Monitoring Neuromotricity On-line: a Cloud Computing Approach

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Abstract. The goal of our experiment is to develop a useful and accessible tool that can be used to evaluate a patient's health by analyzing handwritten strokes. We use a cloud computing approach to analyze stroke data sampled on a commercial tablet working on the Android platform and a distant server to perform complex calculations using the Delta and Sigma lognormal algorithms. A Google Drive account is used to store the data and to ease the development of the project. The communication between the tablet, the cloud and the server is encrypted to ensure biomedical information confidentiality. Highly parameterized biomedical tests are implemented on the tablet as well as a free drawing test to evaluate the validity of the data acquired by the first test compared to the second one. A blurred shape model descriptor pattern recognition algorithm is used to classify the data obtained by the free drawing test. The functions presented in this paper are still currently under development and other improvements are needed before launching the application in the public domain.

1. Introduction

Over the years, at Scribens Laboratory, we have developed algorithms for extracting lognormal parameters that describe handwriting movements. The study of the evolution of these parameters over a longer period of time would allow us to analyze changes in a user's neuro-motor skills. We could monitor the improvements of a child learning to write or detect the loss of neuro-motor skill. These programs were until now restricted to Wacom tablets connected to standard computers and screens. The goal of this work is to transfer the software to a portable Android tablet touch screen to eventually make it more easily accessible to physicians and clinicians.

To accomplish this, Polytechnique Montréal and the Computer Vision Center (Barcelona, CVC) have initiated a collaborative project that aims to create an Android application that is able to:

- Analyze a patient's handwriting strokes to determine relevant biomedical data (Polytechnique Montréal);
- Recognize specific patterns or shapes from a patient's drawing or writing (CVC).

Once completed and fully integrated, this application will be used as a tool for biomedical research. The effects of young children (5-7 years old) learning to write and the effects of aging have already been proven (Plamondon et al. 2013). Another important application for this tool is to characterize a patient's health and follow its progression through time (O'Reilly et al. 2010).

The pattern recognizer developed by the CVC is included in the application to perform word or drawing spotting to assess the potentiality of recovering the same biomedical information about a subject state (learning/aging/health) without the boundaries of a highly parameterized test. If this hypothesis is confirmed, a whole new area of possible applications could be created.

2. Implementation choices and project definition

By using the Android platform, which is very popular for new electronic tablet and smart phone technology, the application will be highly accessible to a very large portion of the targeted population. A Samsung Galaxy Note 10.1 2014 edition was used to test the application.

Because the two algorithms used in the application to analyze biomedical data, namely the Delta-lognormal and Sigma-lognormal algorithms (Plamondon et al. 2009), require a lot of resources (memory, computation power), a distant server is used to take over the analysis and the digitizer (tablet, smart phone, etc.) serves as an acquisition module with a user interface.

This interface first presents itself to the user with two main choices: biomedical tests and free drawing session. The first choice leads to a panel of options representing different predefined highly parameterized and bounded tests that are currently used at the Scribens laboratory (O'Reilly et al. 2014) while the second choice leads to a free drawing area. Here, a shape recognizer algorithm detects shapes, and the associated relevant information about the subject's strokes is retrieved afterwards.

The choice of the shapes for the recognizer to detect is important because we must confirm that a free drawing stroke is similar to a stroke made within a highly parameterized test. The triangle is a good example of shape that can be used (O'Reilly et al. 2011). Therefore, we first focused on the triangle as a shape to be recognized. Other shapes may be defined later on, and the platform's modular design allows for easy integration of new options. The database in the cloud will also have to be organized such that the data corresponding to a specific type of freehand or constrained drawing of a particular shape are easy to recover and analyze.

A Google Drive account was used as a cloud to facilitate the communication between the digitizer and the server. This approach has the advantage of storing all the relevant data in a cloud which allows the application part of the project to be developed independently from the server part. It also procures a facilitated way to transfer and store the data files via Google's application programming interfaces and file manipulation options.

3. Digitizer using the Android platform

This section presents the user interface developed on the Android platform to acquire biomedical data from user handwriting strokes. The tablet used for this project is the Samsung Galaxy Note 10.1 2014. The first thing that we did was replace the SPencanvas data acquisition class with a standard canvas, written in Java, which increased the sampling frequency from 25 to 60 Hz. Then, we focused our efforts on designing three tests: the single stroke test, the triangle test and the free drawing area.

The single stroke test is quite simple: after hearing an audio stimulus, the user must perform a single rapid movement from a black dot at the centre of the screen (start zone) to one of the grey areas situated on either side of the screen (end zones) (Figure 1a).

Figure 1b presents the second biomedical test available on the application, the triangle shape test. The user must draw the triangle shape appearing on the screen using a single sequence of strokes. This shape is defined by three circles that represent the corners of the triangle and by three coloured bands that form the edges of the triangle. The user must start their stroke within the circle identified with tag 1, reach the circle tagged with the number 2 and then the one tagged with a 3 before finishing their stroke back in the first circle. Like the previous test, the stroke must not be drawn until the audio stimulus is launched.

Those two interfaces contain a drawing area (1) where the user must execute the test, a Tutorial button (2) to assist the user by presenting tutorial slides and finally a Settings button (3) to be able to modify the test settings. The Help button (4) appears only when a user needs to be reminded of the test rules. The last button (5), with the user's name, is used to access the user settings and to log out from the application. This last button is always available throughout the application except from the login interface.

Figure 1c presents the free drawing interface, which shows a drawing area, a Settings button to change parameters such as the colour of the pen used, and the user's name button. It also has a Delete button (6) to erase the drawing area and start a new drawing. Functionalities such as saving a drawing or editing a line (without changing the relevant biomedical data) could be added in the future to increase the interface's user-friendliness.
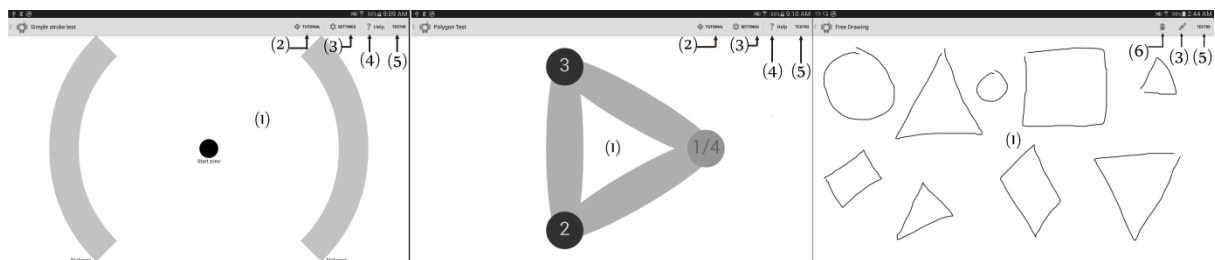

Figure 1: a) the simple stroke test interface, b) the triangle shape test interface and c) the free drawing interface.

The first two interfaces are highly parameterized, and the properties of the geometrical features and of the audio stimulus signal can be modified when accessing the settings menu with the appropriate button (3 on Figures 1a and 1b). Table 1 presents the properties that can be modified for each of the two interfaces and the audio stimulus signal with their associated default values in parentheses. This allows the experimenter to adjust the two tests for each user if necessary. For example, if a particular user suffers from Parkinson's disease, the start zone radius of the interfaces may need to be augmented to accommodate them.

Table 1: The settings of the two interfaces including the properties of the audio stimulus signal. Default values follow the setting in parentheses.

Simple stroke test interface
Velocity threshold (50 mm/s), start zone radius (2.5 mm), end zone inner radius (20 mm), end zone outer radius (50 mm), end zone angle (45°), start zone colour (black), end zone colour (grey)
Triangle test interface

Velocity threshold (50 mm/s), first circle radius (10 mm), second and third circle radius (10 mm), triangle radius (40 mm), edge width (20 mm), triangle orientation (0°), first circle colour (green), second and third circle colour (blue), edge colour (turquoise)
Audio stimulus signal
Frequency (1000 Hz), duration (0.5 s), minimum start time (1 s), maximum start time (10 s), volume (50%)

The velocity threshold parameter is used to limit the movement at the beginning of the stroke before the movement is initialized. The end zone angle parameter in the simple stroke test interface represents the angle of the end zone's arc divided by two. For the triangle test interface, the triangle orientation parameter is the angle between the horizontal line that splits the screen in half on its height and the centre of the first circle. The minimum and maximum start time associated with the audio stimulus signal represent the limits of the uniform distribution of the delay before the audio stimulus is launched. The delay value is picked randomly in this distribution. Every kind of error is distinguished and the strokes containing any errors are identified with a corresponding tag. Those tags are principally used to identify, on the server side of the project, the strokes containing errors, and to analyze them apart from the strokes that were performed correctly.

The purpose of the application's free drawing section is to assess the hypothesis that strokes that are not bound to follow specific rules like the ones used in the biomedical tests (start and stop in specific boundaries, start the stroke at a specific time, etc.) can also be used to analyze a user's biomedical parameters. In order to do that, the free drawing interface only presents a blank drawing area where the user is asked to draw triangles (Figure 1c). Since this shape is already used as a parameterized test, comparison between the data acquired by the triangle test and the data acquired with the free drawing test can provide useful insight on the validity of the free drawing data type. The rectangle or circle are other basic shapes that could also be incorporated to this application to be recognized and analyzed. We are considering a new function that could draw basic flow charts based on the recognition of a few of these basic shapes while at the same time recovering the necessary biomedical information. We may investigate this in the near future.

The data associated with the stroke is saved in an .hws file format which registers the timestamp, position, velocity and pressure of every data point. The velocity is estimated using Euclidian distance. All the meta-data associated with every stroke, such as an error occurrence and its type, are registered in a different text document. Those two files are then transferred from remote to central storage. The Advanced Encryption Standard (AES) encryption algorithm is also used to encrypt the data which must be kept private. The encryption process is password protected. The communication between the Google Drive, the tablet and the server is secured by using a special key that is associated with this specific application's account. This key is hard-coded in the tablet application and in the server.

4. Analysis of the data

This section presents the computation part of the project to analyze the data correctly. Firstly, when the encrypted .hws and text files are uploaded on the Google Drive account from the tablet, they are organized by user and type of test. Then, a distant server is used to fetch all new files and analyze them according to type. The second step is to decrypt the data so that it can be analyzed by the appropriate algorithm. Those algorithms are the Delta-lognormal and the Sigma-lognormal (Plamondon et al. 2009) that are used to respectively analyze the data from single strokes and from more complex strokes, such as the ones produces during the triangle shape test. The algorithms were conceived assuming the data acquired would be sampled at a frequency of 200Hz. This caused a problem with commercial tablets since the highest sampling frequency observed was 60 Hz and that frequency was not steady. To resolve this issue, a pre-processing step was added, by interpolating the data to simulate a 200 Hz frequency sampling. In the end, we want to be able to show the computed results on the tablet, which means going through the steps of re-encrypting the results from the analysis and transferring them from the server to the cloud.

One step must be added to properly analyze the data that is acquired during the free drawing test. The strokes must first be recognized as triangle-shaped before we try to analyze them in order to achieve the goal of validating the use of this kind of data. We use the Blurred Shape Model (BSM) descriptor, which is an improved version of the Zoning descriptor that encodes the probability of pixel densities of image regions (Escalera et al. 2009). This descriptor is computed on the image generated from the stroke that has been drawn on the screen, without taking into account the sampling and the speed. First, the image is divided into a grid of n x n equal-sized sub-regions. Then, each cell in the grid receives votes from the shape points in it and also from the shape points in the neighbouring sub-regions. Each shape point contributes to a density measurement of its cell and its neighboring cells. This contribution is weighted according to the distance between the point and the centroid of each region. Finally the descriptor is normalized within the range 0 to 1. In order to recognize the input symbol, the Euclidean distance is used to compute the similarity between the symbols stored in the database. Those symbols are specific to each user and are stored in the Google Drive cloud. Then, a k-Nearest Neighbour

algorithm is used for classification in order to differentiate different symbols such as rectangle and circles. This allows for further development of the application to recognize other shapes than the triangle. Finally, a second and a third classification processes are used to distinguish different types of triangles. Because the stroke order is important in the biomedical analysis, we make the distinction between the same symbols depending on whether they were drawn clockwise or counter-clockwise. The orientation of the stroke (clockwise/counter-clockwise) is determined using the formula [1]. The stroke orientation is determined by comparing whether the result is greater than 0. If this is the case, then the triangle was drawn clockwise; otherwise it was drawn counter-clockwise. This formula comes from the Shoelace formula for computing the area of a polygon. The constant factor from the Shoelace formula can be omitted since our sole interest is to compute the orientation and not the total area.

$$\text{Area} = \Sigma\ (x_{i+1}-x_i)\ (y_{i+1}+y_i) \qquad [1]$$

The third classification process is useful for spatially locating the triangle's starting point. To classify the starting point of the triangle, nine different classes are used: up_left, up_centre, up_right, middle_left, middle_centre, middle_right, down_left, down_centre and down_right. This classification is performed by placing the point in a grid and analyzing where it is placed.

The BSM algorithm needs to be trained before the user draws the first free drawing strokes. The triangle biomedical test is used to accomplish that. In fact, if the user has not tried the triangle biomedical test before the free drawing program, they are automatically redirected towards the triangle biomedical test in order to train the recognizer. Once the training is done, the reference data is uploaded into their folder in the cloud and the user can use the application's free drawing test.

Once the data is analyzed, a new type of file with the results is created (.ana). Those results contain the lognormal parameters that model the velocity curves. For the Delta-lognormal algorithm, only one lognormal is sufficient to model the data while for the Sigma-lognormal algorithm, multiple lognormals are needed.

5. Conclusion

This work aims ultimately to produce a useful clinical tool that is able to detect early signs of specific diseases by analyzing handwriting-related data. The prototype presented in this paper supports the basic functionalities that we want to include in this work, such as the simple stroke and triangle shape tests. It also supports a more advanced function which is the detection of freely drawn triangles. Biomedical data is analyzed on a server in a secure way but the results still need to be interpreted and investigated.

A big issue with this process is its duration. Using a computer with low random-access memory for the server, the process of computing all the data to create a results file can take up to one minute. A substantial part of the processing time can be attributed to the booting of some programs needed by the lognormal algorithms. The processing time includes the time required for data transmission, but the transmission part of the process is insignificant (less than a second) compared to the computation time. In real-time mobile application, such a delay might create user dissatisfaction. Future optimization of the lognormal algorithms and a better understanding of the parameters useful in the interpretation of human movement might help reducing the processing time.

Overall, the goal was to create a working prototype – a goal which was successfully reached. All the steps were completed, from doing a test to receiving its results, the only downfall being the processing time, which can be easily improved by acquiring or designing an optimized server for the required calculations. Optimizing this delay is one of the requirements of being able to develop a large-scale application. A number of improvements can also be added to the application, such as a results window that interprets the analyzed data and the creation of experimenter accounts that would make it possible to change specific aspects of the application. The influence of the interpolated sampling frequency is also still yet to be evaluated. Interpreting the resulting data for neural pathology will be the final significant step in this work.

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