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Co-integrating thermal and hemodynamic imaging for physiological monitoring

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Abstract

Photoplethysmographic imaging (PPGI) has gained popularity for non-intrusive cardiovascular monitoring. However, certain symptoms (e.g., fever) may not be easily detectable using cardiovascular biomarkers. Here, we investigate the co-integration of PPGI and thermal imaging to create a non-contact, widefield, multimodal physiological monitoring system. To achieve strong PPGI performance, high-power infrared LED stability was investigated by evaluating two LED driver boards. Results show that the multimodal imaging system was able to acquire spatially consistent hemodynamic pulsatility and heat distributions in a case study. This multimodal system may lead to improved systemic disease detection and monitoring.

1 Introduction

Physiological monitoring technologies are crucial for detecting and monitoring human disease. Non-contact imaging technologies such as photoplethysmographic imaging (PPGI), have recently gained interest largely because of their non-intrusive manner of assessing cardiovascular health, enabling long-term, continuous monitoring in naturalistic environments [1]. However, PPGI systems are constrained to cardiovascular monitoring, limiting the diseases that can be detected. Multimodal imaging systems can provide important additional physiological information for increased health monitoring. Two technologies that provide complementary non-contact, non-intrusive physiological monitoring in diverse lighting environments are infrared PPGI and thermal imaging. However, the performance and integration of these systems require careful design consideration.

The quality of spatial blood pulse perfusion data that the PPGI system can capture depends on the stability of the infrared light available. The pulsatile component of the diffuse reflectance is quite small; any temporal instability from the illumination source will result in larger instability in the reflected pulsatile signal. Utilizing an active lighting system would create infrared illumination that can be controlled, allowing the device to be fully integrative, self-contained and used more readily in a wider variety of environments. However, such a system must introduce as little noise as possible, and must also integrate with the preexisting interface of the chassis. The existing chassis was designed to interface with high-powered light emitting diodes (LEDs) on its front panel [2]. However, high-powered LEDs are prone to large and frequent fluctuations in forward voltage and rapid increases in temperature, producing fluctuations in current and ultimately resulting in unstable radiant flux [3]. To eliminate the current's reliance on unstable forward voltages, constant-current LED drivers are commonly used to provide stability to high-powered LEDs [3]. Here, we evaluate the output stability of two LED driver boards for use in PPGI.

Additionally, co-integrating a thermal imaging module was investigated due to the known relationship between body temperature and cardiovascular health [4, 5]. Recent improved quality, decreased price and decreased size of thermal imaging technology have generated interest in its use as an embedded component in custom imaging devices, as well as to assess skin temperature [5]. In order to maintain a highly regular core temperature, the skin temperature of the human body is changed rapidly and is thus a helpful benchmark for the presence of many medical ailments, such as chronic diseases, fever, musculoskeletal injury and even melanomas [5, 6]. Most illnesses result in some alteration of skin temperature as a byproduct of the body regulating its core temperature and metabolic rate [6]. A study on the circadian rhythm of metabolic processes found that heart rate and skin temperature are inherently linked; they increase and decrease almost synchronously [4]. Thus, co-integrating thermal and hemodynamic imaging can provide complementary yet distinct physiological information for more robust and informative health monitoring.

2 Methods

The proposed imaging system combines existing mechanical housing with improved LED driving capabilities and an integrated thermal imaging system. The mechanical housing was designed to maximize portability and support the swapping of multiple parts for ongoing analysis of different components [2]. The chassis can be seen in Fig. 1 with its near-infrared active illumination system, near-infrared camera, integrated thermal camera, and photoplethysmography finger-cuff. The highly adjustable and portable imaging device has previously displayed its ability to capture, record and analyze spatial blood pulse perfusion in a laying or seated position, positioned 1 m away [2]. The next necessary improvement was to integrate stable, active infrared illumination and thermal imaging systems.

Fig. 1: The proposed imaging system co-integrating thermal imaging (red), near-infrared PPGI (blue), and a finger-cuff PPG for validation (green).

2.1 Inclusion of Active Illumination System

A crucial part of the system's stability and usability came from careful selection of high-powered LEDs and a new LED driver board, based on multiple performance tests. The two near-infrared, high-powered LEDs chosen for further analysis were 850 nm and 940 nm LEDs from LEDEngin, with typical radiant fluxes of 515 and 1150 mW respectively. These LEDs were thermally regulated through custom, thermally-adhered heat sinks to prevent temperature-induced decreases in LED stability, and were mounted in the chassis (indicated by red arrow). It was determined that an improved LED driving system was required for hemodynamic imaging. It was empirically suspected that the existing LED driver was producing unstable LED current, which would add unnecessary noise to the blood pulse perfusion images. A replacement driver must have improved constant current regulating mechanisms, produce only minimal temporal current fluctuations and result in stable radiant flux output from the selected LEDs.

Based on this list of requirements, two constant-current drivers were selected: Maxim Integrated's MAX16832 and Texas Instruments' LM3414. Evaluation modules for each driver were tested for their ability to provide a stable current to each of the LEDs in the system. The protocol for this testing utilized the TSL260 light-to-voltage converting photo-diode from Texas Instruments to evaluate temporal photon density fluctuations. For test one, the LED's radiant flux output was read by this sensor as it blinked, and measured using an oscilloscope. In test two, the driver board output voltage to the LEDs was also measured and visualized using the oscilloscope. These tests were performed with various optical settings, and with both LEDs. In a final test, the boards were stress tested to see if either LED's current or light output decreased in stability over a longer period of time. First, each board's light output was plotted over 5 minutes for each LED. After cooling sufficiently, the LEDs were each powered again for 10 minutes, with three different samples taken from across the +/- output terminals of the board by an oscilloscope at the start, middle and end of the trial. To also assess fluctuations in the current going to the LEDs, the same readings were repeated across the 0.05 Ω current sense resistor placed at the LED+ terminal of the board.

2.2 Integration of Thermal Imaging

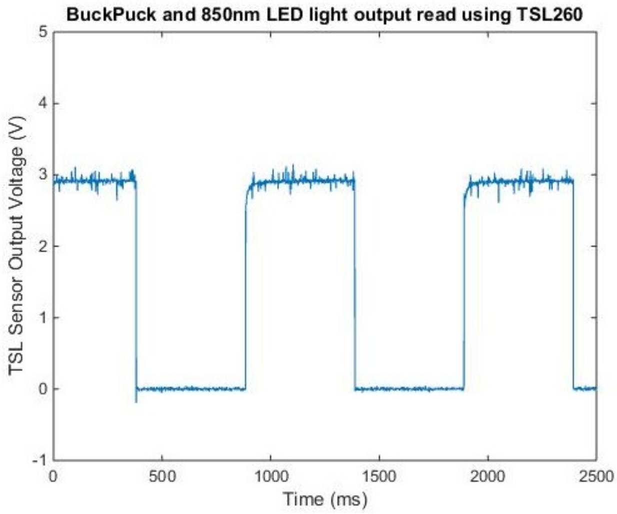
Thermal imaging added multi-functionality to the original imaging system as a secondary form of non-contact physiological monitoring. Thermal imaging generally employs the sensing of long-wave infrared light that is passively emitted as heat by the human body, the intensity of which corresponds to the amount of heat being produced [3]. Some very simple, small and affordable options for thermal imaging are commercially available, and for this proposed system, the FLIR *Lepton* breakout module was used. The *Lepton* was mounted onto the chassis using a 3D-printed, altered version of the LED mounting clamp, allowing it to interface with the mechanical chassis as displayed in Fig. 1 (indicated by red arrow).

Some FLIR breakout modules allow the *Lepton* to be used through a camera interface, supporting the thermal image's co-alignment with the spatial blood pulse perfusion images. The active infrared lighting system is used to acquire images from which a proposed signal processing framework [7] can extract spatial blood pulse perfusion data, creating a geometrically and temporally synchronized hemodynamic and thermal monitoring system.

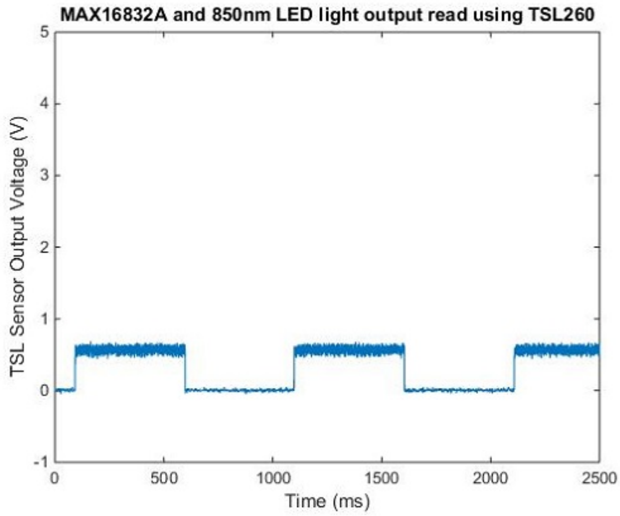
3 Results

3.1 Evaluation of LED Driver Boards

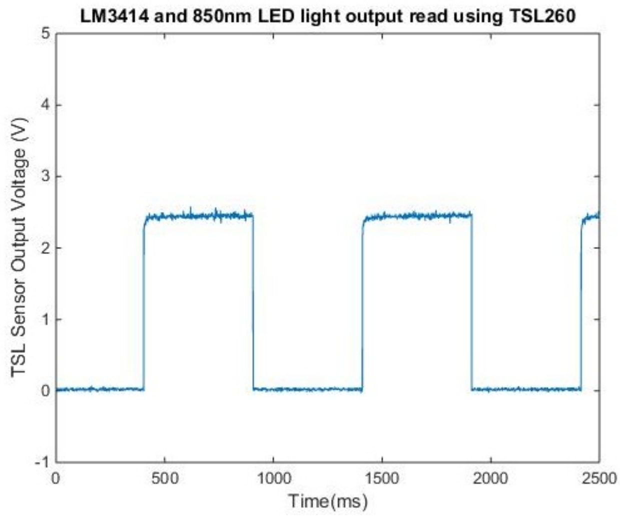
The oscilloscope readings from the first test in the protocol can be seen in Fig. 2 for the 850nm LED powered by the BuckPuck, MAX16832 and LM3414 LED drivers, with the LEDs modulating between high and low ("on" and "off"). It is visually apparent from these figures that the LM3414 produced the least fluctuations in radiant flux output of the LEDs, with the most consistent "on" section of the cycle and a nearly square wave. In 200 ms long samples from the "on" portions of each board, the LM3414 showed a $\pm$4.90% fluctuation from its mean "on" value. In comparison, the MAX16832 showed a $\pm$19.4% fluctuation – worse than the BuckPuck's $\pm$7.37% fluctuation. The LED+/- terminal readings in the second test resulted in figures similar to Fig. 2: the LM3414 again exhibited the least fluctuations in output voltage. Thus, the LM3414 was run through the stress tests to assess its performance over a longer time period. Although there was a steady change in both LEDs' light outputs over time (due to increases in temperature), the LM3414 continued to supply a constant 1 A of current to each of them, with very little fluctuation. The LM3414 evaluation board was selected to be the best constant-current LED driver.



(a)



(b)

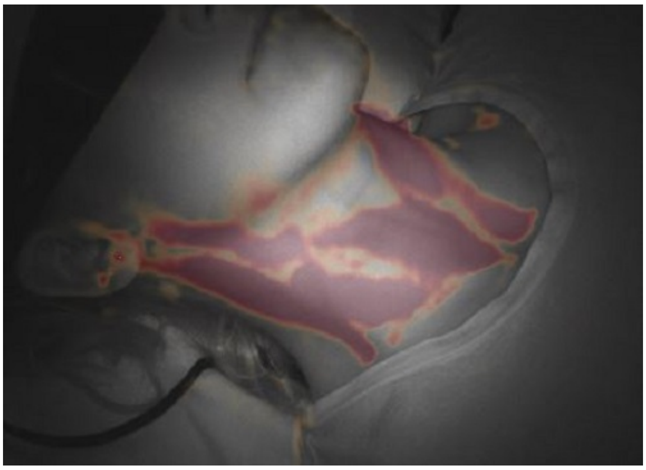


(c)

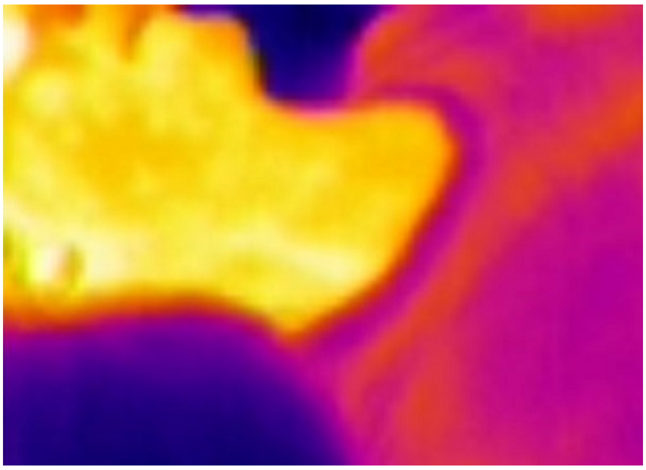
Fig. 2: Plots of oscilloscope readings taken from across the TSL260 light-voltage sensor using an 850nm LED powered by (a) BuckPuck, (b) MAX16832 and (c) LM3414 LED driver boards.

3.2 Combining Thermal and PPG Imaging

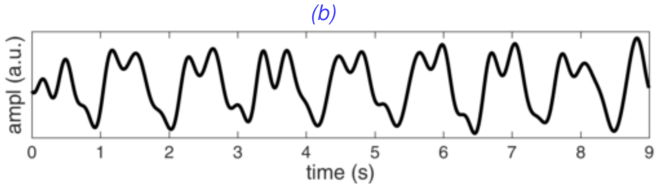
Fig. 3 shows the two types of data that can be collected with the duo-function imaging system. Fig. 3(a) shows the signal-to-noise ratio (SNR) of spatial blood pulse perfusion data gathered with the improved system, displaying cardiovascular function of the subject. Darker red indicates a higher SNR. Fig. 3(b) shows temperature distribution which is indicative of the subject's metabolic processes. It is important to notice the white areas of warmer temperature on the neck in Fig. 3(b) which correspond to darker red areas in Fig. 3(a), such as along large blood vessels. Fig. 3(c) shows the extracted blood pulse waveform information for the participant in a high SNR region.



(a)



(b)



(c)

Fig. 3: (a) Spatial blood perfusion and (b) thermal images of a subject's neck, and (c) blood pulse waveform captured by PPGI.

4 Discussion

It was earlier determined that with a stable illumination input, a strong pulsatile signal could be received as output. After changes were made to the LED driving circuitry in an attempt to make their current supply and radiant flux output more stable, the data shown in Fig. 3(a) and (c) were collected. The spectral SNR of this data was 4.13 dB, indicating a strong PPGI pulse signal relative to the noise floor. Thus, sufficient improvements were made to the quality of the hemodynamic data collected, due to the integration of a stable active illumination system.

Combining thermal and blood pulse perfusion data can lead to a more complete non-contact physiological assessment in a wider variety of environments and applications, both natural and clinical. With this system's ability to visualize both hemodynamic and thermal indicators, users could concurrently assess both metabolic and cardiovascular activity, such as skin temperature and heart rate. This systematic correlation may allow for quicker and more accurate confirmation and diagnoses of many medical ailments with both cardiovascular and metabolic biomarkers, such as early detection of influenza, arthritis, and peripheral arterial disease. The system has the potential to replace the current PPG finger clips, which only provide hemodynamic data from a very small area of the body. Non-contact monitoring is especially important for subjects that cannot be touched with the current PPG clip, such as quarantined patients, small infants, and burn victims. Since the system passively monitors subjects, it reduces the risk of contamination between uses; this enables multi-individual monitoring in high-risk, high-density areas such as long-term-care homes, emergency waiting rooms, and sports training sessions. The added portability and long-term use of the integrated PPGI system introduces the possibility of at-home monitoring, supporting the shift toward personalized healthcare. The addition of thermal imaging capabilities results in a non-contact physiological monitoring system possibly capable of assessing both hemodynamic and metabolic health of multiple subjects simultaneously.

5 Conclusion

A multimodal thermal and hemodynamic imaging system is proposed with the possibility to provide a groundbreaking combination of physiological information from a single device. Active, reliable infrared lighting was incorporated into the existing hemodynamic monitoring system to improve the quality of the data collected as well as increase its usability. Integrating thermal imaging as a secondary non-contact monitoring method extended the system's physiological monitoring capabilities.

Acknowledgments

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References

[1] Sun, Y. and Thakor, N. Photoplethysmography revisited: from contact to noncontact, from point to imaging. *IEEE Transactions on Biomedical Imaging* (2016).

[2] Amelard, R., et al. A portable plug-and-play imaging system for physiological monitoring. *Vision Letters* (2015).

[3] Day, M. LED-driver considerations. *Analog Applications Journal, Analog and Mixed-Signal Products* (2004).

[4] Krauchi, K. and Wirz-Justice, A. Circadian rhythm of heat production, heart rate, and skin and core temperature under unmasking conditions in men. *American Journal of Physiology* (1994).

[5] Ring, E.F.J. and Ammer, K. Infrared thermal imaging in medicine. *Physiological Measurement* (2012).

[6] Pascoe, D.D., Mercer, J.B., and de Weerd, L. Physiology of thermal signals. *Medical Infrared Imaging: Principles and Practices* (2013).

[7] Amelard, R., et al. Feasibility of long-distance heart rate monitoring using transmittance photoplethysmographic imaging (PPGI). *Scientific Reports* (2015).