ACOUSTIC SIGNAL PROCESSING DEVELOPMENTS FOR NON-INVASIVE MONITORING OF VITAL SIGNS AND ULTRASOUND INTRACRANIAL SYSTEMS

Stergios Stergiopoulos
CANAMET Inc., 1120, Finch Ave West, Suite 201, Toronto ON, M3J-3H7, stergios@canamet.com

1. BACKGROUND

Current system concepts for non-invasive monitoring of vital signs are limited in providing estimates for blood pressure, ECG, pulse oxymetry and tympanic core temperature. Although this information is considered to be sufficient in most emergency and search and rescue operations, the lack of accuracy of these vital signs measurements makes the relevant system concepts unattractive to medical practitioners.

For the specific case of monitoring the blood pressure, the traditional system concepts are based on the oscillometric technique rather that the auscultatory method that monitors the sounds as blood flows through the brachial artery (i.e. Korotkoff sounds) in the same way as the medical practitioner employs a stethoscope along with a mercury sphygmomanometer. In noisy and vibration intensive environments the pressure fluctuations caused by these disturbances are sizable compared to the pressure fluctuations that need to be detected for the proper operation of the technique, thereby reducing the accuracy. Furthermore, in noisy environments, such as onboard (or near) a rescue helicopter or ambulance, the environmental noise frequently overwhelms the acoustic signal of interest, making it impossible to make a measurement using the conventional auscultatory method.

2. SYSTEM CONCEPT AND IMPLEMENTATION

Canamet Corporation has overcome these issues by using adaptive signal processing techniques that include adaptive interference cancellation, band pass filtering, and peak discrimination (pattern recognition) algorithms.[1,2]. The use of these advanced signal processing techniques leads to a feasible system for providing vital sign measurements in challenging noisy environments, such as ambulances and helicopters. The block diagram in Figure 1 shows the block diagram layout for the blood pressure measurement system. More specifically, Canamet's Piesometer MK-1 portable blood pressure monitor has a primary acoustic sensor integrated with the cuff and placed on the brachial artery to collect the Korotkoff sounds and any environmental noise. A secondary acoustic sensor (on the back of the patient's arm) collects only the environmental noise, as shown in Figure 1. The adaptive interference cancellation algorithm is a non-linear filter that removes the interference measured by the secondary sensor from the desired signal received by the primary sensor that was corrupted by environmental noise. The band pass filter removes any noise outside the frequency of interest. Finally, the peak discrimination algorithm extracts valid peaks from the Korotkoff sounds in the acoustic signal that result from heartbeats. Peaks that do not satisfy these constraints are discarded; however a degree of arrhythmia is accounted for during this process. In summary, Canamet's Piesometer MK-1 system is based the auscultatory technique that emulates the operations of the medical practitioner using the mercury sphygmomanometer and the stethoscope. This system has proven with clinical trials to have accuracy equivalent to that of a medical practitioner for patients at resting position [1,2].

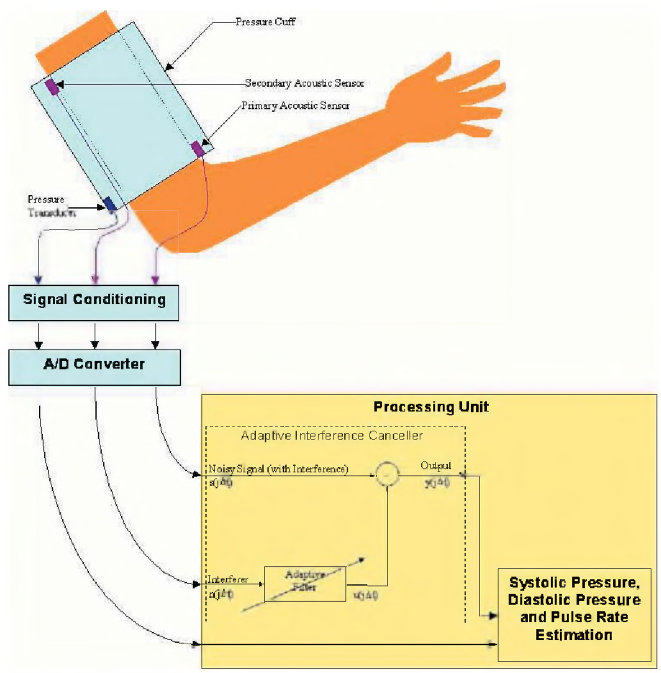

Fig 1: System Concept of Adaptive Noise Cancellation for Blood Pressure Systems based on the auscultatory method

However, advanced adaptive algorithms are extremely computationally intensive, requiring the execution of billions of operations per second (GOPS), and relying heavily on the use of Fast Fourier Transforms (FFTs) for frequency domain operations, such as time delays and spectral analysis. Conventional DSP architectures are not up to the task. Fixed-point computing architectures do not possess the appropriate processing capabilities to efficiently execute these computationally intensive algorithms and tend to introduce inaccuracies in the weight vector calculation that actually increase the noise in the system. Floating-point arithmetic enables much more accurate calculations and provides faster development cycles because the C-code does not have to be translated to a fixed point format.

In addition to the computationally intensive requirements, the need for miniaturization and portability with the requirement to include into the system's architecture a real time clock, microcontrollers, I/O analog/digital peripherals, telemedicine functionality through serial port/USB and graphic interfaces for user friendly operations, makes the existing floating point DSP processors not very attractive for this kind of advanced and portable medical system applications. An ideal DSP processor architecture should include all the above peripherals and functionalities. Canamet's Adaptive blood pressure system is designed to be part of an open system. This type of open system design is shown in Figure 2. It allows for the integration of a number of modular designs into the complete system, based on need.

An addition to the system shown in Figure 2 is the non-invasive monitoring of the density variations of the brain due to changes of temperature or pressure, stroke, heat stroke, head injuries, hemorrhage, variations of blood flow in the skull due to drug effects, variations in metabolism and stress [3]. This is a new system innovation, called intracranial ultrasound technology. The design of this system mirrors the design of the blood pressure monitoring system as a monitoring intracranial vital signs system. Furthermore, a portable 3D ultrasound system technology [4,5] can be integrated as a modular unit into the above open system design.

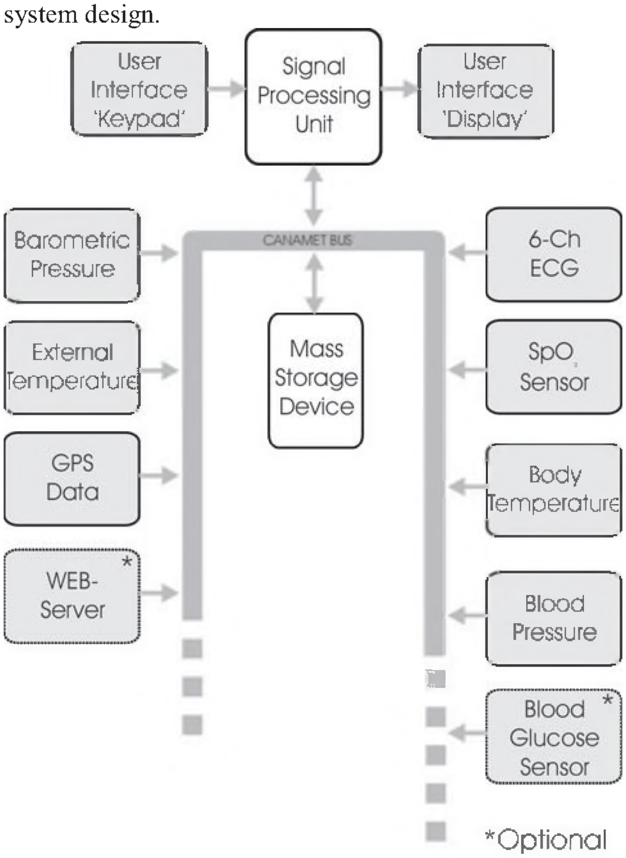

Fig. 2: Canamet's Open Modular System Design for Monitoring Vital Signs.

3 CONCLUSION

This article describes the evolution of innovative new acoustic signal processing algorithms and DSP architectures implemented in a wide variety of new medical electronics applications that form the EMERGING TRENDS IN THE FIELD OF NON-INVASIVE MEDICAL DIAGNOSTIC TECHNOLOGIES.

The advance signal processing structure of the present development and its implementation into a system computing architecture has demonstrated successful performance in obtaining:

- Blood Pressure Monitoring of systolic - diastolic pressure in noise intense environments, such as helicopters, ambulances, emergency rooms, etc.
- Implementation of an open system architecture with a common system bus to allow the design through a generic system design.
- Non-invasive monitoring of the density variations of the brain due by intracranial ultrasound technology.
- Continuous 24-hour monitoring of vital signs, such as pulse oxymetry, six-electrode (vector) ECG with high sampling rate (1KHz) to allow diagnosis of a wide spectrum heart diseases, tympanic ear thermometer.

It is anticipated that the present development would address most of the medical requirements for non-invasive monitoring of vital signs for Home Care, in Hospital Emergency Departments, Ambulances, Hospital Intensive & After Care, and applications for Family Medical Clinics, Insurances and Old-Age Nursing Homes.

REFERENCES

[1] Pinto L., Dhanantwari A., Wong W. and Stergiopoulos S., "Blood Pressure Measurements in Noise Intense Environments Using Adaptive Interference Cancellation", Annals of Biomedical Engineering, 30, 657-670, 2002.

[2] Stergios Stergiopoulos and Amar Dhanantwari, "Method and Device for Measuring Systolic and Diastolic Blood Pressure and Heart Rate in an Environment with Extreme Levels of Noise and Vibrations", US Patent 6,520,918, issued 18 February 2003.

[3] Stergiopoulos S. and Wrobel M. "Non-Invasive Diagnostic Ultrasound System Monitoring Brain Abnormalities", US Patent application (DND File No. 1416-01/007 USA), Dec-2001.

[4] A. Dhanantwari, S. Stergiopoulos, C. Parodi, F. Bertora, P. Pellegretti, A. Questa, "An efficient 3D beamformer implementation for real-time 4D ultrasound systems deploying planar array probes", Proceedinds of the IEEE UFFC'04 Symposium, Montreal, Canada, Aug 2004.

[5] Stergiopoulos S. and Dhanantwari A., "High Resolution 3D Ultrasound Imaging System Deploying A Multi-Dimensional Array of Sensors and Method for Multi-Dimensional Beamforming Sensor Signals", United States Patent 6,482,160, 19 Nov-2002.