



## THEMATIC PRIORITY

## AN AMBIENT INTELLIGENCE SYSTEM TO SUPPORT TEAM TRAINING IN CYCLING

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*In den letzten Jahren werden vermehrt hoch entwickelte Technologien eingesetzt, um das Training im Radsport zu unterstützen. Parameter wie Leistung, Geschwindigkeit, Puls werden nicht nur im Hochleistungsbereich, sondern zunehmend auch im Freizeit- und Breitensport online während des Trainings erfasst und zur Optimierung der Belastung des einzelnen Sportlers herangezogen. Obgleich der Fokus im Radsport hauptsächlich auf der Leistung des einzelnen Athleten liegt, wird im Training auch häufig in der Gruppe gefahren. In einer typischen Teamkonstellation hängt die Beanspruchung des einzelnen Fahrers von der Position in der Gruppe und bedingt u. a. durch Führungswechsel vom Leistungszustand der gesamten Mannschaft ab (Neumann, 2000). Zur Optimierung des Gruppentrainings wurde ein Team Cycling Training System (TCTS) entwickelt, das auf einem kommerziellen Leistungsmesssystem basiert und über eine funkbasierte Kommunikation alle Fahrer miteinander verbindet. Basierend auf Trainingsvorgaben und aktuellen Messwerten für jeden einzelnen Sportlers wurde ein Algorithmus entwickelt, der durch Führungswechsel und Geschwindigkeitsregulation das Training für die gesamte Gruppe so optimieren soll, dass individuelle Abweichungen von der vorgegebenen Leistung und Herzfrequenz minimiert werden. Neben physiologischen und biomechanischen Leistungsparametern wird das subjektive Beanspruchungsempfinden anhand einer BORG-Skala (Borg 1998) erfasst und bei der Trainingssteuerung berücksichtigt. Nach den bisherigen Ergebnissen mit dem ersten Prototyp könnte das TCTS vor allem in Bereich des Nachwuchstrainings erheblich zur Effektivierung des Trainings beitragen.*

Schlüsselwörter: Radsport, Informationstechnologie, Messplatztraining, Feedback, adaptive Software-Architektur

*In recent years, sophisticated technologies have been developed to support the training in cycling. Professionals as well as an increasing number of recreational cyclists monitor parameters such as power, speed, or heart rate to adapt the training load according to the actual physical state and to improve performance. Although the focus is primarily on the performance of the single athlete, cycling in teams is a very common method in training. In a typical team constellation, the load of each cyclist depends on the position within the group as well as on the level of performance of the whole team (Neumann, 2000). A Team Cycling Training System (TCTS) has been developed that is based on a commercial powermeter and provides a Wi-Fi communication between all cyclists. Based on predefined exercise intensities and dynamically collected status data an algorithm has been developed to improve team training such that each cyclist is as close to his individual exercise intensity as possible. The TCTS adjusts training parameters, for instance by advising the group to change the formation or to increase or*

*decrease the speed. Besides physiological and biomechanical parameters subjective sensations are measured on a BORG scale (Borg 1998) and considered for the optimization of the training load. According to the preliminary results with the first prototype, the TCTS might be considerably support a more effective cycling training, especially for youth athletes.*

Keywords: cycling, information technology, feedback training, adaptive software architecture

## Introduction

In recent years, sophisticated technologies have been developed to support the training in cycling. Commercial powermeters such as SRM™, Ergomo™ or Powertab™ are meanwhile part of the standard equipment of professional cyclists, but also used by an increasing number of recreational cyclists. These systems provide long time measurement and storage of heart rate, speed, cadence and especially pedal power during training and competition. Hence, performance-related data of the most crucial parameters are available to direct and control the training. Further, actual values of these parameters are monitored online which helps the cyclists to train close at their planned intensity. Especially for athletes on a high level of performance, a deliberate regulation of the training load is of particular importance to improve performance and prevent overtraining (Jeukendrup & van Diemen, 1998; Lindner, 2005).

The power exerted on the pedal can be considered as an objective and reliable indicator of the external load. To estimate the internal load or physical stress that results from an external load the heart rate is the widely chosen parameter, especially under conditions of training. However, the heart rate is subject to considerable fluctuations that might be caused by external conditions (temperature, height, e.g.), physical abilities and dispositions (fatigue, nutrition, health, e.g.) or technical skills (seating position, e.g.) (Gregor & Conconi, 2000; Achten & Jekendrup, 2003). During long lasting aerobic exercises with constant load also a

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cardiovascular drift of up to 15 beats per minute has been observed (Mognoni et al., 1990).

Due to these uncertainties, the heart rate must be handled with care especially during the exercise. Besides the physiological and biomechanical measures subjective sensations are considered as a reliable and highly relevant indicator for the determination of the appropriate exercise intensity (Gregor & Conconi, 2000). Athletes (as well as trainers) on a high level of expertise have developed a distinct perception of one's own body (or the body of athletes they are responsible for, respectively). They can regulate their physical stress according to the actual physical disposition or state by adapting the external load in an optimal way. Young and less experienced athletes still need to develop these perception skills. Hence, it seems promising to apply self evaluation techniques during training. Up to now, commercial powermeters or comparable technological systems in cycling do not measure subject's sensations. The RPE scale (Borg 1998) is a well known and easy-to-use method for the evaluation of physical exertion and it consist of a rating scale that is also applicable for exercise and training.

Although the focus in cycling is primarily on the performance of the single athlete, cycling in teams is very common. The team pursuit and the team sprint are standard race formats in track cycling. In road cycling, events like the team trial during the Tour de France are well known. Cyclists even train in groups, especially for long lasting training sessions (Gregor & Conconi, 2000). In a typical team constellation, a group of cyclists covers a distance of up to 200km, with a varying road profile. For best training effects, each cyclist should ride with his predetermined exercise intensity that at least will slightly differ between athletes due to individual physical capabilities and skills. While cycling in a group the speed for all cyclists must be the same, whereas the power output to maintain the speed depends on the position within the group. Because of the head wind the power output of the leading cyclist is up to 36% higher than the power output of subsequent cyclists (Neumann, 2000). In consequence, a cyclist being pulled by the leader may achieve the same speed with lower cardiocirculatory and metabolic efforts. To improve team training such that each cyclist is as close to his individual exercise intensity as possible, the cyclists might regularly change positions, adjust the speed of the whole group or arrange their positions according to individual differences in exercise intensities (e.g. Lindner, 2005; Schmidt, 2001)

An ambient intelligence system has been developed to support the training of a group of cyclists. Ambient Intelligence represents an "intelligent environment", which reacts in a sensitive and adaptive way to the presence of humans and objects in order to provide various services to people (Litz, Wehn & Schürmann, 2004). The technological basis is a network of computing nodes; which collect and process information using various sensors in order to interact, to influence or to alter the

environment accordingly. The objective of this system is (1) to improve training for the single athlete considering physiological and biomechanical data as well as subjective sensations and (2) to improve team training such that each cyclist is as close to his individual predetermined exercise intensity as possible.

In this paper, the focus is on the basic concept of a Team Training Cycling System. A first prototype has been established that is described in the following sections. Though this system has been applied under conditions of training, it also serves as a platform on which further technologies as well as applications for training will be developed.

### Team Cycling Training System

The Team Cycling Training System (TCTS) consists of hardware components, a software system and an algorithm to direct and control the training as well as a simulator for ergometer training (fig. 1).

#### Hardware setting

Each bicycle is equipped with a powermeter (Ergomo™) and an Ultra Mobile Personal Computer (UMPC). The cable connection between the Ergomo™-System and the UMPC has been established via the serial port (RS232). Actual sensor data of the heart rate, speed, cadence und power serve as input data for the training control algorithm which is maintained by the software system. All UMPCs are connected among each other using Wi-Fi technology forming an ad-hoc network. With this hardware setting, the system runs under field or outdoor conditions.

Alternatively, the bicycles can be mounted on ergometers (Tacx™ T1680 Flow) for indoor training. The processing of real sensor values as well as conversion of control variables of the eddy-current brake that result of the force information generated by a simulator are done on a control board. These boards are connected via CAN-Bus with an external computer on which the simulation software runs.

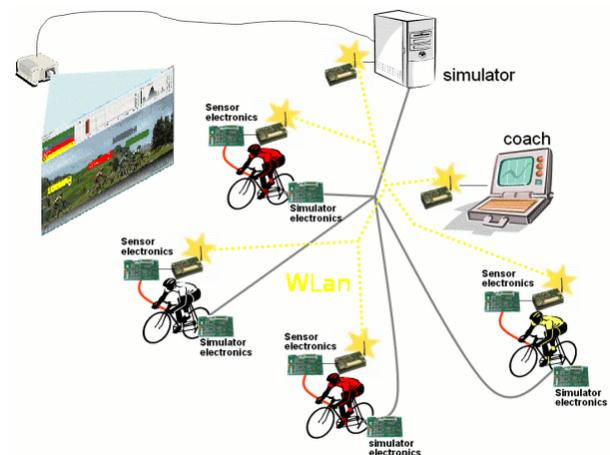


Figure 1. Diagram of the Team Cycling Training System including the simulator for indoor training.

## Software Architecture

To keep the training control application very flexible, it is based on a service-oriented software architecture (SOA) (Bartelt et. al., 2005). Therefore, this application consists basically of all services offered by the available system components. The quality of the services can range from the simple delivery of sensor values to the complex computation of new training parameters. In terms of SOA, system components may be hardware components, like a pulse sensor or a PDA, as well as software components like a training control algorithm. Each component offers at least one service but may offer a large number of services. To be able to offer a service, a component may need several other services offered by other components. The training control algorithm, for instance, offers new training parameters (like the sequence of the cyclists) based on several sensor values offered by differed sensor components.

Each service is identified by its software interface only. An interface describes what kind of service it represents and how to use this service. Thus, it is not necessary to know the exact type or vendor of a specific service to use it. This allows a flexible usage of several hardware configurations. For example, the training control algorithm needs the current power the cyclist pedals. Due to the service oriented architecture, the training control components searches for a component that offers a "current pedal power delivery" service. Regardless of the vendor or brand of the power meter used by the cyclist, the training control component uses the available service based on its interface only. This flexible exchangeability of hardware is necessary since we cannot assume that all cyclists use the same components like pulse sensors or power meters.

This flexibility is enabled by a so called configuration service which manages and orchestrates all services within the system. Every component registers services it offers and services it needs at the configuration service. Then the configuration service automatically connects the services accordingly. For example, the training control algorithm component registers at the configuration service, stating that it needs a pulse sensor service, a power sensor service, and many services more in order to offer the current training parameters. The Configuration Service determines automatically the best set of services (if there are several services with the same interface) and connects them.

Additionally, components can use several services with the same interface in parallel. For example, the group training algorithm needs input data from all cyclists currently participating in the training session. Therefore, it simply has to state during registration at the configuration service that it wants to use all available data services from all cyclists. The configuration service connects them automatically.

Different configuration sets allow the components, and thus the system, to be more flexible. For example the training control algorithm compo-

nent could offer a very simple control based on a basic set with only the pulse sensor as needed service and the more advanced control set, containing the power sensor as well as a needed service. This enables a flexible configuration at run-time since the configuration service checks for better configurations and notifies the application if applicable. Therefore it is possible to change the configuration (for example, introducing a new sensor) without changing the software or restarting the system.

As the configuration process is performed during run-time of the system, components can easily be added or removed. Thus, new cyclists can join an established training group, or a single cyclist can leave the group. In both cases, the re-configuration is performed automatically without user interference. Thereby, it is easily possible to switch between single training and group training, for example if a cyclist meets another cyclist during a training session. If both want to form a group, they can simply switch to group training without stopping and reconfigure the system manually.

A cyclist mainly interacts with the training application via a graphical user interface (GUI) displayed on the touch screen of the mini PC (see figure 2). The GUI is able to display all currently available sensor values (like pulse, power, speed, etc.) and training parameters (recommended position within a group, target pulse corridor). Each cyclist can personalize the sensor values currently displayed using the touch screen of the mini PC. Every visual message is displayed in the upper large message panel of the GUI and additionally supported by an audio signal. This is very important, as during training the cyclist has to concentrate on his environment and cannot always focus on the GUI. Important messages are for example "Go faster!", "Slow down!", "Take the lead!".

After starting the training the main manual input will be the current "Rating of perceived exertion (RPE) (Borg, 1998). Therefore, the cyclist uses the



Figure 2. For each cyclist, heart rate ("Puls"), power ("Leistung"), cadence ("Trittfrequenz") and time as well as the position are monitored on the touch screen of the UMPC. On top, feedback as well as advice from the TCTS is displayed (e.g. "Drive slowly"/"Fahren Sie langsamer"). The bottom line shows the current rate of perceived exhaustion on the Borg scale. With the two buttons on the left and the right, cyclists can adjust their rating.

large arrow buttons on the lower left and lower right of the GUI to easily adjust the RPE.

### Training control algorithm

In the following the single training control which serves as a basis for the group training control is described. An individual training plan composed of training phases is given as input for the system. Every phase is described by its duration as well as the cadence the cyclist should pedal, the power exerted on the pedal and the expected heart rate during this phase. These target values define the exercise intensity and can be derived as example by an incremental cycling test.

The primary task of the TCTS is to control the cyclist's heart rate by controlling the target power of every training phase. A range of tolerance for each parameter is defined in advance. If the difference between actual and target values exceeds the range of tolerance for a given time, the exercise intensity will be decreased or increased, respectively, by adjusting the target values. The range of tolerance, latencies as well as the gradient for the adaptation of exercise intensity can be adjusted individually.

The effect of the training control algorithm might be explained by two examples. If a cyclist is above the upper threshold of the heart rate tolerance corridor for the current training phase over a period of 30 seconds, the target power will be decreased by 10 Watt (example 1). The cyclist now cycles with lower power and the heart rate should decrease. If the cyclist's heart rate remains above the upper threshold, the system lowers the value again. This procedure will be repeated until the target value is reduced to 80% of the initial value. Then the TCTS will not lower this value even if the heart rate is still too high. The system reacts in the opposite way every time the cyclist stays below the lower threshold of the heart rate corridor for 30 seconds. The athlete will be advised to cycle at a higher speed by increasing the target value for the power (example 2).

The group training control is based on the single training control that is described above. A group must be formed by a minimum of two cyclists. The group control maximizes the training effect of every single cyclist within the group while keeping the group together. The optimal group speed is calculated by minimizing the sum of differences for all cyclists between the target values of their initial training plans and the new target values of the group. Moreover, the formation of the group (e.g. cycling in one or two rows) as well as the positions of each cyclist within the group are determined.

As set of rules has been specified in hierarchical order to optimize the group training if a cyclist's sensor values exceed the tolerance corridor:

1. Change the cyclist's position: The new position is calculated in a way that the cyclist's heart rate will move towards the tolerance corridor. A cyclist will be sent to front when his values are lower than the tolerance corridor and vice versa.

2. Change the formation: If at least two cyclists are overstrained for a longer period of time and even after change of position, and at least two cyclists are not challenged enough for a longer period the formation should be changed ordering the cyclists in two lines for minimizing the load difference between front row and back row cyclists

3. Adapt the group speed: If either all cyclists are overstrained or all cyclists are not challenged enough for a longer period of time and the previous rules did not help, the group speed has to be adapted accordingly.

All data gathered during the single or group training are stored persistently and can be used for evaluations afterwards.

Based on the examples for the single training control the control algorithm for the group training will be explained in the following. The cyclist in example 1 might cycle in leading position whereas the cyclist in example 2 follows in second position. Then the leading cyclist will be advised to change into a rearmost position to exploit the slipstream and the second cyclist will take the lead. If for all cyclists the actual values exceed the range of tolerance (example 1) and the positions are changed permanently, the speed of the whole group will be adapted.

Subjective sensations are implemented as a further control parameter of the TCTS. During the whole training the system asks the cyclist frequently to enter her/his current rating of perceived exertion as feedback about her/his current physical condition. The RPE scales ranges from 6 to 20. Low values are chosen, if the physical stress that results from the applied training load is perceived as low. High values (<14) stand for a high or very high amount of perceived exertion and indicate that the athletes is exhausted or overstrained.

Every time a new value is entered the range of tolerance of the cyclist's heart rate will be adjusted as described below (fig. 3). A RPE value of 12 is assumed for normal training conditions. Different values affect the range of tolerance for the initial heart rate set point values. If the cyclist enters a value between 6 and 9 the upper threshold of the tolerance corridor will be increased one point for

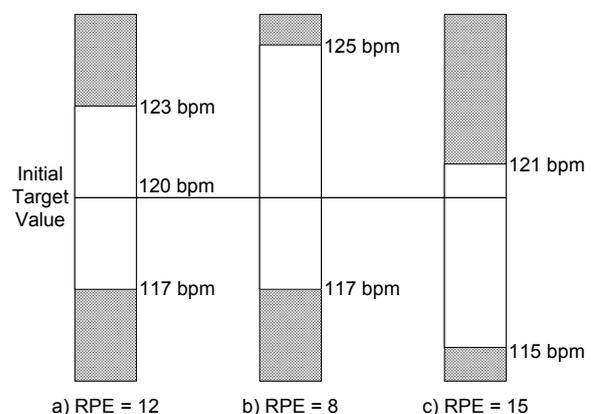


Figure 3. Influence of the rating on the Borg scale on the target values and the range of tolerance of the heart rate: (a) initial state, (b) a rating  $\leq 9$  increases the upper boundary, (c) a rating  $\geq 14$  leads to a downwards shift of the range of tolerance.

every value lower than 10 (see figure 3(b)). If the cyclist enters a value between 14 and 17 the lower threshold of the tolerance corridor will be increased one point for every value greater than 13 (see figure 3(c)). A value between 10 and 13 does not affect the tolerance corridor. If the cyclist enters a value of 18 or greater, the system recommends stopping the training. In addition, the recommended target power will be immediately set to a value that corresponds to 120 bpm according to the cyclist's personal profile. The cyclist is in the cool down phase of the training. The recommendation to stop the training will only be given if the RPE value is too high, not if the expected target power will not be reached.

### Simulation of head wind and road profile

The TCTS can also be used for indoor training. In that case, all bicycles must be mounted on ergo meters that are controlled by a simulator. This simulator has been developed to simulate environmental conditions that are as closed as possible to the conditions outdoor, e.g. while cycling on the road.

A specific road profile can be defined in advance. The simulator then calculates the influence of head wind and road profile on the pedal power at a given speed and time. Thus, the ergometer braking forces are adjusted for each cyclist differently according to the actual position within the group as well as the actual distance between subsequent cyclists.

The power generated by the cyclist can only be gathered indirectly with knowledge of speed and the imposed force or moment of crank torque, respectively. For the static case the power is derived as:

$$P = \frac{W}{t} = \frac{F \cdot s}{t} = F \cdot v = \frac{D}{r} \cdot v$$

Equitation 1.

(with  $P$  = power,  $t$  = time,  $F$  = force,  $s$  = distance,  $D$  = torque,  $r$  = radius und  $v$  = speed). The moment of torque which is the force normalized to the radius is assumed to be approximately equal at crank and rear wheel. Hence in our current experimental setup the power can only be determined with help of the ergometer which serves as adjustable brake for the rear wheel. The given formula for static values (eq.1) can be applied as the brake force at the ergometer as well as the speed is dedicated to discrete time intervals.

Based on a simplified model of physics the brake force results as the sum of dynamic friction ( $F_R$ ), the wind resistance ( $F_W$ ) and the slope dependent lift force ( $F_G$ ):

$$F = F_G + F_R + F_W^*$$

Equitation 2.

The inertial force which has to be overcome at acceleration is disregarded as it could only be derived by differentiation of the speed which would lead to immense errors. The single components of the braking force therefore are determined as follows:

(with  $m$  = mass of cyclist and bicycle,  $g$  = earth acceleration,  $\alpha$  = slope at current position,  $c_R$  = coefficient of friction,  $\rho$  = density of air,  $c_W$  air drag coefficient,  $A$  = front surface and  $v_W$  = wind velocity in counter direction).

$$F_G = m \cdot g \cdot \sin(\alpha)$$

$$F_R = c_R \cdot \sqrt{(m \cdot g)^2 - F_g^2}$$

$$F_W = \frac{1}{2} \cdot \rho \cdot c_W \cdot A \cdot (v + v_W)^2$$

Equitation 3-5.

For cyclists on subsequent positions the wind resistance can be reduced considerably due to the exploitation of the slipstream. According to Gressmann (2003) and Neumann (2000) the effects of the slipstream can be calculated by linear approximation considering the speed, the distance between two consecutive cyclists as well as the

$$F_W^* = F_W \cdot \left(1 - \sum_i c_v \cdot \left(1 - \frac{d_i}{d_{max}}\right)\right)$$

Equitation 6.

position within the group.

(with  $c_v$  = maximum reduction of the wind resistance depending on the speed (for  $v = 20\text{km/h} = 0,2$ ),  $d_i$  = distance to at most three leading cyclists, in case  $d_i < d_{max}$ , with  $d_{max} = 10\text{m}$ ,  $d_{max}$  = maximum distance to exploit the slipstream).

A particular case is cycling downhill. Because the ergometers used here are not motor driven, the cyclists cannot be accelerated. Therefore, the velocity calculated for the downhill grade is compared to the speed the cyclist generates actually. The maximum of both values is considered for the simulation.

While the athletes cycle on the ergometers, the progress of each cyclist is visualized by virtual cyclists (fig. 4). Thus, changes in the formation of the group or within the position, overtakes or breakouts can be monitored online. Additionally, for each cyclists the actual position and velocity, the covered distance as well as the distance to the next cyclists are displayed. A bar indicates to which extent each cyclist exploits the slipstream.

During the exercise all data are stored for later analysis. These data can be synchronized with the data of the TCTS, which are stored on the UMPC.

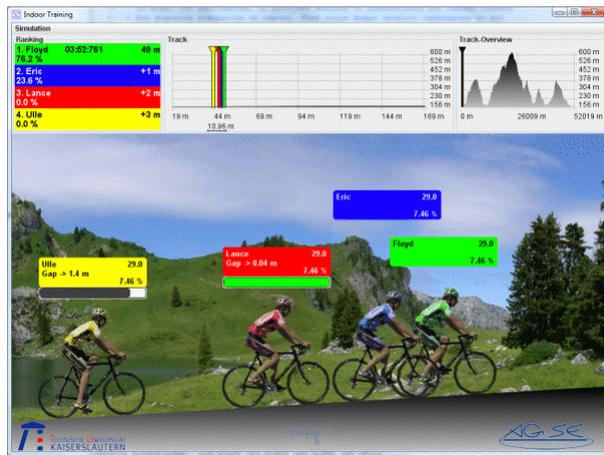


Figure 4. Visualization of the team training under indoor conditions. The actual position of each cyclist according to the track and the team mates is simulated by a virtual athlete. A bar above each virtual rider indicates to which extent the slipstream is exploited. On top, time and covered distance (left and middle) as well as road profile are displayed.

Feedback training vs. non-feedback training

In a pilot study, the effect of feedback training using the TCTS was analyzed. Subjects were competitive cyclists and triathletes with prior experience in team cycling. Team training was performed on a 20km-track, which was cycled twice at a moderate intensity on different days. During the first training session, subjects changed their position at constant time intervals of 3min (non-feedback training). They were advised to keep the speed of the team at a predefined value. During the second session, the position of the cyclists within the group, the time and order of the changes as well as the speed of the whole team was controlled by the TCTS (feedback training). Care was taken on the environmental conditions as well as on the physical state of the subjects. The training sessions were scheduled in a way that the environmental conditions (weather, wind, temperature etc) were nearly equal. Subjects did not perform any exhausting training sessions in

Table 1. Average of the heart rate, power, cadence and speed during two training sessions for subjects KG and MN. For each subjects, the results for the training without feedback (constant time intervals) and with feedback control by the TCTS are shown in the subsequent columns.

setting	subject KG		subject MN	
	constant time intervals	TCTS	constant time intervals	TCTS
heart rate [bpm]	148	143	155	152
power [W]	176	180	151	130
cadence [rpm]	92	90	81	84
speed [km/h]	26,6	26,5	26.6	26,5

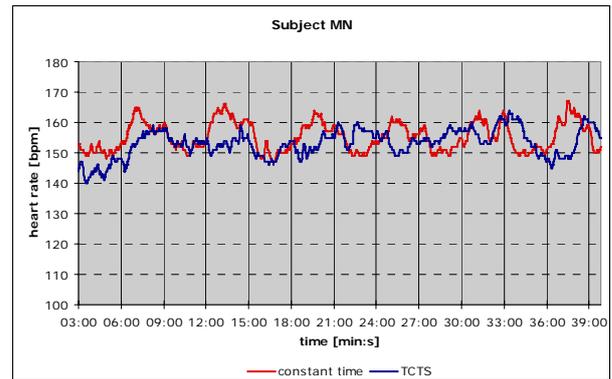


Figure 5. Heart rate of subject KG the training session with feedback control by the TCTS (blue) and without feedback (red).

the previous days and therefore they were in a good physical condition.

Average heart rate, power, cadence and speed of two subjects are shown in table 1, exemplarily. In both conditions, feedback training as well non-feedback training, the average speed was equal. The TCTS controlled training lead to a lower heart rate for both subjects. Power was decreased for subject MN compared to the non-feedback condition, whereas subject KG showed a slight increase.

The decrease of power for subject MN results from the control strategy of the TCTS. During the initial phase of the training, subjects changed their positions at time intervals of 3 min as for the non-feedback condition. When the heart rate of subject MN exceeded its range of tolerance during the leading phases, subjects were advised to change their position at short time. Overall, subject MN cycled a greater a percentage of time at a subsequent position exploiting the slipstream. Therefore, average heart rate was closer at the target value (150 bpm). Furthermore, the heart rate distribution indicates that the maximum heart rate was lower and higher values occurred for a shorter period (fig. 5).

Due to the heterogeneous level of performance within this group, subject KG performed below the desired intensity most of the time during both training conditions. Target values were only reached in a leading position. However, the power distribution indicates that due to the TCTS the percentage of high intensity phases were increased (fig. 6).

Discussion and conclusions

So far, information technologies in the area of on-line monitoring and feedback training had the major focus on the single athlete. In this paper, a new approach is presented that considers the complex interaction between individuals as well. The core item is a flexible, adaptive software architecture that supports the integration of different hardware

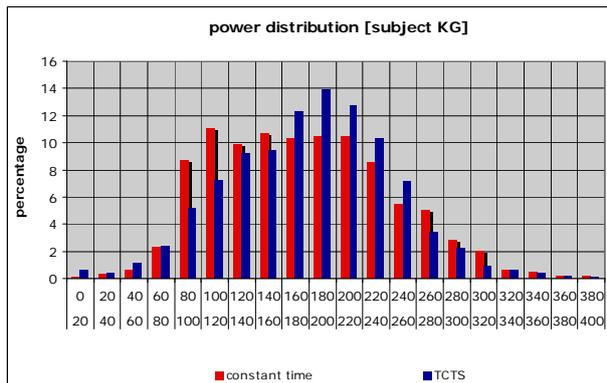


Figure 6. Percentage power distribution for subject KG during the training session with feedback control by the TCTS (blue) and without feedback (red).

(sensors, output peripherals, e.g.) and software components (training routines, e.g.) during runtime. The high flexibility offers a wide range of applications not only in cycling. As example, cyclists with different powermeters are enabled to train in one team. Further, athletes might change their sensors and peripherals as for the transitions from swimming to cycling or from cycling to running in triathlon. In this case, data collection will proceed without interruption or restart of the system. Even the spontaneous formation or splitting of cycling groups can be supported.

The first prototype of the TCTS has been applied successfully. Due to the feedback given by cyclists and trainers the TCTS can substantially support team training. The control algorithm modifies the training load already at moderate exhaustion, whereas traditionally trainers can only interfere if the exhaustion of a cyclist is quite apparent. However, there are several technical limitations. Compared to commercial cycling computers, the UMPCs are quite large. Outdoor training is restricted by battery capacity as well as weather conditions. Moreover, test runs have shown that the advice on the display might be hard to read, especially if the sun is shining. Therefore, a voice output has been implemented alternatively. Besides the integration of new sensors (GPS, inclination sensors, e.g.) future work will be on more adequate output devices.

According to the preliminary results, the TCTS including the indoor simulator as well as the feedback control system can support a more effective

cycling training. So far, further training experiments with youth athletes will be organized. However, the actual training algorithm is quite simple. In a next step, the ranges of tolerance for cyclists of different levels of performance should be optimized. Secondly, the implementation of a more sophisticated algorithm that considers the influence of cardiovascular drift and fatigue is planned (Le, Jaitner & Litz, 2007). Additionally, a comparison of different performance models such as the PerPot-Model (Perl, 2005; Perl & Endler 2006) is taken into account.

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