Evaluation of Oxa's R-Peak Detection Algorithm.

A product evaluation project

NANOLEQ

Abstract Heart rate variability (HRV) and heart rate (HR) are essential bio-markers for assessing autonomic nervous system (ANS) activity and monitoring changes in physiological and psychological states. Nanoleq AG has developed an advanced R-peak detection algorithm to improve the capabilities of the Oxa smart-garment. This project aimed to evaluate the algorithm's performance and compare it with state-of-the-art methods and additionally a widely used heart rate belt. We observed that Oxa's R-peak detection outperforms traditional algorithms. It showed better true positive and false negative scores at rest, walking and during different activities. The belt struggled especially under very dry skin conditions.

Introduction Heart rate variability (HRV) is a valuable metric derived from electrocardiogram (ECG) signals that provides insights into ANS activity and stress levels. Existing R-peak detection algorithms have limitations in robustness and sensitivity to noise and artifacts. Nanoleq AG has developed a robust, real-time R-peak detection algorithm to address these challenges. This report evaluates the algorithm's performance and robustness, comparing its performance with six highly cited R-peak detection methods on available open-database sets and in real-time recordings. In addition, the algorithm was compared to a commercially available and widely used heart rate belt.

Method and Results The evaluation utilized two publicly available ECG databases: the Glasgow University Database (GUDB) and the MIT-BIH Arrhythmia Database. These databases, with annotated R-peaks, served as references for comparing the performance of different R-peak detection methods. The Neurokit tool was used for R-peak detection of the six highly-cited algorithms (Neurokit, Pan-Tompkins, Hamilton, Christov, Engzee, and Rodrigues) embedded in the Neurokit database.

To evaluate performance of the Oxa algorithm in comparison to the state-of-the-art, true positive rate (TPR) and false positive rate (FPR) were used as measures of accuracy. The results demonstrate that Nanoleq's algorithm outperforms classical methods, showing higher accuracy and robustness (Table 1, Figure 1). The algorithm's improved false positive rate makes it more suitable for detecting arrhythmia.

In a next step, ECG data was recorded using Oxa in a subject with arrhythmia to evaluate the algorithm's efficiency during abrupt changes in activity. For additional comparison, the volunteer was also wearing commercially available tracking devices (on PPG basis). The collected Oxa ECG signal was analyzed using both Nanoleq's algorithm and the state-of-the-art algorithms implemented in Neurokit. The results indicate that Nanoleq's algorithm and the commercially available device show high consistency in measuring RR values during activities (Figure 2), while the results indicate that the Neurokit algorithms missed some R-peaks in the presented condition (Figure 3).

To further challenge the algorithm and assess its robustness, the analysis was conducted under suboptimal ECG recording conditions. Data was collected of a volunteer with especially dry skin. As in the previous condition, the volunteer wore the Oxa and the commercially available heart rate belt for comparison. In addition, the ECG signal was analyzed using the different algorithms mentioned above. The results indicate that Nanoleq's algorithm provides more reasonable heart rate values for the given condition and protocol, despite the strong artifacts present in the ECG signal (Figure 4).

Conclusion The evaluation results demonstrate that Nanoleq's R-peak detection algorithm performs equally or better than state-of-the-art methods in terms of accuracy and robustness. The algorithm's accuracy, robustness, and resilience to noise and artifacts make it a valuable addition to the Oxa product. The algorithm shows promising potential for improving HRV analysis in well-being products.

Table 1: Nanoleq algorithm in comparison to state-of-the-art methods

	Glasgow University										MIT-BIH Arrhythmia		Total	
	jogging		walking		hand bike		maths		sitting		rest		all activities	
	TPR	FPR	TPR	FPR	TPR	FPR	TPR	FPR	TPR	FPR	TPR	FPR	TPR	FPR
Neurokit	0.966	0.012	0.998	0.001	0.992	0.011	0.999	3e-4	0.998	3e-4	0.959	0.049	0.985	0.012
Pantompkins1985	0.886	0.100	0.835	0.057	0.892	0.097	0.866	0.056	0.740	0.019	0.910	0.066	0.854	0.066
Hamilton2002	0.960	0.030	0.986	0.032	0.974	0.046	0.996	0.003	0.998	5e-4	0.942	0.058	0.976	0.028
Christov2004	0.957	0.096	0.996	0.122	0.971	0.201	0.998	0.045	0.998	0.120	0.929	0.331	0.974	0.152
Engzeemod2012	0.715	0.129	0.862	0.195	0.786	0.319	0.853	0.119	0.840	0.202	0.940	0.113	0.833	0.179
rodrigues2020	0.854	0.028	0.978	0.023	0.971	0.041	0.981	0.000	0.985	0.000	0.926	0.048	0.949	0.023
Nanoleq	0.981	0.021	0.998	0.001	0.992	0.007	0.999	0.000	0.999	0.000	0.960	0.038	0.989	0.011

Figure 1: The plots from top to bottom are as follows: (a) ECG signal for a subject in GUDB while they were jogging, (b) Heart rate calculated using annotated R-peaks as a reference, (c) The measured heart rate by Neurokit algorithm as the best classical method, (d) The measured heart rate by Nanoleq's algorithm.

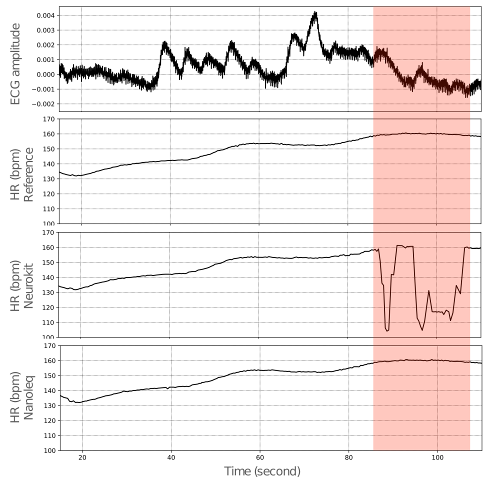

Figure 2: The green and red highlights demonstrate resting and running on treadmill phases according to the protocol, respectively. The plots from top to bottom as follows: (a) ECG signal for a subject with arrhythmia, (b) RR values measured by a widely used heart rate belt, (c) The measured RR by Neurokit algorithm as the best classical method, (d) The measured RR by Nanoleq's algorithm.

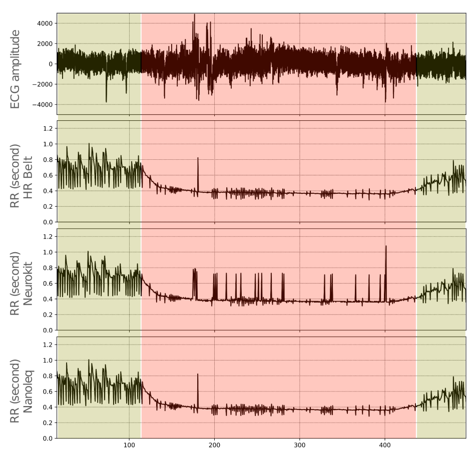

Figure 3: A snapshot of an ECG signal of a subject having arrhythmia and running with the detected R-peaks using Nanoleq (top) and Neurokit (bottom). Red dots are the detected R-peaks, and red ellipses indicate the missed R-peaks.

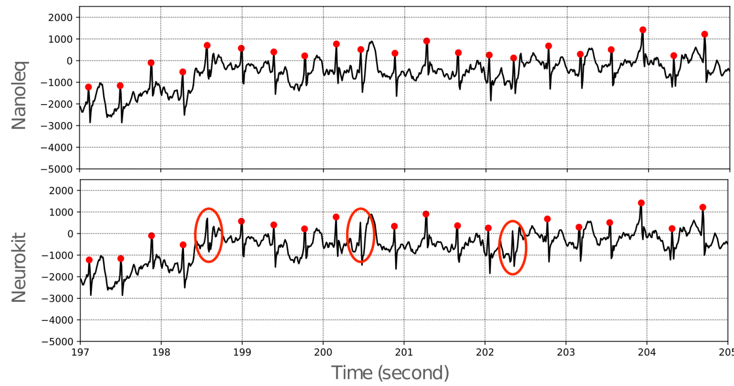

Figure 4: The green and red highlights demonstrate resting and running on treadmill phases according to the protocol, respectively. The plots from top to bottom as follows: (a) ECG signal for a subject with dry skin, (b) RR values measured by a widely used heart rate belt, (c) the measured RR by the Neurokit algorithm as the best classical method and (d) the measured RR by Nanoleq's algorithm.