Artificial Intelligence Based Web Platform for Home Screening in Digital Neurology

Francesca Laganaro[1], Raffaella Calabrese[2], Annalisa Mancini[1], Matteo Angelucci[2] and Antonio Pallotti[2,3,*]

[1]*Sapienza Università di Roma,Piazzale Aldo Moro 5, Roma, 00185, Italy*
[2]*Università San Raffaele Roma, via di Val Cannuta, 247, Roma, 00166, Italy*
[3] *Consorzio Parco Scientifico e Tecnologico Technoscience, Via Enrico Toti, 15, Latina, 04100, Italy*

Abstract

Worldwide, Parkinson's disease (PD) is one of the most common neurodegenerative diseases affecting millions of people. Over the past 25 years, there has been a considerable evolution regarding Parkinson's diagnosis; initially, the only available tools were neurological examinations and autopsies. Subsequently, brain scintigraphy with DATSCAN was introduced and, in recent years, it has been added the magnetic resonance, an examination that doesn't use ionizing radiation, but only involves exposure to a magnetic field, capable of identifying neuromelanin's changes, visible as contrast reduction. In literature several studies have shown how impaired writing and vocal insufficiencies are important elements for the early detection of disease. In 2021, two studies by our research group on Parkinson's classification through telemedicine tools were carried out, one on graph signal (77.5The objective of our preliminary study is the development of a telemonitoring system of the voice and graph signal for neurological diseases' screening such as Parkinson's, thanks to artificial intelligence techniques (machine learning). The system is based on a simple Android/iOS application (on a smartphone or tablet), in which two tasks are required. The first one is vocal, and it consists of sounds recording, while the second one is related of writing letters and drawing geometric shapes. We enrolled 2 subjects, one healthy and the other one with advanced PD. Data are acquired via bluetooth wireless communication, stored locally, and sent to a web platform. Those data can be used to be processed both with standard analyses and through machine learning models (Artificial Intelligence) to support the specialist decision. Immediately afterwards, the two subjects underwent an MRI of the brain. The images are sent to the web platform and saved together with the data acquired through the application. Compared to previous research that used a professional tablet, a digital pen, and a microphone, our study introduced two novelties: the use of smartphones and tablets, and the archiving of radiological images on a platform. This system is a disease development control/monitoring tool that could save patients' time, allowing specialists to have all the patient's clinical and instrumental data on the platform, and having a positive impact on hospitals' resources. nd instrumental data on the platform, and having a positive impact on hospitals' resources.

Keywords

Telemedicine, Telemonitoring, Teleconsulting, Artificial Intellingence, Machine Learning, Home Screening, Digital Neurology

1. Introduction

It was observed the changing healthcare needs of individuals due to the progressive increase in the average age of the population, with a growing number of elderly people and chronic diseases. This requires a reorganization and structural redesign of the healthcare service network, with a focus on strengthening the territorial area of assistance. The increasing digitization we have seen in recent years is also making it possible to spread a range of new technologies that respond to the changing needs of healthcare professionals and patients. The reorganization, together with technological innovation and digitization, is also supporting the shift of healthcare from hospitals to the community through innovative care models focused on citizens, making access to services across the country easier. In this scenario, telemedicine is seen as a fundamental tool, as it allows the delivery of care and assistance services through the use of Information and Communication Technologies (ICT) in different situations, even when the healthcare professional and patient (or two professionals) are not physically in the same location. Telemedicine involves the secure transmission of medical information and data in various forms necessary for the prevention, diagnosis, treatment, and subsequent control of patients. Telemedicine services are comparable to any diagnostic/therapeutic service, not replacing traditional healthcare services in the doctor-patient relationship but integrating and enhancing their effectiveness, efficiency, and appropriateness. At the European level, telemedicine is widespread in many countries (such as Sweden, Norway, Spain, and Great Britain) and is supported by regulatory interventions, strategic

Ital-IA 2023: 3rd National Conference on Artificial Intelligence, organized by CINI, May 29–31, 2023, Pisa, Italy
*Corresponding author.
laganaro.1773908@studenti.uniroma1.it (F. Laganaro); raffaella.calabre@studenti.uniroma5.it (R. Calabrese); mancini.1786844@studenti.uniroma1.it (A. Mancini); matteo.angelucci1@uniroma5.it (M. Angelucci); antonio.pallotti@uniroma5.itt (A. Pallotti)
0000-0002-3185-5795 (A. Pallotti)

documents, and state projects in most cases. In Italy, the National e-Care Observatory was established in 2007 to build the map of e-care networks, promote the exchange of good practices and related technologies, with the aim of improving the accessibility and effectiveness of online services provided to citizens. Given the presence of numerous telemedicine initiatives that too often are not completed and remain incomplete projects, prototypes, or experiments, the Higher Health Council (in 2014, the agreement was signed in the State-Regions Conference), following a telemedicine working group started in 2010, approved the national guidelines for telemedicine in 2012, which will be periodically updated. The last national document concerning telemedicine relates to the National Guidelines for the provision of telemedicine services, resulting from the Permanent Conference for relations between the State, the Regions, and the autonomous provinces of Trento and Bolzano in 2020 and will be periodically updated based on new technologies and needs. In Lombardy in 2020, the telemedicine regulatory scenario was innovated with the entry into force of the DGR n. XI-3528/2020, of 05/08/2020, containing "Indications for the activation of remotely deliverable healthcare services (televisit)." With this act, the Region aimed to provide uniform discipline and some specific operational indications for televisit. The Directive specifies that televisit must be primarily employed in continuity of care (follow-up) for those patients already known to the health service and who do not require an objective examination. Telemedicine, which is the use of technology to provide remote medical services, aims to improve the quality of healthcare, ensure continuity of care, increase access to healthcare, and provide cost savings. Telemedicine includes various services such as teleconsultations with specialists, televisits, telemonitoring, and teleassistance. Telemedicine is applied in different sectors of medicine such as teleradiology, telecardiology, teledermatology, telerhabilitation, telepathology, teleneurophysiology, and telehomecare. Various actors are involved in the organization of telemedicine services, including users who can be patients, caregivers, or medical professionals, and the provider center, which can be a National Health Service facility, a general practitioner, or a pediatrician. The service center manages the health information generated by the user and transmits the outcomes of the service to the user. Wearable devices are biosensors integrated into clothing, shoes, and accessories that measure biological parameters such as heart rate, respiratory rate, blood pressure, glucose, and brainwaves. Wearable devices can provide feedback to the wearer and store data in the cloud for healthcare professionals to access. Continuous monitoring of biometric parameters can educate patients about healthy behaviors and modify their lifestyles to promote health and support diagnostic activities, treatment management, and rehabilitation. In particular the teleradiology, a telemedicine service that enables the electronic transmission of radiographic images from one geographic area to another for reporting or consultation, can provide advantages, such as improved access to medical expertise and reduced time to diagnosis and treatment.

2. Materials and Methods

We consider two previous studies by our research group that focused on the diagnosis of Parkinson's disease using machine learning techniques, specifically in relation to handwriting and graph analysis. The first study, called "Classification-Based Screening of Parkinson's Disease Patients through Graph and Handwriting Signals," [1] conducted in 2021 by Fratello M. et. al., aimed to propose a method for discriminating and classifying Parkinson's disease using artificial intelligence techniques [2]. The study developed a telemonitoring system based on handwriting, which collected data on the inclination, pressure, and position of a digital pen during the execution of various tasks by subjects [3]. The study collected data from 22 healthy individuals and 9 patients with Parkinson's disease(PD), all of whom were right-handed, except for one patient with PD, and between the ages of 60 ± 25 years. The Hoehn and Yahr scale, a clinical scale used to describe the progressive motor impairment of Parkinson's patients, was used to indicate the level of each patient. It was used a commercial Wacom One drawing tablet with a screen for the test to extract both "online"(pressed) and "offline"(unpressed) features. The application used the Unity development platform to collect information on the position (x, y), pressure, and inclination of the pen at a frequency of 133 Hz, and at the same time provided visual feedback on the tablet screen to the subjects. The Wacom tablets are widely used in the analysis of movement and handwriting because they offer high spatial and temporal resolution. The study protocol was divided into four parts: drawing an Archimedean spiral, writing the bigram "le" six times, writing two Italian phrases, drawing ten concentric circles, and writing seven lines of free text. For each section of the protocol, a different screen was shown to the subject. The application had an initial page where the participant could enter their ID and a menu from which they could choose which activity to perform. The data was saved locally in different ".csv" files for each acquisition, and MATLAB software was used for analysis. During the execution of the tasks, the participants were given visual instructions on the tablet screen, and the application recorded the data on the pen's movements. We analyzed the data collected to determine if it could be used to diagnose Parkinson's disease. The study showed that machine learning techniques could successfully discriminate between healthy individuals and those with Parkinson's disease based on

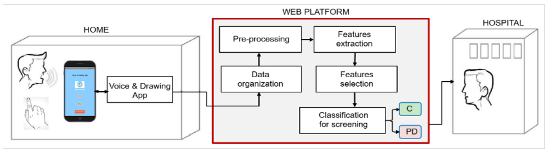

Figure 1: Web platform permits raw data acquisition, feature time variation visualization and machine learnings algorithms implementation

their handwriting movements. Overall, the study suggests that handwriting analysis could be a promising tool for Parkinson's disease diagnosis, and that telemonitoring systems based on digital pens and machine learning techniques may provide a cost-effective and non-invasive method for monitoring and diagnosing the disease. Going on the research work, the new study involved 52 participants, including 16 patients with Parkinson's disease and 42 controls, and was conducted using the same Wacom tablet and digital pen. The participants were asked to perform three tasks: drawing an Archimedean spiral, writing the bigram "le" six times, and writing the sentences "I fiori sono sul prato" and "Nel cielo ci sono le stelle" once each. The data collected were analyzed using MATLAB R2022 software. The data analysis involved applying an bandpass filter to eliminate non-relevant sounds such as coughs, hesitations, and other non-vocal sounds. The bandpass filter was applied to focus attention on the 50Hz to 750Hz frequency range, where most of the vocal signal exhibited its power. Amplitude and temporal thresholds were also applied, and all waveforms were normalized before being passed to the feature extraction algorithm. The features were divided into three types: standard measures, non-standard measures, and cepstral measures. Standard measures consisted of conventional measures of speech analysis such as jitter and shimmer, while non-standard measures were based on recurrence, self-affinity, and pitch dispersion. Cepstral measures were based on estimating the cepstrum. Different types of models were tested on the data using MATLAB's Classification Learner and Weka. SVM, ANN, and KNN models were considered due to the need for future firmware implementation. The models' accuracy was optimized by testing different subsets of features to analyze their robustness and prediction capacity. The best models were selected for the validation session, in which the data were divided into 75In addition to the study's results, the authors proposed an innovative idea to improve telemonitoring activity by creating a "Voice Drawing App" for smartphones or tablets that allowed for direct collection of handwriting and voice data without the need for additional equipment [4] [5] [6][7].

3. Results

We present the results of our two studies focused on the development of machine learning models for the early diagnosis of Parkinson's disease (PD) as in figure 1 . The first study by Fratello M. et al. constructed three models to discriminate between healthy control subjects and PD patients using data from two tasks: a spiral drawing task and a bigram task involving the repeated typing of the letter "le." The models were constructed using linear support vector machines (SVM) and k-nearest neighbor (KNN) algorithms. The results showed that combining data from both tasks led to the highest accuracy (77.5 per cent) and sensitivity (77.8 per cent), while the spiral task alone led to the highest specificity (79 per cent). The best performing model used the medium KNN algorithm for the combined tasks. The second study by Cordella et al. focused on developing a machine learning model to classify PD patients and healthy controls based on speech recordings. The authors tested several classifiers, including SVM, KNN, and multilayer perceptron, on a dataset of 612 observations. The results showed that KNN had the highest accuracy (97.3 per cent) and the lowest standard deviation (less than 1 per cent). SVM had low performance, and optimized SVM models resulted in a higher accuracy of 91.2 per cent but with a risk of overfitting. The authors concluded that KNN was the most robust classifier for this type of data. Overall, both studies suggest that machine learning models can be effective tools for the early diagnosis of Parkinson's disease. The findings also highlight the importance of selecting appropriate algorithms and data features for each task and dataset [8]. The last results explore the possibility of using handwriting analysis as a non-invasive method to diagnose Parkinson's disease (PD). The study included 50 participants, 25 with PD and 25 healthy individuals. The participants were asked to write a spiral, a sentence with the word "sono" (Italian for "are"), a sentence with the phrase "i fiori sono sul prato" (Italian for "the flowers are on the lawn"), and a sentence with the phrase "nel cielo ci sono le stelle" (Italian for "in the sky there are the stars"). The study used various machine learning algorithms to analyze the handwriting samples, including Subspace KNN, Medium KNN, Subspace Discriminant, Bagged Trees, Linear SVM, Fine KNN, Weighted KNN, Cubic SVM, Cubic KMM, and Subspace discriminant. The accuracy, specificity, sensitivity, precision, and area under the curve (AUC) were measured for each algorithm. The results showed that the handwriting analysis using machine learning algorithms had a higher accuracy than the previous study on the same topic. The best performing algorithms were SVM, KNN, and Tree. Additionally, the last study found that the models created with only the sentence "i fiori sono sul prato", the sentence "nel cielo ci sono le stelle", and the word "sono" had the highest accuracy, possibly because they are located in the central part of the sentence where the patients struggle the most, providing more information for the recognition of Parkinson's disease. The study also suggested a possible future work combining handwriting analysis and electromyography of the forearm to understand the relationship between handwriting fatigue and disease. Finally, the study included a confusion matrix showing the performance of the models on the different sentences and the word "sono".

4. Conclusions

We had presented three different studies related to using technology to help diagnose Parkinson's disease (PD) based on changes in handwriting and voice patterns. The first study discussed is by Fratello M. et al. (2021) and involves an application that records data from tablets at a frequency of 133Hz to help with the recognition of PD through changes in handwriting. The tool is simple and easy to use, allowing subjects to complete the test in the comfort of their own homes. The study collected data from 22 healthy subjects and 9 patients with PD and added it to the PaHaW database, which includes data from PD patients and healthy control subjects. Using only two of the eight tasks included in the PaHaW database, the study achieved an accuracy of 77.5 per cent, which is close to the 85.61 per cent accuracy achieved by Drotàr et al [9]. considering all eight tasks together. However, the study's main limitations are related to the small number of subjects involved and the fact that the data was collected from different databases and in different experimental conditions, which could lead to incorrect classification. The second study discussed is by Cordella F. et al. and focuses on voice patterns. The study achieved satisfactory performance in terms of accuracy (up to 98.5 per cent) and stability through different combinations of training. The accuracy had significantly lower fluctuations (<1 per cent) than in other studies, suggesting a more robust algorithm. However, due to an imbalanced dataset with a majority of subjects with PD, sensitivity tends to be higher than specificity. The study shows the importance of analyzing complex sounds such as /iamh/ and /iuh/ and the ability of specific signal analysis to support medical work with a fast and reliable process that could be implemented in telemonitoring systems. The third study discussed is by Mancini A. et al., which collected data from 52 subjects (42 control and 16 with PD) who were asked to draw and write entirely in Italian on a commercial tablet connected to a PC. This allowed for the collection and saving of data. Like the Fratello et al. study, this test was simple, quick, and comfortable to perform, with healthy subjects taking three minutes and those with PD taking four. The Italian database was expanded from 22 control subjects and 9 with PD to include the new data. Overall, the studies show the potential of technology in aiding PD diagnosis through changes in handwriting and voice patterns. However, more research is needed [10] to address limitations and to develop more robust algorithms that can be implemented in telemonitoring systems for accurate and reliable diagnosis.

References

[1] M. Fratello, F. Cordella, G. Albani, G. Veneziano, G. Marano, A. Paffi, A. Pallotti, Classification-based screening of parkinson's disease patients through graph and handwriting signals, Engineering Proceedings 11 (2021) 49.

[2] C. R. Pereira, D. R. Pereira, S. A. Weber, C. Hook, V. H. C. De Albuquerque, J. P. Papa, A survey on computer-assisted parkinson's disease diagnosis, Artificial intelligence in medicine 95 (2019) 48–63.

[3] M. Thomas, A. Lenka, P. Kumar Pal, Handwriting analysis in parkinson's disease: current status and future directions, Movement disorders clinical practice 4 (2017) 806–818.

[4] A. Pompili, A. Abad, P. Romano, I. P. Martins, R. Cardoso, H. Santos, J. Carvalho, I. Guimaraes, J. J. Ferreira, Automatic detection of parkinson's disease: an experimental analysis of common speech production tasks used for diagnosis, in: Text, Speech, and Dialogue: 20th International Conference, TSD 2017, Prague, Czech Republic, August 27-31, 2017, Proceedings 20, Springer, 2017, pp. 411–419.

[5] J. C. Vásquez-Correa, J. Orozco-Arroyave, T. Bocklet, E. Nöth, Towards an automatic evaluation of the dysarthria level of patients with parkinson's disease, Journal of communication disorders 76 (2018) 21–36.

[6] M. Little, P. McSharry, E. Hunter, J. Spielman, L. Ramig, Suitability of dysphonia measurements for telemonitoring of parkinson's disease, Nature Precedings (2008) 1–1.

[7] F. Cordella, A. Paffi, A. Pallotti, Classification-based screening of parkinson's disease patients through voice signal, in: 2021 IEEE International Symposium on Medical Measurements and Applications (MeMeA), IEEE, 2021, pp. 1–6.

[8] M. A. Hall, Correlation-based feature selection for machine learning, Ph.D. thesis, The University of Waikato, 1999.

[9] P. Drotár, J. Mekyska, I. Rektorová, L. Masarová, Z. Smékal, M. Faundez-Zanuy, Evaluation of handwriting kinematics and pressure for differential diagnosis of parkinson's disease, Artificial intelligence in Medicine 67 (2016) 39–46.

[10] A. Pallotti, G. Orengo, G. Saggio, Measurements

comparison of finger joint angles in hand postures between an semg armband and a sensory glove, Biocybernetics and Biomedical Engineering 41 (2021) 605–616.