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Title:

Thermal Time Constant: Improving the accuracy of skin temperature predictive modelling in Lower Limb Prostheses

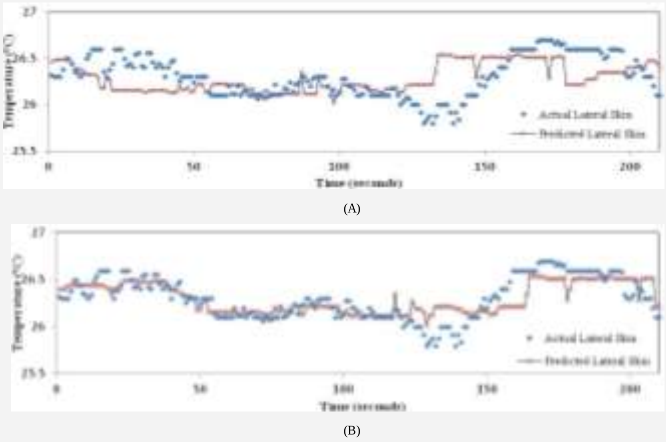
Abstract:

Background Elevated skin temperature at the body/device interface of lower-limb prostheses is one of the major factors that affect tissue health [1]. The heat dissipation in prosthetic sockets is greatly influenced by the thermal conductive properties of the hard socket and liner material employed. This leads to a hypothesis that if the thermal properties of the socket & liner materials are known then the in-socket skin temperature could be accurately predicted by measuring between the socket and interface liner, rather than at the more technically challenging skin interface.

Aim: To predict the residual limb temperature by employing a machine learning algorithm - Gaussian processes, which utilizes the thermal time constant values of commonly used socket and liner materials.

Method: In order to measure the level of thermal responsiveness of the prosthetic material, the thermal time constant is evaluated. The thermal time constant is the time it takes for a material to change to 63.2% of the total difference between its initial and final temperatures. The experimental setup included a heat source whose temperature could be controlled through a proportional-integral-derivative (PID) controller. The liner and socket materials were placed both individually as well as in combination on the heat source and the temperature at each interface was measured by K-type thermocouples attached to a data logger. The time constant of the prosthetic materials was determined using the logarithmic method and was then used in the mathematical model to time shift the data for better predictive accuracy. The materials of interest in our study are the Polyurethane liner and the Thermosetting lay-up socket material.

Results: For Polyurethane liner with a 5mm thickness, the thermal time constant was 3.1minutes. But when it was used in combination with a thermosetting socket material of 4mm thickness, the thermal time constant increased to 5.4 minutes. This implies that the choice of materials in prosthesis influences the body's inability to thermoregulate effectively. The developed Gaussian model [2] does not take into account the effect of thermal time constant of the prosthetic materials. A thermal time delay of 5.4 minutes is in built in the existing model now and as a result the accuracy of the model is improved from ±0.8ºC to ±0.5ºC.



Predictive Model of Stump Skin Temperature (A) Without the thermal delay (B) With thermal delay of 5.4 minutes

Discussion & Conclusion This study highlights the relevance of thermal time constant of prosthetic materials in Gaussian Processes technique which would be useful in addressing the challenge of non-invasively monitoring the residual limb skin temperature. With the introduction of thermal time constant in the model, the accuracy increases, thereby making prediction more reliable. For other liner-socket combinations, the thermal time constant may vary and hence model would need to time shift the data accordingly.

References: [1] J.T. Peery, "Residual-limb skin temperature in transtibial sockets," *JRRD*, Mar./Apr. 2005
[2] N. Mathur, "Skin Temperature Prediction in Lower Limb Prostheses," *IEEE JBHI*, Nov.2014, in press.