

The Right-to-Repair Board Rescuer Deck

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Abstract

Electronic control boards in modern appliances and vehicles are routinely declared unrepairable: a single short-circuited power semiconductor worth a few tens of rupees leads a technician to recommend replacing an entire motherboard costing thousands. This paper presents the thermal instrument of the Right-to-Repair Board Rescuer Deck, built and validated end to end. An ESP32 (a small Wi-Fi microcontroller) and an AMG8833 8x8 infrared array stream raw temperature grids to a server that renders every image element itself and sends it to any browser; a phone camera reuses the same field as a live overlay, and each capture is passed to a vision model that names the device under the hotspot and prices it on Amazon.in or Flipkart in rupees. The uplink costs 1.28 kB/s, a rendered pane is 6.4 kB, and identification completes in about ten seconds, so the whole instrument can be driven from a phone over a mobile hotspot. Captures are kept in a shared gallery and every control is live-synchronised across handsets.

1. The Average Person's Problem

This paper describes a small thermal instrument for finding the failed part on a control board. It is built from parts that cost less than one board replacement, it is driven from an ordinary phone, and it is reported because it has been built and run rather than proposed.

When a washing machine, a modern microwave, or a car dashboard breaks, the local repairman usually says, “The whole motherboard is dead, you need to buy a new one for ₹15,000.” In reality, a single ₹50 power semiconductor (such as a MOSFET or a voltage regulator) has short-circuited. Manufacturers use proprietary software to lock down diagnostics, forcing consumers into expensive replacements. The gap between the cost of the failed part and the price of the repair is the core economic problem. A transistor or regulator costs between ₹10 and ₹100, yet a board replacement for a washing machine or dashboard can be quoted at ₹8,000 to ₹20,000. Because the board is sealed or undocumented, the technician cannot cheaply prove that the fault is localised, so serviceable hardware becomes electronic waste.

2. The Semiconductor Connection

Modern appliance boards are packed with microcontrollers and power semiconductors. When they fail, they usually fail “short” or “open”, creating a detectable thermal or electrical signature.

Power semiconductors fail most often because they carry the largest currents and dissipate the most heat. A MOSFET switching a motor can fail as a drain-to-source short, while a regulator or rectifier can fail short, open, or drift out of specification after mains transients, inrush current, thermal cycling, moisture, or ageing. A shorted device draws abnormal

current and becomes a localised hot spot within seconds, whereas an open device removes current from a whole rail, so a safe, current-limited low voltage can reveal either fault.

3. The Implemented System

The deck is a portable instrument: a thermal array and a camera in the lid, a testing tray with retractable probes and a current-limited supply in the base. This paper reports the half that has been built and run continuously: the thermal instrument. It is deliberately minimal, one sensor, one controller and a phone, and it is exposed as a web service so that the display costs nothing and any handset can drive it. Table 1 lists the elements of the working prototype.

The node pushes frames to a server that stores only the raw 8x8 grid and does all the colouring, stacking and segmentation itself. One normalised field therefore feeds the colour mapping, the segmentation, the hotspot decision and the overlay, so they cannot disagree, and the client only swaps images, which is what makes a phone a viable display.

4. The Sensing Node

The prototype uses a Panasonic AMG8833 Grid-EYE, an 8x8 thermopile array with a 60 degree field of view, a two-wire data bus and a 10 frame-per-second (fps) internal refresh rate. It is the cheapest way to obtain a calibrated absolute temperature grid, which matters because the diagnosis depends on absolute temperature rather than contrast. The sensor shares its 3.3 V rail with an ESP32 DevKit, and it needs only four wires: power, ground, data and clock. The whole node is powered from a single USB lead, so there is no separate supply to bring to the bench.

The controller is an ESP32, a low-cost dual-core microcontroller with Wi-Fi built in. It is the most widely used part in

its class, and the same board already sits in sensor gateways, smart switches, energy meters and lighting controllers. For this instrument its value is simply that it brings a network interface, enough memory to buffer frames and a spare processor core at a price below the sensor itself, so the sampling loop can run independently of the link and a slow network degrades the display without disturbing the measurements. Each frame is 128 bytes: 64 signed 16-bit integers in little-endian order representing degrees Celsius times one hundred. This is a lossless representation of the sensor's own output, it needs no parsing beyond a memory cast (reinterpreting the same bytes as integers), and it costs only 1.28 kB/s of uplink at the sensor's full rate. Frames are posted over a persistent encrypted connection with a token header, and the firmware reads back every reply as it arrives, because an unread reply would otherwise stall the socket. A watchdog (a timer that resets the board if it stops making progress) restarts the node if the link stalls.

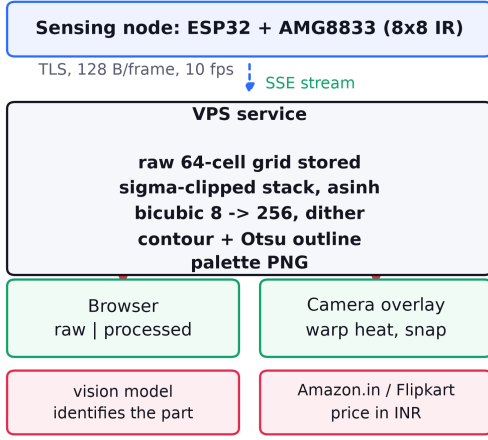


Fig. 1. System architecture. The sensing node streams raw 8x8 temperature grids to the server; rendering is server-side, so every client receives ready-made images. The camera path reuses the same normalised field, keeping the overlay and the panes in agreement.

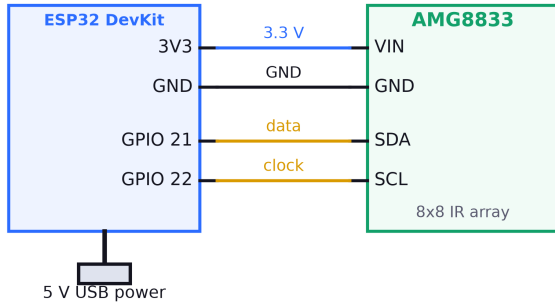


Fig. 2. Sensing front-end. Four wires connect the two boards: 3.3 V, ground, data and clock. The node is powered from a single USB lead.

Element	Part	Function
Thermal sensor	Panasonic AMG8833, 8x8, 60°	absolute temperature grid over I ² C

Element	Part	Function
Controller	ESP32 DevKit V1, 240 MHz	sampling and encrypted uplink at 10 fps
Interconnect	breadboard, jumper leads	3V3 rail, 400 kHz I ² C bus, status LED
Power	5 V USB	single-cable supply
Viewfinder	unmodified phone camera	live overlay and image capture
Compute	small server	rendering, streaming, identification, pricing

Table 1. Elements of the working prototype.

128 bytes = 64 cells x int16 (little-endian, C x 100)



Fig. 3. Wire format: 128 bytes = 64 × int16, degrees Celsius × 100.

5. Server-Side Rendering

A frame is averaged with the previous ones after rejecting outliers (a sigma-clipped rolling mean). The rejection threshold is k times 1.4826 times the median absolute deviation (MAD, a robust measure of spread that a few bad pixels cannot inflate), floored at 0.15 degrees Celsius; the floor exists because a purely statistical threshold discards genuine small differences, which at 64 samples are indistinguishable from sensor noise. The field is then normalised through a colour window that is either automatic or manual. The automatic window uses the 5th and 95th percentiles rather than the extremes, so a single stray cell cannot drag the window and wash the frame to one colour, and the window is smoothed across frames so that it cannot snap between them; taking manual control seeds the sliders from the live window so there is no jump at the handover.

A global asinh stretch (a curve that lifts small values without clipping large ones) compresses the warm end where thermopile response is non-linear, and additive local contrast (extra brightness proportional to how far a pixel sits above its local average) brings out small differences without disturbing the absolute mapping. The 8x8 field is then upsampled to 256x256 with a bicubic kernel, dithered with an 8x8 ordered Bayer pattern (a fixed threshold tile that trades banding for fine texture) so the 32 colour levels do not band, and packed into a 65-colour indexed image that stays small because each pixel stores a palette number rather than a full colour. Contour lines are pre-composited 20 percent darkened twins of each palette entry, so no alpha channel is needed, and the hot region is outlined using a threshold picked automatically by Otsu's method (which chooses the cut that best separates two groups of pixel values) on the same field. Both panes are then sent as small palette images over a single live feed to the browser, which costs about 188 kB/s for the pair and needs no repeated requests.

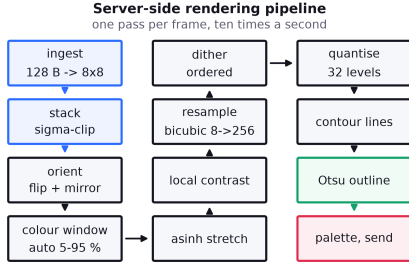


Fig. 4. Rendering pipeline: one pass per frame, ten times a second.

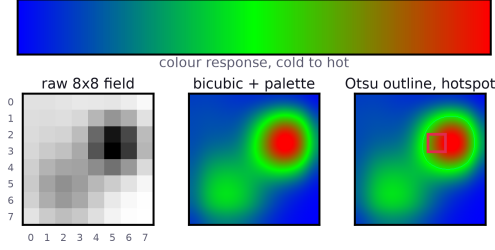


Fig. 5. Colour response and localisation. Top: the palette. Below: the raw 8x8 field, the same field resampled through the palette, and the automatic outline with the hottest cell boxed.

6. Camera Overlay and Calibration

A diagnosis is easier to trust when the heat is drawn on the object that produced it. In the built instrument the phone camera is the viewfinder and the thermal field is warped onto it. Because the sensor is fixed relative to the camera, a single affine transform (one set of translation, scale, rotation and mirror values, applied to every pixel) is enough; it is captured once by dragging the overlay onto something hot and is kept in the browser's local storage on the phone itself, so re-alignment after a knock takes about five seconds. The hottest cell carries a box, a crosshair and its absolute temperature, and the marker is shown during alignment as well, which is what makes the drag accurate. Alignment can also be done automatically. Two small LEDs at diagonally opposite corners of the view are the two brightest spots in the frame; each is looked for inside its own corner of the grid, because the hottest cell elsewhere belongs to the board. Those two pairs give the scale, rotation and offset in a step, and the third hot point, the fault itself, is what the mapping then places. If the node stops sending, the panes fall back to a recorded loop that matches the current render mode, the header reports the link as offline, and live frames resume the moment the node returns.

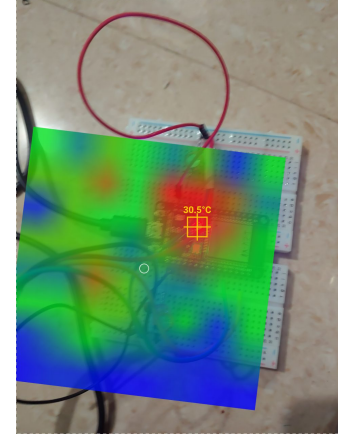


Fig. 6. The live overlay in use; the marked cell reads 30.5 °C.

7. Identification and Sourcing

Two properties of the thermal image make automated identification practical. A hotspot is a strong prior for where to look, and, less obviously, the overlay hides exactly the detail a vision model needs. Each capture therefore stores the composited frame for the record and a second, clean frame with only the marker drawn, which is what the model sees. The model returns the component type, any legible part number, the package and a confidence. A second pass that is allowed to search the live web then locates that part on Amazon.in or Flipkart, restricted to an actual product page rather than a search or comparison listing, and returns a price in rupees; a result whose link is not from those two marketplaces is discarded rather than shown. Captures are kept in a shared gallery that anyone may view, while writing to it (capturing or deleting) requires a passcode checked by the server, and the gallery is capped so that the host cannot fill up. Fig. 7 shows a recorded diagnosis.

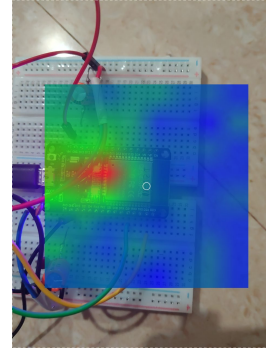


Fig. 7. A recorded diagnosis: hotspot temperature, identified component and sourced price.

8. Results

The instrument has run continuously against a live sensor and a public endpoint. The uplink is negligible, so a shop can run it over a mobile hotspot. Rendering cost is borne by the server and fell once the contour lines were pre-composited: dropping the alpha channel shrank a pane from 10.3 kB to 6.4 kB. Every control is exposed live and synchronised across handsets, which matters because the parameters that make a static scene legible are not the ones that make a hand-held view legible. A line of numbers under each pane also reports the minimum, maximum and mean of the frame, so the reading can be taken without interpreting colours at all. The whole system runs as a single program on one machine and the phone that drives it holds no state beyond the calibration constants for its own camera geometry.

Quantity	Value
Array resolution	8 × 8, 60° field of view
Frame and uplink	128 B at 10 fps = 1.28 kB/s
Rendered pane	6.4 kB image, 256×256, 65 colours
Display refresh	30 fps user interface, sensor-limited to 10 fps
Identification latency	about 10 to 13 s per photograph
Identification cost	about ₹1 per photograph

Table 2. Measured characteristics of the running system.

9. Discussion and Limitations

Resolution. The 8x8 array is the dominant limitation. At a 60 degree field of view each cell subtends about 7.5 degrees, so a cell covers several components at normal working distance; a 32x24 array with 768 pixels, a twelve-fold increase, is the single highest-value upgrade.

Energising. Everything reported here observes heat. The deck's central claim is that it can cause heat to appear at the faulty device by injecting a current-limited rail. The useful current ceiling depends on the appliance class under test, so it is specified as an operator control rather than a firmware constant.

Offline operation. The instrument is specified for a shop that should not depend on a network. Here rendering is centralised and identification calls a remote model, which keeps the field unit cheap but makes the uplink a dependency; a cached catalogue and on-device inference are the route to full offline use.

Advisory results. A vision model reading a phone photograph usually returns the type of a component rather than its exact part number unless a marking is legible, and a web-search price is an estimate rather than a quotation. Both are presented as suggestions with a verification link.

The LEDs. Automatic alignment assumes the two LEDs are visible and bright. In a brightly lit workshop they can be lost against the background, and an LED that has only just been switched on may read below the board's own fault; both cases fall back to the one-off manual drag.

Speed. Identification takes about ten seconds and needs a network, which is slower than a technician's own eye once he knows the board. Its value is therefore in the first encounter with an unfamiliar appliance, not in routine work.

Safety. Injecting current into an unknown board is not risk-free: a limiter bounds total power, but reverse polarity and mains-referenced primaries remain hazards.

10. Future Work

- Move to a Melexis MLX90640 32×24 array and re-validate localisation on dense boards.
- Instrument the tray so the injected current is logged alongside the thermal frame, allowing short and open faults to be classified automatically.
- Hold the board at a controlled temperature in a cooling chamber, so the absolute temperature field becomes repeatable between runs and between boards instead of depending on a steady state being reached.
- Run the identification on the phone itself with the node acting as its server, so that a board can be named and priced over a local connection with no internet at all; the node and the handset would then form a self-contained instrument for a workshop without reliable connectivity.
- Generate the desoldering guide from the identified package and the board photograph, and evaluate the deck with working repair technicians.
- Add a second marker for the coolest cell, so that a board with no hotspot can be shown to be cold rather than merely unremarkable.

11. Conclusion

The economics of electronics repair are distorted by an information problem: the failure is local, but proving it is not cheap. An instrument that energises a board safely and images where the power goes turns that failure into a visible fact, and reduces the repair from a ₹15,000 board replacement to a ₹50 part. The system here implements the thermal half of that instrument and demonstrates the whole reasoning chain on working hardware: image the board, mark the hot component, name it, price it.

12. Cost and Deployment

The instrument costs less than one of the boards it is meant to save. The sensing node is a microcontroller and one sensor on a breadboard, both bought locally; the server is a single program on an ordinary machine; and the display is whatever phone the technician already owns. There is no recurring charge to display a board, and nothing has to be installed on the phone, which matters when the people who need the instrument most are the least likely to install an application.

The same feed serves any number of viewers at once, so a senior technician can watch a junior's board from another room and a disputed diagnosis can be seen by both parties at the same moment. That is precisely the argument that is hardest to make with a photograph taken afterwards.

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