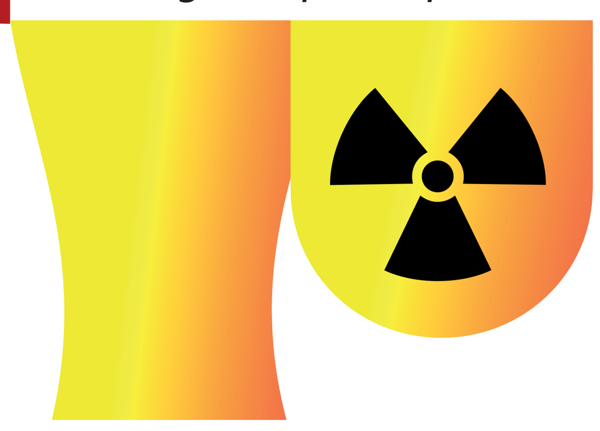
A Low-Cost Single-Pixel Thermographic Camera

Motivation, introduction

75 % of an average building's energy consumption are used for heating!

The main reason is **poor insulation**. *Passive houses do not need to be heated at all – a giant reduction potential to build negative power plants!*



(1) Thermographic camera: **160×120 px**/**10,000 €**/20 fps

detect

(2) Pyrometer: **1 px**/**< 100 €**/5 fps

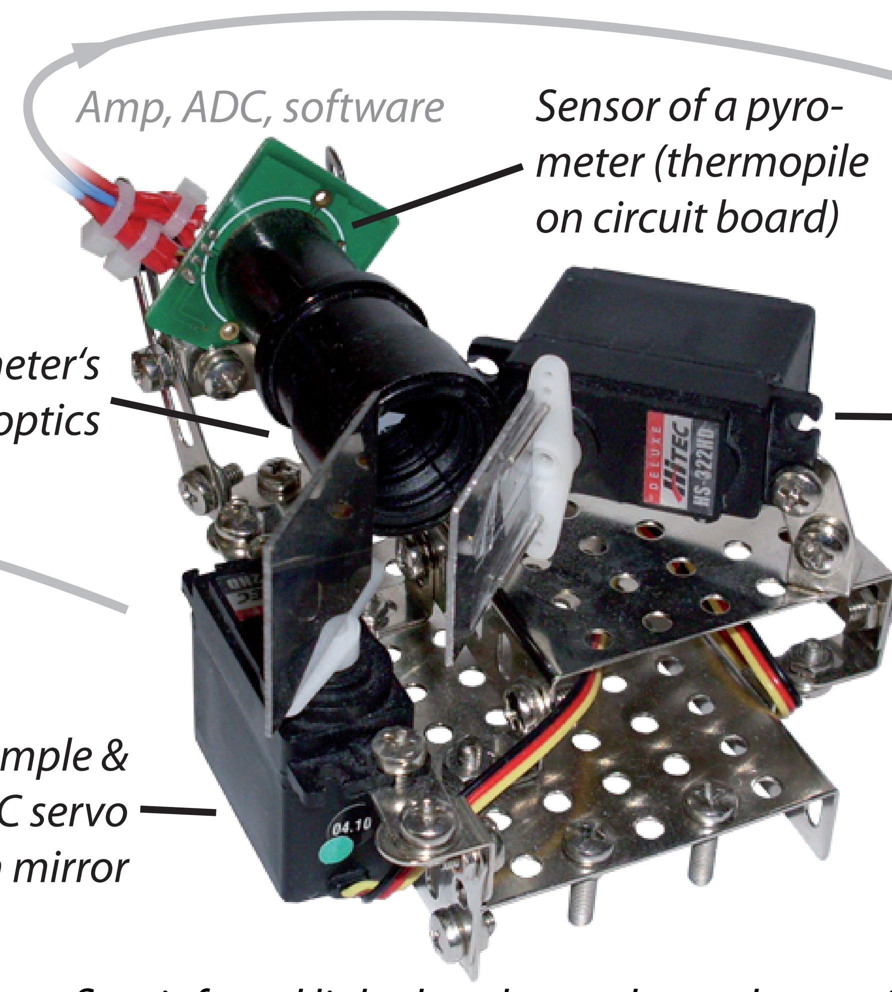
detect

(3) *This work*: **80×80 px**/**100 €**/1 fpmin

detect

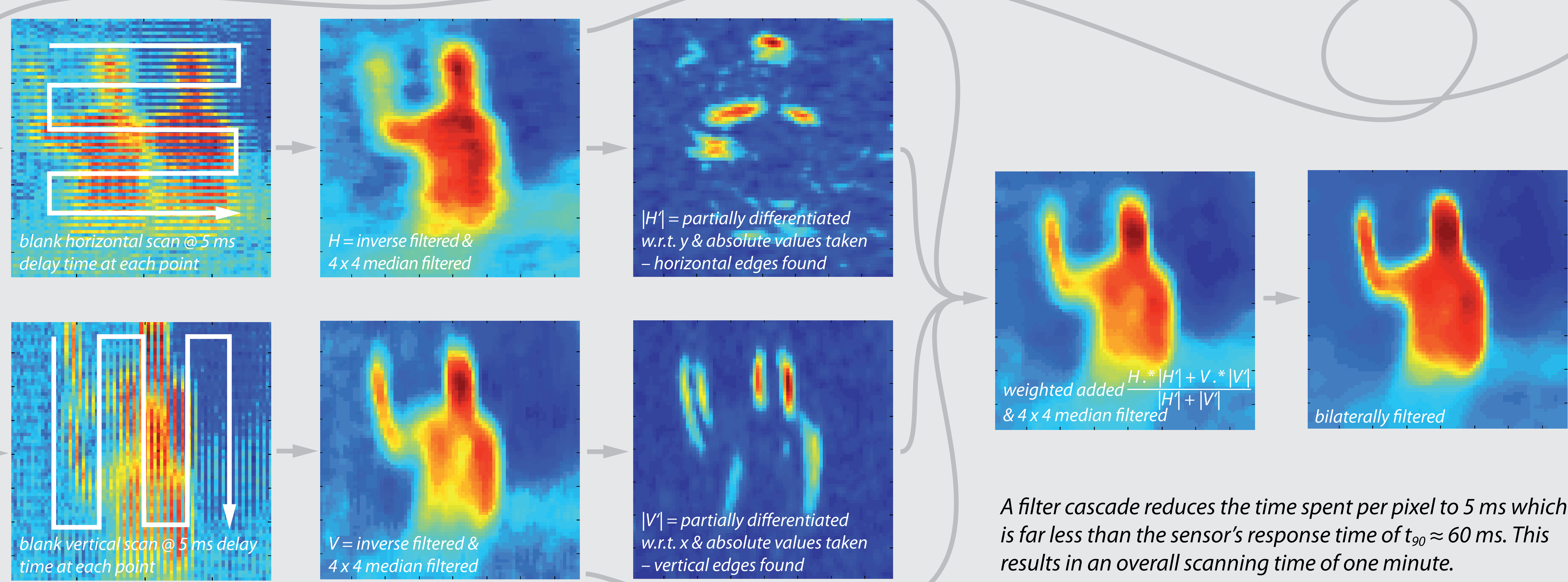
So we present a solution that turns the simple sensor of a pyrometer into a thermographic camera. Unlike earlier approaches of others, two **simple polished metal sheets as mirrors** instead of a bulky, slow and shaky pan-and-tilt head allow a 2D scan…

Hardware



Metallic objects reflect infrared light, but do not themselves emit infrared light according to their temperature (Kirchhoff's law). That enables this simple prototype.

Measurement process and software



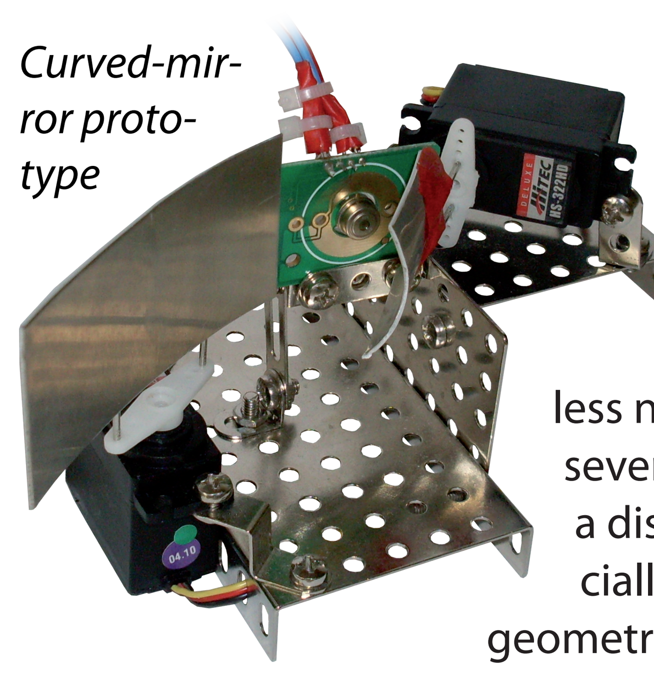
A filter cascade reduces the time spent per pixel to 5 ms which is far less than the sensor's response time of $t_{90} \approx 60$ ms. This results in an overall scanning time of one minute.

The figure above draws the procedure: The scene is scanned twice which yields both sharp horizontal and sharp vertical edges. An **inverse filter** (18-tap FIR) computed from the response time is applied to both scans to suppress the temporal lag of the response. Second, these two scans are **merged** so as to preserve the sharp parts, see equation in the figure above. Additionally, **median filters** and a **bilateral filter** are applied at different stages 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 cheap RC servos. Another approach was to read data from the sensor quasi-continuous through a 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.

Conclusion and outlook

A 100 € thermographic camera is possible. Besides further testing and comparisons, still ample improvements can be made:

- **Usability** like a digital camera if hard- and software goes in one box (e.g. like a projector's one) with: trigger button, display, SD card, USB.
- Less noise and deformations/**more precision** through better analog amplification, better servos and better honed and polished mirrors.
- **Higher optical resolution** through optics with 1:50 distance-to-spot-ratio or more instead of the currently used 1:30.
- **Increased speed** or resolution by a factor of two or more with several sensors and more mirrors working in parallel.
- Sale: Finally, professional product **produced in series** helping to reduce energy waste detection, also with software accessories like temp-bars.



Curved-mirror prototype

We also tested a prototype which employs **cylindrical parabolic** instead of planar mirrors, which simultaneously **deflect and focus** the beam towards the sensor, see the figure on the left. This leads to higher sensitivity and therefore less noise. Here, **multispectral imaging**, through several different sensors in the focal point—also a distance sensor—can be implemented especially easily. It turned out, however, that the geometry is far more difficult to handle with curved mirrors, which results in highly deformed images. Also, more sophisticated data processing needs to be studied to leverage high-speed sample rates which seem particularly promising with this prototype.

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