GT Analyzer – A Basic Tool for Handwriting Movement Data

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***Abstract*—In the presence of neurological and psychiatric diseases, sensorimotor and cognitive skills tend to deteriorate. One of the daily activities that could be easily affected is handwriting. In this paper, we present the open-source software GT Analyzer, developed for visual analysis and feature extraction of the handwriting data acquired by graphic tablet. Data is acquired while patients are working on graphic tasks developed by clinicians. Visual and feature analysis of handwriting data could be of great use in establishing a correct diagnosis or in following the changes during medical therapies for neurological and psychiatric diseases. Furthermore, extracted features can be used later in statistical tools, to improve the classification and determination of therapeutic effects to a greater extent.**

***Index Terms*—handwriting; graphic tablet; depression; Parkinson's disease; open-source**

I. Introduction

Handwriting is a complex motor task consisting of both cognitive and motor processes interplaying together [1, 2]. Computer analysis of handwriting, using a digital writing tablet, has shown its usefulness in clinical studies in the fields of neurology, psychiatry and neuropsychology in both adults and children [3]. Data obtained from handwriting analysis could help clinicians to establish correct diagnosis e.g. in Parkinson's disease and Parkinsonism [4-6], or to track changes in motor functioning and the influence of therapy on it in depression in adult subjects [7] or in attention deficit hyperactivity disorder/ADHD in children [8].

The summary of computer analysis of handwriting is that clinicians are giving patients several specially designed drawing and/or writing tasks, which they have to draw or write on a graphic tablet [2, 3, 4, 6]. During the task, the tablet is acquiring the position of the pen and the pressure with which the pen is pressed on the tablet [2]. Both on-surface and in-air handwriting movements can be analyzed [6]. After the task is completed, acquired data can be operationalized through kinematic handwriting features [2, 4].

This system is favored as it has low complexity of installment, has great ease of use for both patients and clinicians and has low chances of errors while performing the task. Also, kinematic handwriting features acquired using writing tablets show high test-retest reliability [2].

Our previous research [3, 6, 8-10] in the field of handwriting analysis has shown a great need for an open-source, user-friendly software suitable for data acquisition alongside the application software that will be used for later exploration of acquired data. This could help make the research methodology more uniform and to ease data exchange and comparison between different studies.

The aim of this paper is to present a novel, user-friendly, open-source interface for reading, visualization and analysis of data that was acquired during different graphic tasks on digital graphic tablets. This software also stresses out the importance of visual analysis of extracted handwriting features.

The flowchart of the implemented interface and software options are presented in Section II. The software functionality is demonstrated through examples from two different datasets in Section III. A brief overview of software advantages and usage options is presented in the Conclusion section.

II. The Method

Graphic Task Analyzer (GT Analyzer) is an open-source application that enables the reading of recorded pen position (X,Y) and pen pressure (p) data from digital graphic tablets, a simple preview of calculated kinematic features of handwriting over time and export of 173 standard kinematic handwriting features, Fig. 1. An example of visualization for (X,Y,p) input sequence for three drawn figures (figure separators are marked by green arrows) is also presented in Fig. 1.

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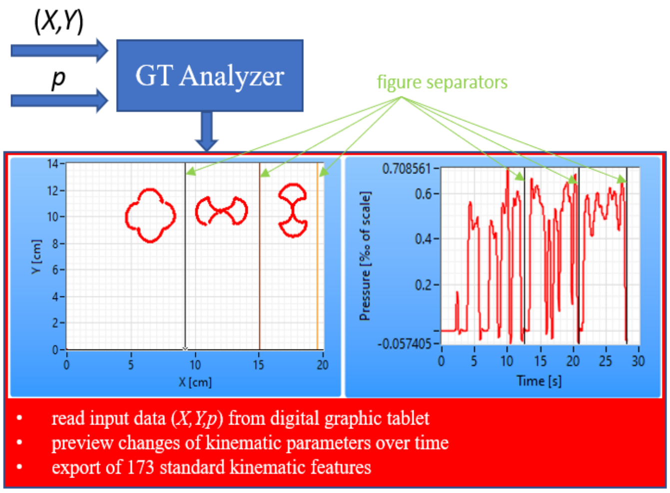

Fig. 1. GT Analyzer software options with preview example of input data (coordinate pair (*X*,*Y*) and pressure *p* of the pen tip)

A. *Software description*

The application was developed in the LabVIEW 2019 environment (National Instruments, Texas, USA). The code of the software is available at the following Github link: https://github.com/MagnumSinum/GT-Analyzer/blob/main/GT%20Analyzer%20source%20code.rar

B. *Kinematic features*

For each (*X*,*Y*,*p*) input sequence, the algorithm calculates the 1st, 2nd and 3rd derivatives. The 1st derivatives of *X(t)* data and *Y(t)* data correspond to the velocity $V_x(t)$ and $V_y(t)$, respectively. The total velocity $V = \sqrt{V_x^{\,2} + V_y^{\,2}}$ was also calculated. The 1st derivative of *p(t)* data corresponds to *dp(t)/dt*. The 2nd derivatives of *X(t)* data and *Y(t)* data correspond to the acceleration $A_x(t)$ and $A_y(t)$, respectively. The total acceleration *A(t)* corresponds to the 1st derivative of *V(t)*. The 2nd derivative of *p(t)* data corresponds to $d^2p(t)/dt^2$. The 3rd derivatives of *X(t)* data and *Y(t)* data correspond to the jerk $J_x(t)$ and $J_y(t)$, respectively. The total jerk *J(t)* corresponds to the 2nd derivative of *V(t)*. The 3rd derivative of *p(t)* data corresponds to $d^3p(t)/dt^3$. The list of implemented statistical handwriting features is presented in Table 1.

TABLE I THE LIST OF STATISTICAL HANDWRITING FEATURES

Data	**Statistical feature**
$X(t)$,$Y(t)$,$p(t)$, $V_x(t)$,$V_y(t)$, $V(t)$, $dp(t)/dt$, $A_x(t)$,$A_y(t)$, $A(t)$, $d^2p(t)/dt^2$, $J_x(t)$,$J_y(t)$, $J(t)$, $d^3p(t)/dt^3$	Median value
	Mean value
	Standard deviation
	Variance
	Coefficient of variation
	Maximum value
	Minimum value
	10th percentile
	25th percentile
	75th percentile
	90th percentile
Total variables =15	*Total number of features=11*

For each figure, 8 kinematic features, so-called "figure features" were calculated. The list of figure features is presented in Table 2.

TABLE II THE LIST OF FIGURE FEATURES

Abbreviation	**Figure feature**
FL [cm]	Figure length
FT [s]	Figure drawing time
FS [cm/s]	Figure drawing speed
NCV [n.u.]	Number of changes in velocity
RNCV [n.u.]	Number of changes in velocity relative to figure drawing time (NCV/FT)
NST [n.u.]	Time spent during drawing on-surface or in-air normalized by the figure drawing time (ON-SURFACE TIME/FT or IN-AIR TIME/FT)
NCA [n.u.]	Number of changes in acceleration
RNCA [s^{-1}]	Number of changes in acceleration relative to figure drawing time (NCA/FT)

C. *Implementation details*

The expected input file format for GT Analyzer tool is a textual file with 3 columns, each column corresponding to *X(t)*, *Y(t)* and *p(t)* data respectively, obtained by the data acquisition software from the digital graphic tablet. Expected units of the position data (*X*,*Y*) are meant to be 10^{-5} m. The pressure data *p(t)* is unitless because it is expected to be expressed relative to the full pressure scale of the digital graphic tablet. Also, it is expected that in the input file name first 4 characters are reserved for the subject ID and the last single digit in the file name is reserved for the number of the performed task by the subject. Each task could include up to eight figures.

Within the GT Analyzer tool, the following setting parameters could be selected:

- input file name (two file names could be selected at once in order to compare results for two subjects (e.g. patient vs. healthy data))
- input folder name (with several input files) for the automatic analysis and export of all kinematic features to one excel file per task.
- sample rate (performed by the data acquisition software used for (*X*,*Y*,*p*) data recording from the digital graphic tablet)
- lower cut-off frequency that will be performed in (*X*,*Y*) data processing by the 3rd order low pass Butterworth filter, the default value is set to 2 Hz
- NCV tolerance (minimal difference between two time-adjacent samples of *V(t)* to count it as a change in velocity, the default value is set to 0.1 cm/s)
- NCA tolerance (minimal difference between two time-adjacent samples of *A(t)* to count it as a change in acceleration, the default value is set to 1 cm/s^2)
- *Width* parameter (the number of consecutive data points to be used in the quadratic least-squares fit when the tool is determining local minimums on V_y – local minimums on V_y

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separate different strides within the figure)

- *Threshold* parameter (maximum value of local minimums that will be accepted when the tool is determining local minimums on V_y).

After the adjustment of parameters, the user can perform the following actions:

- DISPLAY DATA: Process (*X,Y,p*) input sequence from input files – extraction of all features defined in *Section II B Kinematic features*. Display (*X,Y*) data on XY graph, as well as a display of temporal graphics for $p(t)$, $V_y(t)$, $V(t)$, $A(t)$ and $J(t)$ from two selected input files. The software differentiates (*X,Y,p*) samples when the pen was on the surface or in-air and represents it with red and blue color, respectively. Stride ends (found local minimums on V_y) are presented by green circles on $V_y(t)$, $V(t)$, $A(t)$ and $J(t)$ graphics.
- SAVE LIMITS: Figure separators (separators between data for different figures in one task) could be set using cursors on XY graphs (up to eight) and the cursor limits could be saved for each task.
- EXPORT LOADED DATA: Extracted kinematic features could be saved in one .xls file per each selected input file.
- EXPORT FOLDER DATA: Extracted kinematic features could be saved in one .xls file for each file within the selected input folder.

All settings and actions can be repeated while the GT Analyzer application is still running.

D. Dataset description

Two different datasets acquired during graphic tablet tasks have been used to present the functionality of the GT Analyzer software:

- PaHaW adult subjects dataset, presented by Drotar and others [4] - labeled as DS1,
- pediatric subjects dataset used in the Doctoral dissertation of Ivančević N. D. [9] - labeled as DS2.

One pair from each dataset (one healthy and one diseased subject from DS1 and DS2, paired by gender and handedness), was selected to demonstrate the GT Analyzer interface. From DS1, the subject ID 6 (diagnosed with Parkinson's disease) and the healthy subject ID 26 were selected for the "drawing a spiral". During this task, the subject starts the drawing from the center of the spiral. From DS2, the subject ID 17, diagnosed with pediatric-onset major depressive disorder (drug-naive), and the healthy subject ID 25 were selected for the writing of two figures of the consecutive cursive letter "l": 1) figure 1 was drawn in the large rectangle 40x160 mm and 2) figure 2 was drawn in the small rectangle 9x160 mm.

Data acquisition for both DS1 (sample rate 100 Hz) and DS2 (sample rate 200 Hz) was performed using a digital graphic tablet Wacom Intous4 XL (Wacom Europe GmbH, Krefeld, Germany) with the cordless pen that enables on-surface and in-air handwriting. Custom-made data acquisition *LabHand* [10] previously developed in the LabVIEW environment, the same environment as for the GT Analyzer, was used for the data recording.

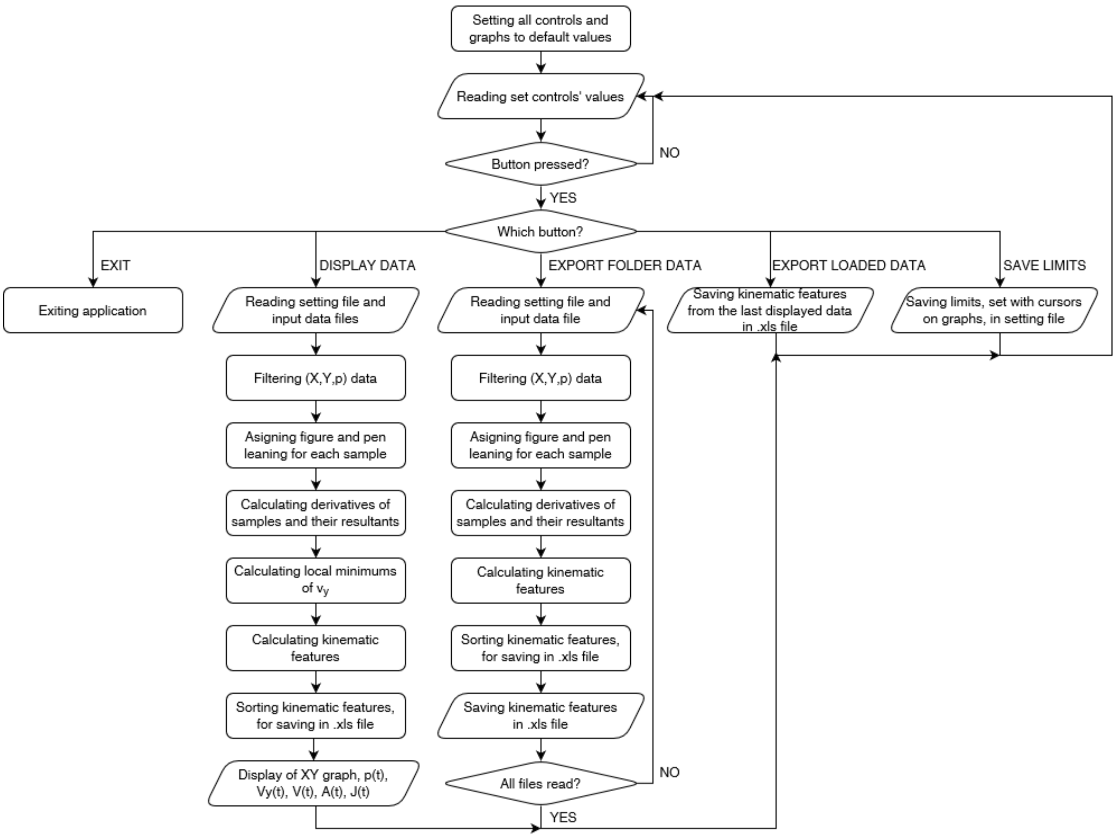

Fig. 2. GT Analyzer flowchart

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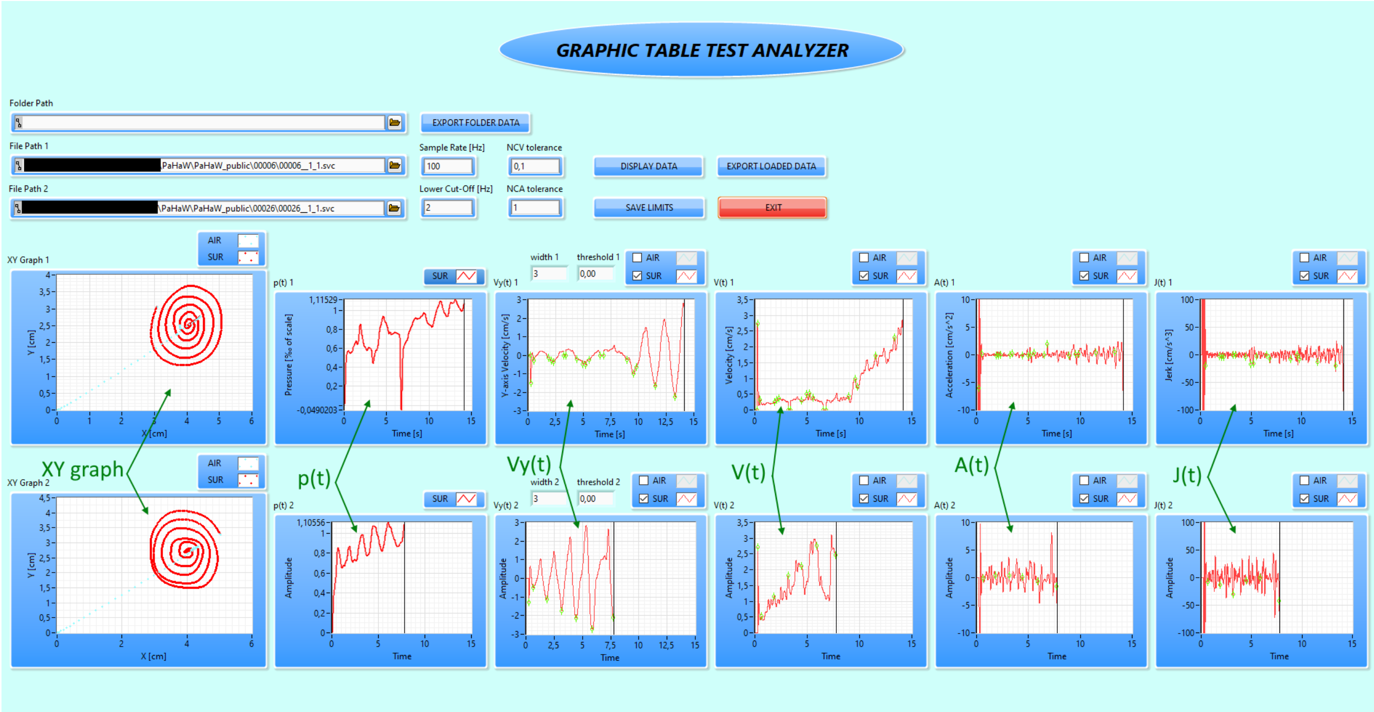

Fig. 3. An example of GT Analyzer interface from DS1 for "drawing a spiral" task (top graphics of subject ID 6 diagnosed with Parkinson's disease and bottom graphics of healthy subject ID 26)

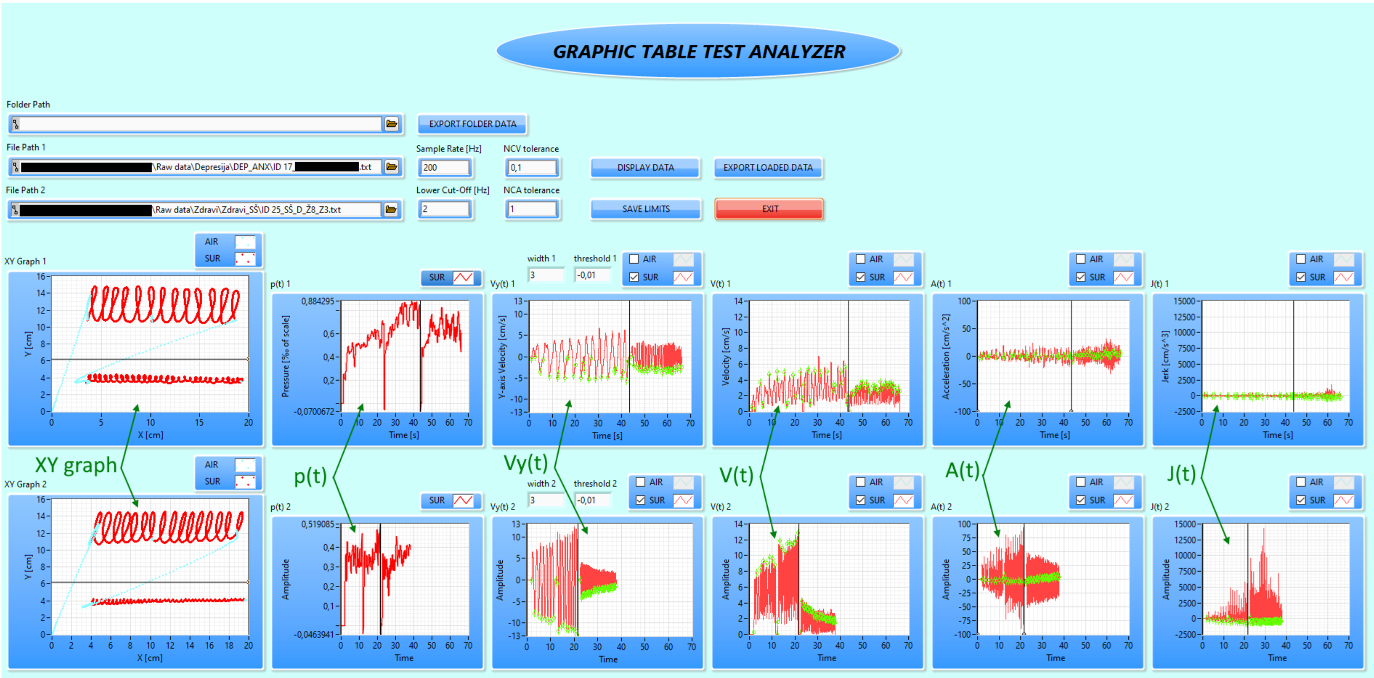

Fig. 4. An example of GT Analyzer interface from DS2 for writing two figures: the cursive letter "l" in 1) large rectangle and 2) small rectangle (top graphics of subject ID 17 diagnosed with major depressive disorder and bottom graphics of healthy subject ID 25)

III. RESULTS

Two examples of the GT Analyzer interface after loading selected subjects from DS1 and DS2 (see *Section II D. Dataset description*) are presented in Fig. 3 and Fig. 4, respectively

In Fig. 3, it is evident that the subject with Parkinson's disease needs more time to finish a task and that he had trouble at the beginning of the task, where fine movements are hampered due to micrographia seen in Parkinson's disease This resulted in a significant increase in local minimums of V_y. Both facts are expected from patients with Parkinson's disease [11].

In Fig. 4, there is a similarity in pressure graphs for the patient with depression and the healthy subject. Both subjects took a break in a similar place while writing the first part of the task (cursive letter “l” in a large rectangle), which is represented as a pressure drop. That is also evident on the XY graph where the blue line presents in-air movement. One of the main kinematic descriptors of depression, psychomotor slowing/retardation, is more pronounced with larger scale movements. That is why a drop in speed amplitude and a significant increase in writing duration are evident in the subject with depression while writing the first part of the task [12].

IV. Conclusion

In this paper, a novel application for visual analysis of handwriting (drawing) tasks is presented. This user-friendly, open-source, clinically validated interface with implemented all standard kinematic features for handwriting analysis has the potential of helping users visually determine differences between healthy and diseased subjects. Furthermore, it can export the conventional kinematic features that can be used later in statistical analysis or classification procedures. The developed analysis software could be integrated with the previously developed data acquisition *LabHand* [10] software as a unique package for the overall handwriting data acquisition, analysis and kinematic feature extraction.

Future work will be focused on greater flexibility and compatibility of the application, as well as on defining and adding new features that will be used for an automatic distinction between different subject groups, including patients with different neurological or psychiatric disorders.

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