# Guest Editorial Special Issue on Drawing and Handwriting Processing for User-Centered Systems

## I. Introduction

AUTOMATIC processing of drawing and handwriting is a field of theoretical and practical relevance. While in the last decades it was thought that manuscript production would decrease with the dissemination of computers, today the trend is reversed and drawing and handwriting play a fundamental role in human–machine interaction, along with the boom of new touch and pen-based interactive devices.

Progress in automatic processing of handwriting and drawing, both online and offline, opens real opportunities to produce a true "graphonomics" continuum from paper to digital practices. Furthermore, the massive use of drawing and handwriting for human–machine interaction is bringing out a multitude of traditional and emerging research issues, like, for instance, those related to pen- and touch-based human–machine interactions, handwriting recognition or drawing interpretation, writer identification and signature verification, human–machine cooperation in education, computer supported handwriting instruction and learning, historical document processing, sketch analysis and retrieval, human–machine cooperation based on handwriting analysis, motor control analysis, learning and adaptation of writing and drawing movements in neuroscience.

All these issues, which generally require specific human-centered solutions, pose a multitude of methodological needs ranging from neuroscience to pattern recognition, from computer science to engineering, from psychology to artificial intelligence, and so on. As matter of fact, research and investigation of human–system interactions based on handwriting and drawing is a very active multidisciplinary field. Three important conferences have been held on a regular basis to foster interaction and exchanges between experts in various domains, including the IGS conferences, started in 1985, the ICFHR workshops and conferences and the ICDAR conferences that began in 1990 and 1991, respectively. Each of these events is held every two years.

The idea of a Special Issue of the IEEE TRANSACTIONS ON HUMAN-MACHINE SYSTEMS (THMS) with a focus on "Drawing and Handwriting Processing for User-Centered Systems" was initiated as a follow-up to the 17th International Biennial Conference of the International Graphomomics Society, held in Pointe-à Pitre, Guadeloupe, from June 21 to 25, 2015. This conference was a celebration and commemoration of the 30th anniversary of the Society (http://www.graphonomics.org/). The Call for Papers for the Special Issue was broadly distributed to the whole scientific community with interest in graphomomics and other related topics. Overall, 33 papers were submitted and 12 papers were selected for publication based on thorough evaluations by three external experts. All expert reviewers were selected by the Guest and Associate Editors of the TRANSACTIONS. The Special Issue aims to bring together some of the most valuable research contributions and applicable solutions in the field of drawing and handwriting processing for human–machine interaction. Specific attention is given to user-centered aspects of proposed systems, including usability, efficiency, collaboration and interaction capabilities, cross-learning options, and other related topics. The papers in this Special Issue address the most important graphomomics issues and results with relevance to complex human–machine relationships that are being addressed across various research communities. The papers also highlight some of the most valuable new directions of research.

## II. Overview

This Special Issue contains 12 scientific contributions. The first contribution addresses the problem of personal verification/identification through handwriting analysis. In item 1) of the Appendix, the authors present a user-centered system for signature verification that uses the kinematic theory of rapid human movements to verify the identity of a user. Parameters extracted from elementary neuromuscular strokes detected in the handwriting are compared by a string edit distance in order to obtain a dissimilarity measure useful for signature verification. When combined with a well-established verification system based on dynamic time warping, the verification performance is superior to the current state-of-the-art results in online signature verification.

The next paper concerns the problem of segmenting historical manuscripts. In item 2) of the Appendix, the authors propose a user-centered segmentation method based on document graphs and scribbling interaction. They demonstrate document graphs for capture of sparse representations of historical document structure and provide a segmentation close to the desired segmentation. In addition, a stylus on a touch-sensitive screen allows editing of the extracted document structure though natural and efficient human interaction.

Human–machine interaction through sketch and drawing analysis and recognition is another relevant field of research. In fact, although several text-based searching methods have

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become increasingly popular in recent years, sketch- and drawing-based search methods are still limited as they do not support generic user input. Sketch- and drawing-based human–machine interaction is addressed by two papers in the Special Issue. In item 3) of the Appendix, the authors present a system for sketch indexing and searching across a large number of sketches, based on sketch similarity. The searching method supports users in generic drawing search queries. Although the technique indexes sketches with extremely compressed representations, it allows for fast, accurate retrieval of drawings, augmented with a multilevel ranking subsystem.

In item 4) of the Appendix, the authors present a system that enables capturing paper-based models with mundane technical means by end-users under uncontrolled conditions. Since modeling and subsequent digital model representations are essential constituents in collaborative endeavors on organizational change, this research aims to reduce the need for sophisticated technical components by enabling stakeholders to capture paper-based models in a situation-sensitive way.

In item 5) of the Appendix, the authors address the problem of dynamics underlying gesture typing, that is, a stroke-based text input method for mobile devices. When gesture typing is considered, a user enters a word by gesturing through all its letters on a virtual keyboard with a single continuous stroke. In this study, a physiological movement model for gesture typing is proposed and a mathematical framework is defined, which provides an accurate representation of the exact trajectories and velocity profiles of most word gestures. Finally, a framework is proposed for extracting model parameters from real gestures and for synthetic gesture generation.

A wide and attractive area of research on drawing and handwriting processing concerns the identification and treatment of handwriting disorders. In item 6) of the Appendix, the authors propose a method for automated diagnosis of dysgraphia, as well as estimation of the level of difficulty in graphomotor output as determined by the Handwriting Proficiency Screening Questionnaire (HPSQ). A well-defined method is used to analyze handwriting and to quantify its kinematic aspects and hidden complexities. After an intrawriter normalization process is applied (in order to promote dysgraphia discrimination) and HPSQ accuracy is estimated, a random forests approach is used for automated diagnosis of dysgraphia. The results demonstrate that digital parametrization of pressure and altitude/tilt patterns in children with dysgraphia can be used to effectively conduct preliminary diagnosis of the writing disorder.

In item 7) of the Appendix, the authors evaluate the influence of a new rehabilitation protocol (Terzi's method) on kinematics of cursive writing. The analysis of well-defined kinematic characteristics of handwriting, calculated before and after a rehabilitation process, is used to estimate the effects of treatments on dysgraphic students. Results showed that Terzi's rehabilitation program is capable of producing a significant velocity increase in tests without linguistic involvement; whereas, a significant slowdown in stroke realization was present in the other tasks.

The combination of handwriting in multimodal contexts is another innovative domain of research that is addressed in item 8) of the Appendix, where the authors present a bimodal system for recognizing mathematical expressions. Since the recognition of handwritten mathematical expressions is a very challenging task prone to many ambiguities, the authors use speech as an additional modality to circumvent limitations that are inherent to the written form. In addition to state-of-the-art solutions for recognizing handwriting and speech, they introduce a multilayer architecture for the merger of modalities, based on the Dempster–Shafer theory. Experimental results demonstrate that large improvements occur when speech and handwriting are combined for expression recognition as compared to the single handwriting modality.

In item 9) of the Appendix, the authors present EMOTHAW, a publicly available database which relates emotional states, namely, anxiety, depression, and stress, to handwriting and drawing. From collected data, the authors extract and identify features that best reveal targeted emotional states. Experimental results demonstrate better performance for anxiety and stress recognition than depression recognition.

Similar to item 1), item 10) of the Appendix is a Technical Correspondence also addressing the problem of personal identification through handwriting. In their work, the authors propose an end-to-end framework for online text-independent writer identification by using a recurrent neural network (RNN). The approach represents the handwriting data of a particular writer by a set of random hybrid strokes (RHS) and uses the RNN model to encode each RHS into a fixed-length vector for final classification. The final identification decision is determined by averaging the posterior probabilities of the classification of all RHS of a writer. The experimental results, carried out on both English and Chinese databases, demonstrate advantages of the new method compared with other state-of-the-art approaches.

Item 11) of the Appendix is another Technical Correspondence but with a focus on identification of handwriting disorders, as in items 6) and 7) of the Appendix. In their work, the authors present a new method for automatic identification and characterization of dysgraphia in third grade children. Several features were considered and machine learning methodologies were used to infer a statistical model, which is capable of discriminating dysgraphic products from proficient products and to detect the most discriminative features, related to dynamic properties of the writing and typographic properties.

Like item 8), item 12) of the Appendix is a final Technical Correspondence addressing handwriting in a multimodal context. In their work, the authors address the problem of handwriting sonification, that is, the transformation of some characteristics of handwriting movement into sounds. Sonification can be used to make perceptible and useful for novice or poor writers hidden variables of handwriting, which are not accessible through a visual inspection of a trace. Therefore, handwriting sonification allows for improvement of handwriting perception, evaluation, and control. Thus, this method can be useful for assessing multisensory integration in motor control and learning. In the paper, the main studies on handwriting sonification are described and a specific focus is reported on select variables of handwriting movement and associated sounds.

## III. Conclusion

The Guest Editors hope the readers enjoy the IEEE THMS "Special Issue on Drawing and Handwriting Processing for User-Centered Systems." The issue provides a wide and updated overview of the frontier of research in the field of human-centered systems based on drawing and handwriting processing. Through the papers, some of the most relevant directions of further research are highlighted with specific attention to components related to human–machine interaction.

The Guest Editors hope that this issue brings forth the importance of automated systems related to automatic processing of drawing and handwriting. We believe such systems are some of the most extraordinary products of human intelligence and creativity.

Finally, the Guest Editors want to thank the Editor-in-Chief and all the staff of the IEEE THMS for their valuable support for realization of this issue. We would also like to thank all the authors for their very high-quality submissions that made possible the production of this successful special issue.

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## Appendix
## Related Work

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