Power limitations in embedded sensors impact signal acquisition and data processing strategies

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Introduction.

Telesensing is vital in many critical military as well as civilian applications, such as gathering chemical/bio threat data, remote detection, gathering population data from large numbers of ambulatory subjects (e.g., in mapping potential infection spread, etc.), and similar applications, in effort to detect and predict trends or capture information about emergent changes on large geographical and/or population scale. Non-medical applications include sensor control and interpretation of data from sensor networks, such as shipboard sensors, automotive sensors or airplane sensor grids, where autonomous, remote sensor ensembles are needed. Such sensor networks comprise multiple individual sensing devices that must operate in autonomous mode, without maintenance for extended periods of time, and with sparse communication using minimum communication bandwidth for transmitting sensor signals or data to remote data collection points. In order to transmit data with high fidelity using low data bandwidth and minimal power, individual sensors within the network must use optimized information gathering schemes, be capable of handling unexpected interference, such as motion-generated artifacts, and limit the amount of transmitted data; all using minimum power in order to enable unattended operation over long periods of time.

Significance and scientific merit of the proposed research.

Remote collection of physiologic data from ambulatory persons is fraught with difficulties. Motion artifacts, i.e., spurious signals caused by tissue movement and intermittent contact of the sensor with the body surface corrupt and often mask the desired signal and are the most serious and most difficult to eliminate class of interference factors. Transducer or circuit thermal drift, vibrations, acoustic noise, electromagnetic interference, and other sources often produce artifact signals that are indistinguishable from the (physiologic) signal of interest. Such problems are especially acute and difficult to remedy during measurements on subjects in motion, under changing environmental conditions (e.g. water immersion, temperature swings), or extreme physical exertion, and yet these are the circumstances when reliable physiological data would be most often critical the individual's safety, performance and success of the task or mission. Many of such interfering signals are difficult to remove because they occupy the same frequency and amplitude spectrum, and are correlated with the signal of interest. Analog filtering, various methods of digital non-adaptive and adaptive filtering, transforms (FFT, DFT, wavelets), statistical methods are currently being used in biomedical measurements for the removal of powerline interference, baseline wandering, electrode noise, correlated noise, and only with partial success, for motion artifact elimination (1-19). For example, ECG signal processing techniques that result in high fidelity waveforms when originating with a relatively "clean" signal are still less than effective in removing highly non-stationary, large amplitude motion artifacts with the same spectral range as the ECG signal of interest. Moreover, these techniques almost always require either post-processing of data or the use of powerful, e.g. Pentium class processors, again resulting in high power consumption and large size (20,21). Embedding specialized DSP circuits with sensors is often impractical due to size, power and programming constraints.

Problem summary.

Fast data processing and communication often require high power, which is a limiting factor in remote, battery-powered sensors that must operate autonomously over long periods of time. Therefore, minimizing power requirements of sensor modules by implementing optimized signal acquisition, processing and transmission schemes is a prerequisite to designing remote, autonomous sensor networks.

Proposed direction of research.

We propose a method of solving motion and noise artifact problem in embedded sensors, while minimizing battery power draw and maintaining low data bandwidth, using optimized sampling strategies that limit volume of data that must be processed and transmitted from remote sensor sites to data collection points.

Implementing such methods in embedded controllers integrated with sensors will create basis for designing intelligent, adaptive sensor modules that can be networked to obtain results that up to date are not feasible with currently existing individual sensors. Research should be focused on developing reliable, small footprint, low power and robust hardware and software that provides high signal compression at sensor site, permitting reliable transmission of small amounts of data that can then be reconstituted and processed at data collection sites where ample electrical and computing power are available.

Successful implementation of such methods will enable devices that

(a) fuse data from multiple, networked, independent sensors in order to derive information about the signal of interest and to characterize interfering noise;
(b) use optimal data acquisition algorithms to sample small, optimized data sets that represent sensor signals of interest, and from which the original signal can be recovered with minimal error at remote data processing centers;
(c) provide quantitative measures of data quality and reliability based on error-minimizing optimal sampling criteria;
(d) reduce the impact of motion artifacts on the outcome of a sensor measurement by combining sensor-level signal processing with adaptive, optimal sampling of data from multiple sensors to reduce/eliminate motion

artifacts and determine reliability/uncertainty measures for the entire measurement and data communication process.

Summary

Our initial research indicates that optimized sampling can result in high (of the order of $10^2 - 10^3$) data compression with recovery error of the order of 10^{-2}, and better.
If successful, this research will enable the development of a class of reliable, miniaturized personal telehealth monitoring devices and networks that will be used by the elderly persons, convalescent patients, persons working under hazardous conditions and environments, by athletes during physical conditioning in training and by the military for protective monitoring in the battlefield.

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