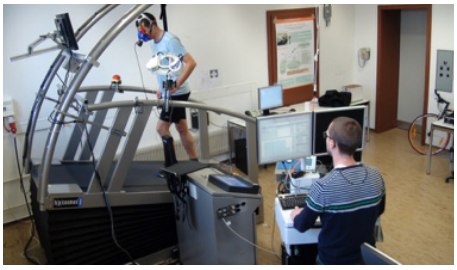
Bern University
of Applied Sciences

Research Group
IRPT – Sports Engineering
Treadmill and Physiological Control Systems

Project Description

Within the field of high-performance sports, it is common practice to evaluate an athlete›s physical training status by carrying out a «max-test» on a treadmill or cycle ergometer. The aim is to take the athlete gradually to their limit of functional capacity, i.e. to exhaustion, over a short period of time.

Cardiopulmonary exercise testing delivers two key outcomes which describe the functional status of the heart and lungs: the Gold Standard for describing the limit of aerobic capacity, which is obtained from a max-test, is the maximal oxygen uptake (V›O2-max); the maximal heart rate, HR-max, is also recorded.



When using a treadmill, the speed and slope are gradually increased with the aim of reaching maximal performance in around 10 minutes. The athlete has to run on the treadmill while the exercise intensity gradually increases, until he signals that he has reached his limit and can no longer continue – the test is then terminated.

The IRPT has applied its expertise in control systems engineering to develop an automatic positioning system for the treadmill: with this system, the runner can freely choose his own speed. The runner's position on the treadmill belt is continuously monitored and the feedback system automatically adapts the treadmill speed to keep the runner at a desired position.

Self-Paced Max-Test

This approach allows a so-called «self-paced» max-test to be implemented, potentially resulting in higher peak V›O2 and HR values.

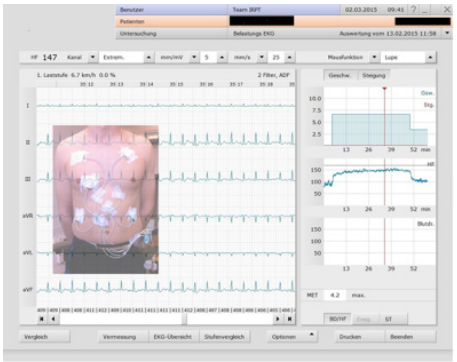
V›O2-max is measured using a breath-by-breath spirometry system which involves the athlete wearing a face mask and a heart rate chest belt. The volumetric rate at which oxygen is taken up at the lungs (V›O2) and carbon dioxide is expelled (V›CO2) are measured. V›O2-max gives a direct indication of the body›s ability to extract oxygen from the air, and to transport it via blood circulation to the muscles doing the work during exercise: doing this well depends on the integrative capacity of both central and peripheral physiological systems, including the heart, lungs and muscles.

Training Intensity and HR Control

The reason measuring V›O2-max is important is that, because it reflects the efficiency of interactions between the cardiovascular, pulmonary and neuromuscular systems, it gives a very direct indication of the athlete›s overall fitness. This information can be used in two ways: to assess the effects of a training programme over time, by periodically re-evaluating V›O2-max; and to prescribe an appropriate level for training intensity, because this is often recommended to take place at a certain frequency and duration and at some percentage of V›O2-max, HR-max or HR-reserve.

To allow the implementation of high-precision training protocols which use heart rate prescription, the IRPT has developed automatic HR control system both for the treadmill and for outdoor running.

A fundamental difficulty in HR control is to ensure the HR tracking is precise, but at the same time that unwanted oscillations in the speed command do not occur. Using ECG measurements and spectral analysis techniques, the IRPT has carried out a pioneering investigation of very-low-frequency heart rate variability, and has used this information to design robust, stable and high-accuracy HR control systems.



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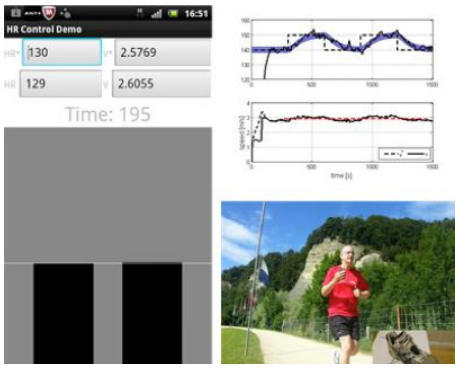
To implement feedback control of HR during outdoor running, the IRPT has employed smartphone and wearable sensor technology. This allows HR and running speed to be monitored in real time: a control algorithm running in the smartphone then updates a speed command signal displayed to the runner to make sure the target HR is maintained.



This work has shown that, even during outdoor running, very precise tracking of HR profiles can be achieved, with root-mean-square tracking errors of less than 2 beats per minute.

Implementation potential

The application of state-of-the-art feedback control technologies has extended the maximum achievable performance during treadmill testing, and has made feasible the implementation of accurate and specific training programmes during both indoor and outdoor exercise.

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