Poster Abstract: Non-Invasive Measurement of Core Body Temperature in Marathon Runners

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Abstract. The core body temperature is a well-known indicator of the human body's effectiveness in maintaining its operating temperature within a constant range. In case of prolonged exercise and extreme conditions, such as in Marathons and iron-man races, precise measurements of core body temperature can be used to optimize the athletic performance and detect health risks such as hypo- or hyperthermia. In this work, we developed a wireless system that unobtrusively measures the core body temperature of Marathon runners and allows to remotely monitor the performance and health of athletes during the race. After describing the design and development of the system, we report the lessons learnt during a pilot deployment on several athletes during the 5^{th} Lübeck Marathon.

1 Background

An increase in Core Body Temperature (CBT) and the onset of sweating are normal responses to physical activity [1]. An excessive heat production during exercise, however, may result in a substantial decrement of physical performance and can increase the risk of circulatory collapse. In case of prolonged exercise, indeed, an excessive heat production in combination with factors such as climate, dehydration, overdressing, and high metabolic rate, may lead to fatal conditions such as hyperthermia and heat stroke [2], [3]. In the context of marathon runs, triathlon, and iron-man races, deaths are actually not uncommon: six cases were reported for the Chicago Marathon alone over the past 14 years, and some of them were correlated to extremely high CBT [4]. Hence, it would be very helpful to accurately measure the core body temperature during exercise to guarantee the safety of athletes and to optimize their performance.

2 Goals and Challenges

Our aim is the development of a telemetric system that unobtrusively measures the CBT of Marathon runners and allows trainers to remotely monitor the performance and health risks of the athletes during the race. In order to be accepted by the runners, the system has to be non-invasive and must not impair the athletic performance.

Fig. 1. Wireless body sensor measuring CBT at the tympanic membrane.

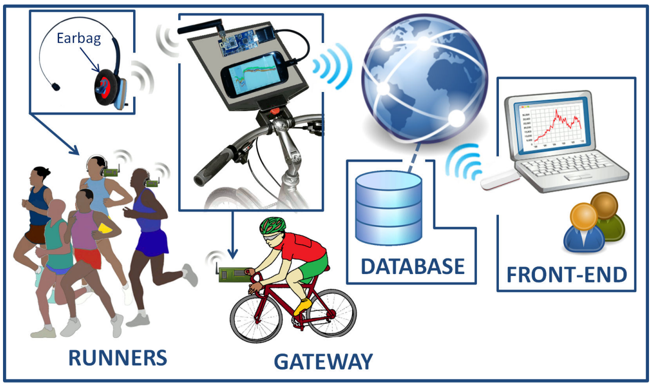


Fig. 2. Overview of the system architecture.

Therefore, differently from earlier works measuring the CBT of exercising athletes using invasive rectal probes [5] or ingestible pills [6], we continuously measure the tympanic temperature using infrared thermopiles.

The measurement of tympanic temperature is a well-established method to estimate CBT [7]. However, obtaining an accurate estimate of CBT in the presence of exercising athletes is not easy. On the one hand, the mobility of the runners may affect the placement of the sensor inside the ear. On the other hand, varying environmental conditions may reduce the accuracy of sensor readings, and this especially applies to infrared thermopiles exposed to thermal variations [8], [9].

With our study, we want to investigate the feasibility of a non-invasive wireless measurement of the tympanic CBT of marathon runners, and examine the influence of physical movements and environmental conditions such as direct sunlight or wind exposure on the accuracy of the measurements under realistic racing conditions.

3 System Architecture

We have designed and developed a telemetric system in which each runner wears an unobtrusive small body sensor that measures CBT by means of an infrared thermopile pointing at the tympanic membrane and which transmits the collected measurements wirelessly (Fig. 1). Support bikers following the marathon runners on the track are equipped with wireless sink nodes that collect the CBT measurements and forward them to a remote database with the help of a mobile phone acting as a gateway. In principle, runners can carry the mobile phone themselves inside a pocket. However, in our setup, we use the mobile phone also to record environmental conditions, and the bikers have the task of signalling any change in the surrounding environment, such as the presence of direct sunlight, wind, or shadow. In addition to environmental conditions, the mobile phone also records the current GPS position and sends these information to a remote database together with the CBT measurements. Trainers and caregivers can monitor the CBT of the athletes during the race by accessing the remote database and can immediately be alerted as soon as the risk for a circulatory collapse becomes too high. Fig. 2 summarizes the architecture of the system.

All sensor nodes use the Contiki operating system [10]. The body sensor nodes worn by the runners are 41x25 cm wide, and are based on the Atmel ATmega128RFA1 chip embedding an IEEE 802.15.4-compliant 2.4 GHz radio transceiver. CBT is measured using a Melexis MLX90614-DCA infrared thermopile with medical accuracy inserted into a Bose StayHear ear tip pointing at the tympanic membrane. Earbags are used to shield the ear from external airflow. In addition to CBT, two precision NFC thermistors are used to measure skin temperature on the outer ear and ambient air temperature in proximity of the ear, following the technique illustrated in [11]. Core body, skin, and environmental temperature are sampled every two seconds, and the data is sent to the sink nodes in groups of 10 samples. Each node is powered using a 150 mAh Li-Polymer rechargeable battery and packaged into an OKW Minitec enclosure attached to a resizeable headset that fixes the infrared thermopile inside the ear. The sink nodes are off-the-shelf Maxfor MTM-5000MSP nodes connected via USB to Google Nexus S smartphones. A custom Android application retrieves the data from the USB serial interface and forwards it, together with the current GPS position, to a remote server through the GSM network every 25 seconds. To inform the caregivers about the risks for the athletes in real-time, a Java application displaying the body temperature of the athletes and their current location has also been developed.

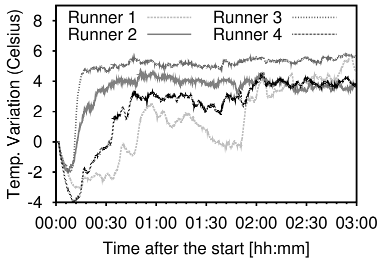
4 Pilot Deployment in the 5^{th} Lübeck Marathon

We have deployed our system on 5 athletes (2 males, 3 females) during the 5^{th} Lübeck Marathon, which took place in Lübeck, Germany, on October 2012.

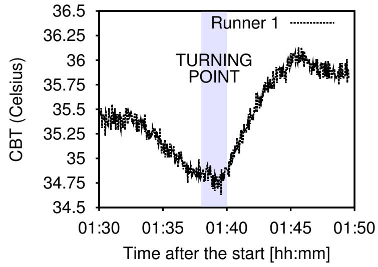
The telemetric acquisition of sensor data was flawless, and all the data was delivered to the caregivers in real-time. On average, temperature measurements were delivered to the mobile phone within 14 seconds, whereas the average delay between the reception of the data on the mobile phone and the storage on the server was 19 seconds. The connectivity between bikers and runners was optimal throughout the race, and less than 2.7% of the packets were retransmitted.

The packaging of the body sensor nodes turned out to be robust to mechanical shocks and was well-accepted by all Marathon runners. During the race, the measured skin temperature resembled the expected trend, with a sharp decrease at the start of the race followed by a continuous increase as a result of sweating (Fig. 3(a)). We also noticed that the plasters used to fix the thermistors to the skin (Physio Tape plasters commonly used in sports) lose their effectiveness after 200 minutes of continuous sweating, i.e., they began to detach after the runners approached the finish line.

The CBT measurements were significantly lower than expected, and turned out to be strongly affected by the surrounding environment. Because of the low outdoor temperature (≈12°C) and the cold wind on the track, the measured CBT was between 34 and 37°C versus an the expected range of 36-38.5°C. The impact of a cold wind blowing against the runners on CBT was very visible at the turning point at half marathon: as soon as the runners turned back and headed the finish line (and therefore were not against wind anymore), the CBT suddenly increased by roughly 1.5°C (Fig. 3(b)). This occurred despite using *earbags* to protect the ear from external airflow. We therefore plan to build a customized silicon prosthesis to further minimize the impact of wind.



(a) Skin temperature



(b) Core body temperature

Fig. 3. Evolution of the skin temperature w.r.t. the start of the race (a) and impact of the wind blowing against the runners on the CBT measurements in proximity of the turning point (b).

5 Conclusions

In this work, we have developed an unobtrusive system to measure the CBT of Marathon runners using wireless body sensors. Preliminary results from a pilot deployment on several athletes during the 5^{th} Lübeck Marathon have shown that the telemetric acquisition of body temperature during a Marathon is feasible, but further work is required to minimize the effects of the environment on the sensor readings.

Acknowledgments. This work has been supported by the DFG-funded Cluster of Excellence 306/1 "Inflammation at Interfaces", and by the EU Commission with contract INFSO-ICT-317826 (RELYonIT).

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