Activity and Age Classification from Handwritten Samples Acquired with a Smart Ink Pen

S. Toffoli, E. Lomurno, F. Lunardini, C. Galán de Isla, P. Cácerers, S. Farace, M. Malavolti, M. Matteucci and S. Ferrante, *Member, IEEE*

I. Introduction

Handwriting deteriorates to some extent in older adults, thus its monitoring in the home setting could allow the early detection of age-related decline. Unsupervised handwriting assessment should be able to i) discriminate informative handwriting activity from noisy data (e.g., drawing) and ii) detect age-related changes according to informative data only. This work aims at assessing whether handwriting indicators extracted from an innovative smart ink pen are effective in discriminating writing from drawing (activity classification) and young from older writers (age classification).

II. Materials and Methods

Free writing and drawing (no constraints on content) data were acquired from 21 young (age = 30.1 ± 5.6 years) and 9 older adults (age = 81.3 ± 3.9), with a smart ink pen [1]. It is used as a normal ink pen, thus suitable for home use by older adults, but the embedded motion and force sensors allow recording quantitative data (50Hz). The acquired data were processed to extract the indicators in [2], characterizing the performance in the domains of time, fluency, exerted force, pen inclination, tremor amplitude, frequency distribution and regularity. The indicators were used to solve two classification problems: activity and age classification. The latter considered writing data only. Five algorithms were tested with a nested k-fold cross validation approach: logistic regression, support vector machines, k-nearest neighbors, random forest and Catboost. Model performances were measured through accuracy, precision, recall, f1-score and specificity. The best model feature ranking was computed through the Shapley Additive Explanations technique (SHAP).

III. Results

The best performances were obtained by a Catboost classifier in both problems. In the activity classification, the model achieved accuracy 93.33%, precision 93.02%, recall 96.77%, f1-score 94.86% and specificity 87.32% on the test set, proving the indicators ability to distinguish writing from drawing. SHAP analysis revealed temporal and kinematic differences between the activities. In the age classification based on writing samples, accuracy 90.00%, precision 87.50%, recall 77.78%, f1-score 82.35% and specificity 95.24% were obtained (test set). The results are promising, given the small dataset. The low recall value, with respect to the other metrics, is likely caused by the class unbalance in the dataset. Nevertheless, peculiar age-related differences in the free handwriting gesture emerged from the SHAP analysis. The execution of the elder group resulted characterized by slower movements (low number of oscillations in angular velocity) and increased hesitation, as captured by more frequent and variable pauses (moments spent with the pen in air longer than 2 seconds). Additionally, more regular tremor oscillations and reduced force applied on the writing surface emerged in the elders, confirming previous studies.

IV. Discussion

The indicators were able to capture the differences between drawing and writing, as well as peculiar characteristics associated to the aging process, independently of the content of the acquired samples. These aspects are crucial for the unsupervised handwriting assessment in the home setting, where there is no supervision on the activities performed by the subjects. Future research should evaluate the longitudinal use of the pen in the home setting, to detect subject-specific anomalies related to the aging process.

*This work was funded by the H2020 grant N.101016112 ESSENCE: Empathic platform to personally monitor, Stimulate, enrich, and aSsist Elders aNd Children in their Environment.

S. Toffoli is with the Department of Electronics, Information and Bioengineering (DEIB), Politecnico di Milano, Milan, 20133, Italy (phone: +390223999004; fax: +390223999003; e-mail: simone.toffoli@polimi.it).

E. Lomurno is with the DEIB, Politecnico di Milano, Milan, 20133, Italy (e-mail: eugenio.lomurno@polimi.it).

F. Lunardini is with the Fondazione IRCCS, Istituto Neurologico Carlo Besta, Milan, 20133, Italy (e-mail: francesca.lunardini@istituto-besta.it)

C. Galán de Isla is with the Fundación para la Formación e la Investigación de los Profesionales de la Salud de Extremadura (FundeSalud), Mérida, 06800, Spain (e-mail: carmen.galan@fundesalud.es).

P. Cáceres is with FundeSalud, Mérida, 06800, Spain (e-mail: pilar.caceres@fundesalud.es).

S. Farace is with FundeSalud, Mérida, 06800, Spain (e-mail: stefania.farace@fundesalud.es).

M. Malavolti is with the DEIB, Politecnico di Milano, Milan, 20133, Italy (e-mail: milad.malavolti@polimi.it).

M. Matteucci is with the DEIB, Politecnico di Milano, Milan, 20133, Italy (e-mail: matteo.matteucci@polimi.it).

S. Ferrante is with the DEIB, Politecnico di Milano, Milan, 20133, Italy (e-mail: simona.ferrante@polimi.it).

References

[1] F. Lunardini, D. D. Febbo, M. Malavolti, M. Cid, M. Serra, L. Piccini, A. L. G. Pedrocchi, N. A. Borghese, and S. Ferrante, "A Smart Ink Pen for the Ecological Assessment of Age-Related Changes in Writing and Tremor Features," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, 2021.

[2] S. Toffoli, F. Lunardini, M. Parati, M. Gallotta, C. Belloni, M. E. Dell'Anna, and S. Ferrante, "Classification of Patients with Parkinson's Disease Using Free Handwriting Features Collected through a Smart Ink Pen", *accepted for the 20th Conference of the International Graphonomics Society (IGS2021)*, 2022.