Signal Quality Enhancement of MBioSigs in the Clinic

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Problem Description: Advancements in electronics and miniaturized device-fabrication technologies have enabled simultaneous acquisition of multiple biosignals (MBioSigs) from the human body both in invasive and non-invasive modes. Perhaps many of us are familiar with the scenario of a patient being admitted to the intensive care unit where several clinical-grade biosignals, such as electrocardiogram (ECG), photoplethysmogram (PPG), electroencephalogram (EEG) and esophageal pressure (P_{eso}) are monitored closely by critical care specialists. Due to the low-frequency and low-amplitude nature of the biosignals, the signals are routinely contaminated with different types of high and low frequency noise during acquisition. Contamination of the biosignals not only exacerbates the task of interpretation for doctors, but also increases the rate of false alarm. While a multitude of biomedical signal quality enhancement techniques have been proposed in the literature to date, all these techniques were biosignal-specific; the algorithms were developed based on generalizations and assumptions of the biosignal's characteristics.

Several state-of-the-art biosignal enhancement techniques have drawn significant attention in recent time. However, there are quite a few technical challenges associated with these techniques that prevent them from being used in the clinical setting. Some major challenges include: (i) dependence on pre-defined parameters and models, which can result in loss of important information if defined incorrectly, and (ii) high computational cost, which imposes limits on real-time implementation.

A biosignal quality enhancement scheme that is capable of adapting to a patient's individual MBioSigs' characteristics would prove useful in not only improving the quality of care provided to patients by their clinicians, but also as a tool used by researchers to understand the underlying physiological processes and interactions in the human body.

Design Solution: We propose a robust and high-performance data-driven signal processing tool for enhancing clinical-grade MBioSigs. Our signal enhancement tool adapts to the individual patient's MBioSigs and allows clinicians and researchers to not only gain better insights to their patient's underlying physiological processes, but also empowers them to personalize their treatment options on a person-to-person basis.

Design Rationale: Biosignals are often captured to monitor the underlying physiological processes of a certain organ system, which makes the acquisition of MBioSigs necessary to holistically assess a patient's health. However, enhancing MBioSigs can be challenging since there are two aspects to the problem that must be considered: (i) the characteristics of the individual MBioSigs, and (ii) the characteristics of the source of interference/noise.

(i) Individual MBioSigs inherently exhibits different characteristics, such as morphology/shape, because they are monitoring different processes. There is also an added layer of complexity when we consider both the inter-patient and intra-patient variability of the individual biosignals.

(ii) The sources of interference and noise vary wildly depending on which MBioSig is being monitored. While common types of noise, such as power-line interference or transducer-induced noise, are relatively easy to remove, physiological contamination caused by one organ system affecting the measurements of another organ system prove to be much more difficult.

To address the challenges associated with the wildly varying nature of MBioSigs and sources of noise and interference in the clinical setting, our proposed signal enhancement tool uses a data-driven approach that can adapt to an individual patient's set of MBioSigs - all in near-real time.

Application: As a proof-of-concept, four different types of commonly encountered noises, namely, power line interference, white Gaussian, random, and baseline wander noise were added with MBioSigs obtained from public datasets as well as from collaborating clinicians. The MBioSigs were enhanced using the proposed signal enhancement tool. Performance of the proposed enhancement tool was tested through both quantitative and qualitative distortion measures. Input signal-to-noise ratio, output signal-to-noise ratio, improvement in signal-to-noise ratio, and percent-root-mean-square difference (PRD) are used as quantitative distortion measures. Semi-blind mean opinion score test of ten evaluators has been carried out. Quality of enhanced MBioSigs were found to be 'good' as per the Gold standard error criteria. Figure 1 shows the workflow of the tool's implementation in the clinic, while Figures 2 to 4 shows the performance of the proposed enhancement tool on three types of biosignals.

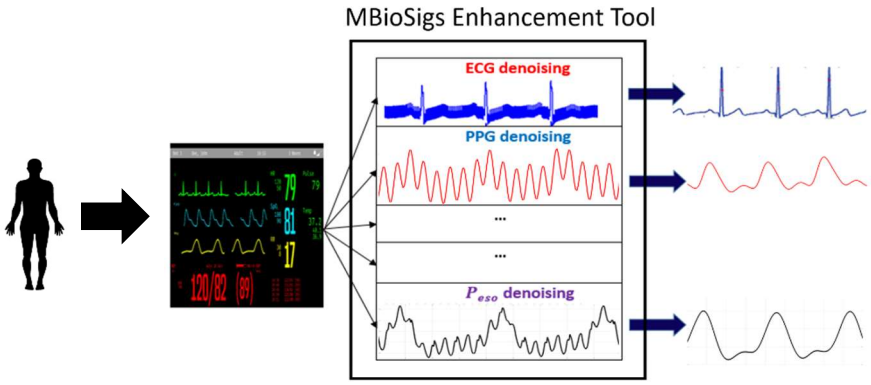

Figure 1: Implementation of the proposed biosignals enhancement tool in the clinic.

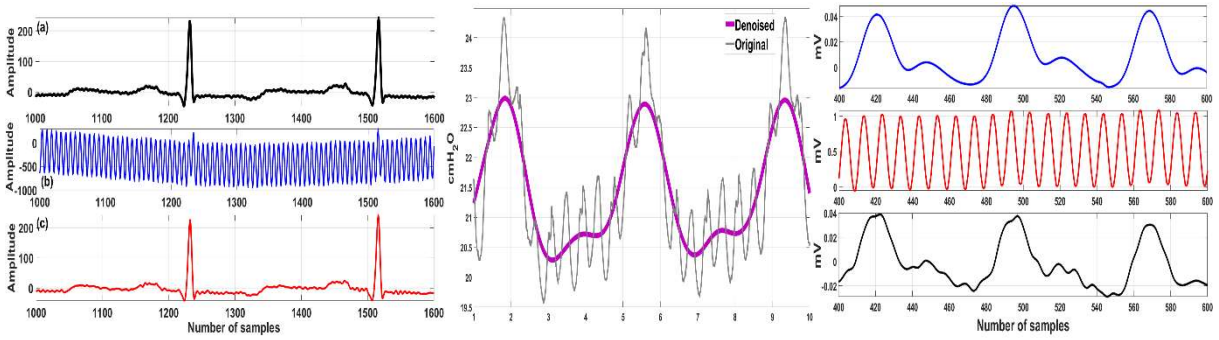

Figure 2: Left image: Top→ Acquired ECG, Middle→ Noisy ECG, bottom→ enhanced ECG, Middle image: noisy and enhanced P_{eso} on top of each other, Right image: Top→ Acquired PPG, Middle→ Noisy PPG, bottom→ enhanced PPG,

Implementation: At its present setting, the proposed MBioSigs signal enhancement tool has been tested on three different types of signals: ECG, PPG and P_{eso}. The main advantages of using this proposed technique are: (i) the parameters are made adaptive to the sampling rates of different biosignals, and therefore the technique does not require any manual intervention, and (ii) the proposed technique is a model-free/function-independent method of signal enhancement. It is possible that the proposed tool could be adapted for enhancing other biomedical signals exhibiting periodic or quasi-periodic nature such as EEG, which may be helpful in other areas of clinical research. Although the proposed signal enhancement tool has shown to be robust, there is still a lot of testing to be done. To further tweak our tool, we will need to test on other types of clinical-grade biosignals from a wide variety of patients. In addition to testing, we will need to consult with domain experts to ensure that our enhanced biosignals are viable for clinical use.