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Preface

Biometrics refers to the recognition of individuals based on their physiological or behavioural characteristics or traits. In this sense, biometrics may be seen to be as old as mankind itself. The possibility to automatise the recognition process and let computers and attached capture devices perform this task has led to the successful development and deployment of numerous biometric technologies. Vascular biometrics have emerged in recent years and are perceived as an attractive, yet still unexplored from many perspectives, alternative to more established biometric modalities like face recognition or fingerprint recognition, respectively. As the name suggests, vascular biometrics are based on vascular patterns, formed by the blood vessel structure inside the human body. While some vascular recognition systems have seen significant commercial deployment (e.g. finger vein and palm vein recognition in financial services and to secure personal devices), others remain niche products to current date (e.g. wrist, retina and sclera recognition). In any case, there is significant commercial and scientific interest in these approaches, also documented by an increasing number of corresponding scientific publications.

In this first edition of the Handbook of Vascular Biometrics, we address the current state of the art in this field. In addition, we intend to provide students, scientists and engineers with a detailed insight into diverse advanced topics in the various fields of vascular biometrics. In-depth investigations, accompanied by comprehensive experimental evaluations, provide the reader with theoretical and empirical explanations of fundamental and current research topics. Furthermore, research directions, open questions and issues yet to be solved are pointed out.

Editors from this first edition would like to thank Mr. Joseph Rice, the inventor of vein recognition and of the concept of wearable wrist vein biometrics, for the Foreword.

Objectives

Selected chapters and topics cover a wide spectrum of research on vascular biometrics; however, the handbook is intended to complement existing literature in the field, and as a pre-requisite for acceptance, each chapter was required to contain a percentage of at least 25–30% novel content as compared to earlier published work. As a key feature, this handbook has a strong focus on reproducible research (RR). All contributions aim to meet the following conditions:

- Experiments should relate to publicly available datasets as a first requirement for RR.
- System scores generated with proposed methods should be openly available as a second requirement for RR.

Additionally, the sharing of plots or performance figures, open-source code of the proposed methods and detailed instructions to reproduce the experiments was strongly encouraged.

Key objectives, which this book is focused on, are as follows:

- Provision of an extended overview of the state of the art in vascular biometrics.
- Guidance and support for researchers in the field regarding the design of capture devices and software systems by providing open-source material in the respective fields.
- Detailed investigations of advanced topics in vascular biometrics ranging from questions related to security and privacy to support for developing efficient large-scale systems.
- A comprehensive collection of references on vascular biometrics.

Audience

The handbook is divided into four parts comprising a total of 17 chapters. Parts, distinct groups of chapters as well as single chapters are meant to be fairly independent and also self-contained, and the reader is encouraged to study only relevant parts or chapters.

This book is intended for a broad readership. The first part provides a description of the state of the art in vascular biometrics including a vast bibliography on the topic. Thus, this part addresses readers wishing to gain an overview of vascular biometrics. Further chapters in the first part provide detailed open-source material for hardware and software construction and thus support graduate students starting to work on this topic or researchers aiming to build their own devices. Subsequent parts delve deeper into research topics and are aimed at the more advanced reader, in particular, graduate and Ph.D. students as well as junior researchers.

Organisation

The handbook contains invited as well as contributed chapters, which all underwent a rigorous 3-round reviewing procedure. The reviewing process for each chapter was led by one of the editors and was based on two independent reviews.

Part I: Introduction

Chapter 1 of the handbook, by Andreas Uhl, *State of the Art in Vascular Biometrics*, provides a comprehensive discussion of the state of the art in vascular biometrics, covering hand-oriented techniques (finger vein, palm vein, (dorsal) hand vein and wrist vein recognition) as well as eye-oriented techniques (retina and sclera recognition). For all these vascular approaches, we discuss commercial capture devices (also referred to as sensors) and systems, major algorithmic approaches in the recognition toolchain, available datasets, public competitions and open-source software, template protection schemes, presentation attacks and presentation attack detection, sample quality assessment, mobile acquisition and acquisition on the move, and finally eventual disease impact on recognition and template privacy issues. The chapter provides more than 350 references in the respective areas.

The second and third chapters provide detailed descriptions of research-oriented, non-commercial finger vein sensors. Chapter 2, by Raymond Veldhuis, Luuk Spreeuwers, Bram Ton and Sjoerd Rozendal, *A High-Quality Finger Vein Dataset Collected Using a Custom-Designed Capture Device*, describes the transillumination scanner used to acquire the UTFVP dataset, one of the first publicly available finger vein datasets and provides experimental recognition results based on publicly available software. The last part of the chapter highlights a new sensor type capable of acquiring finger vein data from three different perspectives (using three NIR cameras). Chapter 3, by Christof Kauba, Bernhard Prommegger and Andreas Uhl, *OpenVein—An Open-Source Modular Multipurpose Finger Vein Scanner Design*, describes a three-finger scanner capable of acquiring transillumination as well as reflected light finger vein data which can be equipped with near-infrared LEDs as well as with near-infrared laser modules. All details regarding the two scanner devices, including technical drawings of all parts, models of the 3D printed parts, control board schematics, the microcontroller firmware, the capturing software, parts lists as well as assembly and set-up instructions, are available as open-source data to facilitate the re-construction by interested readers. Finally, the openly available PLUSVein-FV3 finger vein data set is described. Chapter 4, by Christof Kauba and Andreas Uhl, *An Available Open-Source Vein Recognition Framework*, presents PLUS OpenVein, a full-fledged vein recognition open-source software framework implemented in MATLAB. It contains various well-established and state-of-the-art vein enhancement, feature extraction and template comparison schemes. Moreover, it contains tools to evaluate the recognition performance and provides functions to perform feature- and score-level fusion. To round up, the chapter exemplary describes the conduct of an experimental evaluation on the UTFVP dataset (Chap. 2) using the introduced software framework.

Part II: Hand and Finger Vein Biometrics

The second part of the handbook exclusively focuses on hand-based vascular biometrics, i.e. palm vein and finger vein recognition, respectively. The first two chapters are contributed from the two major commercial players in the filed, i.e. the Japanese companies Fujitsu and Hitachi, respectively. Chapter 5, by Takashi Shinzaki, *Use case of Palm Vein Authentication,* contributed by Fujitsu, describes the diverse application areas in which the contactless Fujitsu palm vein recognition technology is deployed, ranging from device login authentication to access control systems and financial services. Chapter 6, by Mitsutoshi Himaga and Hisao Ogota, *Evolution of Finger Vein Biometric Devices in Terms of Usability*, contributed by Hitachi, describes the evolution of Hitachi's finger vein readers with particular emphasis on usability aspects, highlighting the latest walk-through-style finger vein entrance gates.

The subsequent chapters in this part are devoted to more research-oriented topics. Chapter 7, by Simon Kirchgasser, Christof Kauba and Andreas Uhl, *Towards Understanding Acquisition Conditions Influencing Finger Vein Recognition*, investigates the potential impact of different environmental as well as physiological acquisition conditions on finger vein recognition performance. Although based on a dataset of limited size, the insights gained in this chapter might help to improve finger vein recognition systems in the future by explicitly compensating problematic acquisition conditions. Chapter 8, by Ehsaneddin Jalilian and Andreas Uhl, *Improved CNN-Segmentation-Based Finger Vein Recognition Using Automatically Generated and Fused Training Labels*, investigates the use of recent semantic segmentation convolutional neural networks for finger vein vasculature structure extraction. In particular, the role of training data is highlighted and it is proposed to fuse automatically and manually generated training labels. In Chap. 9, by Benedikt-Alexander Mokroß, Pawel Drozdowski, Christian Rathgeb and Christoph Busch, *Efficient Identification in Large-Scale Vein Recognition Systems Using Spectral Minutiae Representations*, the authors focus on large-scale finger vein identification systems and particularly address the issue of minimising computational cost. Based on a spectral minutiae feature representation, efficient indexing and template comparison schemes are proposed and evaluated. Finally, Chap. 10, by Bernhard Prommegger, Christof Kauba and Andreas Uhl, *Different Views on the Finger—Score-Level Fusion in Multi-Perspective Finger Vein Recognition*, investigates multi-perspective finger vein recognition, i.e. comprising views all around the finger's longitudinal axis, captured using a self-developed rotating multi-perspective finger vein capture device. Besides evaluating the performance of the single views, several score-level fusion experiments involving different fusion strategies are carried out in order to determine the best performing set of views (in terms of recognition accuracy) while minimising the overall number of views involved.

Part III: Sclera and Retina Biometrics

The third part of the handbook focuses on eye-based vascular biometrics, i.e. retina and sclera recognition, respectively. Corresponding to the lesser extent of available literature for these modalities, only three chapters could be included in this part of the book.

Chapter 11, by Lukáš Semerád and Martin Drahanský, *Retinal Vascular Characteristics*, is devoted to retina recognition and covers a wide range of topics. After describing a set of medical and biometric devices for fundus imaging, retinal diseases are discussed exhibiting a potential impact on retina recognition accuracy. For some of these diseases, automated detection algorithms are proposed and evaluated. Additional topics covered are the determination of biometric information content in retinal data and a description of how to generate synthetic fundus imagery (corresponding datasets are released to the public). Chapter 12, by Arathi Arakala, Stephen Davis and K. J. Horadam, *Vascular Biometric Graph Comparison: Theory and Performance,* also covers retina recognition technology, but only as one example for the application of vascular biometric graph comparison, which is also applied to wrist vein, palm vein and hand vein data. This chapter also discusses template protection techniques for this type of feature representation based on anchors (i.e. small connected subgraphs). Chapter 13, by Peter Rot, Matej Vitek, Klemen Grm, Žiga Emeršič, Peter Peer and Vitomir Štruc, *Deep Sclera Segmentation and Recognition*, covers sclera recognition by proposing a sequential combination of deep learning-based segmentation and recognition, respectively. In addition to extensive experimental validation and comparison, the authors also provide a new public dataset including a per-pixel markup of various eye parts, gaze direction and gender labels.

Part IV: Security and Privacy in Vascular Biometrics

The fourth part of the handbook covers topics related to security and privacy aspects of vascular biometrics; in this part, only hand-based vascular modalities are considered (in fact, the attention is restricted entirely to finger vein technology).

Chapter 14, by Jascha Kolberg, Marta Gomez-Barrero, Sushma Venkatesh, Raghavendra Ramachandra and Christoph Busch, *Presentation Attack Detection for Finger Recognition*, deals with Presentation Attack Detection (PAD) techniques. However, contrasting the many papers available dealing with PAD for finger vein recognition systems, this paper uses finger vein imaging of fingerprint artefacts to counter fingerprint PA by using a dual imaging approach.

The subsequent chapters deal with biometric template protection schemes, in particular with cancellable biometric schemes for finger vein recognition. Chapter 15, by Vedrana Krivokuća and Sébastien Marcel, *On the Recognition Performance of BioHash-Protected Finger Vein Templates*, applies BioHashing to finger vein templates generated by classical binarisation feature extraction and evaluates the resulting recognition performance. Chapter 16, by Simon Kirchgasser, Christof Kauba and Andreas Uhl, *Cancellable Biometrics for Finger Vein Recognition—Application in the Feature Domain*, applies the classical cancellable transforms, i.e. block re-mapping and block warping, also to binary features as in Chap. 15 and evaluates the impact on recognition performance and unlinkability. Finally, Chap. 17, by Vedrana Krivokuća, Marta Gomez-Barrero, Sébastien Marcel, Christian Rathgeb and Christoph Busch, *Towards Measuring the Amount of Discriminatory Information in Finger Vein Biometric Characteristics Using a Relative Entropy Estimator*, proposes a methodology to quantify the amount of discriminatory information in features again resulting from classical binarisation feature extraction like in the two chapters before. The derived metric is suggested to be used as a complement to the EER in benchmarking the discriminative capabilities of different biometric systems.

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