Thermal feedback interface requirements for virtual reality

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Abstract. This paper addresses thermal modeling of the heat transfer occurring between the finger skin and any explored surface. The main purpose is to develop a reliable tool that integrates temperature as part of vision and kinaesthetic feedback in virtual reality. Two models are considered.

1 Introduction

The human being is homoeothermic. This allows him to make thermal exchanges by conduction, convection and evaporation. The temperature plays a major role in tactile exploration and in the perception of surrounding objects. Our goal is to extend tactile exploration to virtual and augmented reality haptic feedback providing different touch sensations. In order to achieve efficient thermal feedback interfaces, thermal exchange models between the finger and the explored material during the contact must be developed.

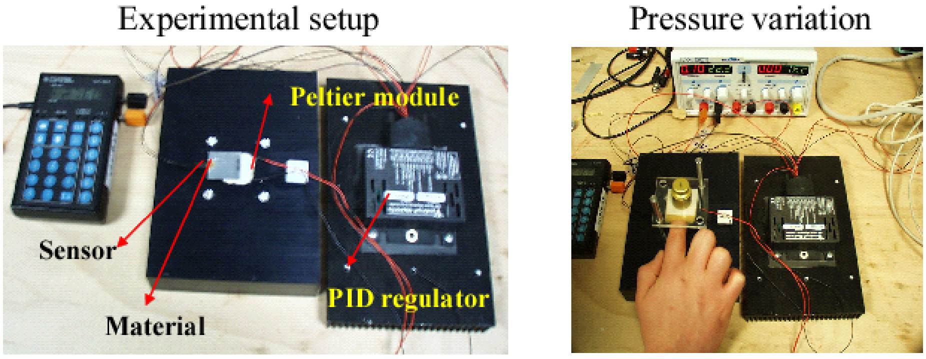
Previous research work on human thermal perception and psychophysical mechanisms involved during haptic exploration, focuses on heat and cold thresholds [1] In [2] a system called TVSS (Tactile Vision Substitution System) having eight thermodes is proposed. Caldwell et al. [3] proposed a telepresence system that incorporates thermal feedback. In [4]an ambient temperature feedback interface, based on air heating system, is described. Finally in [5] authors propose to integrate a thermal feedback (based on Peltier effect) as part of an existing force feedback system.

The concern of this paper is to model the thermal exchanges during haptic exploration.

2 Experimental Setup

In order to measure heat transfer between the finger and different types of materials, an experimental setup composed of different modules is built (figure 1). A radiator with a thermal resistance of 0.6° C/W that supports a 25 x 25 x 3.4 mm^3 Peltier effect cell that reaches a power of 18.1W at a current of 2.1A current and a maximum potential difference of 15.4V.

Different materials of similar volume and surface areas are tested (wood, glass, aluminium and copper). This choice is motivated by their thermal conductivity difference (0.18W/m °K, 0.88W/m °K, 203W/m °K, 380W/m °K respectively).


Experimental setup

Pressure variation

Fig. 1. Temperature display apparatus.

3 Thermal transfer model

First, the heat exchange inside the finger is described. Based on [6] [7], a solution that models the transfer by conduction and convection is proposed. The conduction is due to the contact of the skin with the material whereas the convection is due to the blood (thermoregulation). The global system is divided into two sub-systems. The first (SS1) is composed of the bone, blood and skin. The second (SS2) is composed of the skin and the material. In SS1, T_{s_0} denotes skin's initial temperature. The skin's thermal dissipation/diffusion is:

$$a_s \frac{\lambda_s}{\rho_s C_s} \tag{1}$$

where λ_s is the thermal conductivity of the skin(W/m °K), ρ_s is density (Kg/m^3) and C_s is heat capacity (J/Kg °K). T_b denotes the blood's temperature. The conducto-convective transfer between the blood and the skin is characterized by the coefficient h_b. SS1 is then described by the following equations:

$$\frac{\partial T_s}{\partial t} = a_s \frac{\partial T_s}{\partial y^2} \tag{2}$$

$$\vdots - \lambda_s \frac{\partial T_s}{\partial y}(t) \ \Big|_{y=A} = h_b (T_s(A,t) - T_b) \tag{3}$$

$$\vdots - \lambda_s \frac{\partial T_s}{\partial y}(t)_{y=A} = T_m \Big| \tag{4}$$

$$T_a(y,0) = T_{a_0} \tag{5}$$

Equation (2) represents the conduction effect due to skin, and equation (3) describes the convection effect due to blood. Equations (4) and (5) are temperatures at the skin blood interface and the initial skin temperature. This system takes into account the conducto-convective transfer between the skin and the blood. The solution to this system can be derived using Laplace transform.

In the SS2 case, the transfer is only conductive. To consider the problem we have to solve the thermal contact of two bodies. We suppose that the thermal exchanges are mono-dimensional (see [7]). So the two SS2 elements can be modelled representing the material and the skin by the following equations:

$$\rho_m C_m \frac{\partial T_m}{\partial t} = \lambda \frac{\partial^2 T_m}{\partial y^2} \tag{6}$$

$$\rho_s C_s \frac{\partial T_s}{\partial t} = \lambda \frac{\partial^2 T_s}{\partial y^2} \tag{7}$$

where *m* denotes the material and *s* the skin.

The thermal exchanges at the boundaries (y=0 and y=L) are zero (adiabatic). The conditions at the limits can be summarized as:

$$\vdots - \lambda_s \frac{\partial T_s}{\partial y}(t) \Big|_{y=A} = h_b (T_s(A,t) - T_b) \tag{8}$$

$$T_m(0,t) = T_{Peltier} \tag{9}$$

$$\vdots - \lambda_s \frac{\partial T_s}{\partial y}(t) \Big|_{y=B} = \vdots - \lambda_m \frac{\partial T_m}{\partial y}(t) \Big|_{y=B} \tag{10}$$

at t = 0 we have:

$$T_m(y) = T_{m_o} \tag{11}$$

$$T_s(y) = T_{s_0} \tag{12}$$

In order to see the temperature variation in time, we propose a new transfer model based on a thermo-electric analogy. This model will introduce the temperature variation between the skin and the material starting from the contact temperature value obtained from the first model. The output of model one is the input of model two.

4 Electric model for thermal transfer

The proposed model is composed of a first parallel “RC” circuit that represents the thermal transfer in one of the material parts (R_m , C_m). The other parallel “RC” circuit represents the thermal transfer between the fingertip and the remaining part of the body (R_s , C_s). Between them, a T_{ct} contact temperature between the skin and the material is introduced.

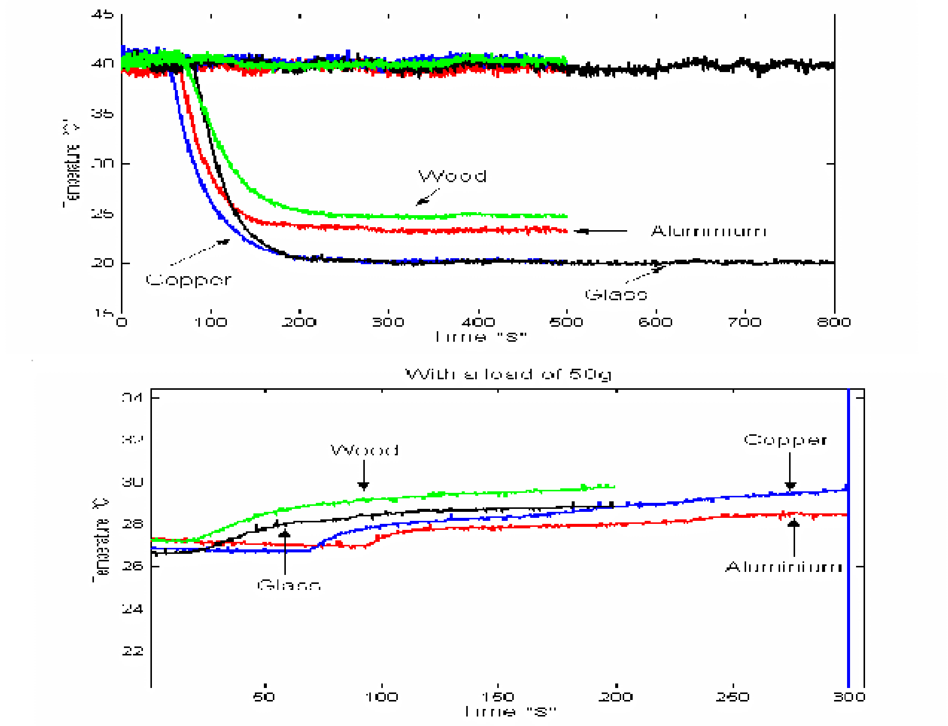


Fig. 2. Experimental cooling temperature variation for the different materials (top) and its variation at the contact point (bottom).

First R_m and C_m , the thermal parameters of a specific material, are computed. Thus we use a method that increases the temperature of each material part (we can fix this temperature to 40 ˚C) and monitor the temperature variation graph during the cooling phase. The experimental results are shown in figure 3, from which the time constant $\tau = RC$ is obtained.

	Aluminum	Copper	Glass	Wood
No load	36.91	40.89	45	56.83
Load of 50g	120	130	68	69
Thickness (mm)	1.1	1.4	0.9	2
Thermal resistance[32] (10mK/W)	0.0054	0.0037	1.023	11.111
Mass (g)	2.47	7.51	2.46	0.74

Results of the obtained constants and other parameters are listed in table 1. In order to have R_s and C_s , representing the temperature transfer model's parameters at the contact point, finger temperature variation is measured by a thermocouple positioned on the surface of the materials (see figure 3).

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