Article

Not peer-reviewed version

Method of Early Diagnosis of Abnormal Movements of Patients with Tremor Symptoms Using Augmented Reality

Volodymyr Hrytsyk * , Maksym Kochut , Uliana Marikutsa , Oleh Lytovchenko , Oleh Berezyuk , Vitalii Hrendus

Posted Date: 7 April 2026

doi: 10.20944/preprints202604.0432.v1

Keywords: augmented reality; neurodegeneration; early diagnosis

Article

Method of Early Diagnosis of Abnormal Movements of Patients with Tremor Symptoms Using Augmented Reality

Volodymyr Hrytsyk [1,*], Maksym Kochut [1], Uliana Marikutsa [1], Oleh Lytovchenko [1], Oleh Berezyuk [2] and Vitalii Hrendus [3]

[1] Lviv Polytechnic National University, Ukraine
[2] Danylo Halytsky Lviv National Medical University, Ukraine
[3] St. Panteleimon Hospital of the First Territorial Medical Association of Lviv, Ukraine
* Correspondence: volodymyr.v.hrytsyk@lpnu.ua

Abstract

The work aims to increase the accuracy and earlier diagnosis of tremor, considering it as a key symptom of Parkinson's disease and a manifestation of neurological disorders caused by injuries. Unlike traditional methods, the proposed approach eliminates the presence of a compensatory "anchor", increasing sensitivity to the slightest manifestations of tremor. The efficiency of the method was experimentally confirmed on 50 healthy people, 6 with Parkinson's disease, and 75 with traumatic brain injuries resulting from military operations. The method was compared with the classical assessment of drawing geometric figures on paper. A comparison showed that all patients with Parkinson's disease passed the paper test, but the most difficult of them could not pass the AR test without a fulcrum. For wounded servicemen, AR showed a visible advantage, though significantly more tests are required to use a deep classifier. Studies using a basic classifier have shown that the proposed method, which utilizes augmented reality as a medium, is more sensitive than the standard one, confirming its promise for early neurodiagnostic systems.

Keywords: augmented reality; neurodegeneration; early diagnosis

---

1. Introduction

The paper explores the concept of early diagnosis of hand tremor as a telltale sign of neurodegenerative diseases such as Alzheimer's, Parkinson's, and impaired brain control of the peripheral limbs (hands) as a result of military injuries. Although not new, these problems remain relevant, in particular, the use of the spiral in the diagnosis of Parkinson's disease [1].

Alzheimer's disease is one of the types of dementia that affects about 6% (one in 16) of people over the age of 65 [2]. In this context, the diagnosis is focused on the determined parameters of abnormal movements of the patient with tremor symptoms (T-object), caused by the negative effects of a certain set of neural nodes. In the USA, the National Institute of Neurological and Communication Disorders and Counseling (NINDS) and the Alzheimer's Association have compiled the most commonly used set of criteria for the diagnosis of Alzheimer's [3].

1. According to the criteria, to make a clinical diagnosis of possible neurological diseases, it is necessary to confirm the presence of cognitive impairment [4].
2. Most often, disorders in neurological diseases affect eight domains (in various combinations): memory, speech skills, ability to perceive the environment, constructive abilities, orientation in space, time, and one's personality, problem-solving skills, functioning, and self-sufficiency. These domains are equivalent to the NINCDS-ADRDA criteria [5] listed in the DSM-IV-TR [6]. Tremor, characterized by involuntary shaking of a body part, is the most common of all movement disorders [7]. Of all these domains, it is most effective to catch the moment of the

doi:10.20944/preprints202604.0432.v1

appearance of tremors as a marker of the beginning of negative processes. Establishing the state of "early/first stage" will allow starting preventive actions before slowing down the progress of the disease.

This work is focused on the early detection of signs of the disease, so we will consider the early stage further. Progressive memory decline [8] and agnosia (disorder of recognition processes) in neurodegenerative diseases, sooner or later, lead to confirmation of the diagnosis. In a small number of patients, it is not memory disorders that come to the fore, but disorders of speech, executive functions, perception, or movement disorders (apraxia (including tremor)) [9]. When drawing, writing, doing self-care activities in the kitchen, or putting on clothes, and other tasks using fine motor skills, a person may seem clumsy due to certain problems with coordination and planning of movements [10]. As the disease progresses, a person is often quite capable of performing many tasks independently, but may require assistance or care when attempting manipulations that require special cognitive effort [9]. Among other effects, Parkinson's disease impairs control of movements, primarily of the upper and lower limbs, and causes tremors and muscle stiffness [11].

The long period during which research is being carried out [12] has shown that the main control of motor activity in the human body is taken over by networks of spinal neurons [13]. Spinal neurons can independently generate rhythmic signals (without going up the hierarchy) that affect synchronization within the structures that generate control impulses [14]. These spinal neural networks, which are responsible for the rhythmic movements of muscle activity, are called central generators of ordered activity [12].

Researchers all over the world are looking for convenient and effective early diagnosis. To date, there have been developments in computational models of movements, for example, walking [15] or admiration gestures [16]. The reaction of the eyes is studied [17], [18]. Eye behavior is considered an informative feature [19]. Therefore, in IT, it is relevant to distinguish characteristic features, in particular, lines [20] or curves [21]. Mathematical solutions for automating the diagnostic process are being studied [22].

Thus, at the first (simplest) stage, patients' reflexes, ability to get up from a chair and walk around the room, as well as muscle tone and strength, are checked. Neurological examination: vision and hearing, coordination, and balance are checked. The first symptoms are often confused with manifestations of aging or a reaction to stress [23]. Examining available diagnostic methods [24], [25], [26] and state assessment methods [27], [28], [29], the authors established a method for detecting tremor of the upper limbs as a basic element of early diagnosis of dementia [30]. In 2017, Australian researchers from RMIT University conducted a study investigating the impact of Parkinson's disease on people's movements. A total of 55 people took part in the study (27 of them had the disease, 28 did not). Each of the participants was asked to draw a spiral on the tablet along the given control points (see Figure 1) [30]:

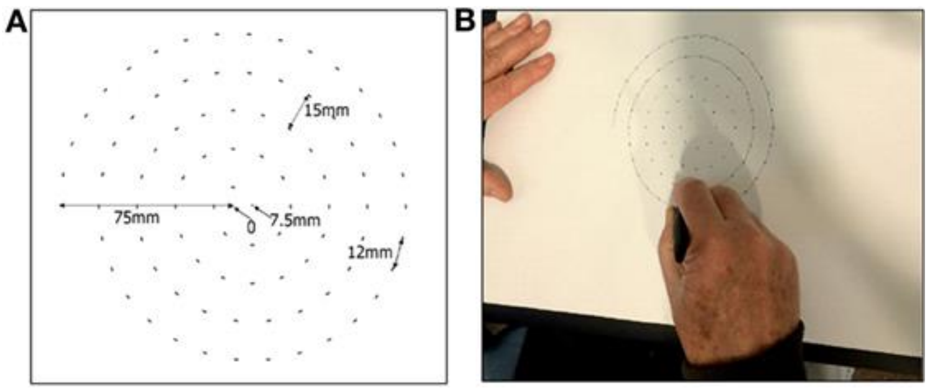


Figure 1. The spiral view and the process of passing the test.

 doi:10.20944/preprints202604.0432.v1

During the test, a tablet with special software measured the speed of movement and the pressure of the pen on the drawing, allowing it to distinguish between those with the disease and the severity of their condition. The researchers combined the speed and pen pressure data into one measurement for each participant and compared the measurements.

In the study, the authors concluded that there is a significant difference in the indicators of persons with the disease compared to healthy persons (see Figure 2) [30].

As can be seen from the figure (see Figure 2), such a significant difference in indicators allows us to make a preliminary assessment of the condition of the patient who underwent testing. David Dexter, deputy director of Parkinson's Research UK, confirmed this finding: "Current tests for the disease cannot accurately measure how advanced a person's condition is. This may affect the ability to select the right people for clinical trials, which is important for developing new and better treatments for Parkinson's disease." [31].

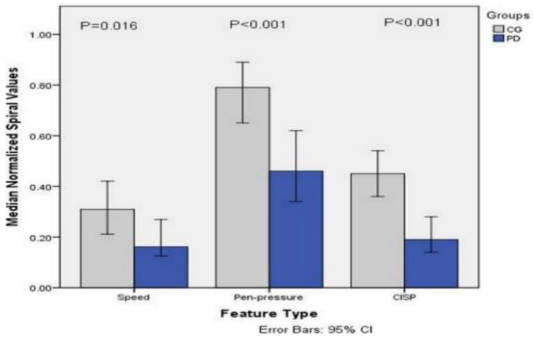


Figure 2. Comparative graph of indicators of healthy (CG) and diseased persons (PD).

Authors of the article "How to use pen and paper tasks to aid tremor diagnosis in the clinic" [32] believe that people with Parkinson's disease often write and draw slowly, producing small handwriting and spirals formed from tight turns. Reduced size and speed of hand movements reflect bradykinesia, the main motor symptom of Parkinson's disease. The authors believe that spiral drawings are more sensitive than small handwriting, especially if the small handwriting is inherent throughout life.

Action tremor is present in almost half of patients with Parkinson's disease during drawing, and most importantly, the reduced diameter and increased density of turns distinguish Parkinson's tremor with sufficient specificity.

Therefore, analyzing the speed and nature of the drawing of the Archimedean spiral by a person, it is possible to conclude about the presence of early symptoms of Alzheimer's/Parkinson's disease, in particular, about the tremors and reduced speed of movements inherent in it.

In subsequent works, this topic was studied using various methods and patient samples [33]. Recent studies have actively pursued the digitalization of the Archimedes spiral test, highlighting the methodological limitations of relying on physical surfaces [1]. Furthermore, emerging approaches increasingly track direct finger movements [34] or analyze spatial kinematics without physical support, such as "aerial" spirals evaluated via wearable sensors [35]. However, having experience in the development of augmented reality systems [36] the authors proposed a method of diagnosing problems with the use of augmented reality. Such a decision allows patients to avoid unnecessary visits to medical institutions, reducing their stress and the burden on the medical system. It also allows for lower equipment costs, as everyone has PCs and/or smartphones with video cameras these days. When selecting a classification assessment [37], [38] were analyzed; «problem of counting cycles» [39] was analyzed too. A modern approach to the state assessment strategy was studied [40]. Changes in node connectivity, not just edge changes, are studied, affecting measurements [41], and ways of working with open neuroimaging databases [42].

The main task of this work is to study the functionality of the method of early diagnosis of the presence of symptoms of Alzheimer's/Parkinson's diseases, which, based on the integrated assessment of the user's actions in augmented reality, will allow for classification of the user's condition.

The given conditions are diagnostic in the mode of augmented reality. Thus, the available data, from which conclusions will be drawn, are the position of the patient's hand *(x, y)* and time *(t)*. Reaction time is an important indicator [4]. Additionally, the ability to perceive objects (such as spirals) and to coordinate one's movements with respect to virtual 3D objects is implicitly evaluated. At this stage of research, the object is a 2D plane-spiral in 3D space.

2. Materials and Methods

The research is based on the method of classification of states through the search for atypical movements (caused by cognitive factors), using interaction with augmented reality and spectral analysis in heterogeneous environments. An approach to constructing hybrid models that describe the state and behavior of abnormal neurological movements (ANM) in certain body parts of a T-object under the cognitive influence of a specific group of neural nodes is proposed.

2.1. Analytical Solution

As it was already mentioned in the paragraph "Statement of the problem", in the conditions of augmented reality, the available data, based on which conclusions will be drawn, are: the patient's hand position (x, y) and time (t). In addition, the augmented reality environment makes it possible to create auxiliary virtual objects for assessing the patient's condition. Continuing the idea of the previously considered study [2], control points will be used to analyze the patient's condition in augmented reality. Control points are a certain number of points that are evenly placed on the trajectory of the spiral, along which the patient must swipe their finger. The advantage of this method is that the patient does not need to know exactly where these points are, and it makes it possible the process of assessing the patient's movements.

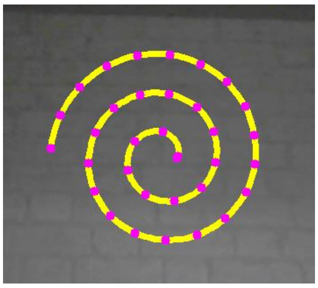


Figure 3. View of the spiral with control points applied to it.

The figure (see Figure 3) shows the trajectory along which the patient should swipe his finger in yellow, and control points based on which the patient's movements will be analyzed in pink.

For the analysis to be as accurate as possible, during the testing, the patient will not see the control points; ideally, he should not be aware of their existence at all, to focus as much as possible on his main task - to move his finger along the trajectory of the spiral. Having introduced the concept of control points and having their coordinates, you can proceed to the description of the analytical solution to the problem of diagnosing the patient's condition based on the trajectory of his movements when moving a finger along a spiral.

Let:

$x, y - coordinates\ of\ the\ finger\ at\ the\ moment\ t,$

$c_x, c_y - coordinates\ of\ the\ next\ control\ point,$

$c_{prev_x}, c_{prev_y} - coordinates\ of\ the\ previous\ control\ point\ ,$

$dist_t - distance\ to\ the\ control\ point\ at\ the\ moment\ t\ \ ,$

$dist_{prev_t} - the\ distance\ to\ the\ previous\ control\ point\ at\ the\ moment\ t,$

$dist_c - the\ distance\ from\ the\ previous\ control\ point\ to\ the\ next,$
then all *dist* distance formulas are calculated using the Euclidean distance formula:

$$dist_t = \sqrt{(x - c_x)^2 + \left(y - c_y\right)^2} \quad (1)$$

$$dist_{prev_t} = \sqrt{\left(x - c_{prev_x}\right)^2 + \left(y - c_{prev_y}\right)^2} \quad (2)$$

$$dist_c = \sqrt{\left(c_{prev_x} - c_x\right)^2 + \left(c_{prev_y} - c_y\right)^2} \quad (3)$$

At the beginning of the test, some score metric has a value of 100. This metric indicates how well the patient swiped the spiral trajectory. In the process of testing, if the patient deviates from the trajectory, he will be charged a penalty, which reduces the value of the score metric.

2.2. Conditions for Registration of Deviation from the Trajectory

2.2.1. The First Condition

$$dist_t > dist_{t-1} * const_1 \quad (4)$$

$$\text{const}_1 \geq 1$$

const₁ – a constant of the difficulty of passing the test. The smaller it is, the more difficult it will be to pass the test. That is, it regulates the degree of loyalty to the patient's mistake and how often the patient will be charged a fine. If *const = 1*, the penalty will be calculated for the minimum deviation from the trajectory.

The amount of the fine is calculated according to the formula:

$$penalty = (dist_{t-1} - dist_t) * p_{const_1}, \quad (5)$$

$$p_{const_1} > 0.$$

Here, p_const_1 – penalty level constant. The bigger it is, the bigger the fine. That is, it regulates the amount of the fine for a mistake made by the patient.

It follows from formula (3) that the amount of the fine depends on the difference in the distance to the control point at times t and *t-1*. That is, the further the patient moves away from the control point at the next moment in time, the greater the fine he will receive. Thus, the algorithm simplifies the diagnosis of tremor manifestations. The more severe the patient's condition, the faster the score metric will drop to 0.

In the conditions of augmented reality, determining the position of the patient's finger is not ideal due to the imperfection of the technology and sensor noises, which cannot be eliminated. Therefore, the constant const1 in formula (2) allows for to reduction of the influence of these factors on diagnostics. For the same reasons, the authors do not recommend setting its value to the absolute minimum.

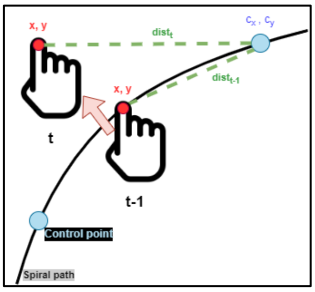


Figure 4. Schematic representation of the operation of the algorithm of the first condition.

2.2.2. The Second Condition

$$dist_{prev_t} + dist_t > dist_c * const_2 \quad (6)$$

$$const_2 \geq 1$$

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 April 2026 doi:10.20944/preprints202604.0432.v1

const₂ – is the constant of the difficulty of passing the test. Its behavior and purpose are identical to *const₁*

The amount of the penalty is calculated according to the formula:

$$penalty = \left(dist_{prev_t} + dist_t - dist_c\right) * p\_const_2 \tag{7}$$
$$p\_const_2 > 0$$

p_const₂ – penalty level constant. Its behavior and purpose are identical to *p_const₁*.

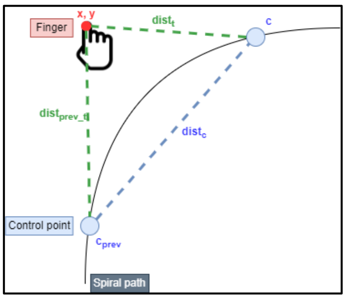


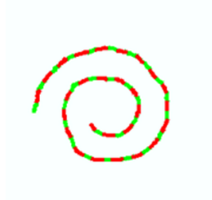
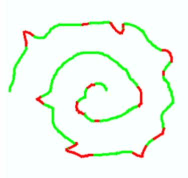
Figure 5. Schematic representation of the operation of the algorithm of the second condition.

3. Results

To study the effects of the values of the constants *const1*, *p_const1*, *const2*, *p_const2*, experiments were conducted, and their influence on the diagnosis of the patient's condition, the reaction to deviations from the trajectory, and the course of the analysis of the diagnosis at different values of the constants were reviewed.

During the experiments, an attempt was made to test at different values of the constants. In addition, during testing, the coordinates of the finger were recorded, and the moments of the calculation of fines according to the given values of the constants were noted.

Table 1. Comparative table of conducted experiments.

$const_1$	p_const_1	$const_2$	p_const_2	finger trajectory	Final score
1	1	1	1		0
1	1	1.3	1		0
1	1	1.3	0.09		0
1	0.7	1.1	0.1		32

In the drawings of the trajectory of the finger, the areas where no fine was charged are shown in green, and the places where the fine was charged are shown in red.

1. From the first experiment, it became clear that $const_2$ must be greater than *1*; otherwise, it is almost impossible to pass the test.
2. The second experiment showed that the penalty calculated by the second algorithm is usually very large, so it should be reduced by a low value of the constant p_const_2.
3. The third experiment showed that when $p\_const_1 = 1$, the fine is also too high, so the value of this constant should be reduced.
4. The fourth experiment showed approximately acceptable values of the constants for which the testing can be completed. When value $const_1 = 1$, $p\_const_1 = 0.7$, $const_2 = 1.1$, $p\_const_2 = 0.1$, with several obvious deviations from the spiral trajectory, the final result is 32/100.

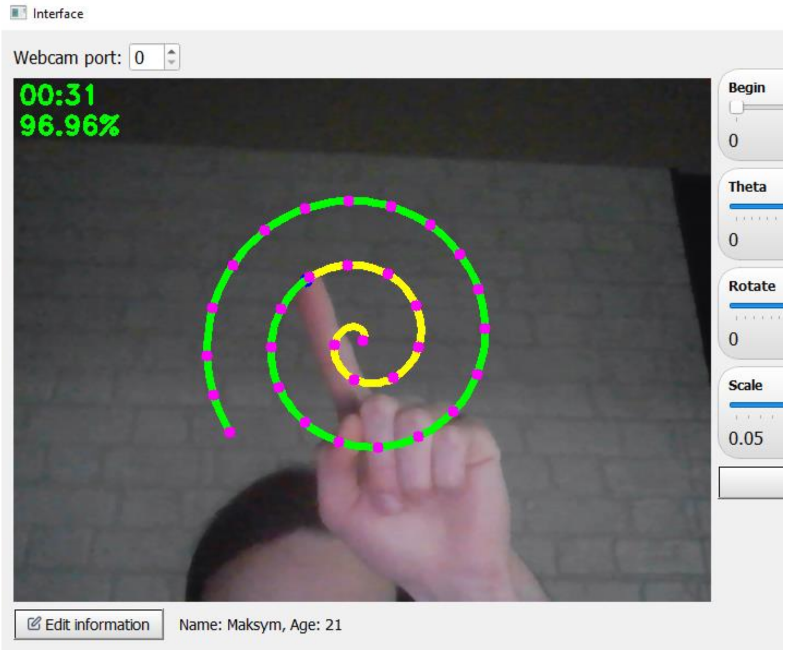


Figure 6. The doctor can perform the early diagnosis procedure remotely, seeing the diagnosis process in real time, with the effect of the doctor and patient being present in augmented reality.

4. Discussion

In this section, we will briefly note that the study was conducted to verify on all potential patient categories that 1) the concept works; 2) to identify unforeseen interferences; 3) to learn how to correct foreseeable interferences. Evaluating these three tasks, it can be stated that 1) the system performs data selection correctly. Therefore, it is potentially possible to take the next step - to explore different classes and try to integrate them. 2.1) This point requires additional interpretation, since, due to the lack of an anchor (point of support), the system turned out to be much more sensitive to tremor than expected. In particular, the patient (advanced Parkinson's disease) was able to draw a standard Archimedean spiral (obviously, with classical diagnostic features); however, she was unable to draw the same spiral in augmented reality due to a concentration problem. We make a preliminary conclusion that the initial assumption regarding the leaf (or electric tablet) serves as an anchor for the brain. And relying on this anchor, the brain partially compensates for the loss of control over the limb of the hand (tremor). In the case of augmented reality, there is no anchor (point of support), and there is nothing to compensate for the loss of control. Currently, the authors are looking for partners for research focused on this problem and the verification of the results. 2.2) Another unexpected result was the phenomenon of the recovery of military personnel (craniocerebral injuries). In particular, the majority of injured military personnel (of different age categories) performed better on the test than the control group. Even in the presence of severe cases. Additionally, taking into account that more than half of the control group are university students, we make an assumption (which we will check in the future). We assume that the stress of society (which is in a war under rocket fire) may be higher than the stress of the military (even with severe injuries and amputations) due to the unpredictability of "tomorrow" (uncertainty). To test this assumption, we are looking for partners to create a control group (healthy patients from a non-belligerent state). 3) The expected problems include lighting problems (spectral problems). Their solution at the moment is to eliminate direct sunlight and bright light sources behind the patient.

5. Conclusions

The proposed method of diagnosing the patient's condition using augmented reality showed technological effectiveness. Its use will simultaneously reduce the price (according to the criteria of price and time of the patient/doctor) and make early diagnosis more convenient and accessible. Due to the presence of two analysis conditions, the method is quite flexible, and four constants provide the possibility of its detailed adjustment. The conducted experiments clearly showed how the values of these constants affect the course of diagnostics. From the fourth experiment, we can conclude that the method works well if the values of the constants are chosen correctly. The number and quality (location and structure) of control points can be changed [37] during process optimization. Instead of pressing force, the concept of point coordination in virtual 3D space is introduced. That is, the method/system evaluates the patient's ability to navigate in 3D space while interacting with augmented reality objects. The effectiveness of the application of this method is investigated and shown.

Author Contributions: Conceptualization, V.Hry.; methodology, V.Hry. and M.K.; software, M.K.; validation, O.B. and V.Hre.; formal analysis, U.M.; data curation, O.L.; writing—original draft preparation, V.Hry. and M.K.; writing—review and editing, O.L.; visualization, M.K. All authors have read and agreed to the published version of the manuscript.

References

1. S. S. T. M. D. B. M. &. H. A. W. Wang, "Clinical Applications and Measurement Properties of the Digitized Archimedes Spiral Drawing Test: A Scoping Review," Movement disorders clinical practice, vol. 12(11), p. 1742–1755, 2025.
2. S. I. Alistair Burns, "Alzheimer's disease," British Medical Journal, Vols. 338, b158, February 2009.
3. F. H. J. C. e. a. Dubois B, "Research criteria for the diagnosis of Alzheimer's disease: revising the NINCDS-ADRDA criteria," Lancet Neurol, vol. 6 (8), p. 734–46, August 2007.
4. Blacker D, Albert MS, Bassett SS, Go RC, Harrell LE, Folstein MF, "Reliability and validity of NINCDS-ADRDA criteria for Alzheimer's disease," Arch. Neurol, vol. 51 (12), p. 198–204, December 1994.
5. Ito N, Hokkaido Igaku Zasshi, "Clinical aspects of dementia," American Psychiatric Association, vol. 71(3), pp. 315-320, 1996.
6. Ito N, Kuzuhara S., "Diagnostic criteria for vascular dementia," Nihon Rinsho, vol. 64, pp. 777-782, November 2006.
7. J. I. Serrano, S.Lambrech, M. D. del Castillo, J. P.Romero, J,Benito-Leóne, E. Rocona, "Identification of activities of daily living in tremorous patients using inertial sensors," Journal of Neuroscience Methods Expert Systems with Applications, vol. 83.
8. Sanz Perl Y, Fittipaldi S, Gonzalez Campo C, Moguilner S, Cruzat J, Fraile-Vazquez ME, Herzog R, Kringelbach ML, Deco G, Prado P, Ibanez A, Tagliazucchi E., "Model-based whole-brain perturbational landscape of neurodegenerative diseases," Elife, 2023. Mar.
9. Förstl H, Kurz A., "Clinical features of Alzheimer's disease," European Archives of Psychiatry and Clinical Neuroscience, no. 249 (6), p. 288–290.
10. T. Benke, "Two Forms of Apraxia in Alzheimer's Disease," Cortex, vol. 29, no. 4, pp. 715-725, Dec. 1993.

11. W. Dauer and S. Przedborski, “Parkinson’s Disease: Mechanisms and Models,” Neuron, vol. 39, no. 6, p. 889–909, 2003.
12. T. G. Brown, “On the nature of the fundamental activity of the nervous centres; together with an analysis of the conditioning of rhythmic activity in progression, and a theory of the evolution of function in the nervous system,” Physiology, vol. 48, no. 1.
13. P. A. Guertin, “Central Pattern Generator for Locomotion: Anatomical, Physiological, and Pathophysiological Considerations,” Front. Neurol, vol. 8, no. 3, p. 183, Feb 2013.
14. E. Amrollah and P. Henaff, “On the Role of Sensory Feedbacks in Rowat–Selverston CPG to Improve Robot Legged Locomotion,” Front Neurorobotics, vol. 4, 2010.
15. V. Muralidharan, P. P. Balasubramani, V. S. Chakravarthy, S. J. G. Lewis, and A. A. Moustafa, “A computational model of altered gait patterns in parkinson’s disease patients negotiating narrow doorways,” 2014.
16. Gupta, A., Balasubramani, P.P., & Chakravarthy, V.S., “Computational model of precision grip in Parkinson’s disease: a utility based approach,” Frontiers in Computational Neuroscience, vol. 7, 2013.
17. Tokushige SI, Matsumoto H, Matsuda SI, Inomata-Terada S, Kotsuki N, Hamada M, Tsuji S, Ugawa Y, Terao Y., “Tokushige SI, Matsumoto H, Matsuda SI, Inomata-Terada S, Kotsuki N, Hamada M, Tsuji S, Ugawa Y, Terao Y., “Early detection of cognitive decline in Alzheimer’s disease using eye tracking,” Front Aging Neurosci, 21 Mar 2023.,” Front Aging Neurosci, vol. 15, 21 Mar 2023.
18. Laurens B, Planche V, Cubizolle S, Declerck L, Dupouy S, Formaglio M, Koric L, Seassau M, Tilikete C, Vighetto A, Ceccaldi M, Tison F. A., “Spatial Decision Eye-Tracking Task in Patients with Prodromal and Mild Alzheimer’s Disease,” J Alzheimers Dis, vol. 71(2), pp. 613-621, Aug 2019.
19. Matsuda S, Matsumoto H, Furubayashi T, Fukuda H, Emoto M, Hanajima R, Tsuji S, Ugawa Y, Terao Y., “Top-down but not bottom-up visual scanning is affected in hereditary pure cerebellar ataxia,” PLoS One, vol. 9, no. 12, 29 Dec 2014..
20. V.Hrytsyk, M. Medykovskyy, M. Nazarkevych, “Estimation of Symmetry in the Recognition System with Adaptive Application of Filters,” Symmetry, vol. 14, no. 5, 2022.
21. V.Hrytsyk, M. Nazarkevych, “Real-Time Sensing, Reasoning and Adaptation for Computer Vision Systems .,” in Lecture Notes on Data Engineering and Communications Technologies, vol. 77, Springer, 2022, pp. 573-585.
22. Omar Alniemi, Hanaa F. Mahmood, “Convolutional neural network for the detection of Parkinson disease based on hand-draw spiral images,” Indonesian Journal of Electrical Engineering and Computer Science, vol. 30, no. 1, pp. 267-275, April 2023.
23. K. Palmer, A. K. Berger, R. Monastero, B. Winblad, L. Bäckman and L. Fratiglioni, “Predictors of progression from mild cognitive impairment to Alzheimer disease,” Neurology, vol. 68(19), pp. 1596-1602, 2007.
24. A.- P. Legrand, I. Rivals, A. Richard, E. Apartis, E. Roze, M. Vidailhet, S. Meunier, E. Hainque., “New insight in spiral drawing analysis methods – Application to action tremor quantification,” J Clinical Neurophysiology, vol. 128, no. 10, p. 1823–1834, 2017.
25. Ibáñez J, Serrano JI, del Castillo MD, Monge-Pereira E, Molina-Rueda F, Alguacil-Diego I, Pons JL., “Detection of the onset of upper-limb movements based on the combined analysis of changes in the sensorimotor rhythms and slow cortical potentials,” Neural, vol. 11, no. 5, August 2014.
26. Eduard Bakstein, Jonathan Burgess, Kevin Warwick, Virginie Ruiz, Tipu Aziz, John Stein, “Parkinsonian tremor identification with multiple local field potential feature classification,” J Neurosci Methods, vol. 209, no. 2, pp. 320-330, 15 August 2012.
27. A Shachykov, P Henaff, A Popov, A Shulyak, “Neuro-musculoskeletal simulator of human rhythmic movements’2017,” in IEEE First Ukraine Conf.in Electrical and Computer Engineering (UKRCON), 2017.
28. Erum Mansoor and Jeroen Van der Mynsbrugge and Martin Head-Gordon and Alexis T. Bell, “Impact of long-range electrostatic and dispersive interactions on theoretical predictions of adsorption and catalysis in zeolites,” Catalysis Today, vol. 312, pp. 51-65, 2018.

 doi:10.20944/preprints202604.0432.v1

29. P. Zham, S. P. Arjunan, S. Raghav and D. K. Kumar, "Efficacy of Guided Spiral Drawing in the Classification of Parkinson's Disease," IEEE Journal of Biomedical and Health Informatics, vol. 2, no. 5, pp. 1648-1652, 2018.
30. Poonam Zham, Dinesh K. Kumar, Peter Dabnichki, Sridhar Poosapadi Arjunan, Sanjay Raghav, "Distinguishing Different Stages of Parkinson's Disease Using Composite Index of Speed and Pen-Pressure of Sketching a Spiral," Front. Neurol, 2017.
31. Spiral drawing test detects signs of Parkinson's, bbc, 2017.
32. Alty J, Cosgrove J, Thorpe D, et al, "How to use pen and paper tasks to aid tremor diagnosis in the clinic," Practical Neurology, vol. 17, no. 6, pp. 456-463, 2017.
33. Megha Kamble, Prashant Shrivastava, Megha Jain, "Digitized spiral drawing classification for Parkinson's disease diagnosis," Measurement: Sensors, vol. 16, 2021.
34. Z. W. E. L. P. S. J. M. M. &. P. Z. Zhu, "Finger drawing on smartphone screens enables early Parkinson's disease detection through hybrid 1D-CNN and BiGRU deep learning architecture," PloS one, vol. 20(7), no. e0327733, 2025.
35. H. C. S. J. Z. &. W. Y. Shi, "Wearable-Sensor-Based Analysis of Aerial Archimedean Spirals for Early Detection of Parkinson's Disease," Sensors (Basel, Switzerland), vol. 25(24), no. 7579, 2025.
36. V.Hrytsyk, A. Grondzal and A. Bilenkyj, "Augmented reality for people with disabilities," in Xth International Scientific and Technical Conference "Computer Sciences and Information Technologies" (CSIT), Lviv, 2015.
37. L. J. V. N. W. R. Fagin Ronalda, On the Number of Quantifiers as a Complexity Measure. Leibniz International Proceedings in Informatics, LIPIcsVolume 2411 August 2022 Article number 4947th International Symposium on Mathematical Foundations of Computer Science, MFCS 2022.
38. Cai, Jin-Yi, Fu, Zhiguo HOLOGRAPHIC ALGORITHM WITH MATCHGATES IS UNIVERSAL FOR PLANAR #CSP OVER BOOLEAN DOMAIN. SIAM Journal on Computing, Volume 51, Issue 2, 2022, DOI 10.1137/17M1145288.
39. Ariel Kellison, Mark Bickford Robert Constable. Implementing Euclid's straightedge and compass constructions in type theory. Annals of Mathematics and Artificial IntelligenceVolume 85, Issue 2-4, Pages 175 – 192, 15 April 2019.
40. Cai, Jin-Yi; Maran, Ashwin. Counting Cycles on Planar Graphs in Subexponential Time, Volume 13595 LNCS, Pages 268 – 279. 2022 28th International Conference on Computing and Combinatorics.
41. Feldman Michal, Shabtai, Galia. Simultaneous 2nd price item auctions with no-underbidding // Games and Economic BehaviorOpen AccessVolume 140, Pages 316 - 340, July 2023. DOI 10.1016/j.geb.2023.03.009.
42. Luo Wenjing, Greene Abigail S, Constable R. Todd. Within node connectivity changes, not simply edge changes, influence graph theory measures in functional connectivity studies of the brain. NeuroImage. Volume 24015 October 2021.