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Problems in the development of a computerized ward monitoring system for a paediatric intensive care unit

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Abstract

A computerised ward monitoring system based on Archimedes PC's at each bedside is under development for the PICU at Killingbeck Hospital in Leeds. This work was initiated with a view to reducing the amount of paperwork in the unit. The present paper charts have been broken down into sections for the purpose of entry into the computer. The completed charts may be viewed in tabular form. There are several alternative displays. The default display mode illustrates the patients principal cardiovascular variables over the previous six hours. Alternative graphical displays include 12 hour trend curves for the cardiovascular variables, a screen with one hour trend graphs and panels illustrating the latest values of other patient variables, and graphical 12 hour reviews for clear fluid balance, blood volume balance and respiratory variables.

The program also serves as a vehicle for testing an alarm generating system and a cardiovascular status index in the paediatric environment. A separate program has been developed which allows the retrospective construction of data bases by using some or all of the data from one or more of the charts for a series of patients.

Finally the difficulties encountered in preliminary trials of the system are discussed. At the present time the program is being run at a central station while attempts are being made to surmount these difficulties.

Introduction

The power of modern microcomputers has encouraged the development of microcomputer based monitoring systems in intensive care situations [4, 5, 7, 9, 11] in recent years. The ward monitoring program described below was developed in response to a desire to reduce the amount of paperwork employed in ward management in the Paediatric Intensive Care Unit at Killingbeck Hospital in Leeds. Computers may also be used to process patient data to produce prompts and alerts [1, 10]. Our program is being used to test two such algorithms. These algorithms which are described in more detail below are concerned with the testing of an immediate alarm system and the development of a univariate index of cardiovascular status.

Hardware

The system is being implemented on Acorn Archimedes A3000 PC's with 2Mb of RAM and a single 3.5" floppy drive, one at each bedside. These machines although relatively inexpensive are very fast.

Software

The program is written in BASIC V which is a highly structured form of BASIC which has most of the features of compiled languages such as Fortran, Pascal or C, but has the advantage of being interpretative; this allows for much more rapid development. If required however the program can be compiled to give extra processing speed. The program can be broken down into the following major sections:
(1) Control algorithms; set up procedures; starting and restarting
(2) Default display
(3) Entering and displaying forms and charts
(4) Alarm algorithms
(5) Cardiovascular status algorithms
(6) Graphical display generation
(7) Alarm, status and chart readback algorithms.
The program has a size of 175K (225K including the space needed for arrays within the program).

Program timing

The computer obtains the current values of the patients cardiovascular variables from the bedside Kontron Colormon every two seconds via a serial line. The program then enters and executes the smoothing and alarm algorithms. All other regularly timed operations are controlled from within the alarm algorithms; for example execution of the cardiovascular status algorithm (default interval one minute) or the issue of a chart update request (default interval one hour). Time is continuously polled during all the on-line modes of operation of the program to ensure that the alarm algorithms are executed at the required intervals.

Program control

Frequently used operations are controlled by means of the computer function keys (suitably labelled) and also four keys devoted to special tasks (Menu, Help, Save chart, Abort chart entry). This mode of control is operational from the program default display.

Facilities controlled by the function keys include viewing and entering data into charts, viewing graphical displays, entering the initials (password) of the user, changing or coming off the ventilator, pacing, cancelling the last entry made in a chart, editing the last blood volume or clear fluid balance entry, and ending or escaping from the program.

Further facilities, not likely to be frequently used by the nursing staff, are accessed through a menu. These include altering the chart headings, the chart display colours, various default intervals and access to a further research menu (see below).

The program may also be operated in an off-line mode which allows development and testing to be carried out away from the bedside. Additionally readback of patient charts generated in the ward, and of alarm and cardiovascular data files may be performed off-line.

Patient data

In order to be able to view patient data on the computer screen, the data normally contained on the patients Cardex file and the ward chart have to be broken down into a number of components. These components are then represented by either forms or charts depending on the nature of the data involved.

(a) Forms

The relevant information contained in the patients Cardex file is split between four forms, while the results of biochemical analysis of samples are also entered in this format.

(b) Charts

The remainder of the information in the ward chart is represented as a series of charts as follows:
1. Cardiovascular variables

2. Respiratory variables
3. Blood balance
4. Fluid balance
5. Electrolytes
6. Blood gases
7. Drug related charts (see below)

The cardiovascular variable chart entries are made automatically each time the program prompts the nurse to update the charts (default interval one hour) using the current values of the variables input from the monitor. At present all remaining data is entered manually.

In the blood and fluid balance charts the various totals and accumulated totals required are automatically calculated and displayed by the computer as the nurse enters the relevant data.

For research purposes special charts can be constructed as composites of information contained in the other charts and forms. One such chart is used to collate information necessary for the assessment of the cardiovascular status index.

(c) Drug charts

There are four charts concerned with the administration of drugs:

1. Drug prescriptions
2. Drugs administered
3. Pump drug prescriptions
4. Pump drugs administered

Drugs are selected from a menu of 57 drugs split down into inotropes, vasodilators, muscle relaxants, sedatives, analgesics, antibiotics, diuretics, heart transplant drugs and other drugs, where each class contains an 'other' category. If a drug is administered by pump, its prescription and dose administered are entered in charts 3 and 4, while all other drugs are entered via charts 1 and 2.

If prescriptions are available these are displayed when the drugs administered charts are being entered, although they can be overridden if required. The dose rate of pump drugs (/Kg/min) is also calculated and the dose level indicated on a five point scale.

Charts may be completed either in response to

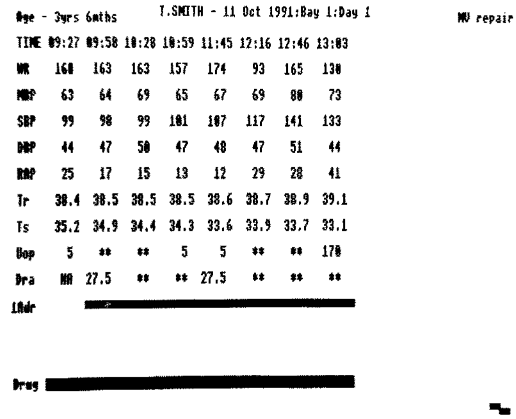

Fig. 1. Default display (fictitious data).

the computers request (default interval one hour), or via function keys at other times.

Start up and restart procedures

At present the program uses a combination of RAM disc and a single 3.5" floppy drive for saving data. The RAM disc allows very rapid retrieval of the data. The floppy drive is used to back up the data on the RAM disc in the event of a computer shutdown and for permanent records.

The patients demographic details may be entered before he has returned to the unit, although only a limited number of entries (all in the first form) are essential for the running of the program.

The program may be quickly restarted without loss of information if either the program crashes during operation (due eg to a hitherto undetected bug, operator misuse or difficulty with sampling from the monitor) or the computer is shutdown (eg when the emergency generators in the hospital are being tested).

Default display

Normally the program is running in the default display mode (Fig. 1). The rows of numerical data in the upper portion of the display illustrate (from

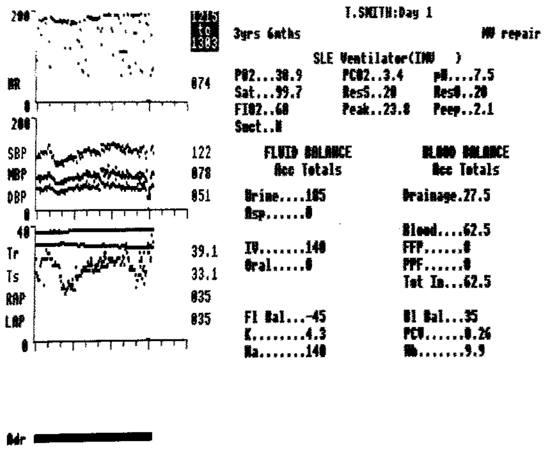

Fig. 2. One hour cardiovascular trend curves and current patient status display (fictitious data).

top to bottom) time of measurement, heart rate, mean, systolic and diastolic blood pressures, right atrial pressure, core temperature, skin temperature, urine output and blood drainage. The times correspond to the default interval of 30 mins, and the final column is updated every ten seconds. The lower portion of the display is used to illustrate the pump drug support being received by the patient. Up to six pump drugs can be illustrated by coloured lines whose thickness varies according to the drug dosage. A default display review facility is also available.

Graphical displays

The graphical display facilities are accessed from the default display via the function keys (in less than one second in each case). These displays are flexible, but at present comprise:

(a) 12 hour cardiovascular trend curves

The 12 hour trend display, which is being continuously updated on a 'hidden' screen at 90 second intervals, consists of three graphs illustrating the trends of (a) heart rate (b) systolic, mean and diastolic blood pressures (c) core and skin temperatures, right and left atrial pressures. The patients pump drug therapy during the period is also illustrated below the graphs.

(b) one hour cardiovascular trend curves

These curves have a similar format to the 12 hour trend curves, but are updated at twenty second intervals on a separate 'hidden' screen of which they occupy the left hand half. When this display is called up, panels are generated in the right hand half of the screen which illustrate a) the current values of PO2, PCO2, pH, oxygen saturation, set respiratory rate, observed respiratory rate, FIO2, peak inflation, PEEP and suction b) fluid balance and electrolyte levels c) blood balance, PCV and haemoglobin levels (Fig. 2).

(c) 12 hour clear fluid balance review

The last 12 entries in the fluid balance chart are illustrated in this display. Accumulated fluid input (intravenous and oral) and accumulated fluid output (urine and aspirate) are illustrated by split bar charts and the times of chart entry and electrolyte levels by rows of numerical values. Fluid balance is illustrated both graphically and numerically.

(d) 12 hour blood volume balance review

The last 12 entries in the blood balance chart are illustrated in this display. Accumulated blood input (blood + FFP + PPF + other) and accumulated blood output (drains 1, 2, 3 and samples) are illustrated in split bar chart form and the times of chart entries, PCV and haemoglobin level as rows of numerical values. The blood balance is depicted both graphically and numerically.

(e) 12 hour respiratory/blood gases review

This display consists of two graphs across the width of the screen with additional information displayed in rows below these graphs.

The upper graph illustrates the trends of pH, pCO2 and base excess over the previous twelve chart entries and the lower graph similarly illustrates the trends of SaO2, FIO2, and the set and observed respiratory rates.

The four rows of data below these graphs indicate the times of the measurements and the ventilation mode, peak inflation and PEEP at these times.

Research programs

1. Immediate alarm generation

One of the principal objectives of setting up the data management system was that the resulting program could also serve as a vehicle for running research projects. One such system currently under test is an immediate alarm system for acute cardiovascular events. The development and initial trials of this system have been described more fully elsewhere [2, 7, 12, 13, 14], but are summarised below. The system is based on the values of mean heart rate (HR) and mean arterial blood pressure (MBP) sampled at two second intervals from the ward monitor. These values are first filtered through an intelligent smoothing algorithm [14] which ignores transients (artefacts) while quickly recognising genuine step changes and changes in slope. This immediately eliminates false alarms which could be generated by such transients. The smoothed variables are then processed by the alarm algorithm, which is at present programmed to recognise seven alarm (and warning) conditions. While the alarm system is undergoing trials the alarms are not normally being displayed at the bedside, although a display can be accessed via the research menu if required. Data relevant to an alarm situation is saved to disc for retrospective analysis.

2. Cardiovascular status index

The second research algorithm currently incorporated in the ward program has been designed to test a univariate index of cardiovascular status based on measurement of the patients cardiovascular variables [3, 12]. The current version of the index uses a chi-squared statistic based on measurements of the patients skin temperature, urine output and mean arterial blood pressure. The necessary parameters for evaluating this statistic were obtained by retrospective analysis of ward charts. Four sets of parameters were obtained for adults and children, with and without inotropic support. The algorithm was tested off line using data for patients with a poor cardiovascular status, again extracted manually from old ward charts. A graphical display of the index can be accessed via the research menu in the program and the performance of the index is currently being assessed using this display. Retrospective analysis of the performance of the index can be carried out using the off-line version of the ward program.

3. Retrospective analysis of patient data

The off-line version of the ward program has a readback facility for viewing forms, charts and default displays generated by the on-line version of the program. Options exist for obtaining typed copies of charts and screen dumps of the default display forms and charts.

A separate program has been developed for establishing data bases using data extracted from one or more charts for groups of any number of patients. The most immediate application of this has been associated with setting up a data base for evaluating the parameters needed for the cardiovascular status index. Such a base was previously established by transferring data from completed ward charts to specially prepared forms, which were then input to the computer. Facilities also exist for adding additional information to bases set up in this way, for printing and viewing the base data, and for plotting pairs of variables against each other.

Implementation of the program in the ward environment

For four months the program was run when possible at two bedsides in the unit. During that period several apparent disadvantages of the system emerged, some of which were general in nature [4, 6], and some of which were more specific to the method of introduction of the program used in this instance. With hindsight many of the latter difficulties could have been avoided. The more general criticisms were:

(i) The whole of the patients history over the previous twelve hours is presented in an integrated fashion in a single paper chart, whereas to obtain the same information from the computer, two or more charts often have to be called up, and these cannot be viewed simultaneously. Unfortunately the graphical displays described above, which might have answered this criticism to some extent, were not developed until after the initial testing phase had been completed.

(ii) Special skills are needed to use the keyboard and operate the computer. This is particularly relevant where temporary staff often have to be drafted in to man the bays.

(iii) The paper charts are flexible insofar as sections or columns in the chart can speedily be adapted for other purposes, and extra information can be easily entered.

(iv) The paper charts are reliable (they do not crash!).

(v) The paper charts are legal [8].

Other difficulties more specific to our particular implementation were:

(vi) The program was continually being developed during the testing period in the light of suggestions from the nursing staff and the experience obtained by running the program on-line. (Note that this continual development was in large measure the cause of the crashes referred to above as the technical backup was not available to exhaustively test new versions of the program as they were produced).

(vii) Technical backup for the nursing staff was not available at all on the night shift and only intermittently during the day, when they could phone for help if needed.

(viii) The computer system was run in parallel with the paper charts without the provision of extra staff.

(ix) The staff were given introductory demonstrations of the system in small groups. However tuition was not in general available when they first started entering data at the bedside, when it would have been of most value.

(x) An integrated policy was not pursued during the introduction of the system. Thus for example, even during periods when the nurses had systematically entered the data into the computer, it was not referred to by the medical staff during the ward round.

(xi) The method adopted for leading a power and serial line to the trolley on which the computer was placed turned out to be unsatisfactory and difficult to modify.

(xii) The computer used up half the space on the trolley top, and also obstructed the view of the patient from certain angles.

(xiii) An attempt was made to use hard discs instead of floppy discs at one stage in the development. In theory this should have led to a faster and more easily managed system, but in practice ran into unforeseen difficulties. External drives were used and the particular batch installed turned out to have a hardware fault. In addition the trolleys on which the computers were placed were being moved more often than anticipated. After a relatively short period the hard discs were withdrawn from use, but not, unfortunately, before they had generated a considerable amount of mistrust in the system.

At present the system is being run at a central station where the research algorithms and improved versions of the program are being tested. A full time assistant has been appointed to test the program thoroughly at the bedside and to liaise with the nursing staff.

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