Fast and cost-effective multispectral imaging for heart rate detection

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We demonstrate a cost-effective multispectral camera based on time-sequential LED-based illumination. We achieve a multispectral frame rate of 56 frames per second (fps) with 9 spectral bands. The system allows for non-invasive heart rate detection simultaneous to multispectral imaging.

1 Introduction

Multispectral imaging captures wavelength information beyond the classic RGB colorspace. Fields of application are, for example, medical imaging, where the cameras are used to increase contrast and help to differentiate different tissue types [1].

There are several variants for the implementation of multispectral imaging [1]. Fast multispectral cameras use wavelength-selective color filters assembled onto the pixels (Snapshot Mosaic Cameras). However, such systems always make a compromise between spatial resolution and the number of spectral bands. This choice cannot be changed after the initial configuration of the camera.

2 Time sequential multispectral detection

By using time sequential illumination, the before mentioned trade-off is transformed to a compromise between the number of spectral bands and the measurement time. However, this compromise can be configured dynamically, based on the number of available light sources. The spatial resolution remains unchanged.

LED light sources in combination with CMOS cameras are suitable for cost-effective imaging.

In the literature, LED-based systems have been demonstrated that use 4-13 spectral regions and achieve frame rates up to 5 Hz [2,3,4].

3 Setup

Compared to the state of the art, we use a fast USB3 mochochrome camera (Ximea MQ013RG-ON) with up to 1000 fps. We use a self-developed microcontroller-based LED light source with 9 different spectral regions for active illumination. The illumination is synchronized to the exposure time of the camera, i.e. each frame "sees" only one LED color (see Fig. 1).

The total cost of the system (camera, lighting, electronics) is less than 1000 €.

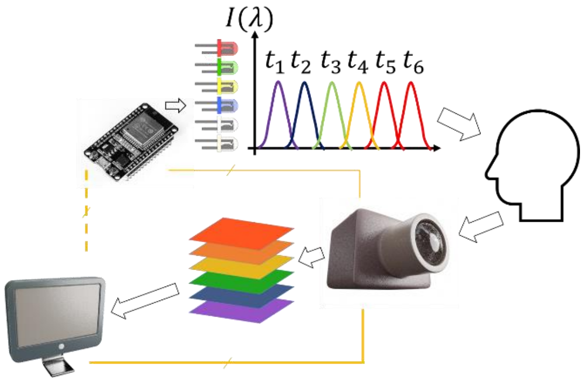

Fig. 1: *System setup for multispectral imaging. The sample is illuminated sequentially by a microcontroller-based LED light source. The individual colors are switched one after the other and are synchronized to the camera. The images are streamed to the control computer.*

4 System Characterization

Fig. 2 shows the selected spectral regions used for active illumination:

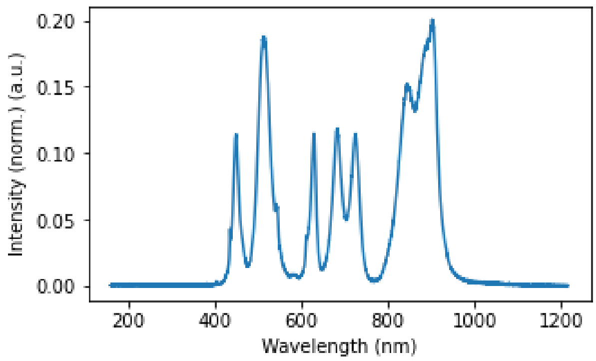

Fig. 2: *Normalized spectrum of the LEDs. In the diagram, the spectrum of each individual LED was measured, normalized to one, and the sum of all spectra was added together.*

9 different LEDs with central wavelengths of approx. 450 nm, 508 nm, 520 nm, 629 nm, 683 nm, 725 nm, 840 nm, 885 nm and 904 nm were used. The full width at half maximum (FWHM) bandwidths ranged from 20 nm to 80 nm, depending on the LED type.

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Our system allows for a frame rate of up to 505 fps, which results in a multispectral frame rate of 56 fps using 9 colors. The exposure time is 1.3 ms per frame.

For heart rate detection, the exposure time is increased to 6 ms for better signal-to-noise ratio (SNR), which corresponds to a frame rate of 160 fps. Using 9 colors, the frame rate per color channel is 17.8 fps.

5 Non-invasive pulse wave extraction

The system can be used for multispectral imaging of tissue. The active illumination in combination with the monochrome camera achieves a high SNR that is suitable for non-invasive human pulse wave extraction:

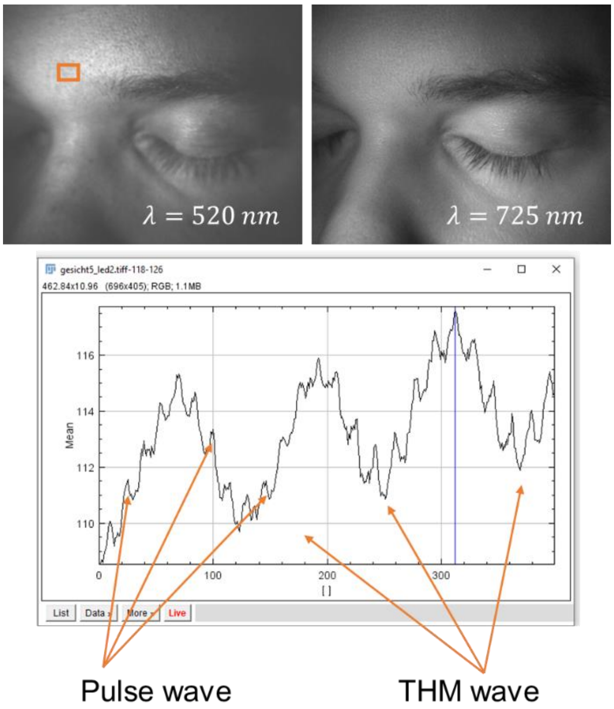

Fig. 3: *Top: Pulse wave extraction on the face (marked area) Top left: Illumination with 520 nm; top right; simultaneous illumination with 725 nm for comparison. Bottom: Evaluation of the averaged pixel intensity at* $\lambda = 520\ nm$ *for 400 frames (*$t = 0\,..\,22\ s; \Delta t = 56\ ms$*).*

Fig. 3 shows the extracted pulse wave from a small area on the face. Within the area of the rectangle, the pixel intensities were averaged and displayed over the measurement time of 22 s. Regular waves are observable with a period of ~14-17 frames, representing the human pulse wave. In addition, a second oscillation is recognizable with a period length of over 100 images. This second oscillation corresponds to the blood pressure regulation by the so-called Traube-Hering-Mayer (THM) wave [5].

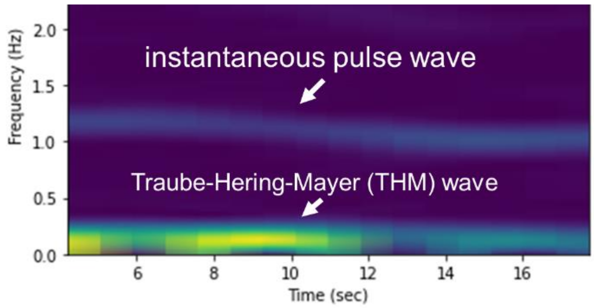

Fig. 4: *Time-frequency analysis of the pixel intensity. Instantaneous pulse wave and THM wave are observable.*

Fig. 4 shows a time-frequency analysis of the measured pixel intensity with green illumination. The instantaneous heart rate is about 1.1 Hz - 1.2 Hz (66 bpm - 72 bpm) (upper line); the THM wave is about 0.13 Hz (lower line).

6 Discussion

The biggest challenge of the setup is the spatial inhomogeneity of the illumination. This can be minimized by dense placement of the LEDs and, if necessary, diffusers.

The measurements were done in a darkened room. However, this can be overcome by using LEDs with higher output power. The dynamic range of the camera has not yet been exhausted.

A higher multispectral rate can be achieved by reducing the number of colors. In contrast to Mosaic cameras, this is can be done dynamically.

7 Conclusion and outlook

The demonstrated system permits fast multispectral imaging with up to 56 fps per color channel. The active illumination allows a high SNR for recording vital signs *in vivo*. Future work might comprise the correlation between further vital signs.

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