A DIGITAL TELEMETRY SYSTEM FOR AMBULATORY SLEEP RECORDING

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INTRODUCTION

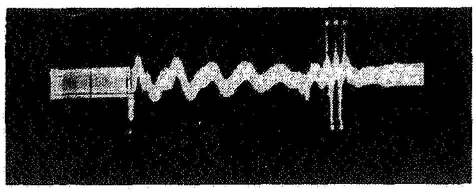
Commonly used cassette recorders for sleep-wake recording require frequent maintenance and have limited capacity for respiration and movement sensors. Signal amplitudes are variable due to the head-tape-head transmission.
We developed a digital ambulatory telemetric system with better signal quality, less service requirements, 14 signals and specified amplitudes. The system is based on modern electronic components and a small PC.

OVERVIEW OF THE SYSTEM

The system consists of three parts: a body-worn "cigarette package" (3 x 7 x 13 cm) amplifies and radio transmits the physiologic signals over a distance of about 10m to another "cigarette package size" receiver that relais the signals to a notebook PC to be positioned near the bedroom. The body-worn package contains batteries, connectors, analogue electronics for 4 bipolar electrode signals, ADC, coding, and the radio transmitter. Sensors, connectors and electronics for 10 additional polygraphic signals were designed and tested and are currently being miniaturized in order to fit in. The system operates for 24-48h (depending on chosen transmitter range) on one load of batteries. We paid relatively much attention to sensors and corresponding electronics. The Analogue to Digital Converter (ADC), in the body-worn part of the system, is relatively rigid (not programmable), but of high quality. On-line storage of the raw signals and on-line as well as off-line analysis is done on standard (at present notebook) PCs.

SENSORS AND ANALOGUE ELECTRONICS

Because ADC is by 14 bits per sample, all signal amplitudes can have very wide dynamic range, thus allowing fixed preamplifier gains even with variable sensor locations.
Silver-silver chloride electrode signals (for any EEG, EOG, EMG or ECG) were connected through special noise-free shielded cables and high-quality connectors to corresponding recently developed (Metting van Rijn et al, 1990, 1991) and slightly improved (by us) preamplifiers with fixed gain and bandwidth. When compared to the usual unguarded cables and corresponding electronics, this strongly reduces sensitivity to 50Hz mains interference, movement of the cables, and static discharges (photo 1). A four-channel (9 electrodes) preamplifier was finalized and fully tested.



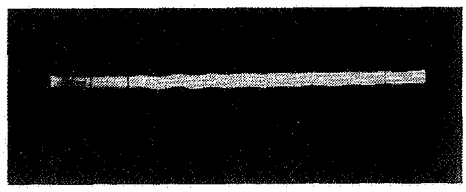


Photo 1: Effect of guarded shield on electrode cable: 2s holding the cable (causing 50Hz interference), followed by 5s free swinging cable (movement artifact), followed by 3 'foot taps' (static charge fluctuations). Left and right are without and with guarded shield, respectively.

Besides these 4 electrode signals, a marker channel and 9 polygraphic signals are sensed as follows (photo 2):
Custom-made hygienic silicone belts, a flexible film thermistor and a microphone record respiration effort (2x), flow and (snoring) sound, respectively.
Blood oxygen saturation through Red and Infrared absorbtion: 2 channels. One additional channel is reserved for large-scale evaluation of the performance of this circuit.
Relatively affordable accelerometers measure gravitational orientation and movement at two body locations.

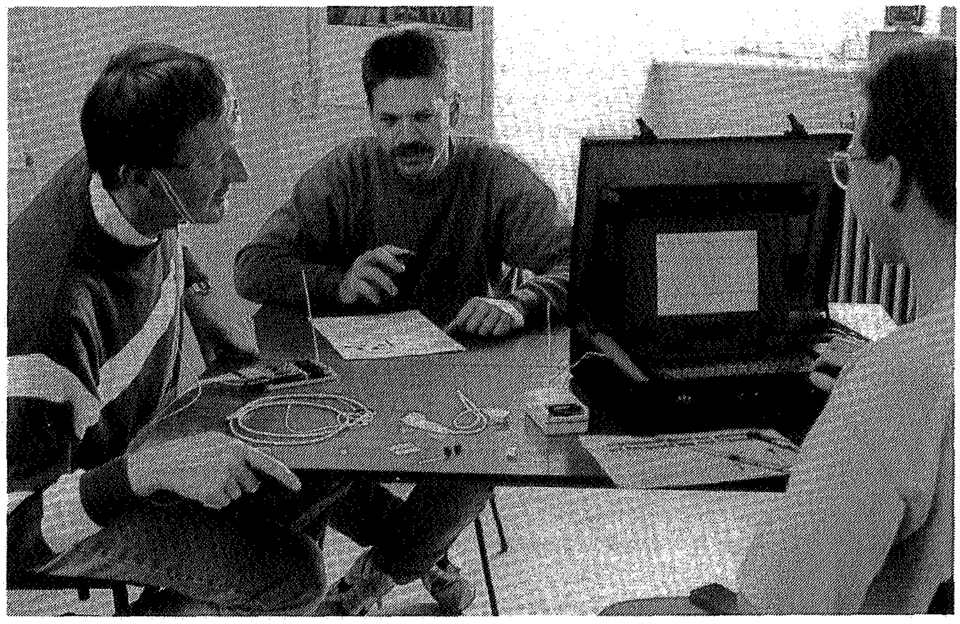


Photo 2: Telemetry system. Around the table (left to right) the authors. On the table (left to right): amplifier/transmitter with connected electrodes; remaining sensors to be connected (belts, marker, microphone, saturation, thermistor, accelerometers); receiver; and notebook PC showing EEG.

DIGITIZATION AND CODING

The 4 electrode signals and 10 polygraphic signals are sampled by 100Hz and 10Hz (interlaced), respectively. Each sample is 14 bits and converted into two serial RS232 'bytes' that are radio transmitted to the notebook PC.

NOTEBOOK SOFTWARE

A Turbo-Pascal program reads the RS232 'bytes' from a standard port, detects the radio link, synchronizes time and channels, and copies the digital signals to a datafile according to a recently developed standard format (Kemp et al 1992). Simultaneously, it displays the signals.

DISCUSSION

The addition of respiration and movement sensors allows a further shift from clinical to paperless home recording of sleep. When compared to the cassette recorders, we expect better reliability and quality as well as greater flexibility because the electrode preamplifiers were improved, and because most mechanical parts were moved to the digital part of the system.

On all, still few, occasions where we tested the assembled system, high-quality EEG, EOG, EMG and ECG were recorded immediately on the notebook screen. The weakest point of the system seems to be the radio link. Depending on the distance, radio wave reflections can sometimes cause the signal to drop out for a few seconds.

The project greatly enhanced our knowledge of sensors and electronics, as well as technical development facilities. Modifications for future technical or medical developments can probably be realized better than would be possible with future commercially available systems. The high dynamic range and quality of the signals, and the wireless connection to a PC, make possible some unique applications.

ACKNOWLEDGEMENTS

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