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VIRTUAL THERMAL MANIKIN – MATHEMATICAL MODELLING OF HUMAN THERMOREGULATION

Ziemowit Ostrowski[1]

[1] Institute of Thermal Technology, Silesian University of Technology
Konarskiego 22, 44-100 Gliwice, Poland
ziemowit.ostrowski@polsl.pl, www.itc.polsl.pl/ostrowski

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Motivation: Thermal manikins are well established research tools in human-environment interaction and thermal comfort studies since over 60 years [1]. While their constructions are better and better – currently including even such processes as breathing and sweating – they does not allow to simulate thermal physiological processes (such as active thermoregulation).

State of the art: The research on mathematical models of heat transfer in humans, started by Pennes [2] resulted in numerous works targeted in virtual thermal manikin design – being mathematical models of human thermal physiology and interaction with changing environment.

Early works on so called segment (compartment) models were based on extremely simplified geometry and covered mainly only passive heat transfer [3,4]. Later developed models were devoted on development of active thermoregulation part, focusing on precise description of changes in: non-shivering thermogenesis (metabolic heat production), perfusion of selected tissues and sweating. The number of segments used was increased as well. Review of segment type models of human heat transfer and thermoregulation is summarized in [5, 6].

In recent years the scientific effort is mostly targeted at:

- Improving of the (thermo)physiological models (i.e. neurophysiological concepts in mathematical thermoregulation models) [7,8],
- Introducing high spatial resolution in 3D whole-body models of human thermoregulation (i.e. voxel model based on real human geometry) [9],
- Accounting for individuals differences, to replace *standard* human with individualized one (i.e. including gender, health state, anthropological differences, etc.) [10, 11].

Objectives and aims: Having in mind problems with medical imaging and tissue segmentation for patient specific full three-dimensional geometry (as for case of voxel model [9]) – enhanced segment (compartment) model seems to be a reasonable compromise.

In the current research the use of segment (compartment) model [3,4,6-8] is proposed. While most of compartment models account only for one-dimensional (radial) heat conduction, the proposed solution extends this into full three-dimensional heat transfer within each segment.

Compared with the standard approach (one-dimensional heat conduction) proposed model is capable of higher spatial resolution and can be used to predict human thermal response for localized or nonuniform thermal boundary conditions.

Methods: As numerical solver the *OpenFOAM* [12] is used. This software, beeing free, open source CFD software package, offers complete freedom to customise and extend its existing functionality. The favorable feature is that it is designed to be a flexible, programmable environment for simulation by having top-level code that is a direct representation of the equations being solved.

Presented model covers both the Pennes [2] bioheat equation (passive part of heat transfer in humans) as well as thermophysiological models (active part of human thermoregulation) implemented simultanously in OpenFOAM environment.

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