# Quantifiable Fatigue Risk Assessment Using a Non-Invasive Multi-Sensor Wearable Device

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## Introduction

Fatigue assessment has been a widely investigated topic in past years. Several ways to detect and estimate fatigue exists based on surveys or physiological measurements. The Swiss Federal Office of Sport is interested in an alert system to prevent severe incidents related to fatigue in soldiers and other physically demanding professions. Heart rate (HR) and heart rate variability (HRV) are relevant indicators in various wearable devices. However, it is currently not well known how HR and HRV are affected by both an individual's physiological and psychological states. This project aims to integrate multiple non-invasive sensors into a single device to estimate fatigue. Physiological measurements are collected and subsequently analysed. Proof of concept for collapse and heat exhaustion estimation were also investigated.

## Materials and Methods

Traditionally, HRV is measured with a chest belt. However, in the military, soldiers prefer to wear sensors on the upper arm because of comfort. Therefore, the proposed embedded system is integrated into an upper arm strap. Furthermore, a well founded decision tree was established, obtained from multivariate data analysis, establishing the basis of the fatigue estimation algorithm. HR, HRV, HRV's standard deviation, and skin temperature means were considered in the algorithm design.

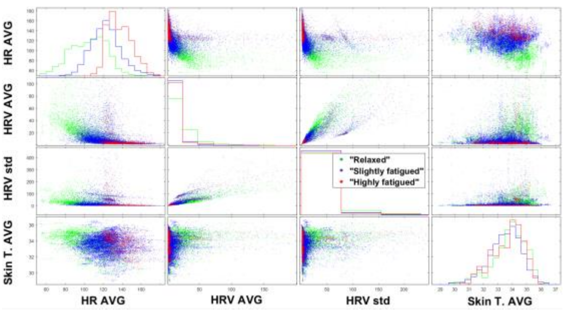


*Fig. 1 Four measured variables are considered for the classification model. The green points correspond to the "Relaxed" classified, the blue to the "Slightly fatigued", and the red to the "Highly fatigued".*

An embedded wearable device was developed composed of ECG, PPG, accelerometer, IR temperature, and several environmental sensor types. Furthermore, a proof of concept concerning measuring the respiration rate (RR), and the blood pressure estimation are established. ECG signals were found to be weak on the upper arm. Thus, three different electrodes with differences in the surface morphology, skin attachment, and produced pressure against the skin were tested.

## Results

The multivariate data analysis showed that multiple variables could lead to reliable fatigue estimation. The cross-validation classification error of the model used is 0.3. This corresponds to a model precision for fatigue estimation of 70%. The resulting algorithm was tested, and the comparison between the model and the survey information led to a model's accuracy of 89%. The overall wearable device is compact and ergonomic, allowing for accurate ECG R peak detection when sitting, walking, lifting, and stepping. PPG HR and $SpO_2$ detection is more prone to motion artefacts during movement. Use of an accelerometer proved to successfully remove all perturbed signal segments. The nickel-gold-plated electrodes showed more satisfactory results concerning R peak detection than the other solutions showing higher SNR, greater comfort, and less complexity.

*Fig. 2 The prototype consists of the overall electronics, sensors, flexible housing, an elastic band.*

## Discussion and Conclusion

ECG and PPG measurements on the upper arm can monitor HR, HRV, $SpO_2$, and all the extracted variables including PAT, RR, and blood pressure. The results showed that measuring physiological parameters could lead to reliable fatigue assessment. Optimisation regarding both algorithm and prototype are suggested before the validation phase.

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