Laser Thermography For Material Classification

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Abstract. This paper presents a study to demonstrate the ability of laser stimulation and thermal imaging to classify families of materials, with the aim of developing a nondestructive, contactless haptic scanner. Thermal data is captured, processed and is subjected to exponential model fitting. Results show a high correlation between the model and samples. Classification works convincingly well between certain types of materials but it provides less conclusive results for others. More features will be incorporated to build a robust haptic scanner.

Keywords: Haptic scanner, laser stimulation, thermal imaging

1 Introduction

Modern 3D scanning is becoming a mature practice for the acquisition of the geometry of objects. However, capturing the physical properties of objects are required to create precise and realistic physical interactions (for instance in Teleoperation applications). The need to scan physical properties of objects is highlighted by the emergence of haptic rendering, haptic display technologies, and multi-modal human computer interaction.

Traditionally, scanning the physical properties of material requires a complex robotic environment and physical contact between the sensing device and the sampled material [1]. Furthermore, contact-based systems to measure haptic surface properties have other fundamental limitations regarding automation as well as preservation of samples. In this paper we present a non-destructive, contactless haptic scanning approach based on laser stimulation and thermal imaging. The rest of the paper is organized as follows: Section 2 gives an overview of existing approaches, section 3 covers the experimental setup, method, and results. Conclusions are drawn, along with stating our future goals, in Section 4.

2 Related Work

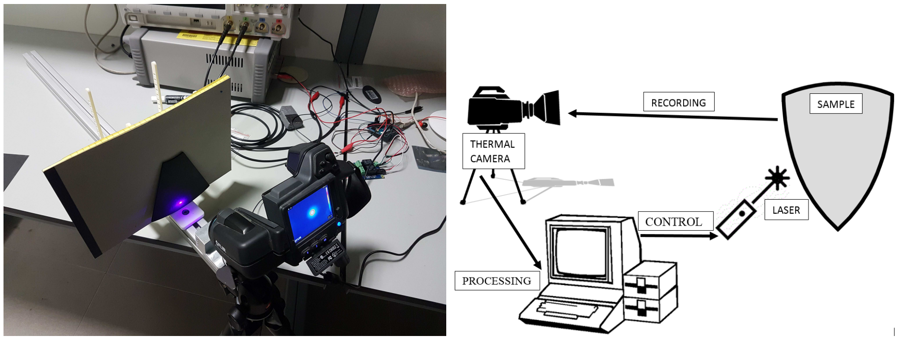
Our proposal lies at the intersections of two fields of research: haptics and thermal imaging. A few studies highlighted the help provided by infrared thermography in the characterization of materials [4]. On the other hand, measurement of physical properties of material is studied by the haptic community. The direction that most research is conducted in involves a contact-based sensor array in the shape of a pen, which is the most convenient arrangement to use when manually guiding the sensor over the surface.

An early proposal [5] presented a device, named WHaT, that employs a pair of 2-axis accelerometers and a piezoresistive force sensor chip. Results indicated a clear difference between different test materials. Andrews and Lang [1] improved on the WHaT using advanced filtering and calibration, and achieved recognition of surface patterns and estimated surface compliance coefficients. Kuchenberger, et al. introduced haptography system with linear prediction of acceleration signals to model and synthesize haptic texture [3][2] Existing work require complex robotic systems and physical contact between the device and the material. We present a preliminary experiment with laser stimulation and thermal imaging to extract thermal properties of materials to map thermal properties into haptic properties.

3 Experimental Setup and Results

A preliminary experiment for the characterization of materials is described here. The setup consists of a 5.6 mm laser source (wavelength: 405nm, maximum power: 400 mW) mounted on a rail, a sample material placed on the same rail, and a thermal camera (FLIR T450sc model). A snapshot of the experimental setup is shown in Figure 1(a). A diagram of the experiment components is shown in Figure 1(b). The samples examined were the following: acrylic glass, cardboard, wooden board, stainless steel, and modeling clay. All samples are painted in black to avoid any biases due to color reflections.

The experimental procedure is as follows. The laser is beamed on the sample for 5 cycles, where each cycle consists of a heating and a cooling period (20 seconds of heating and 40 seconds cooling, for a total of 300 seconds of continuous data captured by the FLIR thermal camera, making altogether one session). The camera transmits temperature data through a USB connection as a video feed with a resolution of 320 by 240 pixels and a frame rate of 10Hz.



(a) The experimental module. (b) Diagram of the experiment.

Fig. 1. The experimental setup.

The peak temperature of each frame is used to plot the graph in Figure 2. Figure 2 shows clearly that the time domain signals are clearly distinguishable and thus the classification of material with laser stimulation and thermal imaging is validated. Note that the stainless steel sample remains largely unaffected by the laser as its point of maximum temperature does not seem to measurably heat up. This corresponds well with the common knowledge that metals are in general good thermal conductors. This makes it clearly distinguishable from the other materials since it is the only near-constant signal in the group. The time-domain data is segmented into heating and cooling periods. The time-domain response suggests an underlying exponential relationship with respect to time. Therefore, an exponential model of $f(x) = A \cdot e^{B \cdot t} + C$ is fitted onto the cooling periods with a nonlinear least squares method. The exponential assumption is seemingly validated by R^2 values consistently over 99%. Figure 3(a) shows the acquired value of B (the decay constant) corresponding to each cooling periods over all sessions for the materials glass, cardboard and wood. It can be seen that these values are sufficiently disjoint to potentially allow for classification between these materials. A higher B-value, such as in the case of glass, corresponds to a slower cool-down than wood for example, which has a lower decay constant value. Figure 3(b) shows that the decay constant is not sufficient to distinguish clay and cardboard. Therefore, our future work will investigate a set of features that uniquely identify the material properties.

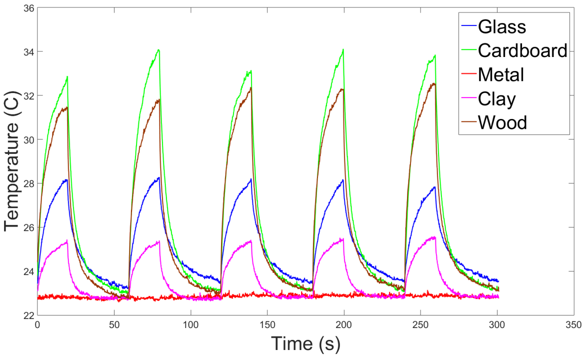
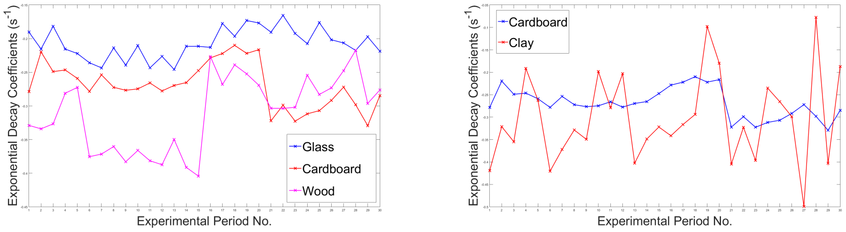


Fig. 2. Time domain data for the five materials.

Another interesting feature could be the magnitude of time-domain response, i.e. the starting value of the cool-down period. This contains information about how much the material can be heated up over a fixed amount of time. This is a property that depends both on thermal conductance and specific heat capacity of the material. These values, along with the density of the material are what form thermal diffusivity, and as such, it can be inferred from the data. Figure 4 shows the peak temperatures for the different materials.



(a) A case of possible discrimination.

(b) A case of impossible discrimination

Fig. 3. The exponential coefficient features.

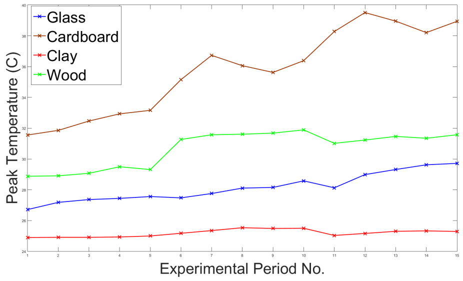


Fig. 4. Peak temperatures

4 Conclusion and Future Work

Our results show that in multiple cases it is certainly possible to classify material using thermal properties. This experiment lays down the groundwork for developing an efficient and effective haptic scanner. Our future work includes investigating other features to provide a robust classification model, considering other materials, and optimizing the heating/cooling attributes.

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