# Mathematical modeling of the human circadian rhythms through wearable devices

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*Abstract*

Circadian rhythms are fundamental to all aspects of physiology and behavior, ranging from cellular dynamics to work performance. Measuring circadian phase has mostly been achieved in carefully controlled laboratory conditions. The development and ubiquitous presence of smartphones and wearable devices have made it possible to passively detect and collect information of user behavior and health. Here, we discuss different methods developed to measure circadian phase from wearable devices in the real life settings. First, we examine tools to estimate phase from noisy data, which shows that existing approaches such as cosinor analysis and cross-correlation produce biased estimates when missing data are consecutive. A simple modification of the least squares approach is then proposed to avoid such bias, and its computational efficiency makes it more favorable to use in practice. This method allows us to estimate phase from heart rate or activity data. Next, we present mathematical models of the human circadian clock, with different types of data collected from both research-grade and consumer-grade wearable devices. We then discuss using activity, which is recorded in almost every wearable device, to predict circadian phase in the real life settings. Finally, we present an application and extension of models of the circadian clock. Coupled with optimal control theory, these models can be used to provide optimal schedules to adjust the human circadian clock in daily life.