Guest Editorial
Camera-Based Health Monitoring in Real-World Scenarios

AT PRESENT, cameras are increasingly used to measure physiological signals from human face and body for contactless health monitoring, thereby eliminating mechanical contact with the skin that are common in wearable sensors. This is an emerging research direction developing rapidly in the last decade and which is now gradually maturing into products for patient monitoring. Advancements in biomedical optics, physiological measurement, computer vision and artificial intelligence (AI) enabled various camera-based measurements, including vital signs like heart rate (HR), respiration rate (RR), oxygen saturation (SpO2), blood pressure (BP), and physiological markers that have diagnostic capabilities, such as the detection of arrhythmia, atrial fibrillation, apnea, hypertension, etc. Image and video analysis also permit the measurement of human semantics, context and behaviours that provide new insights into health informatics (e.g., facial analysis and body actigraphy for the assessment of patient delirium), which is a unique advantage of camera sensors as compared to biomedical sensors, like e.g., photoplethysmography (PPG) and electrocardiogram (ECG). Camera-based health monitoring will bring a rich set of compelling healthcare applications that directly improve upon contact-based monitoring solutions in various scenarios like clinical units including e.g., the intensive care unit (ICU), the neonatal ICU (NICU) or sleep centers, and assisted-living homes (e.g., elderly homes or confinement centers), improving patient care experience and people's quality of life.

After so many years of R&D in the field of camera-based health monitoring, it is time to bring the novel concepts and prototypes (i.e., camera setups and video processing algorithms) from labs to real-world scenarios to demonstrate their actual performance and value in concrete applications like clinical trials or pre-development showcases. Undoutbly, camera-based health monitoring will evolve into a key technology in future healthcare, advancing diagnosis and prognosis, patient care and rehabilitation, telemedicine, and chronic disease management. However, in recent years, we have witnessed abundant technical papers focused on niche algorithm development and "virtual" benchmark competitions (especially for deep learning related works) while very few explored its value "in the wild" or creating tangible novel solutions that address real challenges and necessities from practice. It is important to raise the awareness in this field that developing camera-based health monitoring technology with research questions from pratical needs (e.g., hospitals) is crucial for keeping this direction alive. This is the background intention of organizing this special issue, which promotes the latest developments pertaining to *Camera-based Health Monitoring in Real-world Scenarios*, specifically on innovation, validation and demonstration of camera-based health monitoring in healthcare applications.

This special issue of the IEEE Journal of Biomedical and Health Informatics is meant to present and highlight real-world applications of camera-based health monitoring. It attracted a significant number of submissions from both academia and industry. After critical peer-review and highly-competitive selection, 9 manuscripts were accepted for publication in this special issue, covering a variety of topics in the category of camera-based physiological measurement, health informatics retrieval with AI techniques, and clinical platforms and demonstrations in NICU.

The first paper by Yang et al. [1] focuses on improving the performance of camera photoplethysmography (camera-PPG) It identifies the major problem of this technology to be the poor waveform quality of pulse-signals measured by conventional camera-PPG algorithms. Thus, employing cyclic *Generative Adversarial Networks* (CycleGANs), it proposes a new framework, called *cbPPGGAN*, that enables a flexible incorporation of both unpaired and paired data sources in the training process to enhance the quality of pulse waveforms. This framework can reconstruct high-quality waveforms extracted by traditional model-based camera-PPG algorithms, e.g., Plane-Orthorgonal-to-Skin (POS), for accurate HR and HRV estimation, which may improve the measurement accuracy in unconstrained environments.

The second paper by Zhao et al. [2] also deals with the improvement of camera-PPG for HR estimation. As observed by the authors, the selection of skin region-of-interests (ROIs) is crucial for obtaining high-quality PPG signals, and thus they propose to utilize PPG features measured from multi-scale image resolutions to improve the measurement. Specifically, they designed a deep learning model, called *GLISNet*, that uses a local path to learn representations in the original scale and a global path to learn representations in other scales capturing multi-scale information, and a hybrid loss was used between two paths to learn from the training data directly. The authors report improvements against the state-of-the-art networks for camera-PPG extraction, particularly in low-light environments that may occur in real applications.

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The third paper by Wu et al. [3] introduces a way to estimate blood pressure (BP) from camera-PPG, by exploiting the time difference information from multiple PPG signals measured from the face. To prevent overfitting and solve the issue of data limitation when training a BP regression model, the authors used synthetic data generated by *Generative Adversarial Networks* (GANs) and subject information (e.g., age, body mass index) estimated by a camera to enhance the BP prediction model. The approach was validated on a self-constructed dataset acquired during nighttime and the Taipei Veterans General Hospital dataset that focuses on night-time monitoring. The validation showed improvements on both the systolic and diastolic BP measurement over subject information alone.

Next to vital sign monitoring, motion actigraphy is another important target of camera-based health monitoring, which can provide valuable health-related insights that are complimentary to physiological signals. The fourth paper by Zhou et al. [4] provides a thorough review on depth-based human motion enhancement. They surveyed the current research trends in enhancing and denoising of depth-based motion capture data, and discussed future research issues with an emphasis on real-world clinical applications that require motion estimation. The comprehensive tutorial of this paper can help researchers that are new in the field to quickly capture the most recent developments with respect to methodology and experiments.

The fifth paper by Dousty et al. [5] provides a concrete example of how to use motion estimation for patient rehabilitation assessment. In particular, the authors used egocentric videos captured by a wearable camera to assess the hand function of individuals with spinal cord injury (SCI) at home. They introduce a new hierarchical model to summarize the grasping strategies of individuals with SCI. The model has two levels. The first level classifies hand-object interaction and the second level uses a new deep learning model to incorporate hand postures and hand-object contact points for grasp classification. It was found by the authors that the grasp classification performance is highly dependent on the subject. The proposed method allows clinicians to analyze the quantity and type of hand movements of individuals with SCI at home in the infrastructure of telemedicine.

In addition to hand motion estimation, eye movement was also explored for diagnostic and treatment purposes. The sixth paper by Hassan et al. [6] introduces a camera-based eye tracking method, called *NeuroGaze*, to estimate the symmetry of eye movement while performing a neurological eye examination. The technique detects the center of the pupil for both eyes from a video and measured eye conjugacy by transforming the pupil center coordinates to relative gaze. The method was tested on healthy volunteers performing neurological eye examinations and compared to the state-of-the-art commercial approaches. The results of the study indicate that eye-tracking could measure clinically relevant information regarding eye movement.

The seventh paper by Ji et al. [7] explored the feasibility of using videos and AI techniques to assess the cognitive development risk of infants. The measurement is based on evidence showing that the general movement (GM) performance of infants around 3–4 months after birth might reflect their future cognitive development. This work proposes to extract a series of features that can reflect infant bilateral movement symmetry based on body skeleton landmarks recognized from videos and uses a binary classifier to map these features to high-risk and low-risk groups based on the labeling of the *Bayley Infant Development Scale*. This pilot study demonstrates that it is possible to predict the cognitive development of infants around the age of one year based on their GM recorded in their early life, which may lead to an efficient and portable approach for pediatricians to understand infants' cognitive development status.

Modern AI techniques were also utilized to facilitate the image-based diagnosis for healthcare applications. In the eighth paper, Gupta et al. [7] used wound images with deep learning models to quantify the wound healing status for the purpose of prognosis. The authors report that the best performing model, based on subjective features (manual assessment) and objective features extracted from images, shows an improvement against current standard wound assessment tools across various clinical settings, such as *Pressure Ulcer Scale for Healing* and *Bates-Jensen Wound Assessment* tool. The image-based wound healing analysis can lead to a promising and ubiquitous tool in clinical applications due to its ease of use.

Video-based measurements for hospital settings like the NICU are provided that desire non-contact patient monitoring since infants have fragile skin that may be damaged by contact sensors (e.g., electrodes, probes). The nineth paper by Pigueiras-del-Real et al. [8] presents the design and implementation of a *Neonates Recording Platform* (NRP), a hardware-software recording and processing tool that can be deployed at the bedside in a real NICU environment. It enables data from various sources (e.g., patient monitor, video camera) to be collected, labelled, processed and stored, and it integrates latest signal and image processing algorithms that can extract multiple physiological information channels directly from any patient monitoring device. The presented tool can be a useful platform or a starting point for clinicians to conduct clinical studies on video-based infant monitoring.

All 9 papers tackle different but very relevant domain vectors of Camera-based Health Monitoring in Real-world Scenarios. We believe this special issue will raise awareness in both scientific and industrial communities that video cameras can indeed advance health monitoring technology and bring actual value to real-life applications. Its development needs joint endeavours from multidisciplinary research fields (biomedical sensors, optics, machine vision, health informatics, healthcare, and AI). It is important to associate the research of camera-based health monitoring with concrete applications "in the wild" to build novel and meaningful solutions, as this is the only way that allows the research in this direction to develop a real impact on people's life. We hope that the readers will enjoy this collection of papers and that the special issue can spark and stimulate further research and development in this area.

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