EG UK Theory and Practice of Computer Graphics (2011)
Hamish Carr, Ian Grimstead (Editors)

A Low-Cost Single-Pixel Thermographic Camera

F. Bauer[1] and J. Loviscach[1]

[1]Fachhochschule Bielefeld (University of Applied Sciences), Fachbereich Ingenieurwissenschaften und Mathematik, Germany

Abstract

A working prototype of single-pixel thermographic camera which can be built for 100 Euros is presented. It is based on a pyrometer's sensor (thermopile with optics) and two mirrors mounted on servos to scan horizontally and vertically. Thanks to simple yet powerful filtering, the measurement proceeds at a speed of 5 ms per pixel even though the sensor has an actual response time of $t_{90} \approx 60$ *ms. The scan for the resulting sharp image of* 80×80 *pixels takes one minute. We discuss further improvements to create a product suitable for facade thermography.*

Categories and Subject Descriptors (according to ACM CCS): I.4 [Image Processing and Computer Vision]: Digitization and Image Capture—Sampling and I.4 [Image Processing and Computer Vision]: Enhancement—Filtering

1. Introduction

Three quarters of an average building's energy consumption are used for heating, a prominent reason being poor insulation. Thermographic cameras are vital to detect such issues but come at steep prices of e. g. 10,000 Euros for 160×120 pixels at 20 fps. Pyrometers—that is: infrared thermometers—are already available for less than 100 Euros but measure only a single spot at a rate of several samples per second. Hence, their use for this task is limited. We have developed a solution to turn the simple hardware of a pyrometer's sensor (a thermopile with optics) into a thermographic camera using appropriate hardware and software.

2. Hardware

Whereas [Hob01] proposed to build a cheap thermographic camera from proprietary sensor chips, [Lov09] and [Mar09] leveraged pyrometers for this task. We improve on the latter attempts through hardware that reacts more quickly. Instead if mounting the sensor on a bulky, slow and shaky pan-and-tilt head, we use mirrors that are mounted individually on servos. For the mirrors, we simply use polished metal sheets, see Fig. 1. Here, Kirchhoff's law of thermal radiation comes in handy: Metallic mirrors reflect infrared light, but do not themselves emit infrared light according to their temperature. Everywhere else in thermography, this phenomenon tends to be a nuisance.

The prototype described in the following employs planar mirrors. We also experimented with cylindrical parabolic mirrors. In addition to deflecting the light toward the sensor, these mirrors focus the beam, which leads to higher sensitivity and less noise, in particular as the usual optics in front of the sensor becomes superfluous. It turned out, however, that the geometry is far more difficult to handle with curved mirrors, which results in highly deformed images.

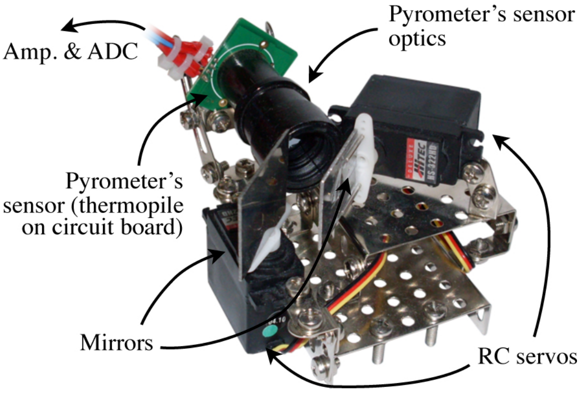
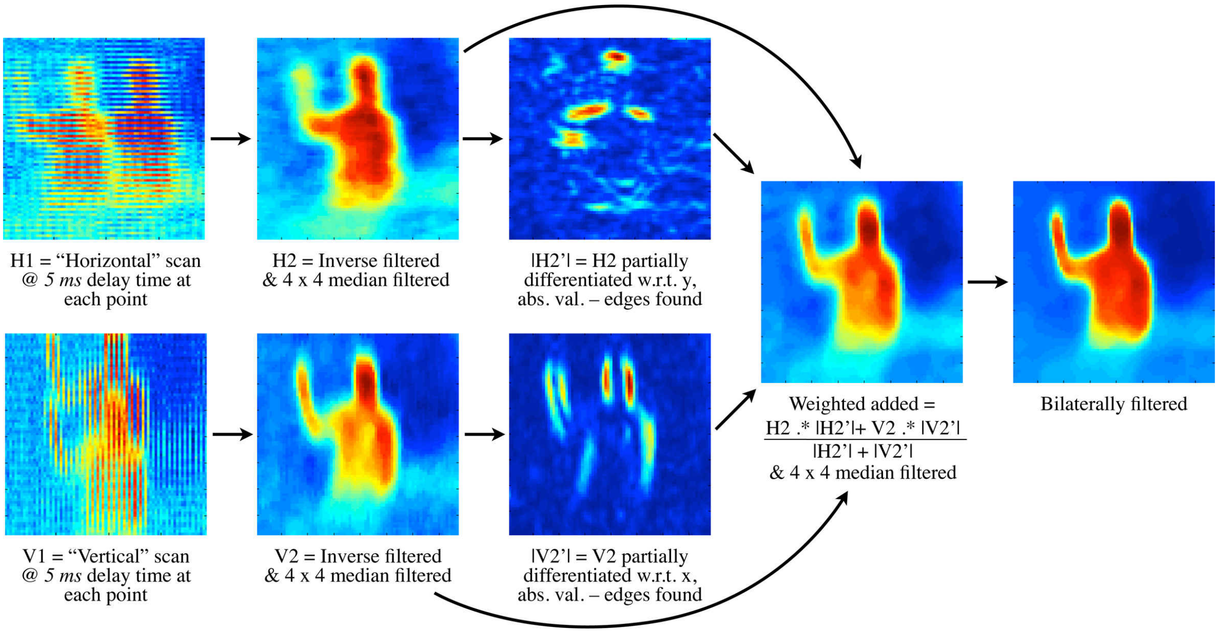


Figure 1: *Two inexpensive RC servos perform a scanning motion with polished metal sheets serving as mirrors.*

3. Measurement process and software

To reduce the scanning time to one minute, the system must move the target point so fast that the time of 5 ms spent per pixel is far less than the response time of the sensor of $t_{90} \approx$

DOI: 10.2312/LocalChapterEvents/TPCG/TPCG11/067-068



H1 = “Horizontal” scan @ *5 ms* delay time at each point

H2 = Inverse filtered & 4 x 4 median filtered

|H2’| = H2 partially differentiated w.r.t. y, abs. val. – edges found

V1 = “Vertical” scan @ *5 ms* delay time at each point

V2 = Inverse filtered & 4 x 4 median filtered

|V2’| = V2 partially differentiated w.r.t. x, abs. val. – edges found

Weighted added = $\frac{H2 .* |H2'| + V2 .* |V2'|}{|H2'| + |V2'|}$ & 4 x 4 median filtered

Bilaterally filtered

Figure 2: *The data from the sensor is processed through a cascade of linear and non-linear filters to undo the slow response and the noise of the measurements.*

60 ms (measured). This smears out hard edges and so requires a range of compensating methods, see Fig. 2.

First, an inverse filter is applied. For that, the derivative of the sensor’s signal is estimated using an 18-element kernel and an appropriate multiple of the derivative to the signal is added to undo the softness of the sensor’s step response. Second, the scene is scanned twice: row by row, which yields sharp horizontal edges, and then column by column, which yields sharp vertical edges. These two scans are merged so as to preserve the sharp parts. Third, median filters and a bilateral filter are applied at different stages of the process to reduce the noise and sharpen the edges.

Before arriving at this procedure, we experimented with other scan patterns, e.g. Hilbert curves, which yielded inferior results, probably due to the poor mechanics of the inexpensive RC servos. Another approach was to read data from the sensor at high resolution and ultra-high speed by feeding the signal into a PC’s sound card, chopped at 2 kHz (to circumvent the DC filter of the sound card). This resulted in image sizes of e. g. 80×8000 pixels. Other experiments included inverse filters based on sampled step responses.

4. Conclusion and outlook

We have demonstrated that it is possible to build a single-pixel thermographic camera for 100 Euros that provides clear images at a sufficient speed. This is work in progress and has ample space for future development. As a final target, it is desirable to achieve a degree of usability similar to that of a digital camera. Hence, the complete system including data processing should go in one box that provides a trigger button, a display, a SD card slot and a USB connector.

Noise and deformations could be diminished considerably through better analog amplification, more precise (and, hence, more expensive) servos, better honed and polished metal as mirrors, and—for the second prototype—precisely bended or carved mirrors. With an optics of 1:50 resolution instead of the the currently used 1:30 optics, finer structures can be mapped. With several sensors and more mirrors working in parallel, the speed could be increased by a factor of two or more. For multispectral imaging, several different sensors could scan the image in parallel, using the same set of mirrors. Possibly, one could even add distance measurements to determine a 3D profile of the scene. More sophisticated data processing needs to be studied to leverage rapidly measuring the sensor’s output voltage several hundred times per pixel. We are also looking into compressed sensing.

References

[Hob01] Hobbs P. C. D.: A $10 thermal infrared imager. In *SPIE Sensors and controls for intelligent manufacturing II* (2001), pp. 42–51. 1

[Lov09] Loviscach J.: Augmenting a camera with a thermometer. SIGGRAPH ’09: Posters, 2009. 1

[Mar09] Martin S.: Thermoscanner. http://www.designer2k2.at/home/arduino/30-thermoscanner.html, last visited 2011-06-25, 2009. 1