

Abstract

The fact that a third of people's lives are spent inside of a bed indicates the essential character of sleep. While some people might opt voluntarily for sleep deprivation, others don't get to choose. Their healthy pattern of sleep is disrupted due to sleep disorders such as sleep apnea, insomnia and restless legs syndrome. Most clinical diagnoses revolve around the presence of complaints of excessive daytime sleepiness. People however usually wait quite long before contacting professional help, and might only do so when complaints have gone from minor to serious. It can be argued that people with minor complaints will have negligible compliance to rather obtrusive therapies, and should also not be treated with pharmaceuticals. Cognitive and behavioral therapies have however proven their effectiveness for clinically diagnosed patients, and might thus also enhance the quality of life for people with minor complaints. Contrary to the rather invasive therapies, cognitive and behavioral therapies can be quite low-cost (and thus cost-effective). Current methods for objective diagnosis of sleep disorders are however too costly, impractical and intrusive, or lack sufficient information and/or accuracy, to be used for long-term screening or follow-up after diagnosis. This PhD work hypothesizes that automated cardiac, respiratory and movement-based analysis could be able to bridge this gap, especially when all signals are monitored off-body in a mechanical way.

The first part of this work investigates the ability to use cardiac, respiratory and movement activity for sleep monitoring in healthy subjects. Using a dataset of 85 nights, several classification models were built to distinguish between Wake, REM, light sleep (N1-N2) and deep sleep (N3). The models were trained with and validated against gold standard polysomnography annotations, derived by sleep experts. Relevant characteristics of the cardiac, respiratory and movement activity are outlined, and limitations and prerequisites of the model discussed. The large amount of variability in heart and lung functioning among different subjects led to difficult-to-avoid misclassifications. Still, agreement values around 80% and kappa values around 0.60 confirm the potential of the method.

The second part of this work investigates the ability to use cardiac and respiratory activity for sleep monitoring in subjects with sleep apnea. Using a dataset of 70 nights, a classification model was built to distinguish between apneic and healthy breathing episodes. This model was again trained with and validated against gold standard polysomnography. Agreement values around 90% and kappa values around 0.80 show great potential of the method. Using a second dataset of 25 nights, containing a high proportion of hypopneic events, a similar classification model led however to agreement values around 75% and kappa values around 0.30, stressing the possible need of oxymetry for reliable detection of hypopneic events. The presence of apneic events also proves to have a significant impact on sleep stage classification model performance, with agreement values dropping to around 70% and kappa values to around 0.40. While the proposed probabilistic representations of the classification model outputs (referred to as the hypnogram and apneagram) are a valuable addition by visualizing uncertainty of correspondence, further improvements might be necessary to make cardiac and respiratory-based sleep monitoring in subjects with sleep apnea reliable.

The third part of this work investigates the ability to monitor cardiac, respiratory and movement activity in an off-body mechanical way. A pressure-based ballistocardiographic setup was implemented inside of a bed, measuring pressure difference fluctuations between two air volumes underneath the chest area of the subject. While respiratory and movement activity can be easily detected, cardiac signal quality varies between postures as well as persons. An adaptation of the Pan-Tompkins algorithm is proposed for accurate detection of cardiac inter beat intervals. The setup and algorithm were evaluated on a dataset of fifteen subjects lying in the four standard sleeping postures. In between episodes of movement activity, an average correspondence of 97% with respect to inter beat intervals detected by electrocardiogram proves the potential of the method.

In conclusion, this PhD thesis supports the opportunity of a biomechanics-based approach in sleep analysis, although its accuracy might be insufficient towards detection of minor early problems. Future work should evaluate whether overall accuracy of sleep stage analysis and apneic breathing detection is sufficient for diagnosis of potential (early) sleep disorders, based on information from multiple nights in a row. Furthermore, specific analysis should be performed towards insomnia and periodic leg movement disorder, which was not included in this thesis.