Lowest-Cost Communication with Light

Optical one-way data transfer using a smartphone when all other methods are too expensive.

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INTRODUCTION

ELPRO Buchs AG with their "Libero" series of trackers is a leading provider of transport monitoring devices for temperature sensitive goods like pharmaceuticals during shipment from the manufacturer to the final user. These devices are typically packed with a full box of goods and communicate their tracking data over USB.

Fig. 1: ELPRO temperature trackers

To track small packages or vaccine doses, ELPRO wanted to develop a much smaller and cheaper device that basically consist only of a battery, a mixed-signal ASIC, a single button and 3 LEDs (green, yellow and red) to indicate, whether the cool chain was maintained or whether the medication is no longer safe to use..

CHALLENGE

While the ASIC has on-chip non-volatile memory to store the exact time and temperature excursion for each deviation, the real challenge was how to get the data out and into the internet cloud for violator evaluation without increasing the product cost. Typical means like USB, WLAN, Bluetooth, ZigBee or LORA are far too expensive. Dedicated readout equipment was also not feasible, as each transport destination would have to be equipped with such a device, also adding to the cost.

Fig. 2: Data transfer via smartphone

As part of an Innosuisse funded research project we explored ways to use the given 3 LEDs to send the data and capture it with a regular smartphone camera. Even in the poorest countries smartphones are ubiquitous with a screen to display the data and an internet connection to upload results to the cloud. A smartphone app, once developed, is a very cheap way to get read-out devices into the field.

SOLUTION

The initial approach was to communicate with the brightness of the LEDs controlling the green, red and yellow LEDs by a fast pulse-width modulation. This however proved to be very unreliable, as the different smartphone cameras had highly non-reproducible camera sensitivity, which was furthermore controlled by non-influenceable camera gain adjustments. As there was no possibility for a back channel from the smartphone to the tracker, the communication had to be fast, robust and self-checking.

At the end, a fixed protocol with repeated training pattern and a slower pulse-width modulation of the LEDs was the solution, where the camera would no longer average the brightness, but capture a very blurred light spot across many pixels and thus record the PWM phases as zones of active and non-active LED, which by the width of the zones were measured to retrieve the signalling values.

Fig. 3: Blury recording of the LEDs with stripes caused by PWM and rolling shutter interaction

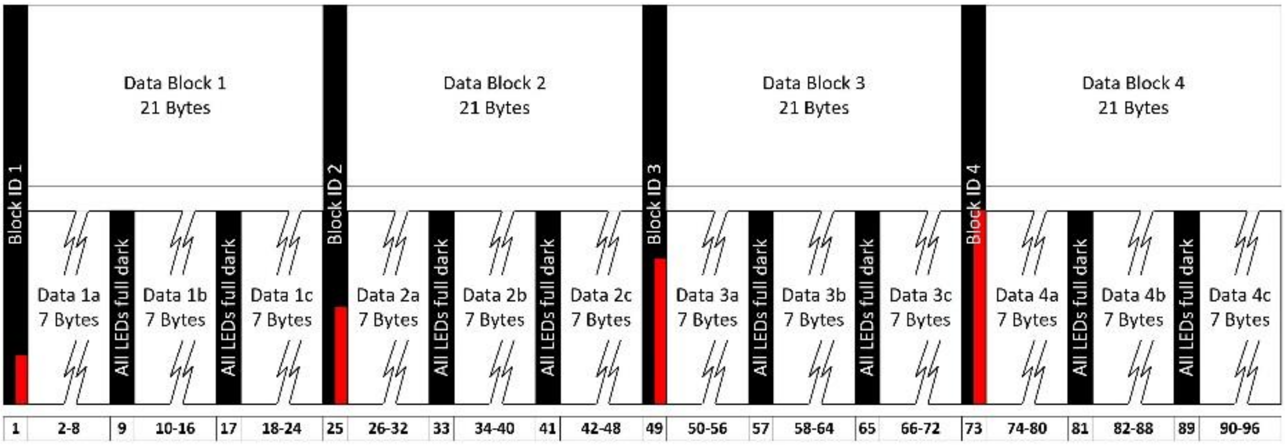

Fig. 4: Communication protocol including synchronization, data and data-block identifications.

As the ASIC had to be very small and efficient, there is no processor implemented, but a hard-coded state machine sending the data using this protocol multiple times, including forward error correction and CRC checksum.

Implementing the entire mixed-signal ASIC content on an FPGA platform, it was possible to develop and test the full implementation including the smartphone app software before the ASIC tape-out, and also to develop verification and qualification test vectors for production.

CONCLUSIONS

While initial assumptions proved to be infeasible, we were successful in finding and implementing a robust mode of fast data transfer of 84 bytes within about 20 seconds, including forward error correction.

- Measuring absolute brightness with a smartphone camera is close to impossible due to lack of camera control and blooming of the pixels where the LED core is pictured.
- Rolling shutter can be a good thing and can be exploited
- It is possible to have a one-way data communication at close to no cost
- Smartphones are a valuable platform for many uses outside their original purpose
- With advanced smartphones it becomes more difficult to control their sophisticated sensors

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