

Online Analysis of Handwriting for Disease Diagnosis: A Review

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Abstract

Background/Objectives: Handwriting is an action governed by brain like any other action. This process is usually unconscious and is closely tied to impulses from brain. Any kind of disease affects the kinetic movement and reflects in subject's handwriting. To understand the health and mental problems, it is important to focus on how subject writes instead of what subject writes. This also makes the process of handwriting analysis independent of any language. Handwriting analysis is a pseudo-science used to study physical and behavioral characteristics of handwriting. In this paper, the general approach used for the disease diagnosis based on digital handwriting analysis has been presented. The research work carried out to diagnose diseases such as Alzheimer, Mild Cognitive Impairment, Dysgraphia, Schizophrenia, Autism, Parkinson's disease and Mental illness based on digital handwriting analysis has been reviewed in this paper. The features related to motion, time and pressure have been used for diagnosis of disease. The experiments and results are also summarized in this paper.

Keywords: Handwriting Analysis, Handwriting Features, Tablet, Disease.

1. Introduction

All actions including writing start in the brain. Like all other movements, the act of writing depends on central nerve system [1]. Our brain sends impulses to hand through nervous signals, achieving the motor act. Graphology is pseudo-science based on combination of psychoanalysis and neuroscience nested in subconscious mind. Though handwriting is driven through pen, it's movement is governed by the central nervous system, which is a process usually unconscious, but most revealing [3]. Handwriting is closely tied to impulses from the brain and therefore it can be reliably used to predict state of physical, emotional and mental health of individual [2]. Handwriting analysis is used to find out disturbance in the subject's handwriting.

The important handwriting features used for disease diagnosis are:

1. *Congestion:* It is shown by letters having ovals and curls full of ink,
2. *Fragmentation:* It is shown by disconnected curves of letters,
3. *Direction of lines*
4. *Layout of Anomalies*
5. *Torsion:* It is an irregularity or luxuriating of part of a letter or entire letter,
6. *Viscosity:* It is unclear or dirty extension of upper and lower parts of letters,
7. *Shakiness:* It is small disruptions in strokes of letters,
8. *Slant:* It is an uneven inclined right movement of pen on paper while drawing letters,
9. *Movement between strokes,*
10. *Variation in size of letters* while writing letters,
11. *Alterations in shape of curves for similar letters,*
12. *Breeze:* It is the part of stroke over sheet paper, when pen went without leaving ink,

13. *Pressure* applied on writing organ while writing,
14. *Accent Marks and Periods* which reflect memory disorders, imagination and attention [4, 5].

The Graphologists make use of combination of two or more features mentioned above for handwriting analysis. These features are extracted and converted into numeric values for statistical analysis and disease diagnosis.

As shown in Figure 1, the online system used for handwriting analysis of patients comprises below three components:

- **Patient:** Patient is a suspect having disease or mental illness.
- **Digitizing tablet:** It is a device used to capture signals from patient's handwriting.
- **Computer:** The computer with general configuration used to run image acquisition software and classification engine to capture measurements of handwriting and to identify kind of disease or mental illness.

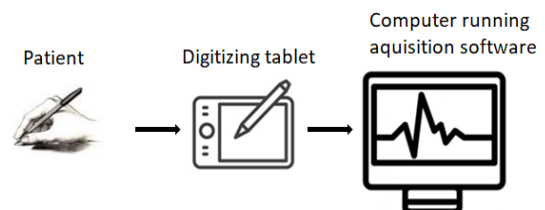


Figure 1: Components of online system used for handwriting analysis of patients

2. Approaches for Handwriting Analysis

Two approaches used for handwriting analysis are explained below.

2.1. Offline Handwriting Analysis

The traditional methods of handwriting analysis are based on text written on paper which is called as off-line handwriting. These methods include Clock Drawing Test (CDT) [6], Mini Mental State Examination (MMSE test) [7], House-Tree-Person (HTP) test [8]. In CDT, subjects have been asked to draw a clock with all digits pointing hands to 11:50. Alzheimer Patients face issues in placing digits; the clock digits may not evenly have been spaced or may show incorrect time. Scores are measured on scale of 15 points, for shape and spatial arrangement of clock digits and hands. MMSE measures cognitive functions related to attention, language, registration, recall, calculation, orientation, and ability to follow simple commands. The test has 11 questions with maximum score of 30-points. In HTP test patients have been asked to draw a tree, a house and a person. Along with drawing tasks, few questions are introduced to understand personality. The test may be extended to evaluate brain damage.

2.2. Online Handwriting Analysis

With evolution of digital world, graphologists started using digital tablet which provided richer set of measures on handwriting called as online handwriting. The online analysis of handwriting finds temporal features such as inclination, time-stamp and pressure applied on pen, and velocity of the pen movements, which is not possible to capture in off-line handwriting [9]. However, on-line handwriting introduces distortion and transition trajectories (curves drawn for continuous or overlapped writing), which need to be removed before processing. Various classification and clustering techniques have been used to find out the best features suited for the analysis of targeted disease.

3. Generalized Approach for Online Handwriting Analysis

The generalized machine learning approach for online handwriting analysis is shown in Figure 2. It consists of two phases namely learning phase and testing phase. The machine learning model is used as it improves classification accuracy based on experience. The process of digital handwriting analysis begins with collecting samples of patients of targeted disease. Subjects having similar age group and same kind of health or mental illness are chosen to train classifier for targeted disease. This phase is called learning phase. The classifier is a model built using knowledge gained from various measures of handwriting. This model is used in testing phase for disease diagnosis.

The various steps of generalized machine learning approach are:

a. Data Acquisition:

The data have been recorded using INTUOS WACOM series 4 digitizing tablet with INTUOS Ink-pen. The device has ability to capture spatial movements and pressure applied on tablet. It also captures pen tip movement even when it is not rested on tablet's surface up-to certain height (6 mm). This feature allows to measure in-air handwriting movements. Five tasks related to writing/drawing are given to subjects with proper instructions. These tasks are based on, drawing and writing tasks well practiced in clinical diagnosis of mental disorders. From these tasks the measurements are extracted.

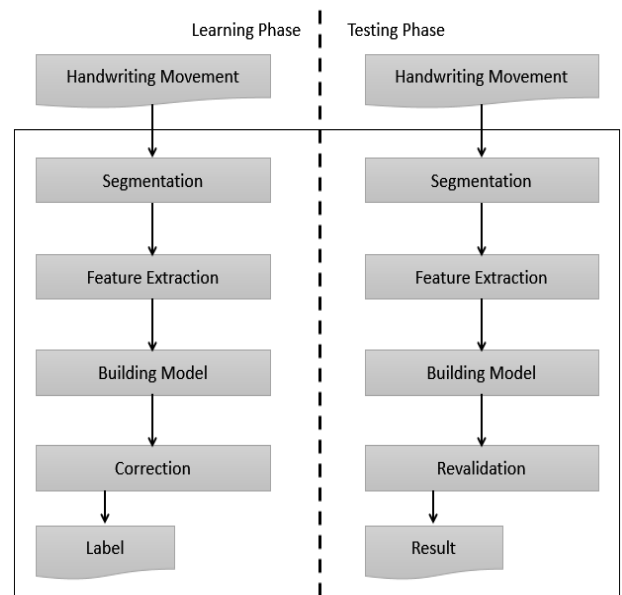


Figure 2: Generalized machine learning approach for online handwriting analysis [19].

As shown in Figure 3, the tasks include:

- 1) Draw and copy two pentagons based on MMSE test
- 2) Draw a House Tree Person based on HTP test
- 3) Write four provided words in capital letters
- 4) Draw a clock pointing hands to specific time based on CDT test
- 5) Copy a phonetically complete sentence in cursive letters

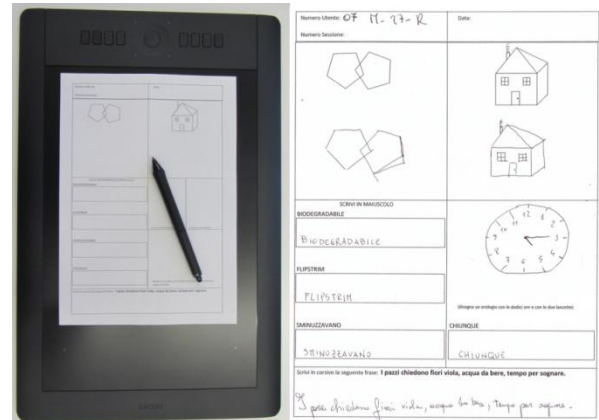


Figure 3: Writing-Drawing Tasks [3]

To reduce distortion while using digital device for handwriting, a normal A4 size paper is laid on the tablet and subject has been asked to write on paper. Using signals recorded by tablet, an image of handwriting can be viewed on the screen of computer connected to it. Based on these signals acquisition software generates a .svc file which has been used for statistical analysis [10]. The .svc file is an ASCII file which can be read using any standard editor application like WORD, NOTEPAD. As shown in Figure 4, the .svc file contains following information:

- Time stamp
- Position on x-axis
- Position on y-axis
- Pen status (up=0 or down =1)
- Pressure applied on pen
- Pen's Azimuth angle with respect to tablet
- Pen's Altitude angle with respect to tablet

sheet and on a blank sheet. The statistical study was carried out based on orientation, slant, ordering, and baseline of letters to derive writing score. This score was obtained using interrater reliability coefficient of statistical program SPSS and the median score of the three separate evaluations computed for each subject. The results showed that patients having a writing score upto five never had a MODA greater than 60 nor a MMSE greater than 20 [19]. They concluded that handwriting is a useful for evaluating the posthumous of testamentary capacity.

Murad Badarna et. al. studied pen motion patterns in patients having low MCI and high MCI. The handwriting analysis was based on spatial measures like width, height, displacement, and curve length, kinematic measures like mean, median, and standard deviation in acceleration, in-air and on-paper duration, pressure and angles. They obtained classification accuracy of 95.23% for patients with low MCI based on the on-surface pen motion pattern and accuracy of 85.80% for patients having high MCI [20].

4.2. Dysgraphia

Dysgraphia is found in school-aged children. Children with Dysgraphia face difficulties in organizing letters and produce uneven patterns of disordered handwriting. Using spatial and temporal measures, children with Dysgraphia can be identified easily [21].

Zdenek Mzourek et. al. analyzed sequential writing of 27 children having Dysgraphia, with 27 age-matched controls having experience of two years of writing in school. The parameters were based on 51 features, divided into three groups: non-linear dynamic features, kinematic features and other features. The observations were based on altitude/tilt and pressure. The features based on pressure found more useful for diagnosis of Dysgraphia. They observed that pressure applied was higher by 17% in case of children having Dysgraphia. To improve accuracy, they proposed an intra-writer normalization method based on subtraction. This method showed increase in accuracy by 4% and decrease in HPSQ score estimation error by 3.48%. This proposed automatic system had 96% sensitivity and specificity towards diagnosis of Dysgraphia and also the system was able to rate developmental Dysgraphia with estimated HPSQ total score with 10% error [22].

Patrice L. Weiss et. al. studied and compared both, online handwriting obtained using digital tablet and traditional handwriting analysis obtained from a pen and paper, among group of children having Dysgraphia and group of children with proficient handwriting. Handwriting samples of 50 proficient students and 50 students of 3rd grade with Dysgraphia were collected. The results showed that both digital and conventional evaluations were able to differentiate between children with Dysgraphia and children with proficient handwriting. By combining both the methods, they got improved understanding of writing difficulties. The spatial and temporal measures of handwriting kinematics were used as primary features. The total length paragraph and total length of in-air and on-paper movement constitute spatial measures whereas total time recorded to finish writing tasks, in-air and on-paper time, were also included as temporal measures. The digital analysis of handwriting showed significantly higher in-air time among the Dysgraphia handwritings as compared to proficient writers. The pencil travelled above writing surface between successive character segments, letters and words among the non-proficient writers as compared to proficient writers. These results provided clues of underlying difficulties limiting performance of children with Dysgraphia [23].

Gideon Dror et. al. proposed a system for characterization and automatic identification of Dysgraphia in third-grade children. The system was based on analysis of child's writing movements. The pressure applied on pen, its orientation and position were measured using a standard digital writing pad. The samples of ninety-nine Dysgraphia writers and proficient writers were collected. The features extracted were based on wide range of dynamic and visual properties of handwriting. The extracted

features were classified using linear support vector machine. They obtained 89.9% accuracy [24].

4.3. Schizophrenia

Schizophrenia (SZ) is found in 1% of population in people of age around 20's. Schizophrenia patients often behave quite different and strange as compared to normal people and sometimes they could not able to relate themselves with real world. Schizophrenia patients can be distinguished by using kinetic features of handwriting like velocity or jerk [25].

Alexander B et. al. studied Schizophrenia patient's handwriting movements to measure drug-induced motor side effects. Six schizophrenia subjects who have not received any antipsychotic medication, 27 schizophrenia subjects treated with risperidone and 46 healthy subjects were enrolled for study. Participants were given exercise to draw loops of different size and writing a sentence. The data was recorded and analysed using MovAlyzeR tool. The up and down successive movements were segmented into strokes. For each stroke, peak vertical velocity, velocity scaling (VS), vertical size, and average normalized jerk (ANJ) across a trial were measured. Results showed that patients treated with risperidone exhibited significantly greater dysfluent handwriting movements than healthy or untreated SZ participants. Differences were observed in some handwriting kinematic measures like ANJ between unmediated SZ patients and healthy participants. The sentences produced by unmediated SZ patients were smoother than medicated patients, and their handwriting movements were more dysfluent [26].

M. Ahmaddou et. al. performed analysis of kinetic features of handwriting among group of healthy people and SZ patients. Subjects were asked to write 'hello' word three times in different scales of height 1cm, 2cm and 4cm. Eight different features were extracted out of which three related to vertical peak velocity (PV) and others are related to velocity scaling slope (VSS), normalized jerk (NJ) and ANJ. An artificial neural network (ANN) of N nodes (N equals to number of selected features) was created with three layers. The first layer was an input layer, next was hidden layer with 1 to 20 nodes and output layer with one node. The results were obtained through 100 different runs. In each run, four data samples were used for testing purpose and other seventeen for learning purpose. The system was able to differentiate SZ subjects from normal people with accuracy of 97.5% [27].

Theo Wayne S. Fenton et. al. suggested a method to analyze performance of lateralized motor in SZ subjects. Patients were asked to draw two straight lines with each hand. These lines were scanned using HP Plotter. To measure deviation in straight line, root mean squared (RMS) error of regression equation was calculated for each line. To measure overall degree of disorder, the average of RMS error of all four lines was taken. Also the difference in RMS values was measured between two hands to compare performance index of motoric laterality. The writing samples were collected from 86 SZ patients diagnosed using statistical and diagnostic manual of mental disorders test. Fourteen employees from housekeeping staff were included as control subjects. To obtain reliable image of scanned drawing sample, four lines drawn by each control subject were selected randomly from database and scanned twice and scores were compared using one-tailed Pearson Correlation for each line drawn by each control subject. The SZ patients and control subjects were compared based on lateralization and motor disorder indices with the help of one-tailed T-tests. The SZ patients poorly performed motor movements than control subjects [28].

4.4. Autism

Autism occurs in school-aged children. Children with Autism often face difficulties in communicating with other people. Also it is difficult to understand their feelings and read their mind. Children with Autism can be identified by analyzing speed, slant

and size of handwriting [29].

Sara Rosenblum studied behavior of children's handwriting with autism spectrum disorder. Sixty children aged 9-12 years from third to sixth grades from different schools were included in the study. Out of sixty, half children had high-functioning autism spectrum disorder having Intelligence Quotient above 80 whereas other 30 were normal children. The degree of pressure applied by subject on paper, the rhythm and speed of handwriting, in-air time, slant and some other features were measured for each subject. The system correctly identified children with autism with accuracy of 91.5%. The letters produced by children with Autism were taller and broader, and degree of pen's slant on paper was smaller, also on-paper and in-air waiting times were longer as compared to normal students [30].

A study by Beth Patricia Johnson et. al. was aimed to characterize handwriting performance in children with Autism Spectrum Disorder(ASD) by using digitized handwriting tasks. The study included 52 boys with 8 to 12 years of age, 29 typically developing (TD) children from control group and 23 patients of ASD. The efficiency of motor movements was measured using MABC-2 test. Five writing sequences were given to each subject in cursive letters (1. emem, 2. eel, 3. eem, 4. eel, 5. eeee) having transition movements among similar (e-to-e) and different letters (e-to-m, e-to-l) with variation in direction and sizing. Tortuosity, size, writing speed and average peak velocity for a writing sequence were measured. The results showed that ASD children were facing greater difficulty in writing as compared to group of TD children of similar age. Also the letters/words were spaced unevenly by ASD children [31].

A review by Evdokia Anagnostou et. al. analyzed existing evidences showing dysfunction in writing movements of children with ASD and documented their handwriting difficulties. They collected and analysed data from January 1943 to January 2011 from ISI Web of Science, PubMed, Google Scholar, Scopus and all English-language related to ASD children [32].

4.5. Mental Illness

Handwriting Analysis has also been used to find people with negative emotions like Stress, Anxiety and Depression. Depression is increasingly affecting people world-wide. It affects motivation, concentration and many other aspects of human life. Stress depends on two things: psychological perception of pressure and body's response to it which involves multiple systems, from metabolism to muscles to memory. Anxiety is reaction to stressful situations which occurs in threatening circumstances. Person with negative emotions show difference in pressure applied on pen while writing, also the strokes are abnormal in time and space [33, 34].

Anna Esposito et. al. proposed a system to detect of negative emotions through writing and drawing tasks. The time-based features were used as they are more efficient to determine the state of mental illness. They measured in-air and on-paper duration, total time and various characteristics of stokes using digitalizing tablet. For each writing or drawing task, in-air, on-paper, and total time taken by candidate was recorded along with number of stokes and ranked using Random Forest approach. The results were validated against DASS [35] and repeating the experiment N times on K candidates by excluding one candidate from population each time to form subset of K-1 candidates. The results showed that stress and anxiety can be recognized more correctly than depression using digital handwriting analysis [11].

Gil Luria et. al. studied relationship between handwriting and mood. Sixty-two subjects from University of Haifa were included in the study with average age of 24.8 ranging between 21 to 29 years. The Computerized Penmanship Evaluation Tool and Software (ComPET) was used for analysis of features. The variation in length, width, height of strokes, duration and pressure applied were measured among group of positive, negative and neutral people. In negative subjects the strokes had shorter

lengths, 9.22mm (SD = 1.60) whereas in positive and neutral subjects they were longer 10.67mm (SD = 2.46) and 10.74mm (SD = 2.89) respectively. The width of strokes was narrower in the negative subjects, 3.03mm (SD = 0.44) as compared to 3.60mm (SD = 0.85) and 3.43mm (SD = 0.77) in positive and neutral subjects respectively. In group of negative subjects, the height of strokes produced was shorter 4.52mm (SD = 0.9) in comparison with negative and neutral subjects 5.32mm (SD = 1.34) and 5.53mm (SD = 1.41) respectively. The duration of on-paper strokes was shorter in the positive and negative moods, 144ms (SD = 19.2) and 143.5ms (SD = 18.4) respectively, whereas for neutral subjects it was 157 ms (SD = 32.5). Also strokes produced by subjects with negative mood had lower pressure than those made in neutral or positive moods [36].

Perla Werner et. al. examined functional disorder in performance of handwriting between elder people with Mild Major Depressive Disorder (MDD). Twenty elder people diagnosed with DSM-IV test of mild MDD were included along with twenty healthy subjects recruited among MDD participant's relatives having similar gender, age and educational level. The space, time and pressure were measured based on four handwriting tasks such as copying a paragraph, writing one's name and surname, writing all alphabets sequentially and filling in a check. The pressure applied by depressed patients was significantly lower and proven to be major factor affecting the writing performance. Also the time required to plan and execute movement of hands was higher. This feature was measured using in-air duration on pen [37].

4.6. Parkinson Disease

Parkinson Disease (PD) is a disorder in motor functions due to damage in central nervous system. It is found in people with age around 50 years and it gets worse over the time. By measuring the jerk and acceleration pattern of handwriting produced PD can be identified [38].

The Quantitative measurement of handwriting was carried out by David Song et. al. to analyse discriminate in every-day handwriting tasks among group of people having Parkinson's disease, people with psychotropic-induced Parkinsonism and normal people. The aim was to find some psycho-parameter to measure degree of Parkinsonism. The experiment included ten subjects (1 female and 9 males) meeting DSM-IV criteria of schizophrenia having clinically observable drug-induced Parkinsonism, thirteen patients (4 females and 9 males) diagnosed with idiopathic PD and Twelve (2 females and 10 males) normal healthy comparison subjects (NC). The velocity analysis of handwriting samples showed that peak velocities of vertical strokes from middle to bottom were nearly doubled, whereas for SZ patient's velocities were constant. In addition, to find degree of smoothness of handwriting, NJ was calculated based on normalized size and duration of strokes. Results showed that both SZ and PD patients had lower velocities than normal people, particularly for stokes larger than 4cm. Significant reduction in VS was observed in both PD and SZ subjects whereas on SZ subjects exhibited lack of smoothness [39].

Rifat Sipahi et. al. introduced method based on analysis of static images of subject's signature or handwriting samples to detect changes in micrographic of subjects with therapeutic response or symptomatic progression in Parkinson's disease. Twelve samples of signature of different subjects corresponding to symptomatic PD conditions, normal health and artificially generated signature with reduced size were used for comparison. Matrices sensitive to the properties of micrographic were chosen with minimal sensitivity to confounding handwriting properties. These metrics included ink utilization, character size-reduction and pixel density of writing samples from left to right. The signatures of subjects were collected and scored for each group before and after clinical diagnosis of subjects. Significant difference was observed in Pixel Density among signature recordings, before versus after [40].

M. Naumann et. al. studied kinetic features of handwriting

movements, speed, stroke duration, size and acceleration of Parkinson's disease subjects. For analysis, subjects were asked to draw combination of letter 'll' of the German words 'helles' (bright) and 'grelles' (glaring). For evaluation, distance of writing traces (in mm) of letter having 'll' combination and maximum positive/negative absolute acceleration (slowing down) were measured in both descending and ascending strokes recorded for each trial. Total writing time (in ms) and maximum/minimum absolute (tangential) velocities were also calculated for comparison. Also number of inversions in the direction of acceleration and velocity profiles with combination of 'll' letters were measured. The analysis was carried out based on mean scores of measurements for each subject. The results showed significant disturbance in kinetics of handwriting movements in PD subjects as compared to healthy normal people [41]. The summary of this research study is tabulated in Table 1.

Table 1: Summary of disease and related important writing features and clinical tests.

Health/Mental Illness	Important Feature	Clinical Test
Alzheimer	In-air time	MMSE
MCI	Orientation, Slant, Ordering, Baseline	MODA
Dysgraphia	Temporal and Spatial measures	HPSQ
Schizophrenia	Avg. Normalized Jerk, Velocity	EPS
Autism	In-air time and slant, Sizing, Tortuosity	IQ
Depression, Anxiety, Stress	In-air, On-paper time	DASS, DSM-IV
Parkinson	Velocity Jerk, Kinetic Measures	UPDRS

5. Conclusion

Handwriting is also called as brain writing. It is used to predict physical, emotional and mental health of an individual. In this paper, a generalized system of digital handwriting analysis for diagnosis of health and mental issues has been presented. A model of machine learning has been used for training and testing.

The research work carried out to diagnose diseases such as Alzheimer, Mild Cognitive Impairment, Dysgraphia, Schizophrenia, Autism, Parkinson's disease and mental illness based on digital handwriting analysis has been reviewed in this paper. Patient's handwriting has been obtained using WACOM's INTUOS digitalizing tablet. The experiments and results are summarized. It is found that features related to motion, time and pressure are very helpful for diagnosis of health and mental diseases using digital handwriting analysis approach.

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