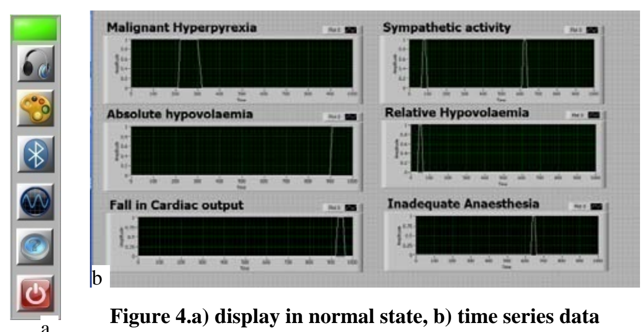

Figure 4.a) display in normal state, b) time series data

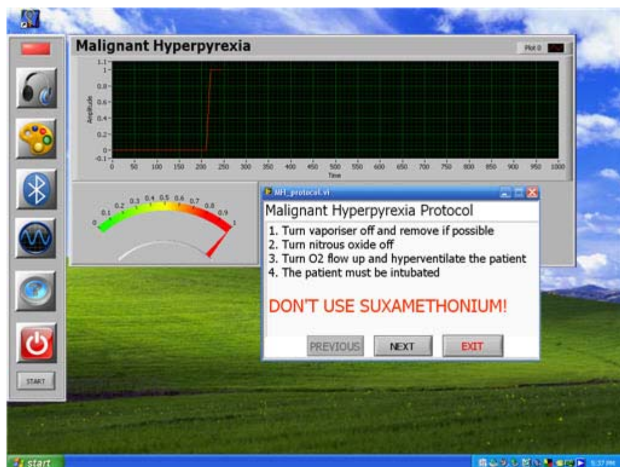

Figure 5. Visualisation of MMAS alert state

4.2 Auditory and Speech Alarm

It is challenging to match the auditory alarm sounds with the clinical events and what is best is subjective to each individual. In order to maximise the correlation between these two, a library of alarm sounds is provided so that the users can choose an alarm sound for each clinical event. In addition to this, the speech alarm will convey diagnostic information to anaesthetists without any requirement for further learning. The speech alarm is implemented in LabVIEW by using the Microsoft Speech SDK 5.1 and adding .NET controls for text-to-speech. The speech is generated from a library of event names and diagnosis conditions. The library can be updated via the user interface. By combining both auditory and speech alarm, high identification rates can be achieved by anaesthetists. Also, it is not required for anaesthetists to memorise each auditory alarm sound for each of the clinical events. This is particularly important because, although critical, some events are very rare.

4.3 Management Protocols

MMAS also includes a treatment protocols for each critical event. When an event occurs the appropriate protocol appears on the touch screen right after the multi-modal alarm. The protocol is usually a series of procedures to follow and users can scroll up and down by pressing 'previous' and 'next' buttons.

5. DISCUSSION

In this project we have explored the requirements for an anaesthesia monitoring and alarm interface. Given the critical nature of the environment a multi-modal system is proposed that incorporates visual and auditory output with touch screen input. Drawing on the literature for standards and design guidelines, the expert knowledge of one of the team members and various other specialists we explored a range of design alternatives using paper prototypes and low-fidelity equivalents for the sound. A functional prototype was then developed in LabView 8.5.

By providing effective audible and visual alarms, we believe MMAS can enhance the usability of a diagnostic system. However, MMAS is a prototype which runs in test mode using simulated input data of the type produced by the prototypical diagnostic system. The next stage of the project is to perform usability test on the prototype in the simulated operating theatre. Once any usability issues are resolved MMAS can be more tightly integrated into RT-SAAM and then be used as a part of this system as it progresses from research to real trials.

6. CONCLUSION

MMAS is a multi-modal alarm system to support anaesthetists. If the system detects certain critical changes in a patient's condition, it produces a distinctive alarm sounds with additional speech information transmitted to a hearing-aid type device using Bluetooth technology. MMAS then displays useful diagnostic information followed by pages of procedures on a screen. This can increase the ability of anaesthetists to detect and respond to unexpected events quickly and correctly.

The next steps in this project are to do user evaluations and trial runs, and eventually implement MMAS into actual systems in operating theatres.

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