ARCHITECTURE LAYOUT AND DESIGN OPTIMIZATION OF MEDICAL ASSISTIVE DEVICE FOR NARCOLEPSY PATIENTS

S. R. I. Gabran, S. Zhang, E. F. El-Saadany, M. M. A. Salama

University of Waterloo / ECE Department, Ontario, Canada

salam@ieee.org
s7zhang@engmail.uwaterloo.ca

Abstract: This paper illustrates the design layout and optimization of a biomedical device intended to provide assistance to narcolepsy patients as well the treating physician. The paper discusses the hardware architecture as well as the software involved in the device.

Introduction

This research activity is a part of project for designing, optimizing and building a portable medical device which provides technological treatment for narcolepsy patients in the form of a portable monitoring device for sleep and alertness.

Narcolepsy patients suffer from a brain disorder characterized by attacks of involuntary sleepiness regardless of the sleeping habits of the patient. The attack can be accompanied by outbursts of paralysis and hallucinations. The narcolepsy attack occurs unexpectedly and an assistive device that would alert the patient or a companion of a potential attack will provide help and improve the patient safety, life style and productivity.

Unlike the available vigilance monitoring systems [1] [2], the narcolepsy assistive device is remarkably different in terms of the tasks, capabilities and the method of sleep detection. This device uses the electroencephalogram (EEG) spectrum to monitor the awareness state of the patient. The tasks of this device are not limited to awarness monitoring and issuing an alert in case of sleepor a potential narcolepsy attack, but expand to further analyze the EEG spectrum for sleep classification, staging, finally keeping a log of the patients condition to provide the objective information required by the treating physycian.

This paper focuses on the device architecture which is optimized for minimum cost as well as minimizng the power consumption using on-shelf commercial components that satisfy the design requirements. Then sleep staging alogrithms which are the main software blocks will be discussed.

Background

Narcolepsy

Narcolepsy is a chronic neurological disorder of sleep regulation characterized by uncontrollable recurring episodes of daytime sleep, hallucinations and cataplexy [3] [4] [5]. The episodes may last from few minutes up to a complete hour and is accompanied by intrusion of the dreaming state -known as the rapid eye movement sleep- into the waking state.

So far, narcolepsy is not curable [6] and the proposed solution is considered a technological treatment for the narcolepsy patients in the form of a portable device for monitoring sleep and alertness states.

The exact cause of narcolepsy is currently unknown, but some theories and studies relate narcolepsy to the lack of hypocretin peptides in the brain which are neurotransmitters in the hypothalamus involved in regulating sleep.

An undiagnosed patient potentially will be subjected to the drawbacks of narcolepsy that will hinder the daily activities and normal flow of life. Referring to a survey carried by the UK narcolepsy patient association based to the Beck Depression Inventory (BDI), degrees of depression are common among narcolepsy patients [7]. This is an expected evolution to a series of social, educational, psychological, and financial difficulties experienced by narcoleptics [2] [3] [4] [5] [8] [9].

Narcolepsy symptoms

In brief, the key symptoms of narcolepsy are excessive daytime sleepiness, cataplexy, sleep paralysis and hypnagogic hallucinations [4] [8] [9].

Narcolepsy symptoms in more elaboration:

- Excessive daytime sleepiness (EDS). A state of involuntary sleepiness and extreme exhaustion which interferes with normal activities regardless of the sleeping habits. The EDS attack may be a micro sleep lasting for few seconds or as long as an hour.
- Cataplexy. A sudden attack of muscle weakness and loss of muscle tone aroused by strong emotional response.
- Sleep paralysis. Momentary inability to move or speak while falling asleep or waking up which is similar to a cataplectic attack affecting the entire body.
- Hypnagogic sleep paralysis. Brief episodes of paralysis occurring when falling asleep.
- Hypnopompic sleep paralysis. Brief episodes of paralysis occurring when waking up.
- Hypnagogic hallucinations. Vivid hallucinations occurring at the onset of sleep.

ISSN: 1727-1983 © 2005 IFMBE

- Hypnopompic hallucinations. Vivid hallucinations occurring when waking up.

The symptoms of this encephalon disorder prevent the patient of being able to provide the physician with detailed information regarding the progress of the illness which affects the conventional treatment practices in a negative way. Accordingly, the device software elicits the required objective information to provide first hand data to the physician.

Device design

The device is designed to be portable thus the architecture is optimized for minimizing power consumption and the size, as well as keeping the cost at minimal while not compromising performance and reliability.

Device block diagram

Referring to figure 1, the system block diagram shows the signal flow starting at the scalp and ending at the device.

Dry electrodes are used to convert the bioelectric potentials into an electric current that is fed into the signal conditioning circiut for pre-amplification and filtering the 50 and 60 Hz mains interference and limiting the signal bandwidth.. Dry electrodes are more suitable in this application than wet gel electrodes due to long operation time and ease of use where no skin prepartion is required. At this stage EEG signals captured have extremely low amplitudes ranging between 10µV to 200 µV, thus low gain preamplification is required to improve signal to noise ratio prior to further signal processing.

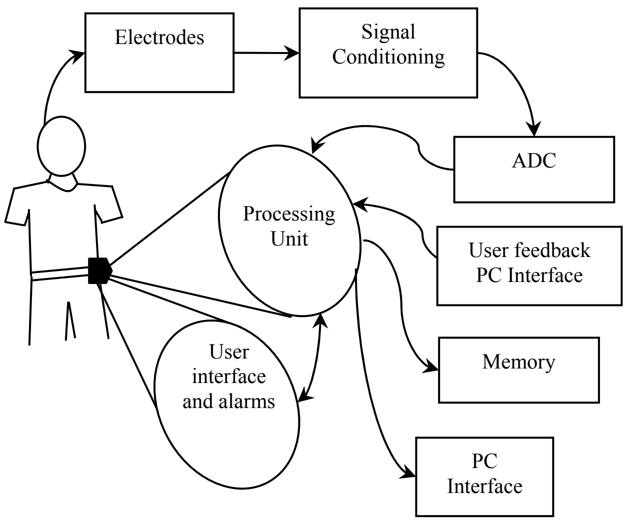

Figure 1: System block diagram

Instrumentation amplifiers are preferred as building blocks for bio-amplifiers because they provide high input impedance in the range of 1000MΩ with no degradation in the common mode rejection ratio (CMRR) which is a critical parameter in differential signal amplification. Performance of several low noise amplifiers was experimentaly compared in terms of amplifier parameters including input impedance which is required to be maximized for high signal quality, also, CMRR which is proportional to improving the interference rejection and electrode artifacts. To overcome the electrochemical effects of the electrode-skin interface which imposes a DC offset of 1-2 volts, low offset values of 2 µV were required. Finally, the power consumption was a constraint in the design optimization which is critical in the case of a portable device.

The following step is the digitization of the EEG signals. Sigma-Delta ADCs showed appropriate performance, but the final design is built around a 10 bits Nyquist rate ADC integrated in the microcontroller that also is the master CPU of the device. This cuts the part count, price as well as the power consumption.

After analogue to digital conversion, the processing unit feeds the EEG stream into the digital signal processor which is dedicated for executing the sleep detection, classification and staging algorithms.

Finally, the user interface displays the information produced by the expert system software briefing the patient about the current state and warning of potential attacks, besides to operational information like a loose electrode and battery status. While the PC interface connects the device to the physician's PC via a serial port to download the objective information required treatment.

The expert system software along with the sleep algorithms resides in the digital signal processor memory while the operating system firmware is stored in the microcontroller's flash memory.

The processing unit

The processing unit is designed to provide a wide range of resources to satisfy the mathematical requirements of the digital signal processing algorithms including fast Fourier transform (FFT) and floating point arithmatics, as well as interfacing capabilities and processing speed.

Different designs were proposed and analysed to identify the architecture which optimizes cost effectiveness and power consumption. Other technologies including PDAs were explored and proved to lack the required processing power and capabilities.

A hybrid processing unit combining the processing power of a digital signal processor and the resources of commercial microcontroller proved to be the most suitable. The microcontroller used has integrated ADC, LCD driver besides to a surplus of peripherals and ports not available in the current DSP processors. But in the same time lacks the required mathematical capabilities. Optimization techniques justified the use of a microcontroller besides to DSP processor as this minimizes component count and power consumption.

The microcontroller is the master processor and controls the system resources and signal flow. While the

ISSN: 1727-1983

digital signal processor runs as a dedicated co-processor for executing the artificial intelligence algorithms which implement the sleep detection, classification and analysis algorithms and finally, this is followed by sending the results to the microcontroller. The processing unit design and customization involved exploring other available technologies including PDAs which proved to lack the required processing power and capabilities.

Software for the Device

Software of the device can be divided into two sections: Operating System of the device and sleep detection algorithms. The Operating system of the device is responsible for resource management, data traffic control and the user and PC interfaces. The operating system resides and runs in the microcontroller memory, which is the master processor as mentioned in the processing unit section above. On the other hand, sleep detection algorithms are stored in the DSP processor program memory. The detection algorithms use functions such as Fast Fourier Transform (FFT) and floating-point instructions, which can be executed efficiently only by the DSP processor.

Detection Algorithm

Figure 2 shows how the Detection Algorithm plays a role in the portable device.

As shown in Figure 2, a major part of Detection

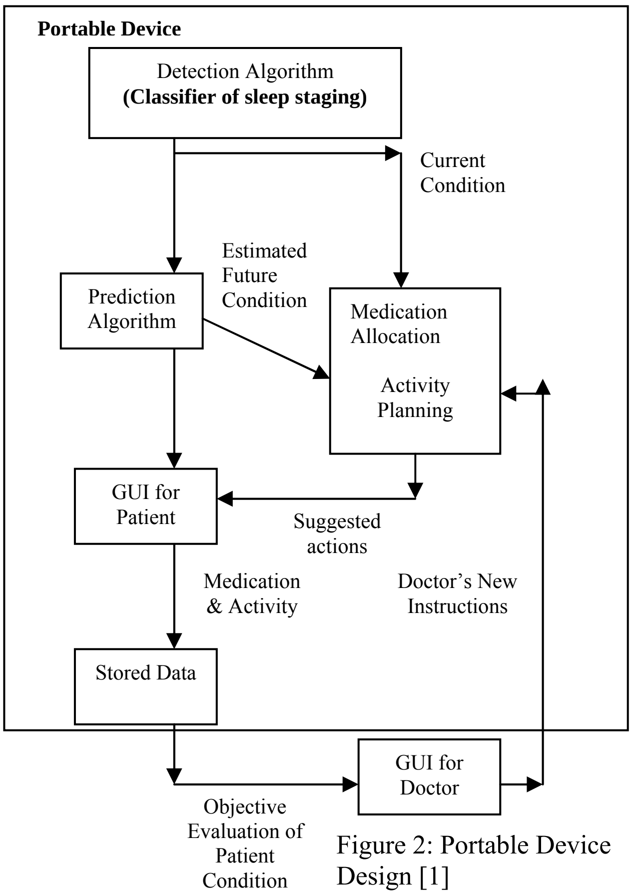

Figure 2: Portable Device Design [1]

Algorithm is the sleep staging classification algorithm. The sleep staging classification algorithm use extracted features from the electroencephalogram (EEG) signal and classify the sleep stages of a sleep cycle.

Sleep cycle is divided into a number of sleep stages: Wake, Non-Rapid Eye Movement (NREM), and Rapid Eye Movement (REM). In a proper sleep cycle, the sleep stages should follow a proper sequence. Through the classification algorithm, the sequence of the sleep stages of patient is recorded and stored in the memory of the portable device. If improper sleep sequency is detected, the device will generate alert signals or warnings.

The classification of the sleep staging is done with the help of the artificial intelligence algorithm. Many classification methodologies are being tested for optimal accuracy.

Conclusion

Architecture layout of a medical assistive device for narcolepsy patient is discussed with emphasis on performance optimization for portability in terms of power consumption, size and cost. The discussion also covers the software algorithms used in sleep staging and analysis.

References

[1] GONZALEZ-MENDOZA, M.; SANTANA-DIAZ, A.; HERNANDEZ-GRESS, N.; TITLI, A. (2002): 'Driver vigilance monitoring, a new approach', IEEE Intelligent Vehicle Symposium, 2002., 2002, P. 358 - 363 vol.2

[2] DIKKERS, H.J.; SPAANS, M.A.; DATCU, D.; NOVAK, M.; ROTHKRANTZ, L.J.M. (2004): 'Facial recognition system for driver vigilance monitoring', IEEE International Conference on Systems, Man and Cybernetics, 2004, P. 3787 - 3792 vol.4

[3] BRUCK, D. (2001): 'The impact of narcolepsy on psychological health and role behaviours: negative effects and comparisons with other illness groups', Sleep Medicine, vol. 2, pp. 437-446, 2001.

[4] National Institute of Neurological Disorders and Strokes.

[5] BEUSTERIEN, KM., ROGERS, AE., et al (1999): 'Health-Related Quality of Life Effects of Modafinil for Treatment of Narcolepsy', Sleep ,vol. 6, pp 757-765, 1999.

[6] KIRK, B.P., LACOURSE, J.R (1997): Proceedings of the 19th Annual International Conference of the IEEE Engineering in Medicine and Biology society, volume 3, p. 1218 – 1219

[7] WILLIAM D. O'NEILL, ALI M. OROUJEH, AND SHARON L. MERRITT (1998): 'Pupil noise is a discriminator between narcoleptics and

controls', IEEE Transactions on Biomedical engineering, p. 314-22.

[8] KELLERMAN, H.: 'Sleep Disorders: Insomnia and Narcolepsy', Brunner/Mazel Inc., New York, 1981.

[9] BROUGHTON, W. A., AND BROUGHTON, R. J. (1994): 'Psychosocial Impact of Narcolepsy', Sleep, vol. 17, pp. S45-S49, 1994.

[10] NIAAA http://www.niaaa.nih.gov/publications/arh25-2/101-109.htm

[11] EYEMDLINK http://www.eyemdlink.com/Test.asp?TestID=11

ISSN: 1727-1983