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UroScan

Design and Bench Evaluation of a Low-Cost ESP32-CAM Reader for Ten-Parameter Urine Reagent Strips

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The problem

- Global Chronic kidney disease (**CKD**) mortality rose 41.5% between 1990 and 2017
- Nigerian studies report high but varying CKD prevalence
- The urine dipstick is the cheapest first screening test
- Most clinics still match the pads to a printed chart by eye
- Results depend on the reader and the room light, with no digital record



Where the idea came from

- Clinical posting to LUTH during the biodesign course (BME 325)
- Biodesign approach: find the need first, then choose the solution [5, 6]
- We saw how subjective visual reading is
- The printed chart varied in print quality and its colours were fading
- Design brief: no new test, just a repeatable colour comparison



Aim and objectives

Design, build and test a low-cost, microcontroller-based reader for a ten-parameter urine strip.

1

Build the optical capture and display hardware around an ESP32-CAM

2

Digitise reference colours from the manufacturer's chart

3

Develop a guided, one-pad-at-a-time capture and matching procedure

4

Evaluate the prototype in bench tests and find the main sources of error

Related work and the gap

- Smartphone readers: reference card and colour correctio
- Printed swatches around each pad: 86.7 to 100% performance
- Controlled light: Raspberry Pi in a black box with calibration
- A colour card improved agreement between phones
- ESP32-CAM already used as a low-cost measurement platform

The gap

In the sources we reviewed, no ten-parameter reader runs on a low-cost ESP32-class module with a one-pad-at-a-time workflow and needs no smartphone or computer.

METHODOLOGY

The DUS 10 strip

- DFI DUS 10 Home Test strip with 10 reagent pads
- Leukocytes, nitrite, urobilinogen, protein, pH, blood, specific gravity, ketones, bilirubin, glucose
- Manufacturer chart gives 3 to 7 colour blocks per pad
- Read at 60 s; leukocytes at 90 to 120 s
- Measured pad pitch: about 7.8 to 8.3 mm



Hardware

- ESP32-CAM (AI-Thinker) with a GC2145 camera sensor
- 0.96 in SSD1306 OLED on I2C, GPIO 13 and GPIO 15
- Buzzer, push button and the board's flash LED (GPIO 4)
- 3.7 V, 3200 mAh Li-ion cell with MT3608 boost to 5 V
- Firmware in Arduino IDE (C++)



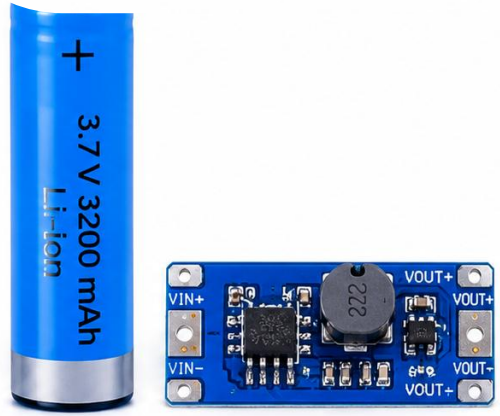
ESP32-CAM (AI-Thinker) with a CC2145 camera sensor



0.96 in SSD1306 OLED on I2C, GPIO 13 and GPIO 15



Buzzer, push button and the board's flash LED



3.7 V, 3200 mAh Li-ion cell with MT3608 boost to 5 V

How it works

- Pad n under the optical window
- Button press: flash LED on, camera captures
- Mean RGB of the centre region
- Nearest reference colour for that pad
- Beep, OLED shows result, repeat for 10 pads

$$d = \sqrt{[(R - Rk)^2 + (G - Gk)^2 + (B - Bk)^2]}$$

Rk, Gk, Bk: stored reference colour k. The smallest d is reported.

DUS-10 Workflow

1

Set Up

Prepare the device



2

Capture

Take a photo



3

Analyse

Read the strip and detect colour



4

Display

Show result



5

Get Result

Check and act



Colour Analysis Formula

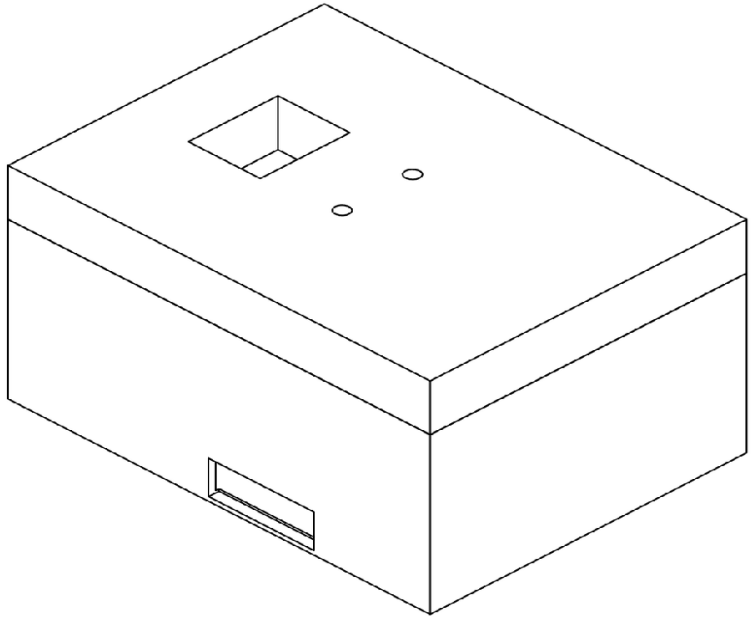
$$d = \sqrt{\left[(R - Rk)^2 + (G - Gk)^2 + (B - Bk)^2\right]}$$

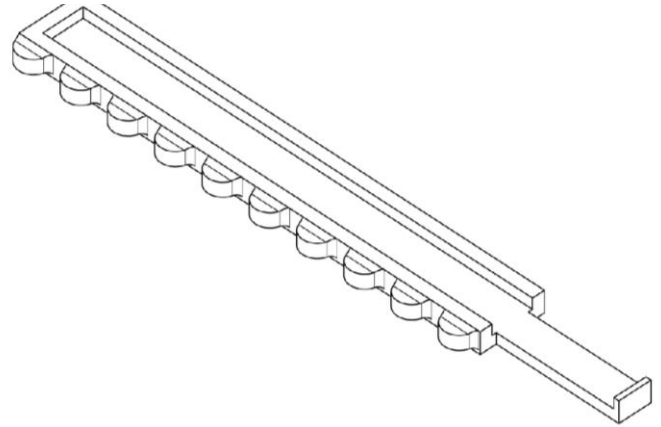
Rk, Gk, Bk: Stored reference colour

k: Pad index (1 – 10)

Enclosure and sliding carrier

- Designed in Autodesk Inventor; enclosure 120 mm × 90 mm in plan
- Carrier 79.00 mm × 11.00 mm with a 76.96 × 6.91 mm strip track
- Rack of 10 teeth at 8.10 mm pitch, about 73 mm first to last
- Pitch sits inside the measured 7.8 to 8.3 mm pad pitch
- Final enclosure printed in orange filament





Lessons from the build

- **GC2145, not OV2640.** No JPEG (error 0x106), so raw RGB565 at 153,600 bytes per frame
- **Byte order.** Frames looked like static until decoded as big-endian
- **Power.** Brownout resets on laptop USB at camera and Wi-Fi start-up
- **OLED address.** A solder jumper picks 0x3C or 0x3D, so the firmware scans the bus

Bench trial results

20
pad captures

13
frames received

7
failed in transfer

4
plausible frames

2 bench trials in room light, no enclosure, strip held by hand, frames sent to a laptop over Wi-Fi.

Of the 13 received: 7 underexposed, 2 saturated, 4 plausible. Distance to the assigned reference: 51 to 284 RGB units.

What the results show

A black frame and a white frame each got a label

The same class in both trials hid very different RGB values

Nitrite: (229, 184, 111) then (248, 252, 248), both read Neg

Neighbouring chart colours differ by a median of 47 RGB units; plausible frames sat 71 to 101 away

We make no claim of accuracy

Leukocytes	0, 4, 0 (U)	+++500 (284)	247, 252, 248 (S)	Neg (51)
Nitrite	229, 184, 111	Neg (101)	248, 252, 248 (S)	Neg (53)
Urobilinogen	134, 74, 39	8(131) (97)	18, 16, 8 (U)	8(131) (218)
Protein	3, 4, 0 (U)	++++1000 (246)	0, 4, 0 (U)	++++1000 (247)
pH	174, 86, 19	5 (81)	16, 16, 2 (U)	8.5 (186)
Blood	183, 166, 161	+25 (71)	no frame	n/a
Specific gravity	no frame	n/a	no frame	n/a
Ketones	0, 4, 0 (U)	++++160(16) (135)	no frame	n/a
Bilirubin	no frame	n/a	no frame	n/a
Glucose	0, 4, 0 (U)	++++2000(111) (97)	no frame	n/a

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THANK YOU