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Anesthesia support systems

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Introduction

Rapid growth in computer technology in producing high performance systems with superior ergonomic design, has opened new avenues in various application areas in different segments of engineering which demand visual presentation and communication capabilities in addition to excellent number-crunching power. Incidentally, most of these applications are related to a category of monitoring, real time model simulation, intelligent alarm annunciation and maintaining record of events. This new trend of development has very recently diversified into medical monitoring and computing. As cost is a major criteria from the point of wide spread acceptance, these systems were not economical until recently. Today, many high-end personal computer systems can provide an excellent platform for many concepts in medical monitoring to become a reality. The promises, such a progress would offer, are phenomenal. With good co-operation among industries and between industries and users and with well defined set of standards, certainly computerized monitoring can become, in a couple of years, the nucleus of support systems for anesthesia.

Computerized monitoring

With the proliferation of non-invasive measurement techniques, which have clear merits beyond doubts, monitoring the various equipments has become a key issue. The pieces of information delivered by these equipments are certainly in favour of improving the standard of delivering anesthesia. But if monitoring these information itself would be considered as a hindrance, it strongly suggests the need for an equipment to handle these information to simplify the task of monitoring and improve the efficiency of the use of other equipments. In that context, computerized monitoring should not be viewed as yet another equipment pushed into Intensive and Critical Care areas. Computerized monitoring is a new generation of technology, it is a platform, where ease-of-use and quality of care are all that what count. With the possibility to be able to connect various different standard pieces of equipments from different manufacturers and present the physiological state of the patient in a simple and coherent manner, computerized monitoring represents a milestone in support systems for anesthesia.

Use of computerized monitoring may not look fulfilling directly any real demands in the Intensive Care or Critical Care environments, but they offer a form of assistance to improve the quality and efficiency of patient care. An analogy here is worth mentioning, couple of years back, when word-processing entered secretary offices to improve productivity, there were reluctance and opposition to accept it considering the learning cycle, necessity etc. But today the view has totally changed and their contribution to productivity is unquestioned. The trend will be roughly the same in monitoring. The potential benefits of computerized monitoring

may not be readily apparent but as its use becomes more and more common, its full potentials and their spin-offs would be realized.

Recent developments

The current trends in computerized monitoring are strongly characterized by the recent developments in computer technology. Graphic presentation and communication capability would be the key factors to decide a monitoring system. Graphic presentation would refer to present data in a form easily comprehensible at a glance, for instance as bar graphs or curves. Communication capability would refer to the possibility to connect one computerized systems with another with support for remote and central monitoring. With these as major supporting features, the chief functions of a monitoring workstation will be:

1. To interface with various medical instruments and coalesce the data to form a device independent description to have a single, common physiological state description that can be exchanged between different functional modules for analysis and alarm detection.
2. To achieve realtime graphic display schemes to facilitate quick identification of abnormalities at a very early stage.
3. To have powerful network communication capabilities between the workstations to facilitate remote monitoring, online analysis of patient data for research investigations and to generate high quality graphic print-out of selected portions of the realtime and trend data on a central printer for record keeping.

The minimum set of monitoring functions for both hemodynamics and respiration would include the following:

1. Front-end monitoring of real time curves and the trends:
   a) Hemodynamic monitoring:
   Blood pressure, SaO2, Analysis of ECG changes.
   b) Respiratory monitoring:
   End-tidal CO2, Shunt and Dead space calculation, Pressure-volume & Flow-volume loops.
2. User callable decision support analysis functions:
   a) O2-CO2, Iso-shunt diagrams
   b) Hemodynamic derivatives like Cardiac Indices, Peripheral Resistance, etc
   c) Acid-Base disorders evaluation

Apart from monitoring tasks, the system can easily provide a rich set of record keeping functions like maintaining a record of drugs given at different times, blood and fluid losses, laboratory reports on blood gas analysis and other forms of remarks and comments.

Figure 1 shows, functionally, how one such system would look like. Bottom of the picture shows various medical instruments from which the data are collected and distributed. Top of the picture shows computer output devices. Various blocks, in the middle, represent the software modules which perform the specified task. The term workstation is used in the context of a computer used for a specific application, as in this case for monitoring.

The transformation

Today there are not many systems for computerized monitoring. There are few inhouse or prototype systems, but as mentioned, the cost of such system is the major factor, and with current rapid growth in computer technology, new such systems, economically priced, should be arriving soon in the market place. There are presently few entry-level products in the market, but most of them are for managing the trend values and to do record keeping (We shall discuss later in this chapter the usefulness of such record keeping systems for Anesthesia). The concern is that these systems do not exploit sufficiently the potential capabilities of the computers that are used. But, assuming that versatile computerized monitoring systems would be available in the not-too-far distant future, as it is a matter of absorption lag of the new technology, various pieces of invasive and non-invasive should be purchased with care to ensure that they support standard computer interfaces or at least, it is assured that it will be supported in the future. Every equipment apart from the reliability and accuracy

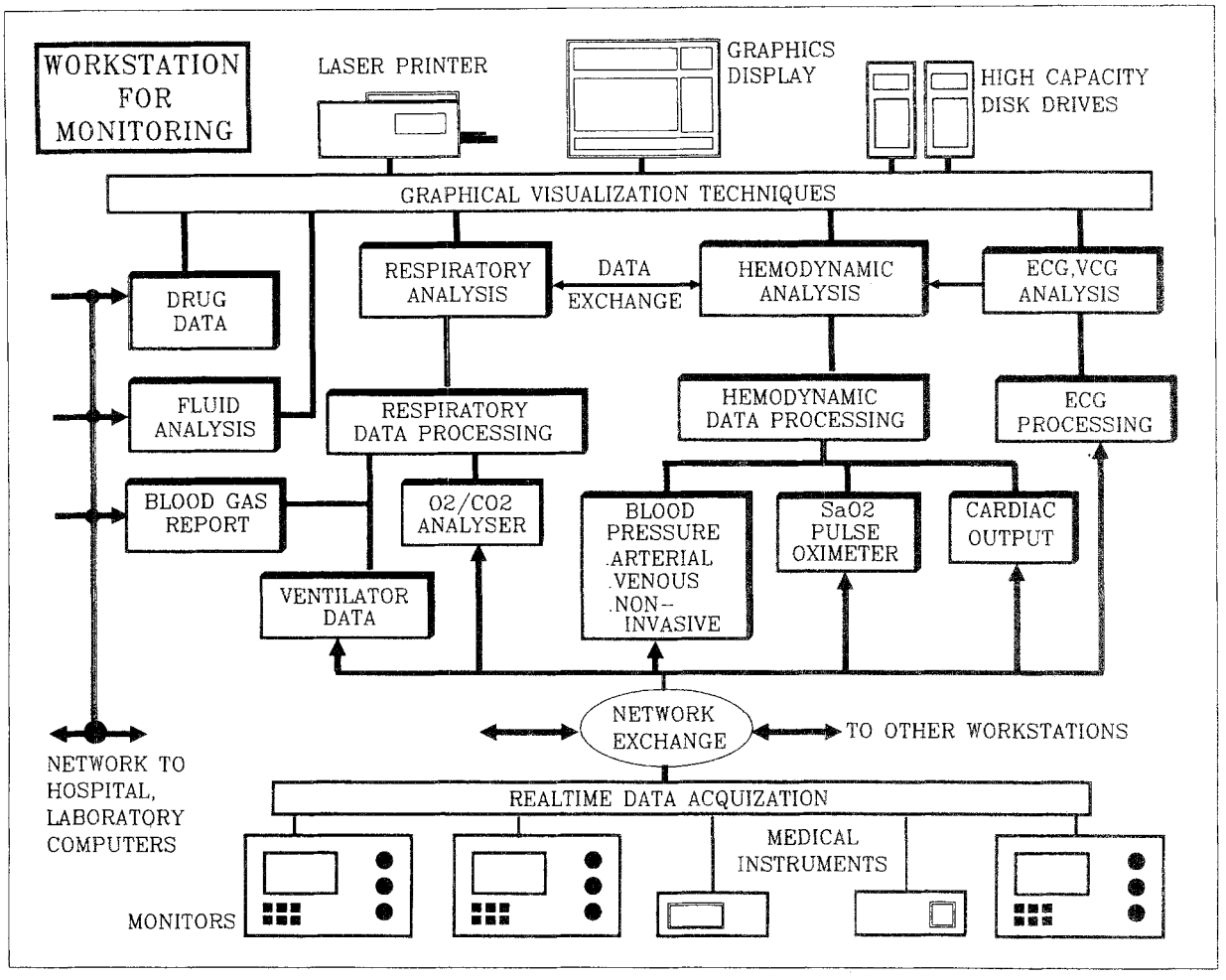

Fig. 1. The functional layout of various modules in a workstation for real-time monitoring in Anesthesia.

of the data it presents, it should have connectivity to outside world to deliver data and alarm information. There should be trade-off between an excellent self-complete system with no external connectivity and a normal standard equipment with good possibility for external interface to computers. Whether, in future, will every computerized monitoring system support the possibility to interface with all the different equipments in the high dependency area is a matter of concern only for the manufacturer of computerized monitoring systems. Eventually, the systems which will survive in the market will be those which support connectivity to equipments of various different manufacturers, for, that will be a marketing strength by itself. But, from maintenance point of view it would be preferable to have a common supplier for the medical equipments and the computerized monitoring systems, if one such would be available.

Automated Anesthesia Records

Automated Anesthesia records are entry-level systems for computerizing the monitoring in anesthesia. Though Automated Records represent only a subset of an integrated computerized monitoring system, it addresses a real demand that exists today in Anesthesia in the high dependency area. Also, interestingly, dissemination of experience has been

quite extensive in this area mostly with conflicting views. It would be worth while discussing the history and importance of automated records.

History

Anesthesia Records though they were prescribed as a normal method for keeping account of an anesthesiologist's interaction with the patient, it is natural that it was given a low profile, in what has always been one of the more action oriented medical specialities. For a long time, it was used as an *aide memoire* for the anesthesiologist as a 'personal use record'. But today, the growing complexity of pharmacological interventions with the patient demand more sophisticated physiological monitoring which has created a strong demand and necessity for a legible, well documented, self-complete, more informative anesthesia record. In recent times, there has been considerable advances in the overall health care delivery especially in the post-operative care. This has made the anesthesiologist's personal record even more important as the record now becomes more of 'common-property' as a template of the physiological state profile of the patient. Consequently, this lays profound emphasis on the quality, clarity, accuracy and visual form of the presentation of the data in the anesthesiologist's record.

Today, If Anesthesia Monitoring could be compared to cockpit monitoring in an airplane (later we shall see how striking this similarity is) then the anesthesia record would prove to be the 'black-box' of the cockpit – as a vital source of information.

In the following paragraphs, we will present a concise account on the purpose, clinical use of Automated Anesthesia Records, its contribution to Quality Patient Care and experts' views and anesthesiologists' reaction to the most often debated issue of the pros and cons, the merits and demerits of automated anesthesia records.

Automated anesthesia record

Early efforts for an automatic anesthesia recording system were by Hallen et al. 1968; Schneider et al. 1979; Newbower et al. 1981. The major problems confronted when building an automated anesthetic record were multiple. In fact, even before the actual design of the system, considerable analysis of fundamental and practical issues surrounding the anesthesia record will be necessary. Such an analysis should answer the following issues:

Purpose of the Record:
- What should it contain?
- Who needs to have access – to what information?
- When does the information need to be available?

Format of the Record:
- in what form should the data be recorded?
- in what form should data be presented?
- in what levels of detail?
- what text information should be included?
- what form of graphical presentation should be included?
- how should all the information be displayed?

Input of the data:
- what are the sources of data and information?
- which can be input automatically?
- how can integrity and accuracy of input be assured?
- what are the time dependent constraints for input?
- what are the practical human interface considerations for non-automated input?

Clinical use of automated record

During a routine anesthetic procedure, the anesthesiologist's major clinical functions are: the primary task of anesthetizing the patient safely, to monitor and manage the patient's medical condition, and to maintain a current record of the procedure. Perhaps, most of the time, the record may just serve as a *memoire* role, but irrespective of its usefulness at later time, it is an important requirement for quality patient care. Just as it is important

to determine the exact nature of the patient's status at any moment, so too is it helpful to be able to plot the trend of this information overtime to gain a broader perspective of the patient's progress through the anesthetic procedure. It can even prove critical should an alarm state occur whose treatment may require a detailed review of what has occurred up to that moment.[1] Furthermore, during induction and other times when the patient demands the undivided attention of the clinician, it is difficult or impossible to manually maintain a record of even the simplest and most basic information[1]. The paradox of an incomplete to non-existent record during the very time it is most important to be aware of the significant and rapid changes known to occur during such periods, and during which more physical and pharmacological manipulation of the patient is occurring, has been commented by several authors (e.g. Whitcher, Feldman, Lerou et al.). While the handwritten record has historically fulfilled this *aide memoire* reasonably well, the frequent and more detailed monitoring of modern anesthetic procedure makes even the clerical portion of this function increasingly difficult. The proliferation of various monitor used during anesthetic procedure for improved patient care itself makes it challenging enough for the anesthesiologist to maintain a handwritten record in an integrated, meaningful format even at the coarse resolution of a normal manual record keeping, let alone at the finer resolution that might later be desired in the analysis of critical event. It is quite strange to notice that despite the significant increase in monitored parameters since the mid-1970s, there has been little change in the number of average entries per manual anesthetic record to date (Gravenstein and Feldman, 1989).

Anesthesia records will find even greater importance when preparing for repeat anesthesia whether during the same admission or at a future time. It is from this point on that the clarity, completeness, accuracy and detail in the record play major role than during the case, if only as the attending clinician may not be available to supplement the record with unrecorded information. It is difficult to conjure up a scenario where these attributes of a good record would be desirable at anything less than optimal quality.

The anesthesia 'Cockpit'

In the publication on Information Management in Anesthesia [1] a striking comparison between the growing complexity of the anesthesia environment and the cockpit in aviation technology has been presented. From its inception, the practice of anesthesiology has been characterized by a particularly intimate relationship between man and machine, such that anesthesiologists have long been among the more technology-literate physicians.

The parallels between anesthesia environment and its aviation counterpart are indeed remarkable, from the characterization of long hours of sheer boredom penetrated by moments of abject terror, to their emphasis on quality assurance and the excellence of the overall safety record[1]. In aviation technology, as more and more data was delivered to the cockpit, the point was reached at which paradoxically pilot became less efficient and actually less vigilant, a situation ultimately relieved by greater computerization of the cockpit.

The critiques

Since its introduction, the use of automated anesthesia records have been debated frequently on its pros and cons, the merits and demerits. Manual record keeping has been supported as a process that helps the anesthesiologist to be fully aware of anesthetic procedure. 'The act of recording information on the chart forces the anesthesiologist to be aware of the time course and detail of anesthetic events' (Noel, 1986). Similarly there is little written on the appropriateness of reliance on this clerical task as a means to apprise the clinician of what is happening to his or her patient. When one considers the problems of boredom and distraction during manual record keeping, it is questionable whether removing the need for this clerical function would indeed have an adverse effect on vigilance. In a review of 6000 anesthetics performed with auto-

mated record keeping the sole method of charting, Edsall and colleagues found vigilance enhanced rather than impaired!

Another concern that surfaces very often during discussions on Automated Anesthetic Records are artifacts. Artifacts are probably inevitable in clinical monitoring. Whether they are due to true transient physiological changes or whether they are due to interference with monitor input or output. Disregarding the values corresponding to artifacts is another common contributor to 'smoothing' of the record. The justification given for smoothing are many, ranging from the scientifically valid concern that inclusion of an aberrant value has some potential for distorting trend analysis, to the fear that such an aberrant value will be regarded by others as physiologically true and thereby be the cause of embarrassment at least or impeachment at worst.

It should be strongly emphasized that artifacts are in fact problem of monitoring rather than record keeping. Good record keeping is designed to report what was observed rather than obscure it. If it fails to perform this function, then the record itself becomes an artifact.[1]

Third party oversight of a well made automated anesthesia record is a frequent topic of discussion in the literature. This is where the clarity and completeness of the automated anesthesia record with eliminates clinician's ability to selectively record readings, faces unspoken resistance, presumably on the premise that 'Big Brother' might detect something untoward in the record that might harm the interests of the record creator. The 'Big Brother' issue is one of philosophy rather than technology [1]. In fact, it has been found that the clinicians respond positively to the 'Big Brother' issue, they saw the clarity and completeness of automated anesthesia records as an opportunity to document the quality of their anesthesia care.

Practice of Automated Charting in Thorax Centre, Erasmus University

Realizing the benefits of automated recording, a microprocessor based automated charting system was developed at the Thorax Centre, Erasmus University, Rotterdam in early 70's. This charting was upgraded when newer technology became available. Over 10,000 records have been produced in total to date. Use of Automated Charting System is a *de-facto* routine procedure in Thorax Centre. In fact, during breakdown and maintenance periods of the charting systems, severe complaints have been brought up by practising anesthesiologists that the lack of a charting system has caused considerable inconvenience in his or her attention to the quality of patient care. With the advent powerful personal computers, laser printers, cheap and efficient network communication capabilities, fast and large capacity storage mediums, the whole complexion of automated anesthesia recording systems can change drastically. Presently, at Thorax Centre, Erasmus University, we are developing a powerful computerized anesthesia recording systems based on IBM Personal Systems/2 on a Token Ring Network with the experience we gained in our earlier implementation of the automated charting systems.

The future issues

High technology has become a hallmark of most areas of medical practice in the last third of the 20th century. In the operating room, as in other data-intensive areas of medical practice, its introduction has been particularly rapid. To derive maximum benefits from new advances in modern anesthesiology and to focus on quality of patient care, practice of automation of certain periphery tasks should be cultivated.

The primary concern in 1990s should be, not just whether Automation of Anesthesia Recording is necessary, but on setting standards for the functional specifications, quality, reliability and uniformity of presentation. Lack of such a standardization may lead to outburst of too many different types of automated recording systems.

At Thorax Centre, Erasmus University, we are presently working on possible standardization schemes, we will present here a short description of our standardization philosophy. We expect that the rapid growth in processing capabilities of personal

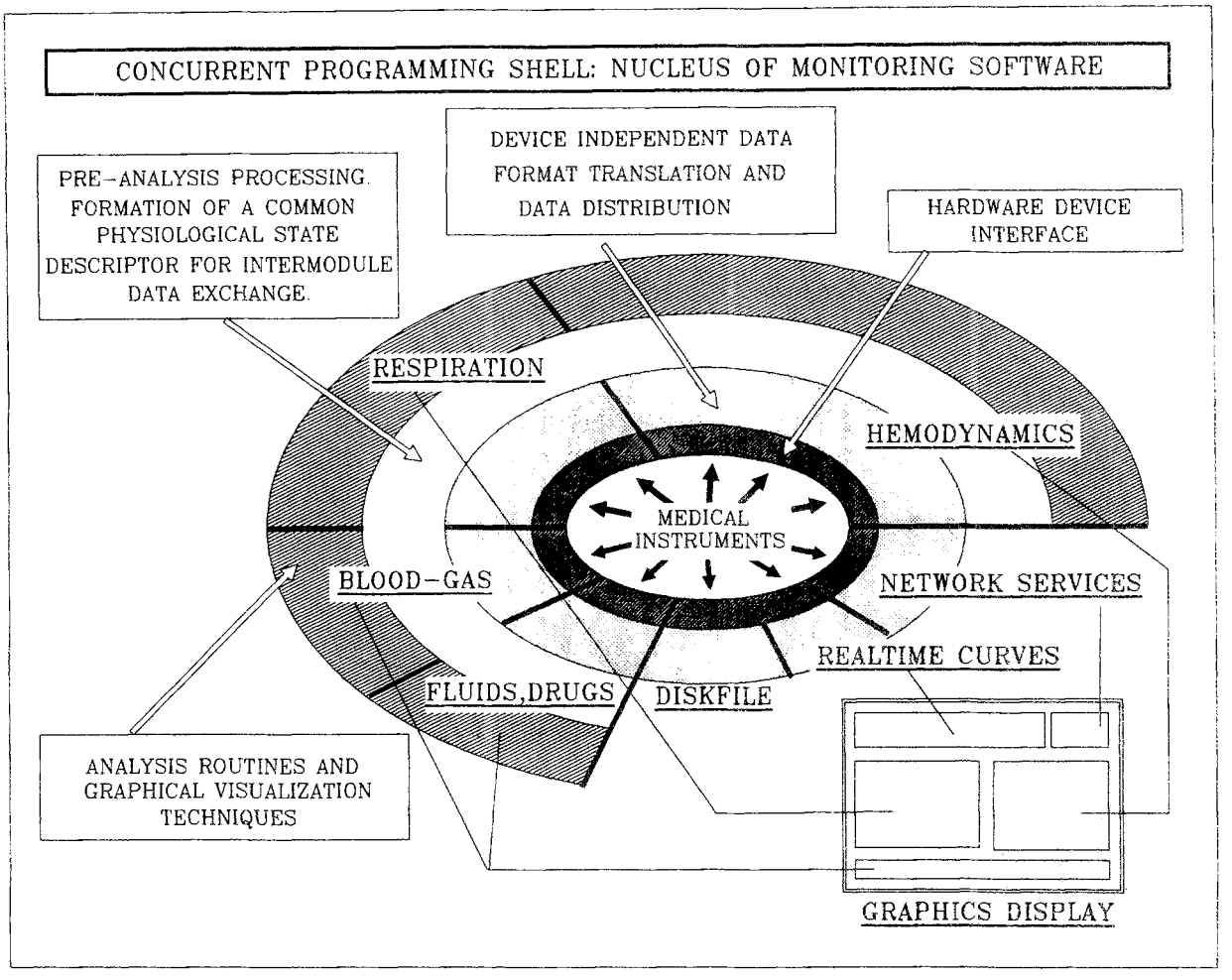

Fig. 2. Standardizing the processing of data from various equipments. The shell diagrammatically illustrates the flow of information from the instruments to the user through different layers.

computer would eventually bring 'supervisory' monitoring (all-in-one screen monitoring compared to monitoring the different instruments directly), intelligent alarm techniques, real-time data record management, network communication for remote monitoring and the automated recording systems all under one roof. With this general structure as our design frame work, we are studying the following development approach to 'fuse' various monitoring related medical computing techniques so that as and when different pieces are developed they can be quickly integrated within the general frame work to produce a versatile monitoring workstation.

In Fig. 2, the shell describes various monitoring related software functions at different levels or layers with interconnection to various medical instruments as its central part. The picture represents the dynamic state of the software that will be running on the workstation. Concurrent programming will be the key element of the software. The different activities in various sectors will appear to progress concurrently from the centre along the radial direction, through different layers. The layers are formed for standardization convenience so that future changes could be limited to small part of the software rather than for the entire software.

Conclusion

Merits of workstation based approach for monitoring are many. Quick adaptability to new requirements, ease of upgrade, remote monitoring and network capabilities are to name a few. Such a workstation built on a standard hardware platform will assure evolutionary growth of the system's intelligence as and when new techniques that can substantially improve the monitoring standards become available.

With this ambitious objectives for the computerized monitoring, one might wonder whether an economically viable solution exists using computers that are simple to operate. The answer is quite positive, it is very much possible today to develop such a workstation using powerful personal computers with high resolution, fast graphics display available in the market. Such a workstation can significantly improve the standard of patient care with early warning smart alarm techniques and can also provide a convenient platform for various research activities. Software to fully utilize the capabilities of these systems for such purposes will be a major area of development in Medical Monitoring in the coming years.

Discouraging experiences in the past with in-house or commercial automated anesthesia recording system can not be a basis, to judge the future systems. Computer technology is far more advanced today than it was few years back and now it has proved to deliver excellent performance to meet diverse real-time application areas for a lesser price. For rapid assimilation of this new advancement in medical monitoring, clinicians who use automated systems should express freely his or her opinions and constructive criticisms about such systems in the popular literature circle. That will be of great help not only for other clinicians but also for the industries to conceive 'matured' and intelligent systems.

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