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Aspects of a Standardized Automated System for Screening Children's Handwriting

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Abstract— Perceptual and practical aspects of child's drawing and handwriting, plus the importance of early identification of developmental disorders in children, arise the essential need for screening pupils' handwritings; testing their handwriting abilities and readiness. This research summarizes approaches in an automated screening system that can assist teachers, occupational therapist and psychologists monitor pupils for difficulties that result in improper handwriting. The following clarifies its importance and effects; discusses its aspects of system implementation and resources needed; plus its prospect benefits and outcomes. This new insight to children's handwriting assessment and screening systems provides new openings to targeted research in several fields of study interrelated to this issue. Ultimate system will in fact benefit educational system and public health in addition to generation of new knowledge about complicated human performances, children development and different languages inspirations. In the following, shortcoming in handwriting standards are mentioned, position features are introduced and global features are discussed. Multi-feature acquisition and fusion in different levels are considered in system implementation.

Keywords- Handwriting; global features; handwriting position features; fusion; children development; handwriting standards

I. INTRODUCTION

Advance presentation of language in written format, writing, is indeed one of the great astonishing early inventions of human. Moreover, calligraphy bears an extra spiritual perception within itself as well as conveying a message. Beautiful handwriting is used to convey holly messages, valuable versus and rich meaningful poems in their best and most effective way. Thus, the gift of digitalized modern world, keyboard, and its fast typing task, can never be a substitution for handwriting. Hence, penmanship should be a process associated with joy, esprit and self expression; rather than a stressful, tedious, complicated job for beginners.

Children's intellectual and mechanical skills are developed with handwriting. Bad handwriting can limit exam success [1-2]. "There is a need for children to develop the sub skills for handwriting at a young age, improving their motor coordination, balance, visual perception and basic hand eye coordination. Children need to be taught handwriting regularly and systematically from an early age and their developing skills continually monitored"[3].

Academics believe handwriting is a language and motor act [2]. Fluent handwriting prevent interfere with other mental writing processes [2, 4]. Legible handwriting is still an important life skill that deserves greater attention from educators and health specialists[5]. Unfortunately, evidences indicate that 10-30% of pupils suffer from handwriting difficulties while not getting the right intervention [5]. Hand drawing & writing tasks also provide a quick and efficient method for clinical profiling evaluations[6].

In this review, impediments preventing researches from achieving the desired automated handwriting screening system for children in educational institutions are briefly stated. The scope of this research and similar efforts done outskirt this issue, are mentioned and the outlook of the system is presented.

II. DESIRES AND OBSTACLE

One of the noticeable advantages of using an automated system for any task evaluations is its fair assessment giving comparable, reliable results not being subjective. Moreover, an automated handwriting screening system can be used widespread by all educational institutions dealing with pupils; based on this general use and its coverage, meaningful information can be deduced about student population related to handwriting issue and its performance. However, the crucial point is that none of these can be achieved if there is no general inter-rate reliable agreement about how to evaluate handwriting process.

Emphasis on handwriting and its curriculum is dependent on the policies of educational systems. With a survey on educational standards for kindergarten and first grades(e.g.[7-8]), it is apparent that standards do not present a clear, assessable explanation of what legible handwriting is. Correct way of positioning body organs in performing handwriting is barely found in any standard. Though such instructions usually are given to students implicitly based on teacher's way of teaching and experience. There are handwriting associations proclaiming the need for educational society awareness to consider the significance of handwriting in modern education: UK National Handwriting Association, IAMPETH, NeuroScript LLC, IGS, Times Educational Supplement (TES), Handwriting Without Tears, Peterson Directed Handwriting; but these organizations need to come together and present a general

handwriting standard. Unfortunately even Common Core State Standards, does not emphasize on handwriting yet, though it is recently established and the aim is to create shared high education standards for USA[8]. A set of Handwriting Standards was developed in consultant with occupational therapists [9]; which can serve as a base for further advance development of standards. This also includes simple shape drawing for beginners. By a combination of handwriting and drawing tasks, a set of tests were also proposed for students by Fairhurst et al. and consultant clinicians, but with the scope of dyspraxia diagnosis[6]. On the other hand, for this prospective system, tests should be organized for the target population of general kindergarteners and elementary pupils (not clinical patients); and may have prospects on discovering new knowledge about human development.

Manual method tools have also been provided by occupational therapists as purchasable products. Three of such tools are SHS, ETCH and Minnesota Handwriting Assessment(MHA). SHS and ETCH presuppose handwriting test conditions that do not cover illiterate kindergarteners; this is while according to the literatures, analysis of drawing tasks for handwriting abilities is of great concern[6, 10-11]. MHA scores does not account important features as pencil angles, and pressure; nonetheless, academic evaluation has been done on this product[12]. These products did not take any advantage of strategy features such as stroke sequence and start/stop points. ETCH [13-14] has also been mentioned to need improvement in terms of Individual score reliability, variability in handwriting changes and writing quality and seem to be subjective; Thus again lack of a common accepted standard system for measurement, evaluation and decision making is apparent. General mental and physical behaviors related to children's general health and development can be assessed through handwriting/drawing tests (e.g. IQ, Bender tests). Therefore designing assessment tests should be considered in a broader area where all psychometrics, neuropsychologists, cognitive psychologists, movement analyzers, physicians and brain mapping scientists can comment on issues that should be considered by the automated system. Such tests can be considered as sub-content of the standard or may accompany it as a complementary document. Collaboration with engineers in terms of potentialities generating automated assessment systems and accessing newly available features is also critical for presenting a system at the state-of-the-art knowledge based on a well developed standard.

III. EFFORTS

Handwriting has been of interest from a variety of aspects; its entity, indications, and aesthetic. Subsequently automated handwriting analysis looked deeper into the matter in the hunt for quantitative features and key indicators to digitally understand and recognize this multifaceted human performance. Study branches of automated handwriting analysis can emanate from a

viewpoint of recognizing the writer (e.g. [15]), the text written (e.g. [16]), movement and procedure (e.g. [17-18]), or even semantic content of the text (e.g. [19]). More or less each of these issues can, and have been investigated either offline or online related to the available data. In our prospect system, analysis of the manuscript and movements are used to evaluate children's handwriting. Ignoring body movement aspect in child's automated handwriting analysis up to now may be due to preventing multisensory implementation and complex process. Overlooking visible positioning features, recent researches emphasize on dynamic features especially in relation to children difficulties [6, 10, 20].

Referring that children at risk of handwriting difficulties may display varied graphomotor performance; Khalid reported the feasibility of using drawing behavior in identifying children at risk [20]. The relative contribution of the use of graphic rules to writing ability was investigated in another research [10]. As a result it is reported that poor printers use more non-analytic strategies to reproduce the figures. various forms of guidance using multi-sensory instructions (including visual, auditory, verbalization, and kinesthetic) and screening them in children can improve perceptual abilities [4]. There is a need for further research in investigating reliable, effective assessment features of handwriting and its difficulties, for a standard system with global, commensurable characteristics.

There are a few projects currently running related to automated systems for children's handwriting with similar research platforms. Table II at the end of the paper presents a brief explanation and comparison of the efforts. Mentioning TRAZO[21], NSF Haptic Writing Simulator [22-24], and MEDDRAW[6]; we compared their aim to the aim of our prospective system. Concisely, TRAZO and NSF Haptic Writing Simulator are more focused on learning assistance with the former focal point on practicing overlays and the later on mimic and proprioception. The applications of such system are more in handwriting improvement and rehabilitation. In contrast, MEDDRAW is focusing on diagnosis; with patient population being its target population and of so "accurate dyspraxia diagnosis" the goal, its application is in health centers assisting clinicians in diagnosing disorders with handwriting difficulty symptoms. ComPET is another system developed recently for clinical use. It is used to study children with dysgraphia, DCD, and ADHD [25-27]. The system reported that children with poor handwriting held the pen above the writing surface for a significantly larger percentage of the total writing time than those who were proficient. This system is not used for beginners in handwriting since children should know how to read and write in which they are asked to copy a written paragraph (though in any language). Research on the writing simulator reports quantitative variations of the mean values of writing parameters (force, speed, position), and general qualitative pattern of the distribution, are same for experts [24]. Hence, such features can efficiently be used in the

screening system as assessment criteria for identifying students with handwriting difficulties. MEDDRAW study seriously condemns ignorance of online data which results in no indicator of the underlying execution process [6]. The system takes advantage of online features in order to improve diagnosing. It inserts temporal data into typical clinical tests. As a result, this study has shown the existence of common behavioral characteristics, important in clinical profiling, among different patient populations studied. This flexible, user-friendly system has the capability of becoming a base platform for automated pupils' handwriting screening system. However further on we have given controversy discussions about analysis and feature selection in this system.

IV. SYSTEM OUTLOOK

Our prospective system's target populations are in general all children beginning to write while focusing on diagnosis. The goal is to identify common, prevalent handwriting difficulties among children and prospect new knowledge about child's development and human performances. Such a system should be able to gather as much info as possible related to handwriting performance; the whole process should be understood by scrutinizing the outcome and carefully monitoring the procedure and positioning. Omitting any source of info will diminish the robustness, accuracy and reliability of the screening system. A set of overlooked features mentioned above are what we are going to call *position features*. Hand and finger figures, head and body positions, eye distance from paper, paper positioning, and pen position in hand while writing are

among position features. We strongly believe such features also affect fluency and legibility in addition to those dynamic data studied in previous researches as [6] and [10, 20]. Teachers already consider like features intentionally or inadvertently as a commonsense, to guide students write in class. Such features fairly play a critical role in performing the task properly; regarding clinical profiling, handwriting difficulties in dysgraphia is seen with tight, awkward pencil grip and body position while writing [6]. Fig.1 illustrates the processing outlook of the system and inputs/outputs. As depicted, there are three set of inputs related to three set of features: 1) static, 2) dynamic, and 3) position. Static features are the ones that can be extracted from the manuscript (obtainable offline). **Dynamic features are on the other hand temporal and sequential features related to online observation. Position features introduced here can cover any information about the positions and figures of the body, pen, and paper while writing. Some of these position features may be acquired from still pictures (obtainable offline) while some may be related to the sequence of movement and should be obtained through recording sequential frames of writing process (online).** The first two set of data related to static and dynamic features in general, can be captured using a tablet PC. However, to capture the positioning data, cameras are needed. Dynamic features can be processed by actual values, means and time derivatives; or they may be processed by ordering sequences and strategies as inferred dynamic features. Strategy features carry info about how a single pattern can be performed differently according to perceptual and motor skill capabilities.

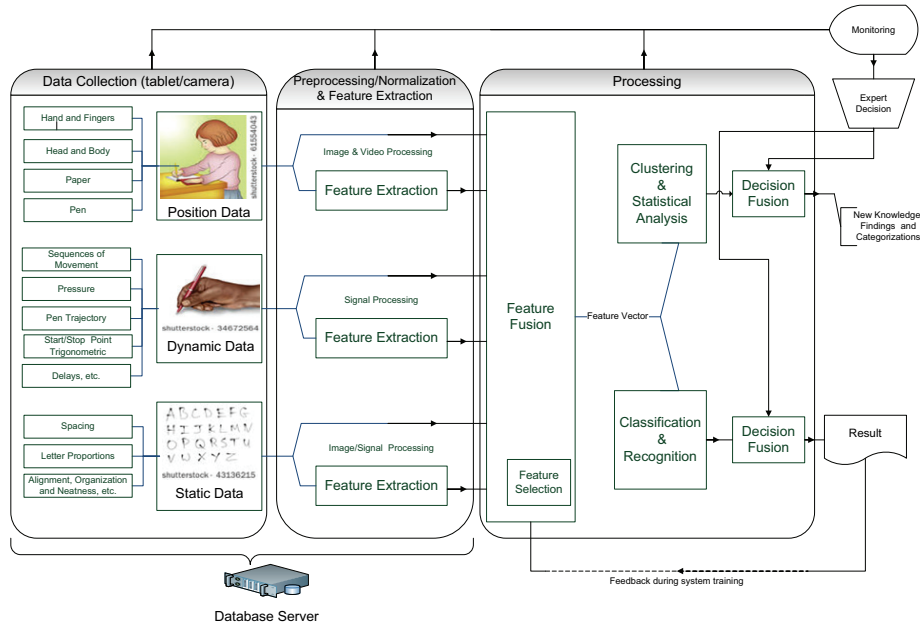


Figure 1. Outlook of the Automated Screening System

Features can also be classified according to their fundamentality. Although different evaluation tests usually emphasize on different aspect of handwriting, a lot of the tasks are common. Moreover when not having a standard common evaluation system, extracting features that are common among various tests and fundamentally describe one's handwriting performance are vital for comparison of different results and deducing conclusions. Such global features can accommodate less processing in implementation of automated system analysis and benefit best info acquisition from data. Fairhurst et al. defined global features as to "consider elements of commonality in measurement between the two conditions"[6]. We would like to point out that this is not enough; those commonly measured elements should be extracted in a way to be comparable to one another apart from their test ground; since they are supposed to be test-independent. Thereby, in contrast to [6] total time, number of segments, time ratios for pen up/pen down, and traversed distance are not global features since they are not comparable among different tests. The correct way of defining a global feature is to quantify a quality per some basic issue/problem or fact. This ratio should induce a meaning by itself in order to be test-independent and hence global. Such features will then be comparable to one another no matter where they were extracted from. For example the width/height ratio for shapes defined as global in [6] is totally related to the shape drawn and therefore cannot be global. However when dividing this ratio by the same ratio in the original sample pattern, it becomes global. The feature indicates whether the pupil has been committed to the aspect ratio of the original shape or not; no matter what the shape was whether a square or a tall rectangle. It is also robust to the size of drawing since pupils usually draw and write in various scales. Such similar features can illustrate subjective and objective aspects of pupil's handwriting performance. Table I presents examples of dynamic features and their indications. The table shows some new features and clarifies the type of the features whether they are global or test dependent. These features along with acceleration, velocity profiles, duration of stops, number-of-peaks in the estimated velocity graph for a single stroke, pressure variations, directional features,

starting point and other strategic features will present a good summary of pupil's handwriting effort. Considering zero crossing velocity, acceleration and jerk in each x and y directions (presented in [6]) we would like to declare that generally zero crossings are related to the drawn shape in drawing tests. However, in writing tests where the written text is same or at least it is in an amount that can be statistically generalized, then the quantity can be considered as a global feature.

Data normalization is also an important preprocessing stage though not enough attention is paid to it. This crucial mapping of data can affect the comparability of the data within a system as well as exterior result comparison among similar researches and systems. Standardization $((\text{value} - \text{mean}) / \text{std})$ is a good way of normalizing data. Khalid et al. normalized the velocity and pressure values to each child self max-min (0:1) [10, 20]. When normalizing a parameter, for example velocity, the normalization can be done according to all the writings collected from a pupil or it can be done according to a specific single shape or pattern that was performed. This is a key point; Khalid has applied the latter. In order to model an individual handwriting performance it would be preferred to use the former; so, the maximum speed of the writer among all drawn patterns would be assigned to 1. In this fashion, the variation of speed of an individual in performing different patterns would become prominent. Another key point in processing is the method of fusing features into a proficient feature vector that would result in the best classification. Fusion algorithms also may use artificial intelligent algorithms where the fusing will be determined by feedbacks from training classifier/s. Regarding the contribution of artificial intelligent systems to handwriting deficiency classification, Richardson et al. have reported successful differentiation between poor to proficient handwriting performances adapting learning and data mining techniques [27]. Khalid et al. approaches used statistical methods to measure the influence of each feature [10, 20]. Contrary, artificial intelligence in advance can compare the degree of importance of each feature by comparing their trained weights related to their effect in classifying the data.

TABLE I. SAMPLES OF DYNAMIC FEATURES AND THEIR INDICATIONS FOR AUTOMATIC HANDWRITING EVALUATION

No.	Feature Description (Formula)	Indication	Type
1	$\frac{(\text{width/height})_{\text{drawn}}}{(\text{width/height})_{\text{sample}}}$	Perception of aspect ratios in patterns	Global
2	$\frac{(\# \text{ of pen off paper})}{(\# \text{ of intersections of stroke in the drawn pattern})}$	Perception of segmenting & planning complex jammed patterns	Global
3	$\frac{(\# \text{ of pen off paper})}{(\# \text{ of separate strokes in the drawn pattern})}$	Preference of continuous drawing/writing or segmenting	Global
4	Number of erasing and rewriting or redrawing when performing a certain test	Uncertainty	Test- dependant
5	Delays while performing drawing or writing	Planning time	Test dependents
6	$\frac{(\text{Duration of pen-down pauses})}{(\# \text{ of pauses})}$ (from [6])	Average pausing disturbance while writing	Global (but slightly dependent on test complexity)
7	# of peaks in velocity profile for straight line (from [20])	Fluency in drawing straight lines	Test-dependent
8	Progression preference in drawing a given triangles (order of drawing the triangle lines and moving directions), (from [10])	Planning and skill tendencies	Test-dependent

V. SYSTEM BENEFITS & DISCUSSION

Screening a vast majority of handwriting beginners, foregrounds the necessity of an automated system; not only to increase the processing speed but also to collect data and keep tracks and increase accuracy. In addition, it will significantly help experts monitor improvements and come up with modified new standards based on real large amount of data collected by the system. This will truly benefit the educational system and consequently the whole society's psychological and physical health. Movement studies targeting children handwriting performance mostly focused on children with known psychological or physical problems. Yet not all problems can be categorized as clear cut disease and conditions. It is of great importance that attention be paid to milder, more subtle conditions in order to limit their effect on child's lifelong productivity. Automated systems directly related to screening children in general, and addressing difficulties are rare and the research is in its early stage. We proposed inserting position features into automated systems for handwriting analysis. Novel dynamic features, and now dominant detailed position features can bring valuable rewards in understanding children handwriting performance and diagnosing disorders accurately. Ideally, global features are not test-dependent; and should generally demonstrate student's challenge in drawing and writing. There is a need for implementation of handwriting standards and designing new drawing/writing tests in consultant with medical and educational communities based on new features. Taking advantage of multi features and feature fusion, plus sophisticated feature extraction and classification prospect a robust system. This system benefits scientific knowledge about human behavior. It can support studies comparing different handwriting procedures in different languages and evaluating their affect on children developing skills. From this prospect, left-to-right and right-to-left languages have a lot of potentialities in inducing different practical procedures and movement strategies in children. Such probable effects on creativity and perceptual/practical performance abilities can be taken under study. The behavior of special groups of children like as left-handed pupils may also be watched through the screening system. Usually special groups choose special strategies that refer to their physical or mental specialty. Inspecting and monitoring strategic features in handwriting movements can shed light on perceptual understanding and planning capabilities of children. It is interesting and valuable to discover the effect of structural differences among languages on children practicing them. System analysis of this supreme framework consists of signal processing, fusion, image and video processing, plus pattern recognition and classification.

Automated Handwriting Screening System for School Children is the best solution for screening beginners' readiness and capabilities in handwriting. No matter what strategies are going to be used in order to achieve this ideal

system, what is important, is considering all kinds of features, multi sensing and fusing as much info as possible into the automated system for further accurate and reliable analysis. Another crucial issue is having a common standard criteria approved by expert's communities and authorities to build the basic structure of the system on that. Novel analysis plus merging sparse research studies to present a complete coherent system with the best performance, requires in-depth study. Taking advantage of existing similar systems (such as MEDDRWAW) to initiate the ideal system can speed up the attempt.

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TABLE II. CURRENT RUNNING PROJECTS ON AUTOMATED SYSTEMS FOR CHILDREN'S HANDWRITING

Project Name	TRAZO	NSF Haptic Writing Simulator	MEDDRAW	ComPET
Nature	An assisting tool developed to assist teachers	A writing Simulator	Computer-based drawing task diagnosis system	Clinical use to study children with dysgraphia, DCD and ADHD
Aim	Assist teachers, teaching handwriting & evaluating pupil's handwriting development & develop children handwriting skills through effective use of tablet PC devices	Support advanced learning and training through perception and manipulation of objects using the senses of touch and proprioception.	Assisting clinicians for diagnosis in clinical environment	To quickly diagnose handwriting problems
Prospect	Assist students learn handwriting effectively and more personalized related to their weaknesses and progress	Actually teaching handwriting through mimicking senses of touch, and proprioception	Assisting clinicians in diagnosing diseases and disorders with handwriting difficulty symptoms; Current focus on: accurate dyspraxia diagnosis and CVA	To further develop the modular to automatically extracting features tools, measuring smoothness & quality of handwriting
Observed Hand-writing Features	The direction, pressure and pencil grip	number of segments, curvature of characters, direction of movements, and time series of pen pressure and pen orientation	Sequence of pen movement, angle, tilt, and pressure are collected Static and dynamic features with focus on dynamic such as : pressure, velocity, acceleration, and timing info	pen trajectories, on paper and in air paper time plus velocity, acceleration and pressure & record number of segments and direction reversals while writing
Characteristics	designed specifically for children in the first year of pre-school (3 years) & Created to teachers' requirements & Developed for 2 years in the classroom & Use friendly & It is completely configurable to add new exercises; & Defines some algorithms to obtain indicators for each writing exercise; & It includes a graphical monitor to show the individual and classroom progress.	Encodes force information involved in writing characters. The beginner can share the haptic sensation of an expert and consequently learning the procedure and practicing fluency much more effectively	User friendly: playback mode and "allowing real-time replay" for remote monitoring; & being able to explore through different particular aspect of the test performance; visualizing change of a feature value over the course of the test	criteria for poor handwriting are defined as irregularly spaced and formed letters (related to static features), number of corrections and deletions while writing, plus abundance of in air time
Disadvantages	Children faced parallax problems because of using tablet PC without any paper & Children not being able to turn the tablet according to their comfort as with papers & Scores and conclusions derived from the teacher's evaluations only (no consultant from clinicians)	The orientation of the tablet was fixed in related researches (final product presents a virtual semi-real environment for writing)	Target population are patient population & Focus on dyspraxia diagnosis and CVA disorders	Not used for illiterates since asks to copy a written paragraph (though in any language)
Data Collected	Data gathered during refining its interface in a formative evaluation process in a pre-school (3- 4 years old) during the last two years. Many photos and videos have been taken to study other external elements such as the position and posture of the children, apart from other indicators calculated by the system.	Alphabets handwriting data were collected from 12, male, Right handed proficient (not children) in writing Tamil and English for this research.	CVA patients at four clinical test centers within the county of Kent in U.K. Alongside with, a group of 13 healthy age-matched control (AMC) subjects. Dyspraxia, data were collected in two separate centers in Rouen, France: first in a series of schools, to obtain a reference population(178), and within a clinical environment, to obtain a sample of dyspraxic children(8).	Studied: Dysgraphic children vs proficient Also used for elderly populations. Under study: 8-11 years olds who were born prematurely