Abstract

Electrodermal Activity or simply EDA is the bio-electrical activity observed on the human dermal surface. The activity is recorded in the form of responses due to electrical stimulus, known as exosomatic EDA or in the form of potential differences without any electrical stimulus, known as endosomatic EDA. Exosomatic EDA signals are mostly recorded for psychophysiological assessments of human being, though physiological information can be captured more accurately using endosomatic EDA.

Differential dermal potential or DDP signal is a specific type of endosomatic EDA that has been proposed recently and is finding uses in various applications. The DDP is the potential difference between two adjacent active sites on the skin surface without any electrical stimuli, typically the intermediate phalanges of the index and middle fingers of hands and feet. This signal has initially been acquired using the commercially available RISH Multi 18S multimeter based data acquisition system (DAS). This DAS is capable of acquiring low voltage signals (in order of 10μV) from multiple locations simultaneously with moderate speed, good accuracy and acceptable precision. It also has optical isolation to provide electrical safety. However, its major limitations are the lack of compatibility of its computer interface software Rishcom 100 with Windows 7 onwards updated OS platforms and its lack of portability, specially when the number of channels are more.

In view of this, two other advanced acquisition systems (Advantech USB-4704 and Keysight LXI) have been tested in this study but these did not perform as expected. Advantech USB-4704 lacks the required accuracy as well as precision, while the Keysight LXI lacks in portability and consumes much power. Along with that, it is unable to acquire data with required sampling speed in high resolution.

The limitations of the RISH Multi 18S based system and the unsuitability of the other two systems tested led to the calibration and testing of a dedicated 4-channel data acquisition system that was designed and developed indigenously by Somen Biswas, a co-author in [1], in the same research laboratory in which the present study is done.

A standard protocol has been developed in this work for balancing and calibrating the 4-channel DAS. This starts with a preliminary static calibra-

tion of the 4-channel DAS to estimate its nominal performance. Thereafter, for the balancing of the 4 channels, the addition of error curve method is employed after comparing its performance with those of the inverse slope multiplication and spline fitting methods. A comparison of the calibration results of the RISH Multi 18S and the balanced and standardized 4-channel DAS show that both these systems exhibit comparable performances. Thus, while both these systems have been used in the present work, the preferred system is the 4-channel DAS due to its enhanced portability and updated interfacing abilities.

In order to fulfill the multiple objectives of this present study, four (4) specific experiments have been designed and conducted to acquire 4 different data sets for 6 applications in total as listed hereafter. The data sets collected from these experiments are labelled henceforth as DS1, DS2, DS3 and DS4, while the terms LH, RH, LL and RL denote left hand, right hand, left leg and right leg respectively.

Experiments : DS1: DDP signals are acquired from only LH for 20 minutes which include 2 minutes in sitting posture, then 2 minutes during change in posture from sitting to supine and last 16 minutes in supine posture

DS2: DDP signals are acquired from LH and RH of supine subjects for 10 minutes

DS3: DDP signals are acquired from LH, RH of subjects for a specific set sequence: supine for 4 minutes, then sitting and then standing for 2 minutes each. This is followed by a no recording 1 minute activity session. Then subject sits again and DDP signals are acquired till a specified condition is met.

DS4: DDP signals acquired continuously from LH, RH, LL and RL of supine subjects for 10 minutes

Applications : Application1: Validation of the DDP signal by comparing it with standard recommended endosomatic EDA signals (golden reference) using DS1 dataset

Application2: Study unilateral characteristics of DDP signals using DS2, DS3 and DS4 data sets

Application3: Study bilateral characteristics of DDP signals using DS4 data set

Application4: Classification of hypertensive and normotensive subjects using LH and RH of DS2

Application5: Classification of different postures using LH of DS1 and both LH and RH data of DS3

Application6: Determination of the effective duration of rest in supine posture from LH of DS1, both hands data (LH and RH) of DS2 and all 4 channel data (LH, RH, LL and RL) of DS4 data sets and in sitting posture from both hands data (LH and RH) of DS3 data set

In Application1, the DDP signals have been validated by establishing the physiological basis and comparison with 2 standard endosomatic EDA signals as well as their difference signal. Since this signal is recorded in the DC mode, hence it is inferred from the standard RC model of the skin that this signal primarily records the differential information communicated by the nerve endings or the capillaries in the dermis and hypodermis, rather than the sweat gland activity recorded in usual EDA signals. The autocorrelation functions (ACF) of these differential signals confirmed that these signals are non-random signals originating from inherent time-varying processes. It is further verified that these signals are stable with settling times typically within 2 minutes, thus validating their usability in real-time applications.

Application2 deals with the unilateral characterization of these signals for which all the LH, RH, LL and RL signals from the DS2, DS3 and DS4 data sets have been clubbed together into their respective classes. The characteristics of these 4 classes of acquired signals were studied, followed by a study of their mean values and then the study of the (mean subtracted) debiased signals. The aspects studied include their polarities, trends, statistical, linear regression and spectral characteristics. A significant finding is that the spectral moment SM1, which can be considered as the gain-bandwidth product (GBP), are almost identical indicating that a constant GBP is maintained in the system.

Application3 deals with the study of the bilateral characteristics of the hand and feet signals using the DS4 data set. The aspects studied include the trends of signal pairs, study of the derived bilateral signals, Gap and Pair Sum (PS), as well as the interdependence of both the hand signals and both the feet signals.

Based on the characteristics studied, two bias parameters have been proposed in this study, namely differential bias μ_{diff} and common mode bias μ_{cb}, to quantify the hemispheric dominance between the bias of acquired signals. Furthermore, 4 other bilateral parameters using the debiased signals have also been proposed in this study, namely the ratios of the zero crossing instants (ZCI_{ratio}), the ratios of the slopes (m_{ratio}), the debias ratio (DR_k) to represent the instantaneous behaviours of the debiased pair of signals and the log SD ratio (ξ_{sd}). All these proposed parameters have been statistically characterized for hands as well as for feet signals.

Finally, three different human condition monitoring applications have been presented in detail. Application4 pertains to hypertensive and normotensive subject classification, Application5 to different posture classification and Application6 to the estimation of the effective duration of rest. In Application4 and Application5, the attribute selection and classification have been done in WEKA version 3.9.4 using the random forest (RF) classifier using all the unilateral as well as the bilateral parameters studied in Application2 and Application3 along with two additional derived features, namely normalized variance and normalized kurtosis. However, mainly spectral characteristics have been studied for the assessment of rest duration in Application6.

In Application4, DS3 data has been used for classification of hypertensive and normotensive subjects. Attribute selection filter selected only 5 attributes among all, of which 4 are bilateral parameters. However, the most preferred attribute for differentiating hypertension is the SD of the left hand. It is to be noted that while the SD is indicative of the random variations in the signal, the LH signal is from a location that is physically closer to the heart than the RH signal. Although the classification results are significantly low at 75% in comparison to existing methods based on ECG, which can differentiate these classes with accuracies well above 90%, yet the minimal subject discomfort during its acquisition using the simple 10 minutes rest protocol and the simplicity of the protocol that allows even nominally skilled health workers to handle this procedure can be useful for primary monitoring and screening purposes.

In Application5, sitting and supine postures have been classified almost flawlessly using the relevant 2 minute subsets of the LH signals in the DS1 data sets, while a 3-level classification of supine, sitting and standing postures have also been done fairly accurately at 80% using the relevant subsets of the DS3 data sets. In both cases, the mean, ZCI and slope m of the signals are the major chosen attributes.

In Application6, the *effective* duration of rest of no-nap supine subjects has been estimated using all three data sets DS1, DS2 and DS4 based on the maxima of the system entropy. It is inferred from this study that if a subject maintains a supine posture typically for 4 to 6 minutes, it provides effective rest to the system. This result differs significantly from the other results of effective duration of rest, which are typically based on short nap condition. The same study done on subjects in sitting posture in the DS3 experiment show trends but are not conclusive, possibly since the acquisition was not continuous but was stopped after every 2 minutes.

Thus it can be concluded that the differential dermal potential is an unique signal, which is similar but not identical to the difference between respective endosomatic EDA signals. These can be acquired reliably using both RISH Multi 18S ans and 4 channel DAS in well designed, yet simple experimental protocols. It is further validated that their various statistical, spectral, linear regression and other characteristics are useful in screening hypertensive and normotensive subjects, classifying posture changes as well as estimating effective duration of rest.