Journal of Advanced Biomedical & Pathobiology Research Vol.2 No.3, September 2012, 121-128

# An Audible Display Integrating Patient Monitors.

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Article Info

Received: 11th July 2012
Accepted: 17th August 2012
Published online: 1st September 2012

ISSN: 2231-8313


## Abstract

Audible alarms in monitors play an important role in providing information during patient monitoring. However an overabundance of separately informative alarm sounds produces unpleasant noise and becomes a nuisance to medical personnel. Consequently, a new approach to alarm sounds has to be taken, which is both informative and not annoying, even in a chorus of different monitoring systems. In order to research this question, we demonstrate here an interface, which is able to present choosable audible outputs from a set of commercially available monitors. As proof of principle, we connect a capnograph and a cerebral oximeter to a smart phone embedded processor in order to display EtCO2 and rSO2 values, respectively in an audible form. The output is frequency coded into distinct harmonies, with optimal sound synthesis to be researched in the future.

***Keywords:*** **audible, alarm, smartphone processor, BeagleBoard, capnography, cerebral oximetry.**

## 1. Introduction

Intensive care units (ICU) and operating rooms are full of sophisticated patient monitoring technology (Fig. 1). Each monitor has at least one alarm intended to alert the clinical experts to the problems concerning the monitored patient. Thus, audible alarms in monitors play an important role in providing information during patient monitoring (Morris and Montano, 1996). Eventhough, the medical alarms are standardized by IEC 60601-1-8, overabundance of thememits harsh and unpleasant noise, which is gradually becoming a nuisance to the clinical personals (Cropp and Woods,1994; Donchin and Seagull ,2002).

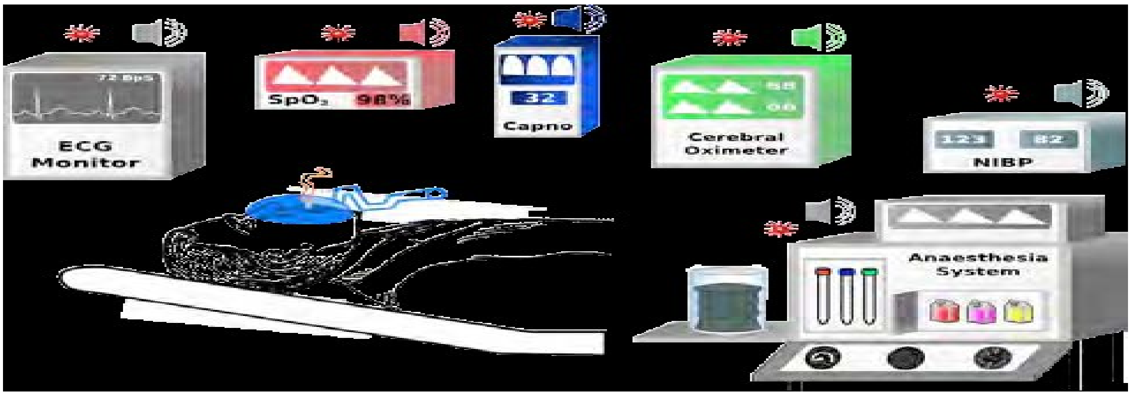


Fig. 1: A general scenario in patient monitoring.

Pulse beep audible alarm is widely used and highly undistinguishable during multi-parametric patient monitoring such as capnometry, pulse oximetry, electrocardiography etc. It has been observed that the medical staff frequently disable the pulse beeps (Craven and Mcindoe ,1999) . Standardization of alarm sounds for patient parametric changes is one of the alternatives to resolve the problems currently encountered with the use of alarms (Osinaike, 2010).

In this study, we demonstrate an interface in which distinguishable and non-annoying alarm sounds are produced along with the realtime patient data plotting. Nowadays, many of the commercial patient monitors facilitate a real-time digital data-out at serial or USB port. We have endeavored to utilize the benefits of these interfaces and integrate thus several monitors into one single platform. Our goal is to produce distinct alarm for each patient parameter and also visualize them simultaneously.

At the time of this writing, two of such monitors, a capnograph and a cerebral oximeter have been connected to a smart phone embedded processor in order to display end-tidal CO2 (EtCO2) and regional cerebral oxygen saturation (rSO2) values, respectively in an audible form (Fig. 2). The programs called CapnoPlot and CerePlot display the collected data on the screen along with the chosen alarm sounds for each signal.

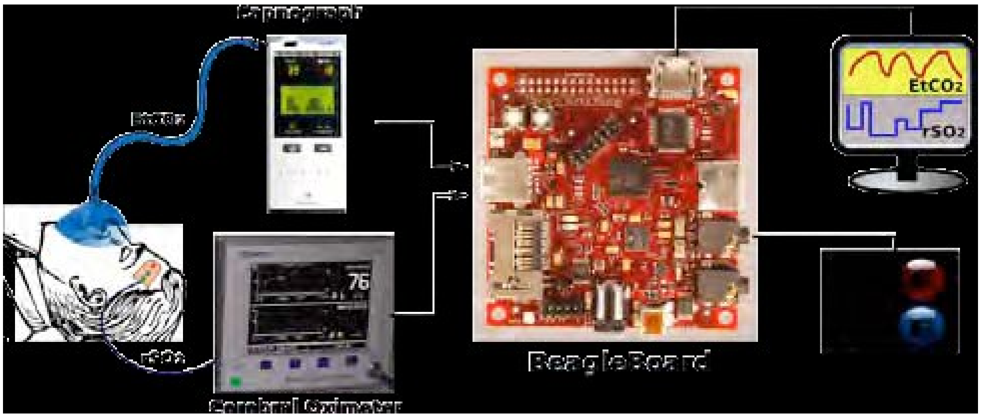


Fig 2 : A conceptual diagram for integrating two monitors by an embedded system.

## 2. Methodology

Materials & Methods

Capnograph :Capnography is a method of monitoring the concentration of carbon dioxide ($CO_2$) in the expiratory gases and is highly required during patient's intubation (van Weerden,2008) . We use a microstream portable capnograph, Microcap.Plus (Oridion Capnography Inc., USA) which provides $EtCO_2$ data of intubated or non-intubated patients. Infrared based microstream technology is $CO_2$ specific and unaffected by other exhaled gases. Exhaled gas from patient's mask is mainstream transferred via a pipe for $EtCO_2$ measurement to the monitor. This capnograph shows instantaneous $EtCO_2$ value and near real-time plot on its screen. A communication adaptor kit provided with this monitor facilitates data output via serial port with 50msec time lag (Communication Interface,2004) .


Fig. 3 : (a) Patient's $EtCO_2$ pipe, (b) Microcap□Plus and (c) a communication adaptor kit.

Cerebral Oximeter: Near infrared spectroscopy provides continuous, noninvasive assessment of brain oxygen saturation and is widely used in surgery to monitor anesthesia depth (Prough et al.,1997). Our setup uses an INVOS 4100 (Somanetics, USA), which is a dualchannel continuous wave spatially resolved spectrometer. It measures changes in regional oxygen saturation ($rSO_2$) by light emitting diodes (LED) at 730nm and 810nm and differentially spaced receiving optrodes to assess bifrontal cortical oxygenation (Murkin ,2009) (Fig. 4). Optical units are located in a forehead patch (SomaSensor, Somanetics, USA), which collects the raw $rSO_2$ signal and feeds them to the amplifier module (Fig. 4 b) for analog processing and digitization. The monitor (Fig. 4 c) receives the digitized signal for further processing and display. It makes the data available on its serial port (RS 232) output every 5 seconds.


Fig. 4 : (a) A SomaSensor for performing cerebral oximetry on patient's forehead, (b) its amplifier module and (c) INVOS 4100 station.

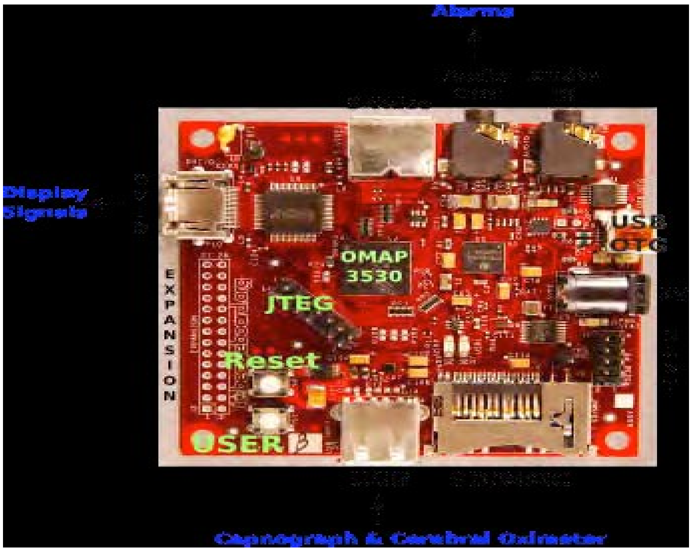


Fig. 5 : A BeagleBoard and its components.

Smartphone embedded-processor - OMAP3 A low power and small size embedded system board has been chosen as a processor to perform digital data collection and creating an appropriate user interface. The 3”x3” USB-powered BeagleBoard (BeagleBoard.org, USA) is a low-cost, fan-less single board computer based on a TI OMAP3530 applications processor that gives laptop-like performance and integrates a 600MHz ARM Cortex-A8 core with a high-end 430MHz DSP-TMS320C64x core.

The OMAP3530 supports high-level operating systems (OSs), such as Windows CE, Linux and others (Beagle Board System Reference Manual ,2009; Mankodiya et al.,2009). The USB port makes the BeagleBoard a host device and lets it connect to USB client devices such as mice, keyboards, network interfaces, and hard disks (Beagle Board System Reference Manual, 2009). In our application, the Microcap Plus and INVOS 4100 are connecting to the Beagle Board USB port via a USB hub (Fig. 5). Beagle Board runs an OpenEmbedded operating system, Ångström (Ångström Distribution) stored on an SD-Card. BeagleBoard links to a self-powered monitor via a DVI-D port to visualize desktop and the patient’s data plots. BeagleBoard in particular provides the sound output for the alarms.

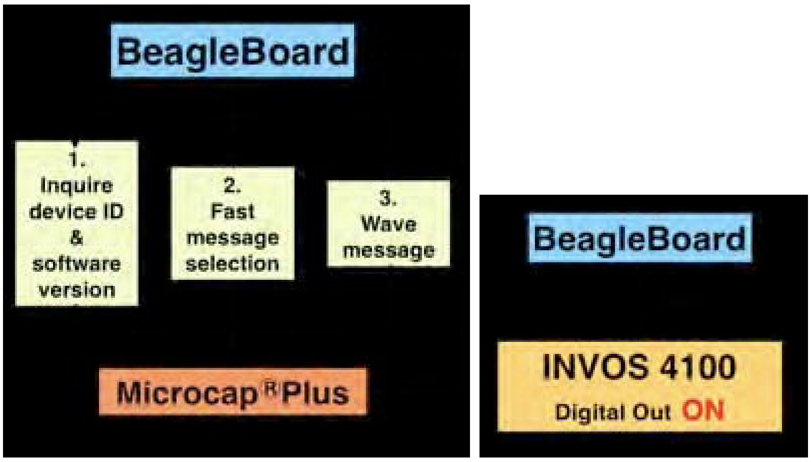


Fig. 6 : Communication flow chart between Beagle Board and two monitors (Microcap in left and INVOS in right).

Communication with Monitors Microcap..Plus is physically connected to a USB port of the BeagleBoard via a serial to USB adaptor. A C++ program called CapnoPlot on BeagleBoard initiates the communication with Microcap..Plus by inquiring a device ID and software version after the serial communication parameters are set. Consecutively, the fast message selection

and wave message commands are sent by the BeagleBoard in order to receive data from the capnograph. The EtCO2 values are sent every 50ms to the Beagle- Board by the capnograph (Communication Interface, 200). Using the SDL libraries, CapnoPlot also produces informative alarm sounds based on the EtCO2 values above set-limits.

Similarly, a C++ program called CerePlot on the Beagle-Board executes the data transfer with the INVOS 4100. CerePlot is based on the same libraries as CapnoPlot to maintain code reuse and prepare for higher integration levels. In this case, the INVOS 4100 requires the digital out ON to be selected by user to transfer the instant data value to the Beagle Board or any other serially connected device. The rSO2 values are sent every 5 seconds from the INVOS 4100 to the BeagleBoard (Instruction Manual, 2004). [ CerePlot not only plots the data but also triggers the alarm in order to inform anaethesiologists.

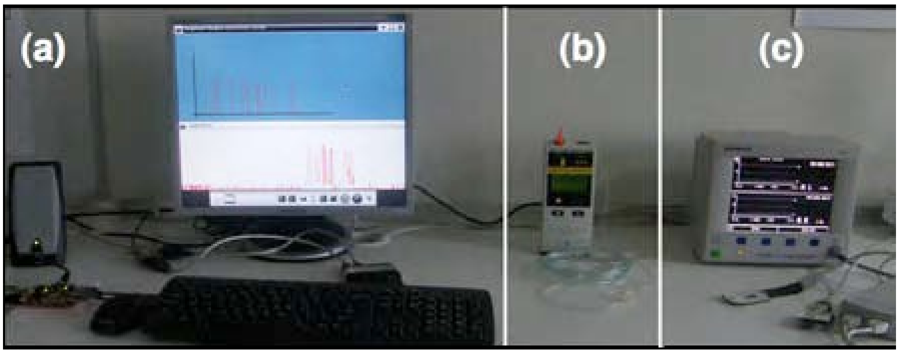


Fig. 7: (a) A BeagleBoard (arrow) with the peripheral connections and display, connected to (b) the Microcap Plus and (c) the INVOS 4100 with the SomaSensor.

## 3. Results & Discussion

Fig. 7 shows the BeagleBoard set-up with the monitors.The CapnoPlot and CerePlot applications display the values of EtCO2 and rSO2 respectively on a single monitor simultaneously. The CapnoPlot requires no trigger from the capnograph to receive instant EtCO2 values, while for.

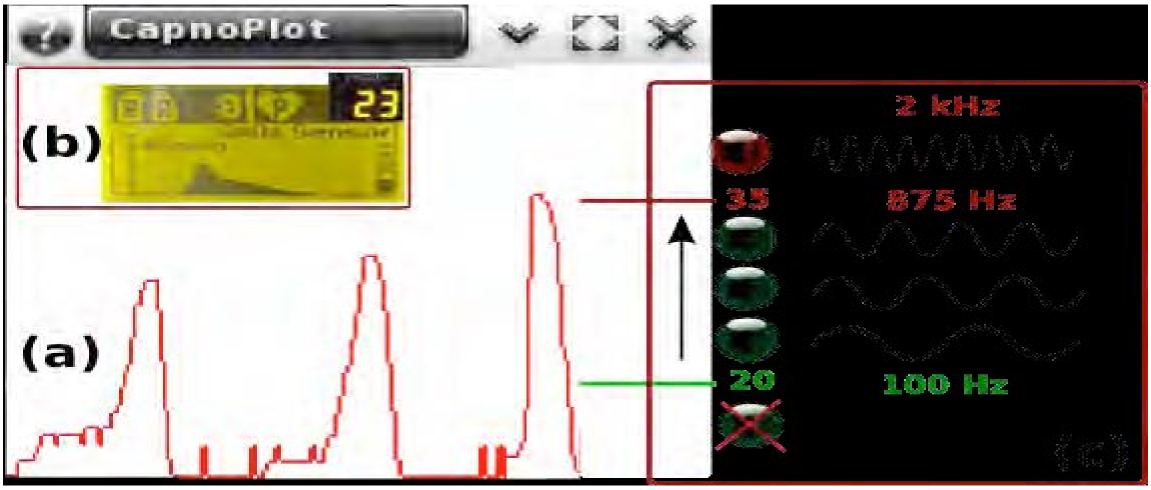

Fig. 8 : (a) A CapnoPlot screenshot over several breathingcycles, (b) corresponding Microcap Plus output and (c) illustration of CapnoPlot audio profile.

The CerePlot, the digital out has to be set on the cerebral monitor.

**CapnoPlot**

Fig. 8b shows the screen capture of Microcap Plus. Although the capnograph does store patient's EtCO2 data for longterm, it displays the current capnogramm only briefly. The EtCO2 value alone is updated every 5 seconds. The monitor sounds for security reasons a beep alarm when the EtCO2 value is zero for a finite time-period. Fig. 8a shows collected EtCO2 data plotted by the Capno-Plot. Quantisation steps in the plot indicate that instant EtCO2 value was sent to BeagleBoard every 50ms. Our EtCO2 graph shows 5 minutes of consecutive patient's data before it is updated. Currently three different types of audio output are enabled related to the EtCO2 level (Fig.8c). For EtCO2 values below a lower limit, no sound is given, in order to reduce noise. For intermediate levels the base frequency of 100Hz (sinusoidal) is presented. This sound is varied proportional to the gathered EtCO2 value,according to the following formula: Output signal = 0.25 x EtCO2 x 100Hz

The third level is a classical alarm to inform the anesthesiologist that the EtCO2 value is currently above the upper limit. This alarm is a continuous sinusoidal audio output with 2 kHz. The upper and lower limits of the EtCO2 trend can be changed in the CapnoPlot program, but will be selectable in the display panel. The current output proofs the principle of audible presentation of monitoring data. Our audio module is under constant improvement until finally the most ergonomic path to convey information will be found for the ICU.

**CerePlot**

A comparison of visual outputs for the cerebral oximetry is shown in Fig. 9. Subplot 9b shows the screen capture of the commercial INVOS 4100. It displays the patient's forehead rSO2 value every 5 sec (here 80) and marks it in

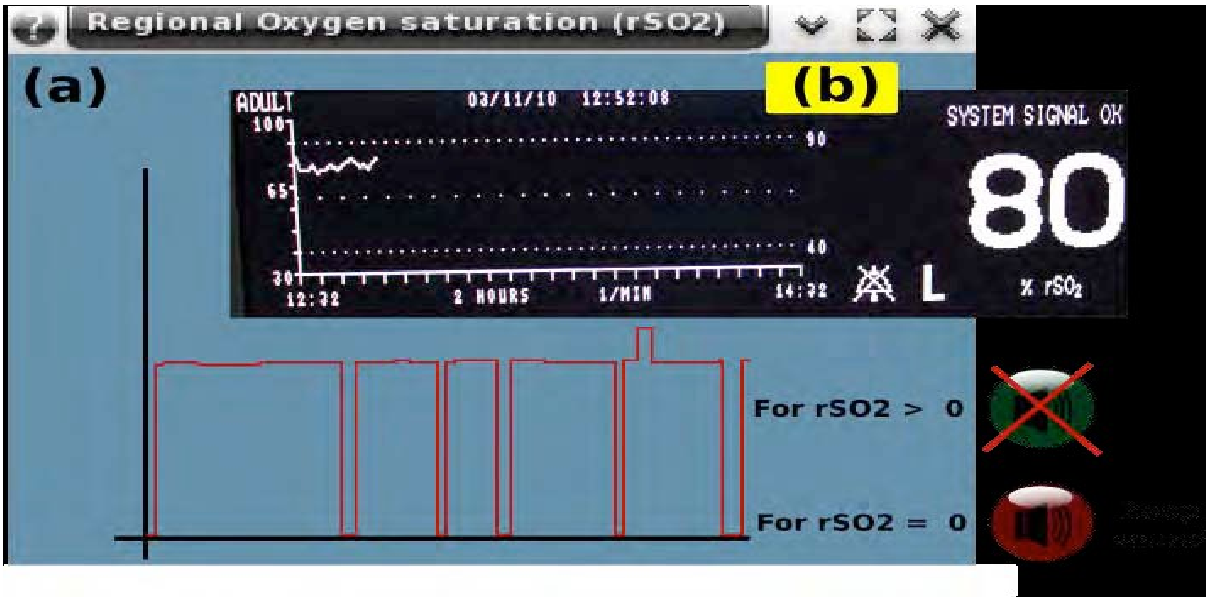


Fig. 9: (a) A CerePlot screenshot over 10min and (b) a corresponding screenshot of the INVOS 4100.

A plot over two hours. It sounds a continuous alarm in case no signal is detected for some minutes. Subplot 9a shows the gathered rSO2 value plotted by CerePlot. The rSO2 value is updated every 5 sec and the trend covers 10 minutes of patient's data before it updates.
Glitches in the CerePlot trend are caused by faulty digital data sent by the INVOS port. The audible alarm scheme of CerePlot is currently set to intermittent, but pleasant sound bursts, to distinguish them from the CapnoPlot alarm.

## 4. Conclusion

Our presented study proofed two different hypotheses: The foremost important was the integration of separately certified commercial patient monitors by a low cost smart phone embedded processor. This enables us to custom design and investigates new ways of audio display of patient data, which was exemplary shown by problem driven sounds for our applications.

## 5. Outlook

Even though the original idea of this audio display was to artificially produce a breathing sound based on the capnograph data, we are currently investigating the ergonomic needs of ICU personnel. Together with the computing power of smart phone embedded processors we envision a whole new paradigm of intensive care by integrated ergonomic monitoring.


## 6. Acknowledgement

We would like thank Alexander Opp for his incessant help in acquiring monitors and handling them.

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