Seamless Healthcare Monitoring

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Editors

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Advancements in Wearable, Attachable, and Invisible Devices

Springer

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ISBN 978-3-319-69361-3 ISBN 978-3-319-69362-0 (eBook)
https://doi.org/10.1007/978-3-319-69362-0

Library of Congress Control Number: 2017959890

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Seamless monitoring of diverse physiological information in various daily life scenarios, whether asleep or awake, indoors or outdoors, is indispensable for long-term healthcare. Devices for such a purpose differ from conventional ones that are hospital-centered and aimed at short-term usage by professional personnel. Through scrutinizing the latest achievements in this realm, we classify the devices into three modalities: wearable, attachable, and invisible.

A wearable device is defined as a monitoring modality that is worn by a user in daily life. It is usually integrated into items used daily (watch, eyeglass, ring, vest, gloves, belt, shirt, brassiere, shoes, necklace, and barrette) as an inseparable component. An individual customized size is usually required. It often moves with the user ubiquitously without any apparent or obtrusive parts.

An attachable device is defined as a monitoring modality that should be attached onto the body noninvasively or can be touched occasionally by a user intentionally. It is not a necessary item but has an unnoticeable impact on daily life such as a tattoo, pad, pedometer, mobile phone, tablet, and other portable devices. It is usually "one-size fits all."

An invisible device is defined as a monitoring modality that is embedded into ambient items (beds, chairs, desks, bathtubs, dressing mirrors, desk lamps, and ceiling lamps) completely without the user's awareness. It is usually immobile and used in a fixed position. Automatic identification of users is indispensable.

In this book, active and prestigious worldwide researchers/scholars are invited to investigate the historical development in a relevant field extensively, summarize the latest advancements thoroughly, and envision future prospects ambitiously for further exploration. Each chapter generally comprises several main sections such as introduction/background, physical/chemical principle and instrumentation, signal processing and data analysis, achieved outcomes and application scenarios, and pros and cons, as well as future research topics.

This book consists of seven Parts in 14 Chapters with a wide coverage of various physical and chemical quantities such as electricity, pressure, flow, motion, force,

temperature, gases, biomarkers, physical activity and nutrition. Multiple professional disciplinary fields are involved from biomechanics to bioelectricity, biochemistry to biophysics, and bioelectronics to biomaterials.

Part 1 describes three typical bioelectric signals including electrocardiogram (ECG), electroencephalogram (EEG), and electromyogram (EMG). Insights are provided into three aspects of human functionalities: synchronization, central commander, and mechanical execution. Chapter 1 highlights the discovery of indiscernible information, such as health condition change, lifestyle change, biorhythmicity, and sleep stage, from ECG/HRV in different analytical domains and various temporal scales. Chapter 2 overviews the state of the art in EEG measurement and, in particular, recent developments in ear EEG and in conformal tattoo electrodes for long-term and emergent monitoring applications. Chapter 3 reviews wireless surface electromyography (SEMG) devices and their applications in medicine and sports. Specific conditions such as lower back pain, stroke, epilepsy, and Parkinson's disease are discussed in detail.

Part 2 describes two approaches for the monitoring of pressure signals in terms of blood pressure and ballistocardiogram. Both are convenient methods used for the evaluation of cardiovascular system dynamics. Chapter 4 provides the latest advances in the development of both cuff-based and cuffless sphygmomanometers. Intermittent and continuous measurements made in various modalities, such as a wristwatch, smartphone, car steering wheel, and chair, are summarized. Chapter 5 describes ballistocardiography (BCG) to observe longitudinal changes in human cardiovascular status and to offer meaningful information for disease diagnosis. Several symptoms and diseases are linked to the abnormal waveforms of BCG.

Part 3 describes the measurement of flow phenomenon in terms of pulse waves and blood flow. Photoplethysmogram and ultrasonic Doppler are commonly used in the evaluation of physiological significance. Chapter 6 reviews photoplethysmography (PPG) using recent optical technology, in particular, the use of high-intensity green LEDs for PPG, and the latest development in wearable monitors for pulse and respiratory rates. Chapter 7 focuses on the ultrasound approach in velocity measurement and imaging and describes the latest development in portable handheld ultrasound devices and their applications in point of care and daily healthcare monitoring.

Part 4 focuses on the latest wearable technologies for the quantification of human motions and forces, such as walking steps, walking strides, walking speed, energy expenditure, and physical performance. Chapter 8 examines the technological principle of wearable units using several types of sensors such as an accelerometer, gyroscope, magnetic sensor, and insole force sensor and assesses these sensors for patient rehabilitation in clinical practice and sports. Chapter 9 highlights a smart textile suit as a continuous daily monitoring platform to recognize posture, gesture, activity, and physical interaction with the environment, in combination with physiological signals, such as EMG, ECG/HRV, and respiratory signals, to provide a complete profile of the subject in terms of physical activity and energy expenditure.

Part 5 describes various forms of wearable thermometers, such as touch, patch, and invisible (radiometry), by contact and noncontact methods for the measurement of skin temperature, deep body temperature, heat flow, and evaporation intermittently and continuously in the environment of daily life. Most wearable thermometers can be connected to a smartphone or a tablet for data processing and visualization. Their applications include monitoring of fever, circadian rhythm, energy expenditure, mental stress, and sweat evaporation.

Part 6 focuses on gases and chemical substances produced in metabolism. The trace elements and biomarkers provide significant hints for accurate diagnostics at the molecular level in the early stages of changes in physiological condition. Chapter 11 reviews historical development and engineering principles in the monitoring of oxygen saturation by a pulse oximeter and monitoring of expired carbon dioxide (CO_2) by a capnometer and discusses their clinical application and limitation. Chapter 12 describes four categories of chemical sensors of gas/odor, glucose, trace elements, and biomarkers. These sensors work on different principles such as electrochemical reactions, optical interactions, and immune antigen–antibody reactions and are used to detect different kinds of chemical substances, such as ethanol, urine, glucose, DNA, and RNA.

Part 7 describes two aspects of metabolism-related monitoring of nutrition intake and energy expenditure in daily activities. Chapter 13 proposes a concept of automatic dietary monitoring (ADM) that intends to derive dietary activities, such as food preparation, intake, and digestion processes, by unobtrusive sensors and a knowledge-based physiological model. Chapter 14 introduces wearable devices targeted at analyzing human kinetics and profiling physical activities in daily life by several approaches such as inertial, biopotential, bioimpedance, and optical sensors and presents a systematic framework for quantitatively assessing energy expenditure and calorie consumption.

All of these dedications and commitments will help identify our common concerns, provide us insights into further endeavors, support seamless life-long healthcare monitoring from the womb to the tomb, formulate innovative business/services, foster a new discipline “metrology of health” or “healthology” based on a holistic view of health, and finally improve our health condition as well as quality of life.

This book can be considered a collection of treatises that provide an introductory tutorial for not only students and young scientists but also a wide range of readers, such as biomedical engineering researchers, computer engineers, healthcare entrepreneurs, administrative officers, policy makers, market vendors, and healthcare personnel, to perceive a whole picture and to ignite their passion and inspiration in this fascinating field.

We appreciate all the authors who have devoted their enthusiasm and shared their expertise on a variety of specialized topics to encourage more dedication and further exploration toward a bright and promising future. It was also our great pleasure to work with Ms. Marta Moldvai and Ms. Brinda Megasyamalan in Springer, and we thank them for their professional support throughout the

preparation of this book. Finally, we thank Nakatani Foundation for the Advancement of Measuring Technologies in Biomedical Engineering, Tokyo, Japan, that helped to make this book a reality.

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Abbreviations

2D	Two dimension
3D	Three dimension
ABI	Ankle–brachial index
ABPM	Ambulatory blood pressure monitoring
AC	Alternating current
ACF	Adaptive comb filter
ADL	Activities of daily living
ADM	Automatic dietary monitoring
AF	Atrial fibrillation
AGI	Age-related indices
ALS	Amyotrophic lateral sclerosis
AMI	Acute myocardial infarction
AMMI	Association for the advancement of medical instrumentation
AMR	Anisotropic magnetoresistance
ANS	Autonomic nervous system
AP	Action potential
APC	Atrial premature contractions
ASSR	Auditory steady-state response
BBS	Berg Balance Scale
BBT	Basal body temperature
BCI	Brain–computer interfaces
BCG	Ballistocardiogram
BHS	British hypertension society
BMI	Body mass index
BP	Blood pressure
BSS	Blind source separation
CBP	Central aortic blood pressure
CE	Conductive elastomer
CGM	Continuous glucose monitor
CLBP	Chronic lower back pain

cNIBP	Continuous noninvasive blood pressure
COHb	Carboxyhemoglobin: a stable complex of carbon monoxide and hemoglobin
CT	Computer tomography
CV	Conduction velocity
DBP	Diastolic blood pressure
DBT	Deep body thermometer
DC	Direct current
DEEG	Depth EEG
DHFM	Dual-heat-flux method
DIT	Diet-induced thermogenesis
DLW	Doubly labeled water
ECG	Electrocardiogram
ECoG	Electrocorticogram
EE	Energy expenditure
EEG	Electroencephalogram
EGG	Electroglottograph
EIT	Electrical impedance tomography
EMG	Electromyography
EPOC	Excess post-exercise oxygen consumption
ERP	Event-related potential
ESH	European society of hypertension
FAS	Functional ability scale
FES	Functional electrical stimulation
FET	Field effect transistor
FFT	Fast Fourier transform
FIM	Functional independence measure
FMA	Fugl-Meyer assessment
FSR	Force-sensitive resistors
GPS	Global positioning system
GRF	Ground reaction force
GTC	Generalized tonic–clonic
HF	High frequency
HMI	Human–machine interface
HR	Heart rate
HRT	Heart rate turbulence
HRV	Heart rate variability
IC	Integrated circuit
ICA	Independent component analysis
ICU	Intensive care units
IED	Interelectrode distance
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IMU	Inertial measurement unit
IR	Infrared

ISO	International Organization for Standardization
KPF	Knitted piezoresistive fabric
LBP	Lower back pain
LED	Light-emitting diode
LF	Low frequency
LMS	Least mean squares
MEMS	Microelectromechanical systems
MET	Metabolic equivalent of task
MetHb	Methemoglobin: the oxygen-carrying metalloprotein hemoglobin
MR	Magnetoresistance
MU	Motor unit
MUAP	Motor unit action potential
MVP	Mode value profile
NFC	Near-field communication
NICU	Neonatal intensive care units
NIR	Near infrared
NREM	Non-rapid eye movement
NTC	Negative temperature coefficient
OPAMP	Operational amplifier
OSA	Obstructive sleep apnea
$PaCO_2$	CO_2 pressure of arterial blood
PAT	Pulse arrival time
PCA	Principal component analysis
PD	Parkinson's disease
PEP	Pre-ejection period
$P_{ET}CO_2$	End tidal CO_2 pressure
PMAF	Periodic moving average filter
PNS	Parasympathetic nervous system
POCUS	Point-of-care ultrasonography
PPG	Photoplethysmogram
PPGi	Photoplethysmographic imaging
PR	Pulse rate
PRF	Pulse repetition frequency
PRV	Pulse rate variability
PSG	Polysomnography
PTT	Pulse transit time
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
PWA	Pulse wave amplitude
PWV	Pulse wave velocity
PZT	Lead zirconate titanate
QUS	Quantitative ultrasound
REM	Rapid eye movement
RGB	Red, green, and blue

RH	Relative humidity
RLS	Recursive least squares
RMS	Root mean square
RMSE	Root mean squared error
RRI	R–R peaks interval
SaO_2	Oxygen saturation of arterial blood
SBP	Systolic blood pressure
SCA	Sudden cardiac arrest
SCG	Seismocardiogram
SDIKW	Signal, data, information, knowledge, wisdom
SDPPG	Second derivative of the photoplethysmogram
SEMG	Surface electromyography
SN	Sinoatrial node
SNR	Signal-to-noise ratio
SNS	Sympathetic nervous system
SPL	Strokes per length
SpO_2	Oxygen saturation of arterial blood by pulse oximeter
SPWVD	Smoothed pseudo-Wigner–Ville distributions
SSVEP	Steady-state visually evoked potential
SWOLF	Swim golf
SWT	Stationary wavelet transform
TCR	Temperature coefficient of resistance
TEE	Transesophageal echocardiography
tHB	Total hemoglobin
TMR	Targeted muscle reinnervation
TTE	Transthoracic echocardiography
TUG	Timed Up and Go
ULF	Ultra low frequency
US	Ultrasound
VCG	Vectorcardiogram
VF	Ventricular fibrillation
VLF	Very low frequency
VO_2	Oxygen uptake
VPC	Ventricular premature contraction
VT	Ventricular tachycardia
WHO	World Health Organization
WMA	Weighted moving average
WPW	Wolff–Parkinson–White syndrome
WTMM	Wavelet transform modulus maxima
ZCM	Zero crossing mode