An Inexpensive Real-Time Computer System For Cardiac Surgery

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Abstract

We have developed an inexpensive mobile computer system for the operating room. This system utilizes an IBM AT computer, 1200 baud modem, wide carriage dot matrix printer, serial interface card and Adalab-PC data acquisition hardware for continuous patient monitoring and data storage. The computer currently interfaces with the main monitor, blood gas machine, heart-lung machine and five Yellow Springs 400 series temperature probes. Flexibility has been built into the software to allow for the use of inline blood gas monitors, centrifugal pumps and up to sixteen continuously recorded parameters. Case data is stored under the patient's hospital number in ASCII disk files and can be transferred to the hospital mainframe computer for detailed statistical analysis.

Patient data is displayed on a color monitor during the case and is automatically printed as a permanent record when the patient leaves the surgery suite. Detailed information, calculated values, pressure trend graphs, temperature trend graphs and event timers are available through simple keystroke commands which change the screen on display.

The software is written by a perfusionist in the easily understood and modified Basic programming language. Under experimental conditions, this program has been used to control the heart-lung machine through the use of established algorithms.

Introduction

The current status of computerized cardiopulmonary monitoring devices has been well documented in the recent literature.[1,5,10,11] However, one aspect of computer integration which we feel has been overlooked is the incorporation of reasonably priced versatile systems into the mainstream of heart surgery. This is unfortunate since at present only a small number of teaching institutions can afford the $10,000 plus necessary to implement any of the current microcomputer systems available.[5]

Providence Medical Center is a community hospital performing 300 heart surgeries per year in a highly competitive and cost conscience environment. In the spring of 1986, the hospital budgeted for a new heart-lung machine. At this time the decision was made to attempt to implement a computer system along with the new pump.

The requirements of this computer system were:

1. The computer must be freestanding and fully portable.
2. It must possess the ability to interface with any of the hospital's present laboratory and monitoring devices including mass spectroscopy.
3. Both the hardware and software must be easily and inexpensively customized and updated as the hospital's needs change.
4. The system must be able to function with centrifugal pumps for long term support as well as all current roller pumps used in the operating room.
5. Communications capability must exist with the hospital mainframe along with the surgeon's and cardiologist's microcomputers and databases.
6. The system must be easy to use and set up.
7. Cost must be less than the amount saved by competitive shopping for the heart-lung machine, which was approximately $5000.

Materials and Methods

After much research and comparison of the three major personal computer systems, IBM, Apple and Digital in areas such as availability of software, expansion capacity and reliability, the hospital purchased the following system consisting of:

1. An IBM AT computer using a 80286 Intel C.P.U. with 512 K memory, C.G.A. board and monitor, serial and parallel ports, one floppy disk drive and a 30 megabyte hard drive.

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2. A Hayes 1200 baud modem.
3. An Epson wide carriage dot matrix printer.
4. An Adalab-PC data acquisition system with optional fast analog to digital (A/D) converter, 16 analog channel sampling capacity and two signal conditioning boards which allow current measurement (an option which must be used when connecting directly with yellow springs thermistor probes).
5. Plastic junction boxes with stereo jack receptacles and cases for the temp probes isolated voltage sources.
6. A surge protector.
7. An isolation transformer.

The remainder of the system was made up of equipment already in use in the operating room. The cart was appropriated from central supply, engineering supplied the keyboard shelf with brackets and cabling was supplied by our biomedical department.

Most of the system is off-the-shelf computer supply and needs no great explanation. The heart of our system, the Adalab A/D converter, is the source of its versatility and real time that has the capability to output a voltage to a recorder (such as pressure monitors and pump consoles) to be connected directly to our computer for data analysis and storage. Without getting too involved in the technical aspects of this board, it can handle unmodified inputs up to 4 volts (with instruments having a higher output a series of resisters must be installed by the biomedical department) at sampling rates up to 20,000 per second.[3] There are assembly language programming routines, included by the manufacturer with the board, which simplify programing data acquisition through the use of call statements.[3]

Computers and their monitors are notorious for electrical leakage and cannot be used unmodified in the operating room. The simple solution to this problem is the incorporation of an isolation transformer into the circuit. This protects the patient and also keeps the operating room's leakage alarms quiet. However, a separate surge suppressor is still required since there is no protection provided the computer by the transformer.

The more advanced laboratory devices, such as blood gas machines and in-line analyzers, use serial ports to output their data at preset time intervals and do not need to be interfaced with the A/D converter.The drawbacks to the use of machines with serial output is that most AT style computers only support two serial ports and the RS232 standards for serial compatibility are liberally interpreted by some manufacturers. This calls for some clever programming along with the use of null modems (devices which alter a transmitted signal's channel) in the connecting cables.

There is extensive variation in perfusion techniques throughout the country.[6] When our computer system was purchased, there was no software available which fulfilled the requirements for our heart surgery protocol. The Providence Medical Center perfusion staff has developed our own perfusion software package and are placing it into public domain. The program is written in interpretive Basic. This language is regarded as the most easily understood programming media for new computer users[7] and allows for display and modification of the program and/or data during the program's execution.

The program requires 128K of memory (memory requirement is kept to a minimum by the use of overlay architecture, where only the part of the program being used is in memory), one disk drive and a color display. Although this language provides many benefits in the initial phases of program development, it is fairly slow and has a combined program and data limit of only 64K.

The language our current program is written in is Borland Turbo Basic, a compiled Basic language which is much faster and eliminates the 64K size limit. The compiled program, however, cannot be modified during execution and is, therefore, of limited use to other hospitals just initiating computer systems.

The software is primarily responsible for data acquisition and display. Samples are taken continuously and area displayed and updated on the monitor. Every thirty seconds, a full set of sample data is recorded into memory. Continuously monitored parameters include pump speed, pump rpm (when a centrifugal pump is used), arterial pressure, central venous (or left atrial) pressure, and several temperatures.

The present temperature sites being monitored include esophageal, bladder, venous line, arterial line and heater/cooler outflow line. Blood gases are samples on an interrupt basis from the in room blood gas machine. All time start and stop times, FIO_2 and gas flow changes, cardioplegia doses, and events (such as the addition of volume to the pump) are recorded manually using single, menu prompted, keystrokes requiring only minimal attention by the perfusionist. A correction menu is included, which allows for the altering of all manually entered parameter during the case. The ability to change patient data after the end of a case is not available for medical-legal considerations.

At the beginning of the case, while priming the heart-lung machine, the perfusionist turns on the computer and enters patient information. A pump check list is then displayed and program execution is halted until it is completed. The patient's customized drug dosage sheet is next printed and the main screen is displayed. The monitors are then connected to the computer, and the system requires no further attention until the initiation of bypass. During this period, modem communication is available along with the ability to access other programming chores. Once bypass is started, these functions are no longer available.

In the case of a late night emergency surgery, a set of default values has been included in the software package requiring only cable connection before starting bypass. This has only added a measured two minutes to our set-up routine (With angioplasties, this has become a frequently used feature).

The main benefit of any computer system is in its ability to process and display information in a meaningful format.The majority of the program has been devoted to data display. The format for the main screen was chosen for its compatibility with our old pump record and is of limited use during the case. By choosing a "S" from the main menu detailed information is presented. The first screen shows conventional blood gas information. The next screen displays blood gas calculated parameters including oxygen consumption and the systemic vascular resistance recorded at the time the blood gas was obtained. The third screen shows a description of events, the fourth screen is a timer listing and the fifth display is a cardioplegia summary. The final text screen shows sweep gas FIO_2 and flow settings along with the time they were adjusted.

The last three screen choices are devoted to graphic display of information during a time period determined by the current length of the pump run. The first graph shows recorded temperatures versus time. The second graphic display relates pump speed, pressures and oxygen contents. The final screen displays systemic vascular resistance, pump speed, oxygen consumption, oxygen extraction and $AVDO_2$. These graphs have become highly used and depended upon due in part to the ease in which subtle trends can be recognized, as compared to the traditional numeric listings.

The formulas used for the calculated values are as follows:[2]

Oxygen Content:
(Hemoglobin(gm%) * 1.34 * SO_2) + (PO_2 * .003)

Systemic Vascular Resistance:
(M.A.P.—C.V.P.) * 79.99344 / C.O.(1/m)

$ADVO_2$:
Arterial O_2 Content—Mixed Venous O_2 Content

Oxygen Consumption:
Cardiac Output(1/m) * ($AVDO_2$ * 10)

Oxygen Extraction:
$AVDO_2$ / Arterial O_2 Content

Oxygen Availability:
Cardiac Output(1/m) * (Arterial O_2 content * 10)

At the termination of bypass, urine output is entered and monitoring is suspended until the next case or a second bypass run is needed. Blood gases and other post-bypass events are still recorded into the patient file during this period. When the surgeon begins closing the chest, a shutdown procedure is started. This routine prints out a hard copy of the case for the patient's chart, stores all of the case's raw data in an ASCII file under the patient's hospital number and creates a DBASE3 file for use with our database. The cables are rolled up, the computer is cleaned off and pushed out of the way and the case is over.

A separate program, which is entered through the DOS main menu, enables full recall of any case data for review in traditional case format by just entering patient's hospital number, but prevents any alteration of data. The database we use is a shareware clone of DBASE 3 called WAMPUM. This data base allows all boolean comparisons[9] along with excellent report generation useful for such chores as quarterly reports and case documentation for recertification. A further aid in patient tracking is the modem hook up with our surgeon's Mumps database as mentioned earlier.

Although we feel that the computer should not replace the perfusionist for in case decision making, there have been alarms installed to attract the operators attention to certain areas drifting out of range. High or low arterial blood pressures, high or low S.V.R., a long delay between blood gases or an extended period between cardiplegia infusions all produce a flashing attention display.

As with any electrical system documented calibration is essential. During the initial case trials of the computer system, calibration of the monitored channels was performed before every case. This added ten minutes to the case's set-up time and was discontinued after analysis showed that there was no significant drift. At present, the system is calibrated once monthly using a two point calibration for the linear response pressure and flow channels and a five point calibration for all temperature channels. This long procedure is performed because the temperature probes follow a nonlinear varying logarithmic curve in their current response to the present isolated voltage source (a simple D cell battery), giving an error of up to .3 degrees Celsius maximum with the standard three point curve fitting equations. The system is also recalibrated whenever a cable or battery is changed, different equipment is being monitored or for documentation after an unusual bypass run.

Part of the uniqueness of this computer system is its realistic price, since cost is now a factor in most perfusion procedures. The breakdown of what implementation of this system would cost the average hospital is as follows:

1. AT clone computer system with C.G.A. monitor and controller, $1595.
   (E.G.A. board and card option), $200.
2. 1200 baud modem, $200.
3. Wide carriage dot matrix printer, $350.
4. Computer cart, $50.
5. Adalab A/D converter plus options, $1400.
   (4 channel IBM A/D converter), $200.
6. Isolation transformer, $200.
7. Plastic case for external A/D board along with cables and connectors, $75.
8. Shareware word processing software, $25.
9. Shareware communications software, $25.
10. Shareware data base software, $25.
11. Providence Perfusion Software, FREE.

Total system price range: $2700 to $4200

Results

The versatility of this system nicely augments its primary perfusion duties. Correspondence quality is improved by the use of a word processor. Patient records are now more easily accessed using a private database. Patient's post-op care has been improved by the availability of the customized drug dosage sheet and the improved case documentation now accessible by the physicians in C.C.U. All inventory and physician equipment preferences can now be quickly recalled and listed or altered to help orient new staff. Finally, the hospital's accounting department along with central supply have been well served by this system, since the case data base has given a good basis for equipment use projections and enabled the elimination of several items for the case cart.

The use of this computer system and software has improved patient care at Providence Medical Center in several ways. First, by the ability to see graphic representation of data, problem trends are identified, before they can adversely affect the patient. We now have increased the frequency of blood gas sampling since a programming option allows their incorporation into the permanent computer file without the patient being billed for these extra tests. Monitors and temperature probes are now more frequency calibrated since the drift is now easily assessed. The most striking example being a discovery of a 1.6 degree error in a "correctly calibrated" temperature monitor box. The use of our cooling protocol has been altered to maintain acceptable gradients,[8] and our implementation of norma-volemic anemia is now governed by oxygen extraction curves rather than hematocrit levels and venous saturations. The complete records the computer keeps have proved to be a very useful educational tool, enabling each case problem to be completely reviewed and decisions analyzed long after the case is over. Finally, the procurement and ultimate publication of research data has been greatly enhanced by the computer's ability to compare large patient groups, in addition to the obvious advantage of more monitored parameters now being stored in our database.

Conclusion

At present, this system is used during a case for data collection and display only. The capabilities of the A/D converter also make computer control of electrical devices containing potentiometers feasible. Following the research of Wada and associates,[10] the computer has been used to control pump speed in response to pressure changes and reservoir levels. This level of automation has only been tried experimentally, and the hospital consensus is that computer controlled bypass runs will be practical only in the distant future.

By having a program which is easily modified, changes can come rapidly in response to new needs. For example, the program version now being used at Providence Medical Center provides a context sensitive help screen along with improved graphics and main screen formatting along with greater use of default values to speed the set-up time.

In conclusion, it has been said that to fully understand a subject a person must teach it to one who is fully ignorant. A computer is just a simple machine that only does basic arithmetic, albeit rather quickly. By implementing this perfusion software package at Providence Medical Center, the whole heart team's knowledge in areas such as physiology has improved and a new tool in the quest for improved mortality and morbidity has emerged.

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Questions from the Audience

Virginia Sellers, Chicago, IL: Question: I would like to compliment you on all of the work you have done in this area. This is something we have all seen as being a big growth factor in our industry. I would like to ask you about the cost factor of your time and your staff's time. We all know that time is something that we have little of. You gave us the cost of equipment, what is the cost of your time in manhours?
Answer: I really couldn't give you a definite answer. Most of the programming was done during angioplasty standby, so the hospital was paying for our services anyway and received a little extra. I think I would probably have 1,000 hours involved with this system.
Question: Over how many years? Would you say it's been a year?
Answer: It's a year and a half.
Questions: Also, I wanted to ask you. You have a tremendous amount of data available to you and you spent a year and a half developing the access to this data, how would this actually change the way that you do a routine case at your institution?
Answer: We are now able to identify trends a little more quickly than we were before. For example, this graph shows you that in this time period the oxygen extraction was going way up. The patient was in the middle of a cooling period and was cross clamped and we could find no rational explanation for this via the traditional means. We finally found out that the anesthesiologist was keeping the patient a little light and a quick dose of fentanyl corrected the problem and was back down to a normal oxygen extraction curve. The next thing we found out was that our heating cooling protocol was in the area that could produce microemboli. Our old protocol was to cool the patient quite rapidly and the heater cooler inflow temps would drop way down creating a sizable gradient. We have since corrected that situation and have a much more acceptable gradient when we cool a patient.