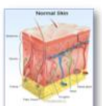
Development of an Automated Pressure Sensitive Thermesthesiometer and Its Application in Characterizing the Thermal Response of Human Tissue with Respect to Warm Surfaces

Paul Soldate, Jintu Fan

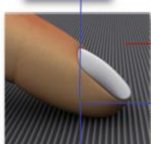
Introduction

What: An advanced thermesthesiometer has been developed to measure the heat flux, touch-force, and internal temperature profile of a simulated body part coming into contact with a warm surface. This instrument is used to characterize various materials for end-use conditions and aims to quantify potential thermal hazards in correlation with human subjective testing.
Why: Computing platforms and wearable electronics dissipate heat. It is not always possible to calculate the heat transferred to the end user since the thermal and surface properties of many electronic devices are often composed of complex composite shells or housed in materials that vary in surface texture.
How: A suitably chosen material with thermal characteristics similar to human tissue is used for bare skin simulation and is thermally regulated using a programmable logic controller (PLC). An automated driving mechanism provides variable touch-occurrences and pressures over specially engineered test-surfaces with varying effusivities and surface roughness.

Thermal Response of Human Skin

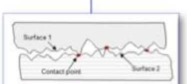


- Nerve endings reside within the dermis, at a depth of 80µm
- By the time you sense pain, the outer layer (epidermis) of the skin has already been damaged



Warm Test Surface Temperature Control

Simulated Skin Tissue Temperature Control



- The thermal response depends on the surface area over which contact occurs

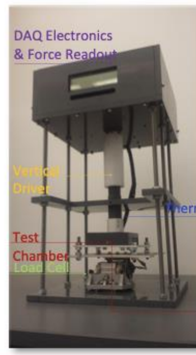
- Heat transfer between two objects is proportional to the density, heat capacity and thermal conductivity of each object, i.e. the effusivity:

$$\lambda = \sqrt{\kappa \rho c_p}$$

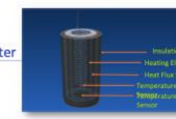
- Unfortuantely, fundamental heat flow is typically not sufficient for calculations involving surface roughness and complex composites
- A room temperature vulcanizing (RTV) silicone can be mixed with Aluminum Oxide (Al_2O_3) to obtain a weighted thermal inertia similar to that of human tissue, e.g. 60% Al_2O_3 + 40% RTV

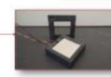
Instrumentation

This instrument includes a test chamber to secure novel composite structures for heating, Kapton (low thermal inertia) heating elements, a load cell for touch force measurements, heat flux & temperature sensors for feedback control and precision, a mechanical driving mechanism, automation and readout hardware/software for repeatability and measurement, as well as a novel silicone mixture to simulate human tissue

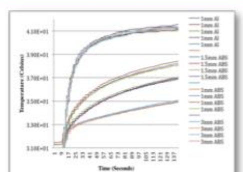


- Fixed Duty Cycle Upon Contact

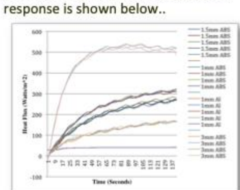




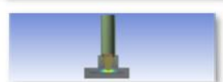
Steady-State Thermal Response

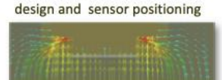


(Left) The temperature response of several test materials, initially heated to 44 ℃, contacting the simulated skin, held initially at 32.5 ℃. The legend describes each material, e.g. "1.5mm ABS" is a composite made of 1mm Aluminum underneath 1.5mm of ABS plastic. **(Below)** Similar to the temperature response paramaters given (Left), the heat flux response is shown below..

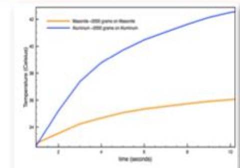


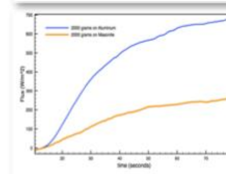
FEA (ANSYS) simulations aid in design and sensor positioning





Effusivity

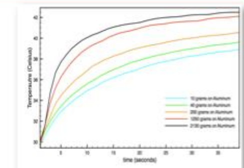


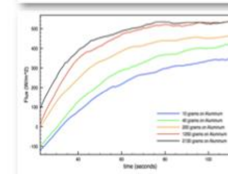


- **(Top)** Comparing the temperature response of the thermesthesiometer (regulated at 32.5°C) touching a 44°C sheet of Aluminum and Masonite. **(Bottom)** Heat flux.

$$\lambda_{Aluminum} > \lambda_{Masonite}$$

Contact Resistance





- **(Top)** The temperature response of the thermesthesiometer (regulated at 32.5°C) coming into contact with a 1mm sheet of 6061 Aluminum under several different contact forces. **(Bottom)** Heat flux.

References

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Acknowledgements

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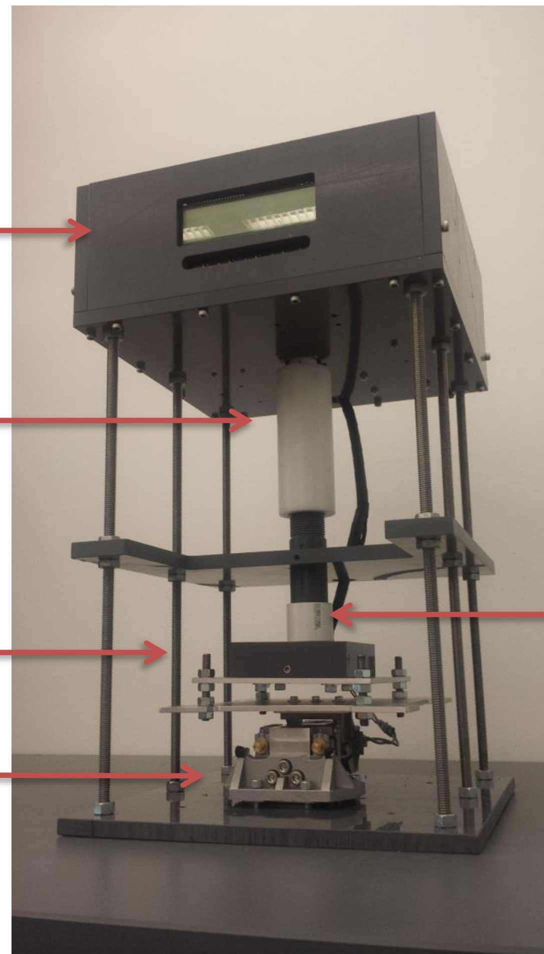
Overview

I. Heat Transfer Instrumentation for Human Factors and Composite Materials Characterization

II. Heat and Mass Transfer Instrumentation for Textiles and Smart Fabrics

I. Heat Transfer Instrumentation for Human Factors and Composite Materials Characterization: Intel Collaboration

Automated Pressure Sensitive Thermesthesiometer

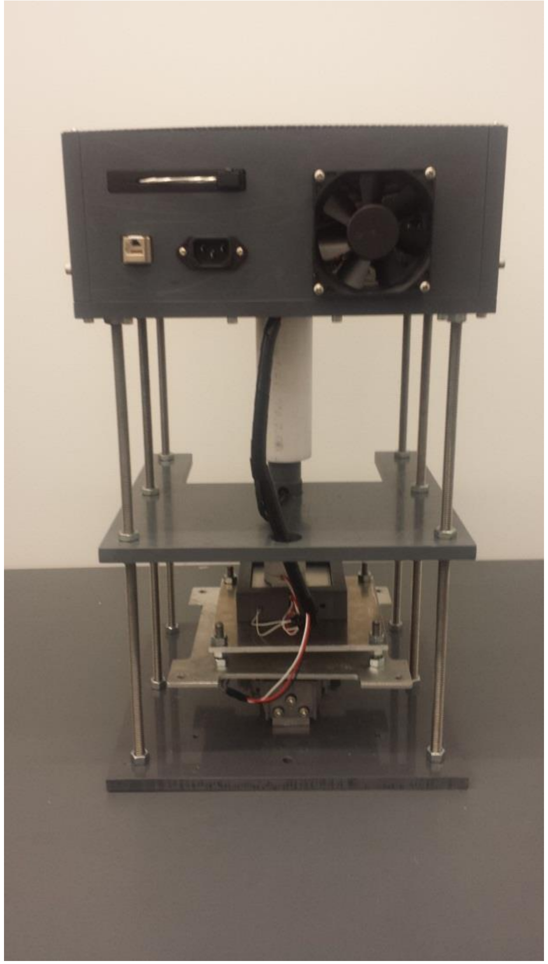


1st Tier: DAQ and Electronics

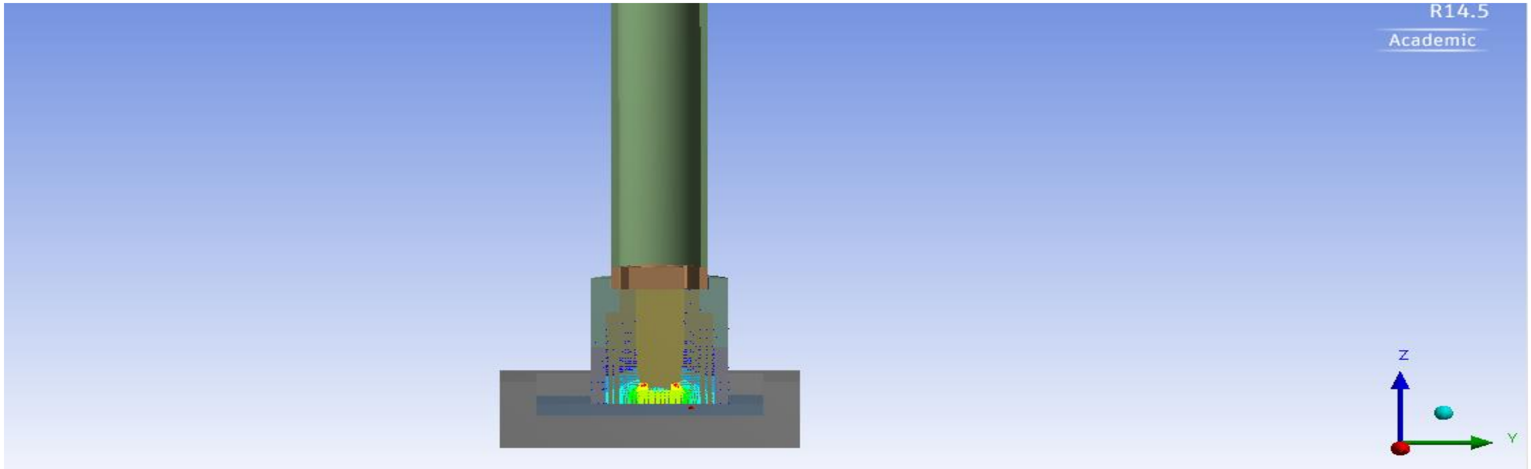
- ✓ DAQ (National Instruments)
  - Digital Out (32 Channel)
  - Analog Read (4 Channel)
- ✓ Micro-controller with Bipolar Stepper Motor
- ✓ Miniaturized heat flux sensor with $\pm$3% accuracy
- ✓ Pt100 RTD with $\pm.1$°C accuracy
- ✓ MSR45 Heat Flux Data Logger
- ✓ Solid-state Relays for PID Controls
- ✓ 12V Power Supply for Stepper and Load Cell
- ✓ 5V Power Supply for Digital Out, Relays and Microcontroller
- ✓ Cooling Fan
- ✓ Kapton, resistive heating element (21^{0}C - 200°C)
- ✓ Load Cell (0 to 6000 grams $\pm.1$g)
- ✓ Housed in a PVC shell:
  - .5'' thick walls
  - Low enough conductivity k = $.19\frac{W}{mK}$

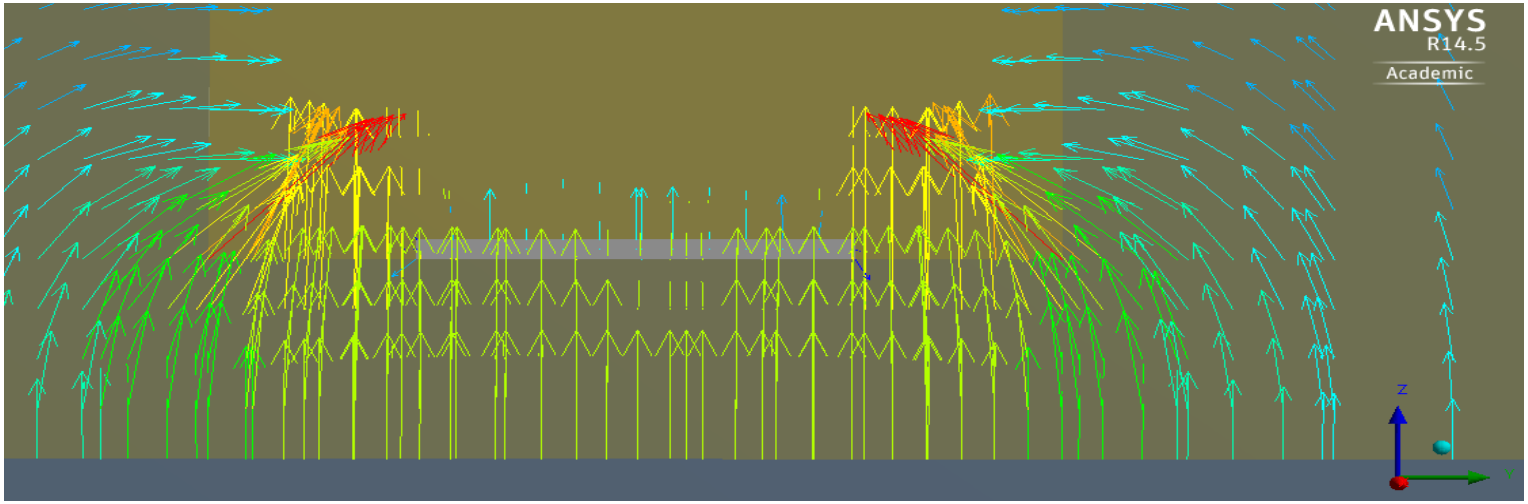
Top and Posterior

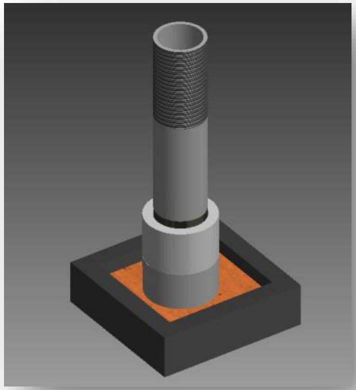
- ✓ Breathable grating for air circulation
- ✓ USB Hub for heat flux sensor data and uploading code to the micro-controller.
- ✓ Ethernet Cable for DAQ System
- ✓ Power Outlet



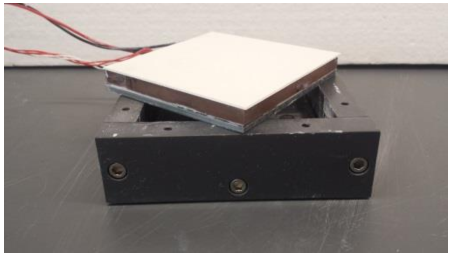
ANSYS Simulations Done to Aid in Design

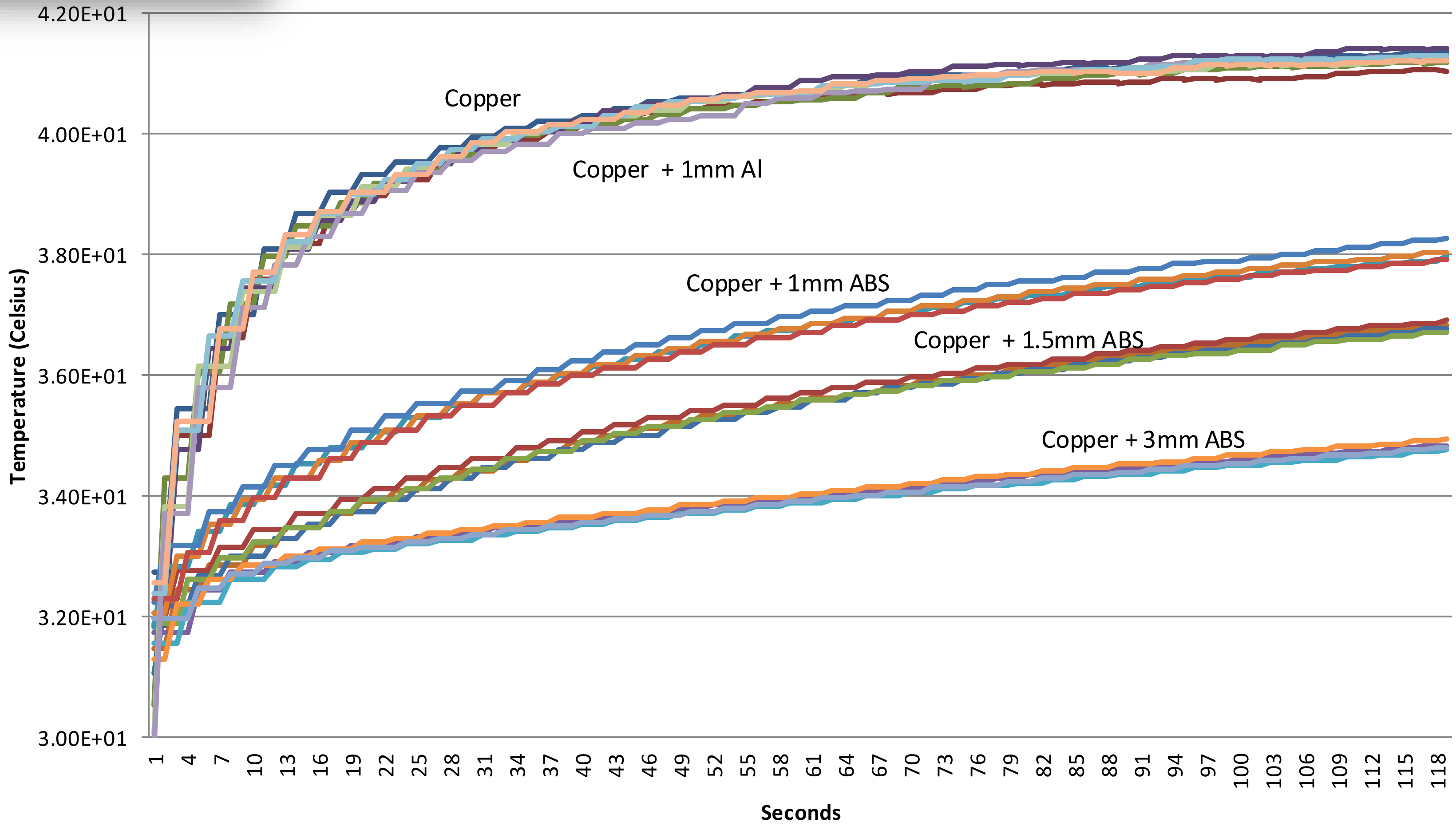






Temperature
Copper + ABS
44 Surface VS 32.5 Skin

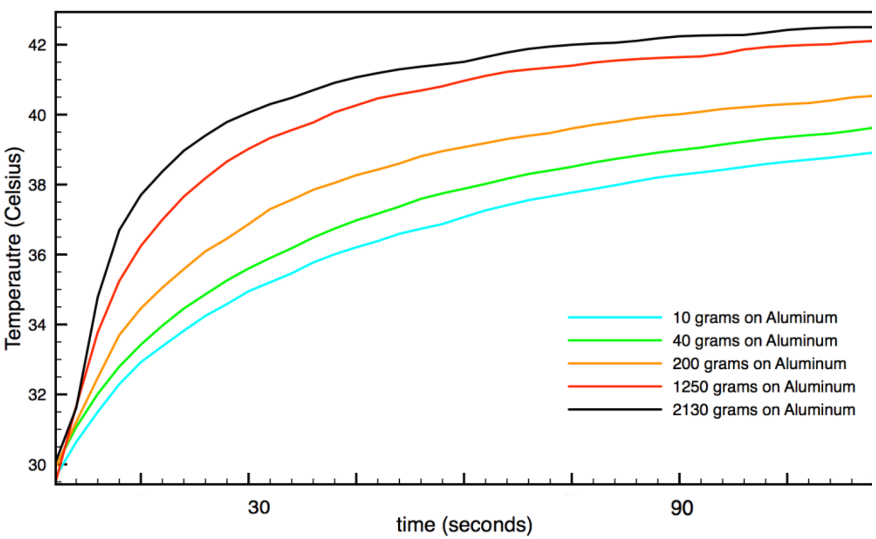


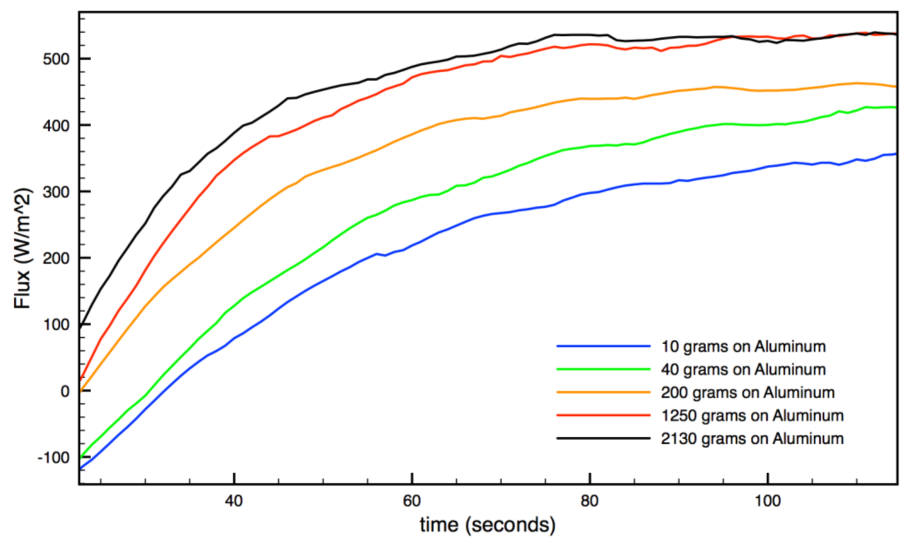


Contact Resistances and the Transient Thermal Response

- The epidermal thickness is related to the heat flux by the amount of time it takes for the heat to transfer to the dermal layer, i.e. the time it takes to feel pain

Setpoint at T = 42°C





Complete System