ABSTRACT

The concept of regular and continuous monitoring of health condition and timely delivery of healthcare has gained more importance for the past few decades. The primary step to reach this objective is possible by recording the vital signs (Heart Rate, SpO2, Respiration Rate, Blood Pressure, etc.) using the Multi-parameter Patient Monitors in the clinical setting to assess the health condition of an individual.

One of those vital signs that are dealt with utmost importance is the blood pressure. Blood Pressure (BP) is the pressure experienced by the blood vessels due to the pulsating blood flow from the heart. It carries valuable information about the physiological properties of the circulatory system. Hypertension, the condition of raised Blood Pressure is one of the predominant factors that is highly associated with the population affected by cardiovascular-related ailments. The behavioral risk factors like the trending lifestyle, level of physical activity and sleeping patterns lead to complications like the chronic heart failure, arrhythmias, stenosis, and atherosclerosis gradually increasing the blood pressure and therefore progressing to multiple organ damage. The early detection and control of BP can reduce the above- mentioned risks which require the continuous, user-convenient and accurate BP measurement systems.

The conventional gold standard BP measurement techniques include the intra-arterial BP monitoring and cuff-based BP monitoring. The former method though provides beat-to-beat BP values; it is invasive causing patient discomfortness and inapplicable for out-of-clinic settin8gs whereas the latter is convenient for home/ ambulatory monitoring yet doesn't yield for continuous monitoring. The other alternatives like tonometry and volume clamp methods though satisfies the objective of non-invasive continuous monitoring, the cost, use in controlled settings and the need of frequent calibration with the gold standard method limits its usefulness as home monitoring systems.

The vital signs obtained from the patient monitors are the result of processing of biological signals that are acquired using various sensors connected to the patient. These biosignals (bio-physiological signals) that can represent the hemodynamic functioning of the circulation system may also contain information relating to the blood pressure variations. Recent research in the field of biomedical signal processing suggests that the information derived from these biosignals can be well utilized to develop the beat-to-beat cuffless BP estimation systems.

One such parameter that is of great interest is the Pulse Arrival Time (PAT) that is computed using the characteristics points from Electrocardiogram (ECG) and Photoplethysmogram (PPG). The studies showed that the correlation between PAT and BP was higher and hence can be used to estimate BP on a beat-to-beat basis. But this method suffers from two limitations of the need of frequent calibration with the conventional method and time synchronization of two signals for the accurate computation of PAT. Further, the multiple signal acquisition not only obstructs the subject's daily routine but also results in incorrect parameter extraction, thus deteriorating the performance of the BP estimation system.

The research now extends to find methods to use a single biosignal that can be sufficient enough to estimate BP continuously. This not only overcomes the limitations posed by multi-signal processing but also establishes a trend for wearable technologies. In particular, the PPG signal that indirectly represents the pressure variations in the form of blood volume changes has not been fully explored for its use in BP monitoring.

This thesis presents the various data-driven approaches with Photoplethysmography that can be implemented for the continuous cuffless monitoring of blood pressure. The first work presented is the linear regression BP prediction model with PAT and two prominent PPG features that are assumed to represent the hemodynamic factors of the systemic circulation. The models are implemented and tested by using the publicly available databases like the Multi-Parameter Intelligent Monitoring in Intensive care (MIMIC) and Queensland University database that house the biosignals recorded from bedside monitors. This model is also extended by using the beat-to-beat changes of these features as input to track the BP changes. The model is validated with the error measures, Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) computed with the actual and predicted BP. According to the standards established by Association of Advancement in Medical Instrumentation (AAMI), the MAE ± RMSE should be within 5 ± 8 mmHg. The system is clinically acceptable only if it complies with the standards.

The linear model relating the BP and PPG holds good for a shorter period beyond which is affected by subject dependent factors. The performance of the model can be improved by including the possible PPG features as they are resulted due to the vascular resistance of the arterial system and the forces exerted by the blood flow. But the linear model with all features results in data overfitting and condition of multicollinearity (high correlation within the features). Though the use of non-linear algorithms is encouraged to get the minimal error, its implementation is hard concerning hardware and computational complexity. The thesis presents a technique of building the ensemble of linear regression system where feature subsets are generated based on correlation factor and models generated from these subsets are selected for the ensemble based on information criterion indices. The system has the advantage of combining the predictions of multiple models in place of a single model to estimate BP.

Further, this thesis also presents the application of sparse coding of PPG pulse wave and features with K-SVD technique as means of feature extraction process and data mapping to higher dimensional space. The K- SVD method which forms an over-complete dictionary of basis vectors with PPG as input is used to generate the sparse vector to characterize the pulse wave. The sparse vector is taken as features, and regression model with random forests algorithm is created for continuous monitoring of BP. This methodology outperforms the previously proposed method with MAE ± RMSE of 4.61 ±5.66 mm Hg for systolic BP and 2.61 ± 3.27 mm Hg for diastolic BP.

Next significant contribution to the thesis is the improved system for the beat-to-beat estimation of BP using the BP class separation approach. This approach is a two-step process where the first step classifies the given input feature vector along with the subject characteristics (age, gender, height, weight) into 4 classes based on recommended BP ranges. The second step creates four regression models based on the training instances from each class. The classified data points are fed to their corresponding regression models for BP estimation. This system outperforms the previously proposed methods and existing methods by presenting a considerable reduction in the MAE ± RMSE of 4.22± 6.43 mmHg for Systolic BP and 3.2 ± 4.73 mm Hg for Diastolic BP. Further, the proposed system is subject independent and prediction on new data gives reduced error irrespective of the trained data. The use of patient characteristics along with the physiological information increases the prediction capability of the system.