Enhancing spatial resolution in perfusion mapping triggered by audio-(de)modulated reference

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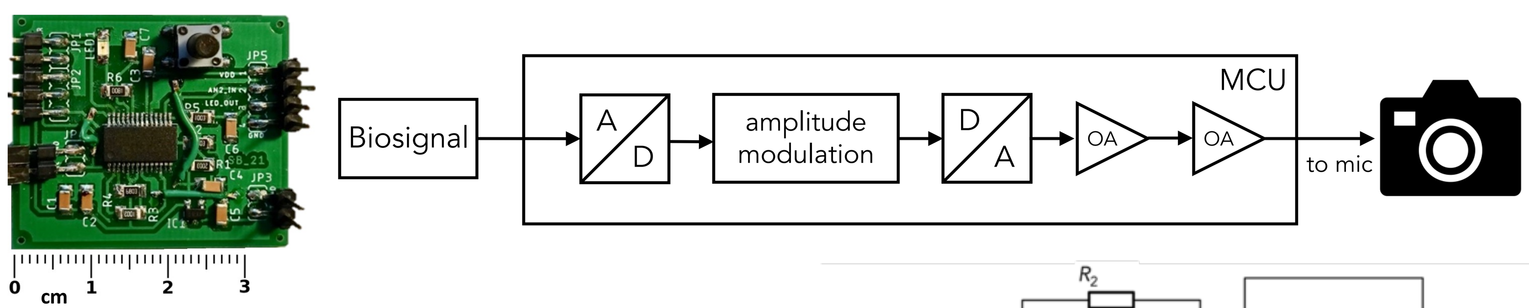
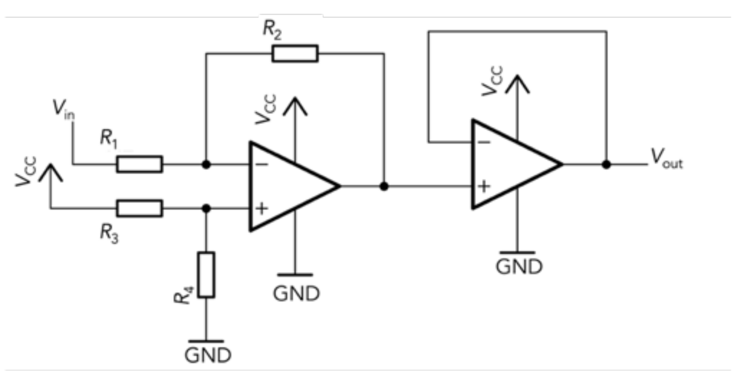
In the last two decades, **photoplethysmography imaging** (PPGI) is the point of interest in many research fields. This technique provides a non-invasive and contactless option for monitoring vital signs such as heart rate, respiratory rate or for assessing the state of the autonomic nervous system.

When investigating some physiological parameters, it is advisable to use a reference signal combined with PPGI. The reference signal also allows for an increase in the spatial resolution of the PPGI system. On the other hand, it increases the complexity of the system and the technical synchronization prerequisites. Our solution is a hardware device that modulates the reference biosignal into the audio frequency band. Such a signal can also be fed to the input of a conventional digital camera or a smartphone, enabling the transformation of such a device into a PPGI measurement system even in the case of compressed video recording using **lock-in amplification** (LIA) techniques. It also brings the possibility of synchronous recording of PPGI and a reference signal such as conventional **photoplethysmography** (PPG) or **electrocardiography** (ECG).



$$V_{out} = -\frac{R_2}{R_1}V_{in} + \left(1+\frac{R_2}{R_1}\right)V_{cc}\frac{R_4}{R_3+R_4}$$

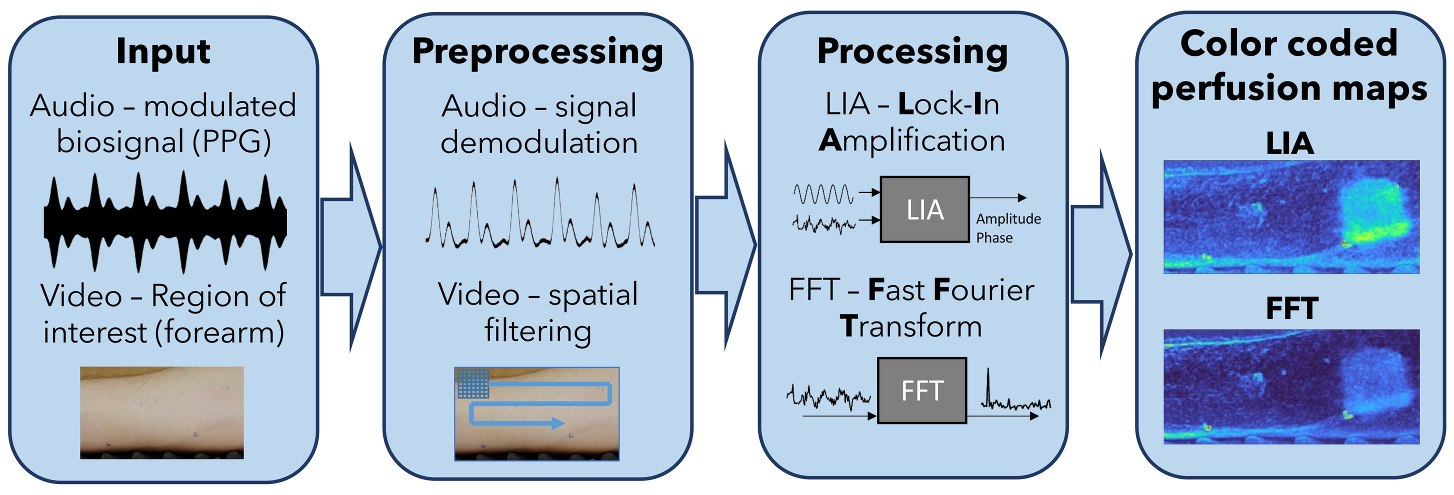
$$V_{out} \cong 0.338 \cdot V_{cc} - 0.015 \cdot V_{in}$$



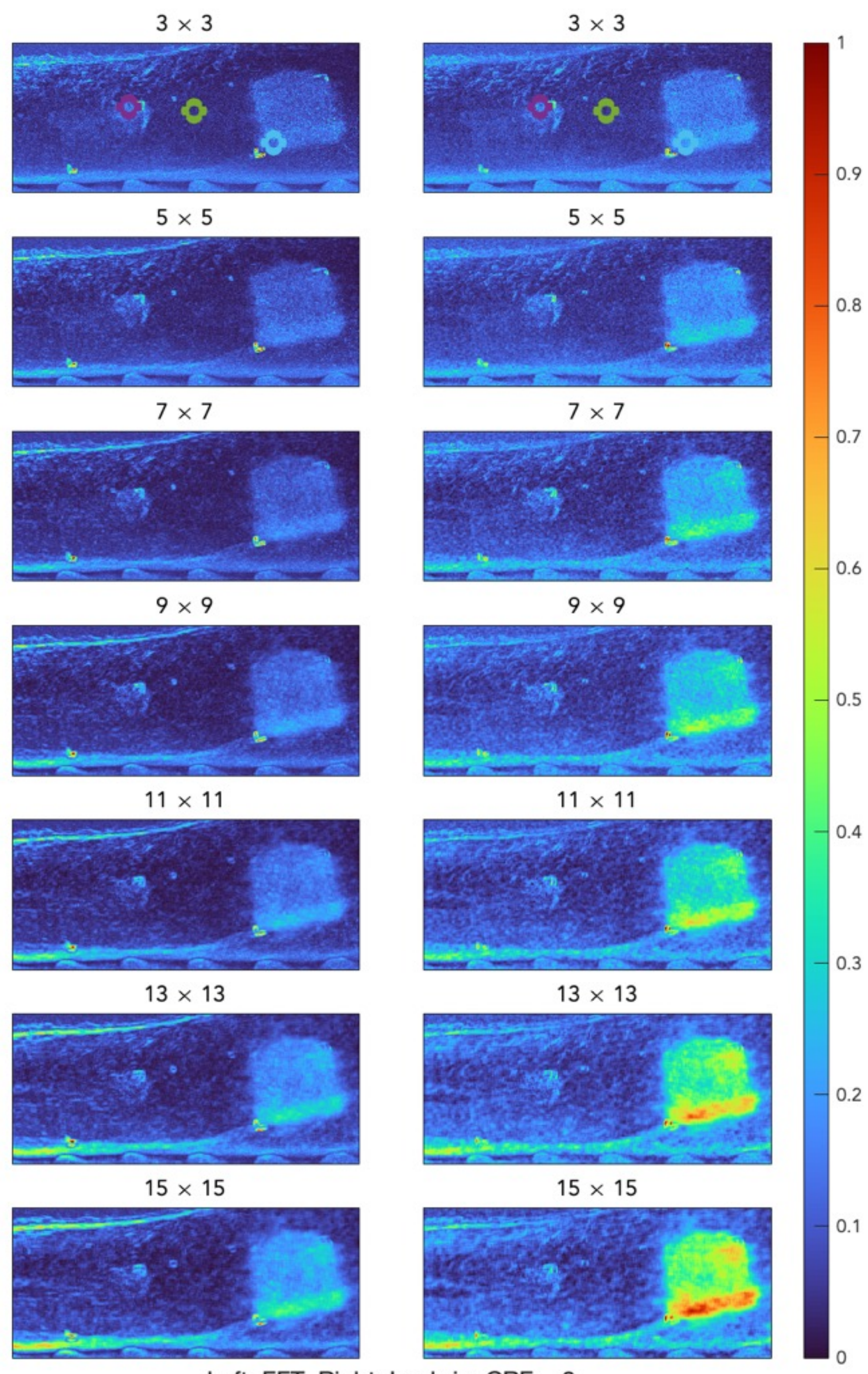
During our measurements, we used as a PPGI sensor a Canon 550D DSLR camera with modified firmware, which allowed us recording raw video in MLV format with a sampling rate of 15 Hz. As sensors of the reference signals, we used a SparkFun Electronics contact PPG sensor placed on the index finger and an ECG analog front-end based on AD8232 (Analog Devices) again on a prototype board from SparkFun Electronics. The ECG signal was recorded from the Einthoven lead I.

To induce a change in subcutaneous perfusion, we applied on the subject's forearm (the region of interest for PPGI signal acquisition) two types of creams:

- **cream 1** (C1) – active ingredient is based on a standardized semi-solid extract of capsaicin (ratio 4-7/1),
- **cream 2** (C2) – two main vasodilators: nonivamide and nicoboxil.



We focused on the effect of moving kernel size and methods comparison for extracting the amplitude of perfusion changes. First, we compressed the raw video obtained from the camera using **H.264 standard**, which is a common format used for recording video via consumer electronics. The parameter we set was constant rate factor CRF the value of which allows us to adjust the compression rate as lossless (**CRF = 0**). We used a terminal-based set of tools for video compression, namely FFmpeg. A RAW video recording of 60 s length in the form of an uncompressed .avi file had an original size of 2.21 GB, whereas, after compression, the size for CRF = 0 was 607.9 MB, respectively.



Left: FFT, Right: Lock-in, CRF = 0

All maps were obtained from the green layer of the image. We gradually increased the kernel size from 3×3 px^2 to 15×15 px^2 with a step size of 3 px. When comparing the quality of the maps in terms of the methods used for extracting the PPG signal amplitude, the LIA performs much better in this compared to the FFT. With lossless compression (CRF = 0), subtle changes in map structure can be discerned even with the FFT method, especially from the 13×13 px^2 kernel size (increased perfusion in the inner region with cream 2 applied). The LIA method reveals this trend already at a kernel of 5×5 px^2. The reference signal obtained from our HW connected to the camera's mic input plays a significant role here. **The HW is already approved and protected by Industrial property office of the Slovak Republic as utility model (No. 108-2021/9484). The results are already under consideration for publication in *Biomedical Optics Express Journal*, Q_1, IF = 3.732.**