- Calibration
- Calibration Details

Previous Next

Calibration

The color-temperature response of the surface coated with a liquid crystal sheet or painted with slurry should be known prior to its use for temperature measurement. This step, called calibration is carried out to develop the intrinsic color-temperature response of the liquid crystals. During calibration, the color image of the LCs is acquired when the surface is held at a known, spatially uniform and steady temperature. The calibration effort can be either successively isothermal or a gradient technique .

Successive isotherm method

In the successive isothermal method, a temperature controlled test surface and the imaging system are used to generate liquid crystal color-to-temperature calibration data. The color image of the test surface is acquired after bringing the test surface and the liquid crystal to its event temperature. An average color value is computed and stored along with the temperature of the test surface. This process is repeated at subsequently higher temperatures until the clearing point temperature is reached. Though it appears to be simple, the successive isotherm method can be very time consuming since the amount of data is large and the processing requirement is acute.

Previous Next

In the gradient method, the liquid crystal is subjected to a variable color-temperature distribution such as a linear temperature gradient. Thus, this technique establishes a hue-temperature calibration over the full range of colors displayed by wide-bandwidth liquid crystal, typically those with a bandwidth of several degrees Celsius or more. The benefit of this approach is that, it provides a continuous representation of the entire color temperature response of liquid crystals using a single color image. It provides a higher color temperature resolution than the successive isotherm method in a fraction of the time and with much less data processing.

Several factors impact the accuracy of liquid crystal measurements. These include

1. irregularities in the liquid crystal layer
2. incident light reflected from the liquid crystal sheet
3. variation in the lighting/viewing angle across the surface
4. variation in temperature of the calibration surface
5. ambient lighting condition, camera conditions (such as circuit gain, filter adjustment, aperture and optical adjustments)
6. characteristics of the transparent surface through which the LCs are viewed
7. hue evaluation technique
8. hysteresis effects

Past investigators have systematically studied and evaluated the effect of these factors. Definitive recommendations are available that reduce the adverse impact of these problems. Recent investigations (Sabatino et al. 2000, Smith et al., 2001) summarize the overall procedure to be followed for LCT measurement of temperature.

Previous Next

A majority of researchers recommend the in-situ mode of calibration. Here, calibration is carried out within the main experimental apparatus itself. A wide-band calibration technique (covering the bandwidth of the liquid crystal material) applied point-wise is proposed. Wide-band calibration employed by the previous researchers mostly calibrate the LCs using a single reference point on the test surface against temperature, and then apply this single-point calibration over the entire test surface (Smith, 2001). The illumination (source) as well as imaging (camera) positions is close to normal with respect to the test surface. For the micro-encapsulated thermochromic LCs, the sensitivity of hue to the viewing and illumination angles is found to be insignificant (Camci, 1992, 1993).

It is worth mentioning here that recent studies have opted for pixel-level calibration- namely generate calibration curves of hue vs temperature for each of the 1024 X 1024 pixels.

For the images discussed in the present chapter, an in-situ , single-point calibration has been performed under no-flow condition. The lighting arrangement and camera position are kept identical for the calibration stage and the full experiment. The parameters of the image processing system including color capturing settings are locked. The imaging camera is mounted at the top of the test section. The illumination system was also located on the camera side of the test surface (called on-axis lighting). With this configuration, the maximum permissible deviations of the viewing inclination and illumination angle from the normal are found to be less than 10^{o} and 20^{o} respectively.

Previous Next

Module 6: Liquid Crystal Thermography

Lecture 37: Calibration of LCT

The image acquisition and processing system used in the present study consist of a high-resolution 3-CCD video camera (SONY XC-003P) with 16 mm focal length lens (VCL-16WM), a 24-bit true color frame grabber board (Imaging Technology Inc., IC-PCI) and a high speed PC. The model XC-003P (Figure 6.5) is a 3-CCD RGB color camera module designed primarily for process control and image processing applications.

Figure 6.3 High resolution 3-CCD camera (SONY XC-003P)

Camera XC-003P works in accordance with EIA video norm of NTSC (National Television Systems Committee of the Electronic Industries Association) which has prepared the TV standard for the USA , Canada , Japan , Central America , half of the Caribbean and half of South America). When referring to NTSC video what is normally meant is 525 line 60 Hz. PAL (phase alternation line) is the TV format used in most of Western Europe , Australia and other countries including India. When referring to PAL video, what is normally meant is the 625 line 50 Hz video. The new 3 CCD C-mount optical prism block achieves three times higher resolution compared to a 1-CCD system. Moreover, the standard C-mount lens system allows the use a wide variety of lenses.

Module 6: Liquid Crystal Thermography

Lecture 37: Calibration of LCT

The quality of a digital image, often referred to as image resolution, is determined by the number of pixels and the range of brightness values available for each pixel utilized in the image. Resolution refers to the capability of the digital image to reproduce fine details that were present in the test surface. In general, the term spatial resolution is reserved to describe the number of pixels utilized in constructing and rendering a digital image. Thus, as the number of pixels acquired during sampling and quantization of a digital image increases, the spatial resolution of the image also increases. In the present LCT based investigation, the image is acquired for a window size of 461 × 345 mm^2. The image is digitized for 768 × 574 pixels, and provides an optical resolution of 0.6 mm/pixel. The color information available at each pixel is in the form of the R, G and B values, each over a scale of 0-255.

Previous Next

The Imaging Technology frame grabber, IC-PCI is a half-slot PCI bus image capture card, which is used in conjunction with the ITEX -IC software. The latter is a generic term for Imaging Technology software functions, callable and linkable with C language application programs. ITEX -IC refers to the aggregate sum of sub-libraries or software modules for the Image capture family. ITEX -IC is supported under Windows and protected mode DOS with the WATCOM 32-bit C/C++ compilers. It provides the full support for Microsoft Visual C/C++ and Visual Basic, allowing Windows programmers the environment of their choice. It features one of the fastest sustained image data transfer rates to PC memory (up to 120 MB/sec to the PCI bus and more than 90 MB/sec to the host memory, depending on the host PC). Transfer rates faster than real time (< 33 ms) allow the good use of the CPU for host based processing, as it is not tied up with arbitrating bus operations. Display is performed completely by the host display processor. Data is transferred out of the IC-PCI over the PCI bus to the display card or the host memory. The frame grabber captures the image at the camera speed of 38 frames per second. The resulting image retains a majority of the characteristic intensities and spatial frequencies of the original. Subsequently, the image is stored on the hard-disk of the computer.

In the experiments reported in the present module, 45 sequential images have been recorded from short-duration transient experiments. The precision timer function allows correct setting and estimation of the intermediate time between sequential images. Using the image processing software these images are digitized frame by frame and converted into a hue matrix. The digitized data becomes the basis for the measurement of temperature. The temperature data can be used for the evaluation of the local heat transfer coefficient.

Previous Next

Calibration details

For calibration, the surface plate mounted with the LC sheet is heated under no flow conditions to a temperature just above its active range. Here, the color of the LC sheet will appear to be uniformly blue (Figure 6.4(a)).

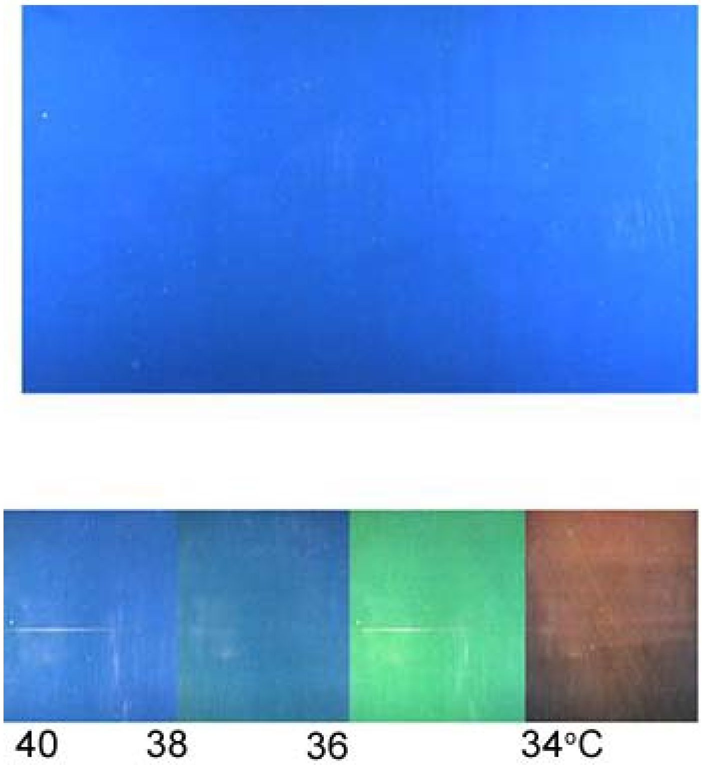

Figure 6.4(a) Test surface heated to the clearing point temperature of the LCT sheet

The heater is turned off and the surface is allowed to cool slowly by natural convection. Several K-type thermocouples can be embedded inside the aluminum plate from underneath. One of these pre-calibrated thermocouples can be utilized for the calibration purpose.

Previous Next

Module 6: Liquid Crystal Thermography

Lecture 37:

As the liquid crystal passes through its active range of colors (blue to red), images are acquired for every 0.2^{o}C drop in the surface temperature. Simultaneously, wall temperatures from thermocouples are recorded using the data acquisition card, NI-4351 (National Instruments). Subsequently the series of images are digitized, and the hue information (in fact, hue, saturation, and intensity) is extracted for a sample region of 50 × 50 pixels, corresponding to an area of 25 × 25 mm^2 . The sample region (Figure 6.4(b)) is selected in such a manner that there is a thermocouple that lies centrally underneath.

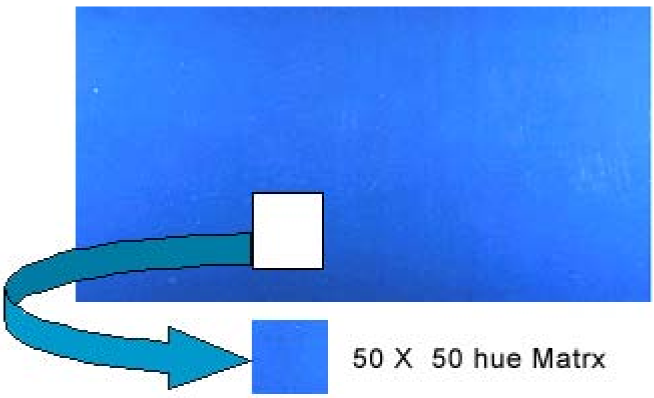

Figure 6.4(b): Using a small patch of area for hue calculation

Previous Next

Subsequently, the average hue for the chosen region along with the measured temperature forms a data point of the calibration curve (Figure 6.4(c).

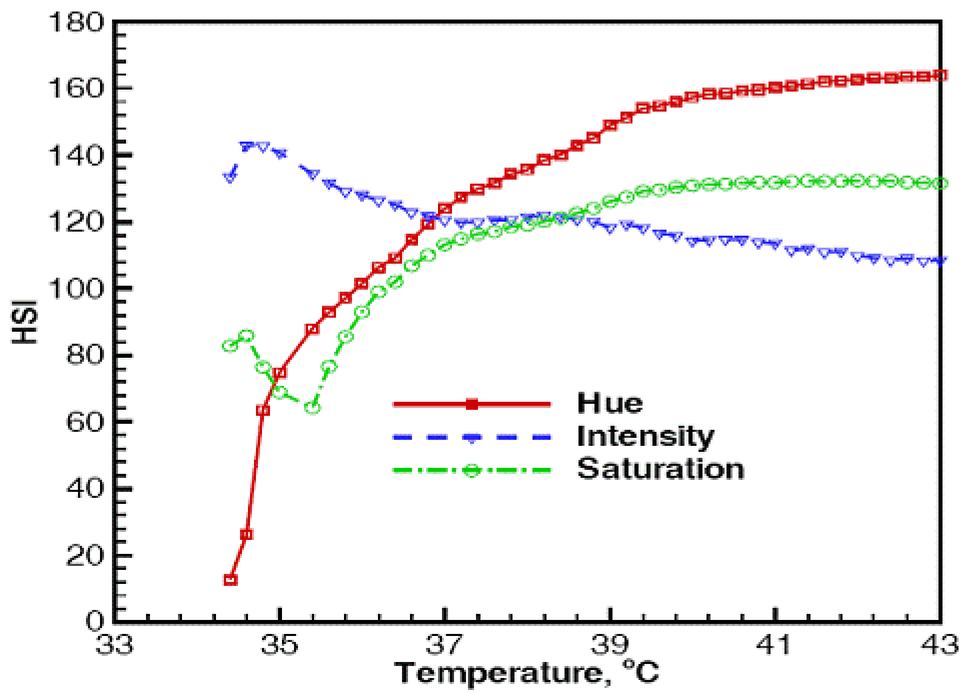

Figure 6.4(c) Calibration curve of the LC sheet relating hue (H), saturation (S), and intensity (I) with temperature

In the experience of the authors, a typical calibration curve consists of 40-50 points. One can expect this data set to be sufficient to resolve the hue-temperature relationship. Further, a suitably high order polynomial can be used to analytically represent the calibration data. This approach can be used for saturation and intensity as well.

Figure 6.4(c) shows a typical calibration curve drawn for a liquid crystal sheet used by the authors.

Previous Next

A companion plot of the variation of the individual colors R,G, and B with temperature is shown in Figure 6.4(d).

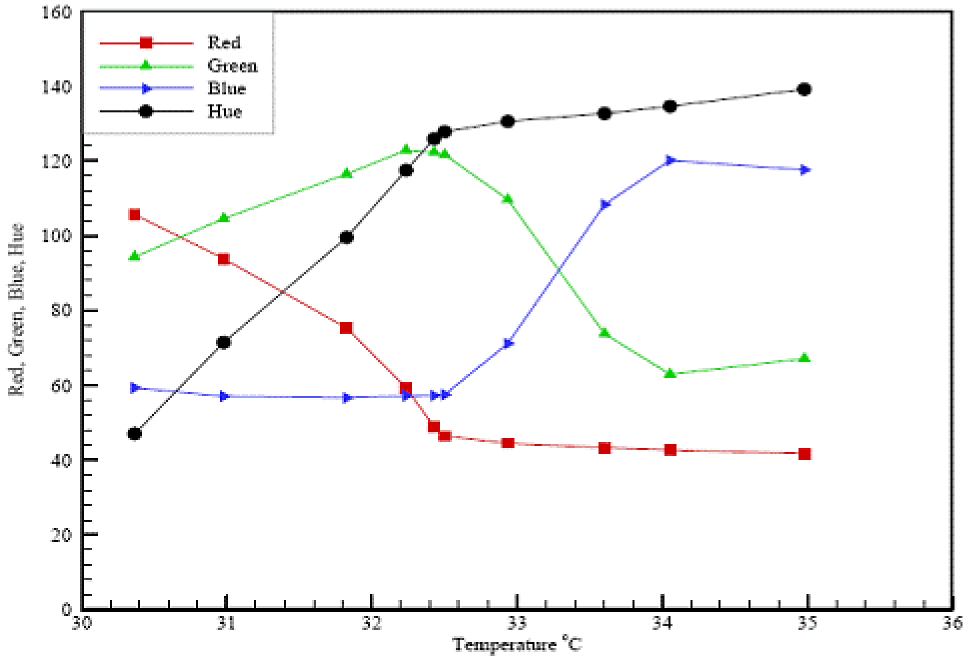

Figure 6.4(d): Variation of individual colors R,G, and B with temperature.

It is to be observed that hue has a monotonic variation with respect to temperature. The uniform level of intensity is itself an indication of the uniform level of illumination over the test-surface. It confirms the quality of lighting arrangement used for the experiments.

To estimate the spread of H, S, and I within the sample region of the LC image, their variance is shown in Figure 6.5.

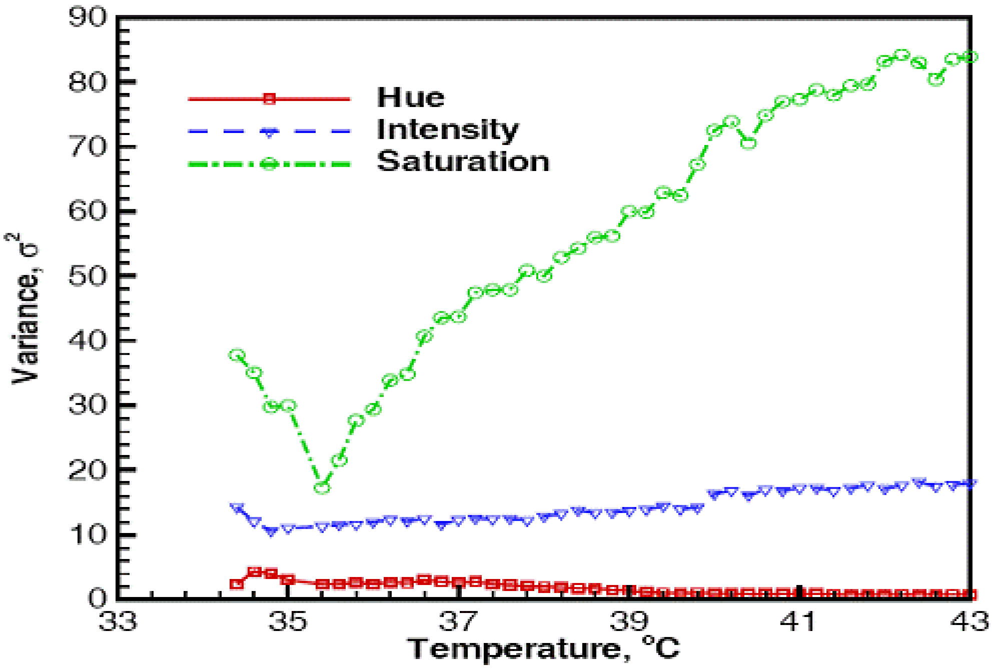

Figure 6.5 A typical HSI variance graph of the LC sheet as a function of temperature

Of the three, hue shows the smallest variance, indicating good quality of isothermal conditions within the sample region around the thermocouple and the suitability of hue as a measure of the color-temperature relationship. The in-situ calibration approach is seen to improve the measurement accuracy by eliminating errors that may arise from differences in viewing angle and lighting, going from calibration to the actual experiment.

Previous Next

Earlier investigations (Baughn, 1999; Sabatino, 2000; Smith, 2001) have reported hysteresis in the liquid crystal response, the hue-temperature behavior during cooling being significantly different from that during heating. Hysteresis is likely to occur if the heating cycle takes the liquid crystal material beyond its clearing point temperature. Conversely, the transient experiment may have been initiated below the event temperature. To eliminate hysteresis effects, proper care is taken to ensure that the test surface operates strictly between the pre-defined temperature limits. In the studies conducted by the authors, calibration of the liquid crystal sheet has been performed during the cooling of plate within the end point temperatures. By performing the calibration test several times, the authors have seen that the calibration curve is repeatable.

Previous Next