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REVIEW ARTICLE

RECENT DEVELOPMENTS IN DATA RECORDING SYSTEMS FOR PHYSIOLOGY

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Data recording devices play a major role in Physiology research and teaching. These devices are used to record and analyze various human and animal physiological parameters such as temperature, blood pressure, electrocardiograms, respiration, blood flow, muscle activity and brain activity. In teaching, recording and analyzing these parameters help students learn about normal physiological functions of the body as well as being useful in understanding the changes that occur during disease data recording devices have improved rapidly as the technology has become more advanced. These have been evolved from kymographs, to chart recorders and polygraphs to more advanced computer based systems. The computer based data recording devices have not only reduced in size but have also improved in recording and analyses, applications and efficiency. A growing body of evidence from classroom assessment supports the effectiveness of computerized data recording system in self-learning, motivation and improved performance and skills development in undergraduate courses of various disciplines. There has been a lot of debate going on whether to use computer simulation or real experiments to be performed on computer-based systems in a teaching setup to provide hands-on experience. Both approaches have merits and demerits. However, it is essential to provide hands-on experience to students as much as possible. Most of the institutions in developed countries offering human and animal physiology courses have adapted to new computer based tools for teaching and research but in developing countries such as Pakistan, this trend is growing at slow pace because of several reasons. The growing importance of computer based data recording devices in Physiology teaching and research has prompted to write this review to provide basic concepts, terms and variables used in this technology to give first hand information to physiologists of developing countries particularly to those from Pakistan.

Key words: Data acquisition, Physiology, computerized data recording, Teaching

INTRODUCTION

Data recording devices play a major role in life sciences research and teaching. These devices are used to record and analyze various human and animal physiological parameters such as temperature, blood pressure, electrocardiograms (electrical activity of the heart), respiration, blood flow, muscle (EMG) and brain activity (EEG) just to list a few. In teaching, recording and analyzing these parameters help students learn about normal physiological functions of the body as well as being useful in understanding the changes that occur during disease (Pathophysiology).[1] Studying the pathophysiology assists scientists to gain a deeper understanding of disease and provide information in developing new treatments and intervention for the betterment of human health. A photograph of a typical data recording set-up from the early 20th century is shown in figure 1.

Data recording devices have improved rapidly as the technology has become more advanced. The first types of data acquisition devices were Kymographs (Figure 2A). These devices consisted of a rotating drum on which graph paper was fixed and recording made using a pen which moved up and down according to the magnitude of the response detected.

Figure 1: A typical photograph of setup of an old ECG machine in which two hands and one foot is immersed in salts solution.
(With permission from website: http://encyclopedia.quickseek.com/images/Willem_Einthoven_ECG.jpg)

The limitations of the kymographs were their inability to record continuously for several hours, low sensitivity and the presence of many moving parts which required constant maintenance. The next stage of development in recording equipment was the chart recorder and polygraph (figure 2B). These analog systems solved some of the problems associated with using kymographs, with one advantage being the ability to record continuously. Polygraphs enjoyed a very good reputation until the 1980's when there was the introduction of the personal computer. This is what we now call the PC revolution. Advancement of computer technology had a break through effect on development of data recording devices, where most of these are now computer based. These systems are commonly referred to as computer-based data acquisition and analyses systems. These devices have not only reduced in size but have also improved recording and analyses, applications and efficiency. These systems have also allowed researchers to conduct what were complicated, time consuming analyses faster, such as Fast Fourier Transform (FFT). With the development of the software as well as the hardware, online and offline analyses has become possible which meant that researchers not only collect more data but also can conduct faster analysis and obtain faster results during and/or after experiments. Figure 2C shows a setup of a modern computer based data recording system, POWERLAB®. Among the currently available data acquisition systems, POWERLAB in conjunction with Chart and Scope software, is the most widely used system in both life science teaching and research laboratories around the world.

Figure 2: Evolution of data recording system; Kymograph (2A), Polygraph (2B) and PowerLab (2C).
(References: Kymograph from Petzold, Wilhelm 1891. Preis-Verzeichniss de Werksttte fr Prcisions-Mechanik von Wilh. Petzold: Abtheilung der Instrumente und Apparate fr physiologische Experimente und Vivisecktionen (p. 0024, fig 80) and polygraph and PowerLab from ADInstruments Pty Ltd, Australia)

A growing body of evidence from classroom assessment supports the effectiveness of computerized data recording system in self-learning, motivation and improved performance and skills development in undergraduate courses of various disciplines (1-7).

There has been a lot of debate going on whether to use computer simulation or real experiments to be performed on computer-based systems in a teaching setup to provide hands-on experience. Both approaches have merits and demerits for example, simulations in teaching provide a safe environment within which students can test hypotheses and study outcomes, students can use the software out of class times for reinforcement or revision and self testing, teacher or demonstrator contact time can be diverted to other tasks, simulations are cheaper, and do not require expertise for setting experiments, and ethical issues in use of animals are also overcome. Conversely, there are quite sound counter claims in favor of traditional labs. These relate primarily to the value of "real life, hands-on" experience, leading to the development of appropriate professional skills, and familiarity with particular tools of the trade for life scientists, e.g. measuring and recording instruments and this is very important for students, teachers, departments and planning units under current funding arrangements (8). However, consensus is the use of both tools at appropriate times to get most out of the facilities available.

Most of the institutions in developed countries offering human and animal physiology courses have adapted to new computer based tools for teaching and research but in developing countries such as Pakistan, this trend is growing at slow pace because of several reasons like, shortage of staff familiar with computer use, misconception of 'computers are delicate and complicated' or fair to use computers, lack of funds to purchase equipment, to some extent this problem is not the major issue as Higher Education Commission of Pakistan is providing a lot of funds for the upgrading of laboratories. Our experience of few years in Pakistan has indicated big generation gaps among senior faculty members, young teaching staff and students. Among these young staff and students are highly receptive to wards the change and willing to accept new challenges. Therefore, the adaptation to new technology will take sometime.

The growing importance of computer based data recording devices in Physiology teaching and research has motivated us to write this review to provide basic concepts of computer based data recording systems, basic terms and variables used in this technology (9). Since PowerLab is the world first data acquisition system for Physiology Teaching and Research we will explain some of the concepts with reference of this system, other systems may differ slightly but the concepts remains the same.

HISTORY

PowerLab systems are used in over 900 research and teaching institutions around the world with around 6000 research papers published citing POWERLAB (or formerly MacLab) as their data recording system. Initially, the system was known as MacLab as the system and software was developed for use with the Macintosh operating system. In 1997 the software was developed for use using the Windows platform and the hardware was renamed, POWERLAB. Prof. Tony Macknight, a physiologist who was based at the University of Otago, New Zealand, had the idea for developing a computer-based recording and analysis system. He presented the idea to his son, Michael Macknight, who then developed a computer based data recording system to replace conventional analog data recorders. Michael started working on this project as part of his Masters of Science degree which resulted in the first generation computer-based data recording system of its kind MacLab and Chart in 1985. MacLab, now known as PowerLab, was further developed after Michael met Boris Schlensky, an Australian with an interest in data acquisition with expertise in electronic engineering. Boris saw the potential of the MacLab system and agreed to co found the company ADInstruments with Michael and manufacture the data acquisition products for a world-wide market. The hardware and software are seen as a gold standard in computer based data acquisition and analysis .

PRINCIPLE OF DATA ACQUISITION

PowerLab systems and Chart are used to acquire, store and analyze data. Figure 3 summarizes the basic principles of data acquisition. A physiological signal, such as pressure changes recorded on the finger tip can be detected using a piezoelectric transducer or sensor. The sensor converts the pressure signal into an analog electrical signal which is then converted to a digital signal in the PowerLab. At this time the signal can be amplified (to amplify small signals), filtered (to remove unwanted frequencies or noise) and digitized. The digitized data is then displayed on the computer as a waveform using CHART or SCOPE software. With the advancing technology in the development of more and better sensors and amplifiers almost any type of signal can be recorded and analyzed using a PowerLab system. As well as processing of recordings within the hardware, signals can also be further processed easily by the user during acquisition using the software. The software displays data in real-time with the system plotting the sampled and digitized data points and reconstructing the original waveform by drawing lines between the points. One of the advantages in collecting data using these systems is that digital data can be stored on disk for later retrieval and analysis.

Figure 3: Principle of computerized data recording system, exemplified by pulse transducer recorded on PowerLab.
(Pictures reproduced with permission of ADInstruments Pty Ltd, Australia)

DIGITIZATION

When analog data such as voltage amplitude is converted to a digital format for use by a computer it must conform to a fixed number of values (for instance, a digital thermometer might only measure temperature to the nearest degree). Any analog values are rounded up or down with the approximation being very good, as the number of values sampled is very large. The analog-to-digital converters (ADCs) that perform the digitization usually generate a number of values equal to a power of two: an ADC with 16-bit resolution can resolve a signal into 2^{16} or 65,536 possible amplitude values. Most PowerLab recording units use 16-bit ADCs. Chart for both Macintosh and Windows, fit 64,000 of the 65,536 values to the range, allowing some room above and below it for signal extremes. For example values in a 10 V range would be divided into 64,000 fixed values from –10 V to +10 V; the minimum change in voltage that could be discerned at that range would be 0.3125 mV. At a 10 mV range, the minimum discernible voltage change would be 0.3125 µV, and so-on.

SAMPLING RATE

Sampling replaces the original continuous analog signal by a series of discrete values (samples) taken at regular time intervals. The sampling rate depends on the signal being measured. If the sampling rate is too low (slow, not low, refer to rates in terms of speed), information is irreversibly lost and the original signal will not be represented correctly (Figure 4). If it is too high (fast), there is no loss of information, but the excess data increases processing time and results in unnecessarily large files. The sampling rate using computer-based systems can be set from 2 up to 200,000 samples/sec, depending on the type of signal to be recorded. For example, slow contractions in smooth muscle would only require slow sampling rates while recording electrical activity of the brain will need high sampling rates. In most recording situations the frequency of a recording signal is known and it is usually recommended that the sampling rate be set at double the expected maximum frequency to ensure good data recording.

Figure 4: Effect of changing sampling rate on integrity of pulse signal, sampling rate 20 samples/sec (upper) and 200 samples/sec (lower)
(Pictures reproduced with permission of ADInstruments Pty Ltd, Australia)

Figure 5: Use of digital filters, a wave consisting of two frequencies (upper) can be resolved in two components; low frequency (middle) and high frequency (lower).
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FILTERING

Any analog waveform can be described mathematically as the sum of a number of pure sine waves at various frequencies and amplitude. Low frequencies are characterized by slowly changing parts of a waveform; while high frequencies, are quickly changing components. There are a number of filters which can be used to remove unwanted frequencies leaving the researcher with only the waveform components of interest. A filter can remove specific frequencies from a signal: for instance, a low-pass filter allows low frequencies to be acquired and prevents high frequencies being recorded. On the other hand, a high-pass filter removes any steady, slow frequency component of a signal. Figure 5 illustrates the effect of separating high and low frequencies from the raw signal. There are a variety of other specific filter types like, bandpass, bandstop, notch filters etc. Filtering of data should be done with care as inappropriate selection may distort the signal of interest.

NOISE

Noise is defined as ‘unwanted signal’. Noise is usually a problem when trying to record signals of very small amplitude and which require considerable amplification. Random noise, such as thermal noise, is inherent in all electronic circuits, including PowerLab recording units, and generally must be filtered to minimize its effect. A method is to select a low-pass filter setting that removes most of the background noise without changing the signal of interest. For biological signals, differential inputs are preferred, and can reduce common-mode noise due to ground loops (Ground loops occur where multiple connected pieces of recording equipment are connected to grounded mains power). Other important causes of noise are stray electromagnetic and electrostatic fields, and include interference (this often includes power mains frequency of 50 Hz or 60 Hz) from unshielded power lines, switching equipment, fluorescent tubes, transformers, computers, network cables, VDUs, and so on. This type of interference can interact significantly with a recorded signal. Figure 8 shows the effect of applying a 50Hz filter to eliminate such noise Figure 6.

APPLICATIONS

Computer based data recording devices are widely used in the teaching of many science subjects such as biology, biochemistry, physics, chemistry, medicine, physiology, pharmacology, sports sciences, psychology as well as being used for basic and clinical research. The number of applications using data acquisition devices is increasing especially with computers becoming more popular and affordable.

ADVANTAGES

Using computer-based data acquisition devices provides ease of use (user-friendly software) with no programming by the user required making them ideal for research and teaching. The cost of consumables in using the old systems such as paper and ink is eliminated. In teaching the students can focus on learning biological principles rather than trying to connect and calibrate chart recorders, as well as saving instructor's time in not having to troubleshoot hardware problems. Students are more likely to take more interest in their experiments using computers and with guiding material and resources such as handouts, protocols, setting files, data files etc encourages independent learning.

Figure 6: Noise from electric main (50Hz) affecting the signal (upper) can be removed using mains or 50Hz filter

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In research, data acquisition systems such as PowerLab and Chart are more versatile as the system can be adopted for many research applications and therefore provide a much more cost effective option. Researchers are also provided with more flexibility in obtaining results with the availability of fast and powerful analyses features. ADInstruments Chart and Scope software provides advanced online and offline analyses which includes integrals, rate calculations, unit conversion, calibrations, smoothing, digital filtering, ECG, Blood Pressure, Spike, Metabolic analysis and many more. In addition, all of these calculations are reversible, which means that the original data is unaffected when using any calculation feature of the software. Therefore, any calculation and setting can be applied without the danger of loss of data.

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