Wearable Biomarker Processing using Speckle Plethysmography based on an Embedded RISC-V ASIP

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Introduction

Increasing load of healthcare system

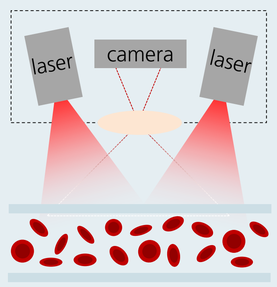
- Demand for remote patient monitoring (without hindering the patients)
- Provide physicians with everyday health insights (e.g. blood pressure, heart rate, blood O_2 saturation)

State of the art: PPG

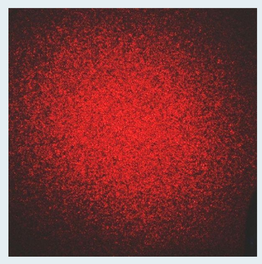
- PPG (photoplethysmography): use illuminated tissue to track blood vessel contractions via (IR) LEDs + photodiodes; extract biomarkers from intensity fluctuations
- Quality suffers from everyday situations, such as motion artifacts

Promising candidate: SPG

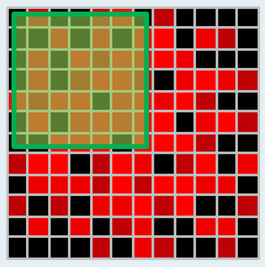
- Speckle plethysmography
- Less susceptible to disruption due to patient movement or skin type (i.e. melanin count) [1,2]



(a) tissue sampling



(b) obtained speckle image



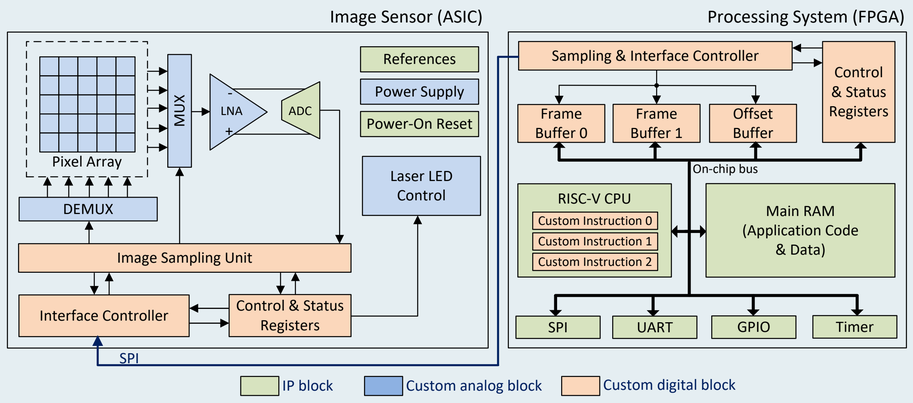
(c) window-based processing

Speckle plethysmography and biomarker data extraction

- Illuminate blood vessel with coherent light (a)
- Blood particles reflect light causing an interference pattern ("speckle") (b)
- Sample and digitize speckle image and process in window-based processing (c) scheme to obtain vital parameters

Our approach: a wearable platform based on a RISC-V Application-Specific Instruction-Set Processor (ASIP)

Wearable SPG Prototyping System



Block diagram: image sensor (left), RISC-V-based processing system (right)

Processing System (ASIP on FPGA)

RISC-V-based processor system

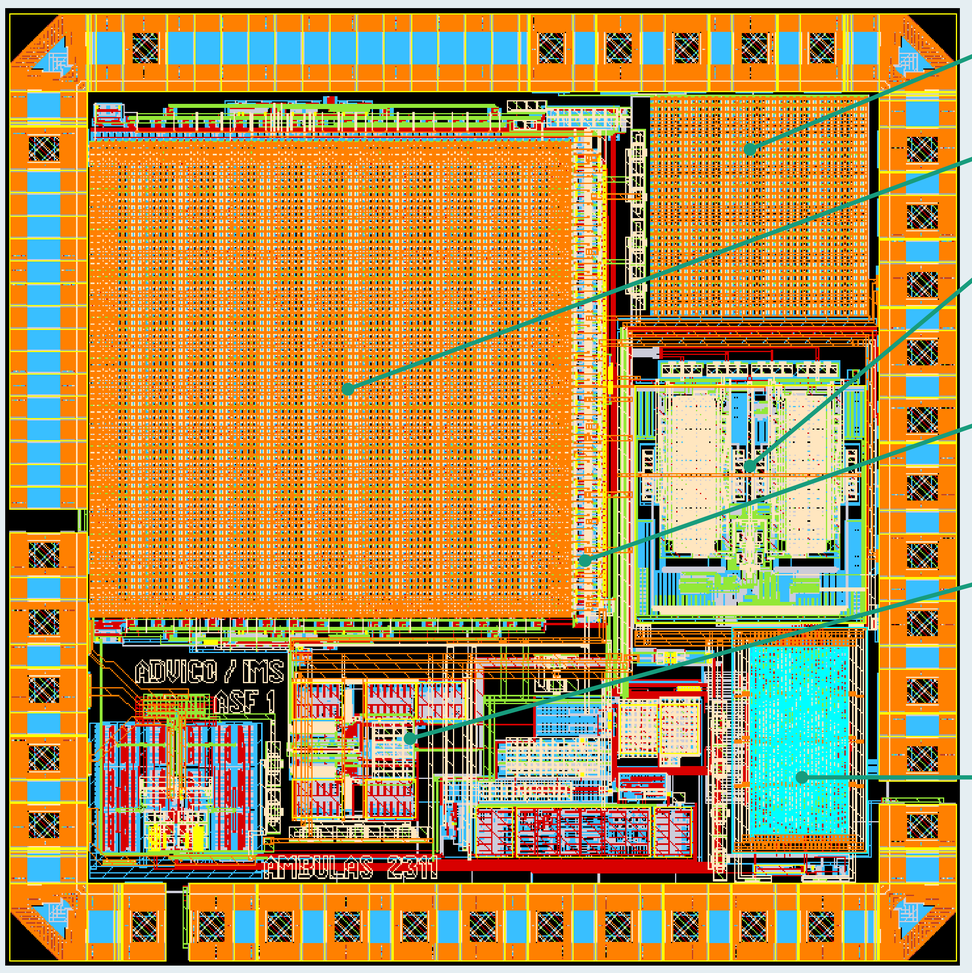
- Base ISA extended with application-specific custom instructions [3]
- Base SoC extended with DMA-based SPI connection to imager chip + special framebuffers to allow double-buffering while processing one speckle image

AIRISC

Requires ~5000 LUT4s, running at 24MHz on a Lattice iCE40up5k FPGA, extracting vital parameters from 15 frames per second [3]

Image Sensor (ASIC)

- Dedicated imager sensor manufactured in 180nm CMOS, 2.1mm x 2.1mm die size
- Highly-adjustable image sampling characteristics (e.g. exposure time)



Test array
for characterization

Photo diodes
64 x 64 pixel

ADC
12-bit, SAR, 1.25MS/s

Readout logic
row/column multiplexer

Analog helpers
amplifiers, PoR, references, laser driver, etc.

Digital control
SPI, control and status registers, finite state machines

Future Work

- Targeted speckle processing framerate: 30fps; further algorithm profiling to add/optimize additional ISA extensions
- In-vitro testing with portable (wireless) FPGA board
- Monolithic ASIC integration: speckle sensor + RISC-V ASIP on single chip
- Long-term goal: integration into medical patches and smart watches

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[1] Nemati M. et al. "*Dynamic light scattering from pulsatile flow in the presence of induced motion artifacts*" Biomed Opt Express, 2014
[2] Cody E. et al. "*Comparison of speckleplethysmographic (SPG) and photoplethysmographic (PPG) imaging by Monte Carlo simulations and in vivo measurements*" Biomed. Opt. Express 9, 2018
[3] Nolting S. et al. "*Developing Custom RISC-V ISA Extensions for General Purpose Embedded Image Processing*", RISC-V Summit EU 2023

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