**Detecting the Severity of Alzheimer's Disease: How Virtual Reality Meets Machine Learning**

Christian Nathaniel Tjandra1, a), Siti Azreena Mubin1, b), Khalifa Djemal 2, c), Amir Ali Feiz3, d)

*1Asia Pacific University of Technology and Innovation, School of Computing, Kuala Lumpur, Malaysia*

2Paris-Saclay University, Univ Evry, IBISC, 91020, Evry, France

*3Paris-Saclay University, Univ Evry, LMEE, 91020, Evry, France*

*a) Corresponding author:* [*christian.tjandra@apu.edu.my*](mailto:christian.tjandra@apu.edu.my) *b)* [*siti.azreena@apu.edu.my*](mailto:siti.azreena@apu.edu.my)

*c)* [*Khalifa.Djemal@univ-evry.fr*](mailto:Khalifa.Djemal@univ-evry.fr)

*d)* [*amirali.feiz@univ-evry.fr*](mailto:amirali.feiz@univ-evry.fr)

**Abstract.** Alzheimer's Disease (AD) is a progressive neurodegenerative disorder that significantly reduces cognitive function, memory, and quality of life. Early and accurate detection of AD severity is crucial for effective prevention and treatment planning. While widely used, traditional cognitive assessments and medical testing present many challenges and limitations. This study explores the integration of Virtual Reality (VR) and Machine Learning (ML) as an innovative approach to detecting AD severity. VR technology provides immersive and interactive environments that can replicate cognitive assessments, while ML models and algorithms analyze data results from VR tests to improve decision-making in severity classification. The proposed system aims to solve limitations within the current diagnostic methods by simulating real-life cognitive tasks within a controlled VR environment. The research methodology includes a literature review, VR-based cognitive test development, data collection, ML model training, and validation. Preliminary findings suggest that VR-ML integration is viable for improving detection and precision and offers a non-invasive, cost-effective alternative for detecting AD severity. Future work will focus on refining ML algorithms, expanding clinical tests, and enhancing VR simulations and cognitive tests to improve diagnostic accuracy.

# INTRODUCTION

Alzheimer's Disease (AD) is a chronic neurodegenerative disease that progressively affects an individual's cognitive ability, which could lead to multiple memory losses, behavioural changes, and impaired functional skills [1,2] . AD will gradually damage the nervous system in the brain of the individual, causing permanent damage to the brain [2,3]. Globally, AD is the primary cause of cognitive impairment and dementia, and age is the leading risk factor that affects individuals aged over 65 [4]. However, people as early as age 45 could suffer from AD, which is specified as early-onset Alzheimer's disease (EOAD), which is less common than late-onset Alzheimer's (above the age of 65) [5].

AD requires a preventive solution to detect the severity of the AD disease as early as possible. By detecting its severity, appropriate medication and treatments can be administered to prevent the individual's condition from worsening [6,7]. While age remains a primary risk factor, other external elements may also contribute to the progression of the disease. Recent studies suggest that air pollution could play a role in exacerbating both the onset and severity of Alzheimer's disease, highlighting the need to consider environmental factors in addition to biological predispositions. [8,9].

Without any medical tests, detecting AD would depend on cognitive tests, by clinical paper tests, which could produce subjective and biased results due to different doctors' examinations [10]. On the other hand, detecting AD severity by utilising medical tests such as laboratory tests (blood test, CSF analysis), CT scans, and Lumbar Punctures would be costly, have limited availability, and possibly cause discomfort or physical harm to the patient during the tests [6,11]. The current methods' limitations and drawbacks to detecting AD severity have driven this research to propose modern solutions from industry 4.0 technologies, such as Virtual Reality (VR) and Machine Learning (ML) [12].

Hence, this research aims to develop a system with VR and ML technology to detect the severity of Alzheimer's disease in patients. VR's capability to create an immersive virtual environment and interaction will simulate a real-life scenario in a controlled environment that matches traditional cognitive assessments. With the data collected from the VR simulation, ML will analyse the data and incorporate clinical and neuropsychological data to improve the data results and accuracy. With the capability of ML, which allows datasets to identify patterns of cognitive and motor impairments, a predictive model will be developed to classify the severity of AD and provide information for treatment plans. The research objectives (RO) that were decided upon for this project consist of **1.)** To identify the advantages and feasibility of multimodal approaches of VR cognitive testing and ML for severity classification in AD, **2.)** To develop a VR-based cognitive testing simulation for patient data collection, integrated with ML models to process data for AD severity classification, **3.)** To evaluate the multimodal approach of the VR and ML system through the accuracy and sensitivity of severity classification of Alzheimer's Disease.

# STATE OF THE ART

A review of related works will be done to understand how Machine Learning and Virtual Reality have impacted the diagnosis of Alzheimer's Disease in patients. This section of the research will review any related studies or experiments that have been done to contribute to detecting AD, mainly utilizing VR or ML.

Research and experiments done by LoTemplio et al. [13] to understand the nature of VR and the world's impact on executive functioning (EF) and stress recovery in older adults. The Researchers have developed a VR environment replicating real-life locations by using Unreal Game Engine and executing the VR simulation through Oculus Quest 3 to experiment. The test is done on 22 older adults with healthy cognitive conditions. According to the test results, VR improves the patient's focus and mental performance and reduces stress in older adults when testing their cognitive abilities. Surprisingly, some results show that VR simulations perform better than real-life ones. However, this research is not purposely aimed at AD patients. Still, the experiment's results show that VR environments can improve cognitive performance for every patient, improving patient performance in cognitive assessment.

Another similar research method is being implemented with the development of VR simulation-based tasks to diagnose potential AD patients. The VR simulation replicates the shopping experience at the supermarket, where the patients are given tasks to shop for items through gamification. The performances are measured by the number of items correctly collected, the number of items matching the shopping lists, and the time spent staring at distractions. However, this research hasn't done any clinical testing to test how effective the prototype is in diagnosing AD patients. Still, this paper provides insights into how some cognitive measures and assessments can be reflected in real-life tasks [14].

With the increasing usage of Machine Learning in multiple industries, some studies have been done to utilize ML to improve AD detection. A study by Alatrany et al. [15], proves which is the best-performing ML algorithm for detecting late-onset AD. This experiment is being done on a dataset requested from the Alzheimer's Disease Neuroimaging Initiative, with the data being trained and tested on different models. From all the results, the ML model Linear Discriminant Analysis (LDA) is tested to be the best viable option by providing better accuracy and sensitivity results for AD diagnosis.

However, another study uses images instead of datasets to be processed and analyzed by ML and deep learning (DL). It is proven that using advanced imaging techniques and utilizing ML-DL significantly increases the accuracy of detecting AD. This study has demonstrated that analyzing image data, such as magnetic resonance imaging (MRI) scans, is more effective when using a Support Vector Machine (SVM). This study has given insight into the idea that the ML model can also process image-based data, which presents the potential to generate image-based data results from cognitive tests [16].

A study by Arya et al. [17] provides a similar study proving that ensemble learning (XGBoost), a machine learning technique, is the best option compared with other models for analyzing AD. This research utilizes datasets to be processed by the ML models to compare which models present the best results. The comparison includes the SVM model and not LDA; however, as mentioned in the previous section, SVM is considered the best for advanced image processing, not datasets. These studies have revealed a research gap, where more research or experiments are needed to prove whether LDA or XGBoost are the best models to process datasets for AD patients.

With the potential of both VR and ML, some studies have researched both methods to produce a better system to diagnose AD or any cognitive impairment in patients. Study done by Patient et al. [18], which independently studies ML, VR, and electrodermal activity for cognitive impairment diagnosis and treatment. This research has proven that ML techniques can improve accuracy by combining different neuropsychological assessments instead of individual assessments. VR and electrodermal activity, however, can provide noninvasive, cost-effective solutions to the diagnosis of cognitive impairments. Combining all these methods may achieve a more comprehensive solution for future research.

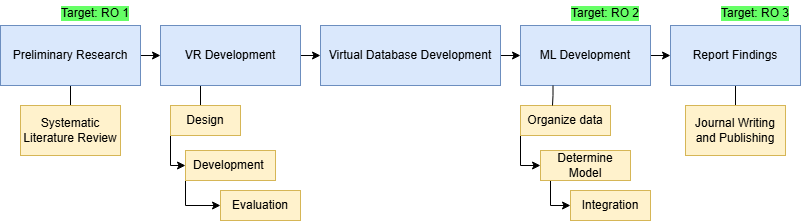
The system was developed and researched by Kim et al. [19] by combining multimodal virtual reality (VR), evoked potential (EP), electroencephalogram (EEG), and magnetic resonance imaging (MRI). Multimodal VR-EP-EEG-MRI biomarkers will be employed to diagnose the patient and to detect mild cognitive impairment (MCI). The results of the tests were done on 21 healthy and 25 impaired patients to compare the differences between the multimodal biomarkers. The experiment within this study has shown 94.12% accuracy in detecting MCI patients from healthy patients after the data gathered was analyzed with ML.

A second study utilized a similar approach by using EEG, MRI, VR, and ML without EP. The study is being done with a total of 54 participants, 22 with healthy conditions and 32 suffering from MCI. The results show 86.66% accuracy, which is lower than the other study. However, remember that one method is not utilized, which is the EP. This study also conducted experiments on a larger number of test subjects [20]. Both similar studies highlight the accuracy of a multimodal approach toward MCI patients. The first study included EP biomarkers, which improved the accuracy of diagnosis. However, the second study might prove more robust due to a larger sample of participants.

The literature review provided insights into how both VR and ML have been utilized for AD diagnosis. The VR system has potential to prevent stress build up which leads to better patient’s cognitive performance. This benefit can be achieved through the development of immersive and natural experience of VR simulation for cognitive assessment. The studies contributed by showing the effectiveness of recreating or designing an environment that is natural to a human sense with tasks that felt more natural to daily life activities which can test cognitive ability more effectively. The availability of ML technology to analyze and process multiple data variables which are shown in the studies with significant results of diagnostic precision of detecting AD using different data types. ML strong ability to identify patterns which can be utilized for predictions of the AD diagnosis. With shown studies using multimodal approaches utilizing ML to analyze the data collected and resulting in high percentage of accuracy. However, there are gaps where these studies only focus on diagnostics rather than severity classification. The VR system will also be developed more rigorously to test different cognitive abilities for severity detection.

# Research methodology

The methodology chapter of this research provides a clear blueprint of how the research objectives and questions will be achieved through the methodology proposed. As stated in the introduction, this research consists of 3 objectives and questions. The selected methodology approach uses mixed methods, combining **qualitative and quantitative** methodologies. The methodology to achieve the success of this research will be divided into 5 phases which are presented through Figure 1.



**FIGURE 1** Research Methodology Flow.

Preliminary Research (Phase I) is set to establish the foundation of the research itself. Ensuring the research was built around existing research (themes and research gaps), which justifies the significance of the proposed study, ensuring its research rigor and credibility. Phase I aims to achieve the first research objective (RO) to gain insight into the advantages of developing a VR-ML solution for AD severity detection and its feasibility as a technological solution for medical diagnosis.

VR Development (Phase II) will focus on designing and developing the VR-based cognitive test simulation. The design phase will decide which traditional cognitive test will be adapted into the simulation and establish participatory design with medical experts to produce qualitative insight. The experts will contribute to the design of the VR simulation to ensure it is medically accepted and able to function similarly to the cognitive tests by designing storyboards and environment design. In the development phase, the VR simulation will be designed and built using the Unity platform, which requires environment design and code scripting. The final step is the evaluation phase, where pilot testing will be performed on the developed VR simulation on real patients. This is to ensure the patients can operate the VR simulation and to evaluate the results provided by the VR cognitive simulation. It is considered complete after the VR simulation is fully developed and medically validated by experts.

Virtual Database Development (Phase III) is necessary to establish a data storage location, which is mandatory before developing the ML model for data analysis. It would accelerate data prepping and organizing, ensure data quality, and integrate with the ML system to process data.

ML Development (Phase IV) is the step in developing the ML to be integrated with the VR simulation for data result processing. Organizing data is the first step, which includes schema design and data labeling to ensure that the training of the ML model will go smoothly and produce better outcomes. Determining the model will be the next step in selecting the best ML models that achieve the best results for the integration by model training and testing. Integration will be the next step, where the chosen ML model will be integrated with the real patient's data to achieve the 2nd RO, which develops a system of VR simulation integrated with ML for data processing.

Report Finding (Phase V) is the final phase, in which all the research progress and results are documented through research papers and journals targeted for publication. This will ensure that the research output receives academic recognition and ensures its research contribution to society. This phase will also finalize all the research objectives by evaluating the entire research results.

# DISCUSSION

The proposed solution of the VR-ML approach for classifying AD severity mainly focuses on the existing cognitive testing evaluation that clinics/ medical centers are conducting to address the mental ability of patients diagnosed with AD. Some of the standardized tests globally used are the Mini-Mental State Examination (MMSE) [21] and the Montreal Cognitive Assessment (MoCA) [22]. Both are paper tests done physically by the patients, with the examination from the doctor. The test results determine the diagnosis of cognitive impairment. For example, the MoCA measures the patients with a result score above 26 are considered non-impaired, and those below are considered impaired. The MoCA has established four severity levels, which are Normal Cognitive Performance (26 and above), Mild Impairment (18-25), Moderate Impairment (10-17), and Severe Impairment (0-9).

Following the certified cognitive testing standard, this research will have to plan how to adapt the test questions and their parameters (memory, visuospatial, etc.) and design the tests within the virtual simulations. This requires the assistance of an expert in this part of the VR development to ensure the VR-based cognitive assessment meets or surpasses the existing clinical standards of traditional cognitive evaluations.

ML and its ability to process data, detect patterns, make predictions, and strengthen decision-making make it the perfect integration for VR simulation to determine the severity from data collected. The strength of ML is in calculations and processing large amounts of data, which allows the VR simulation to be improved by collecting other complex data as well by expanding the data collected, such as task completion time, eye tracking, and other potential data collection for potential for improving the digital biomarkers, to create a more robust severity classification.

Future enhancement, VR could be improved with the other spectrum of XR, Mixed Reality (MR), which merges with the physical and digital worlds to create an immersive, interactable environment where virtual and real objects co-exist and interact in real time. External devices, such as haptic feedback, body trackers, and eye trackers, can be integrated with MR/VR technology, strengthening cognitive test parameters. The more complex numerical data will justify the need for ML to process all the data recorded by the XR system, where the more complicated and varied data will strengthen ML performance. Its prediction ability improved detection AD severity and predict the patient's AD severity within the early stage or during healthy cognitive state.

# CONCLUSION

In conclusion, this study provides a foundation for the conceptual solution for detecting AD severity using the VR-ML approach. It has been proven that VR and ML have a strong potential to be implemented as a modern technological solution to assist clinical and medical institutions in addressing AD patients by determining their severity. Detecting a patient's severity could lead to a more precise prevention protocol and therapy, which can eventually save patients' lives. For future research, this study will continue by conducting more extensive research to understand the field of research, developing VR simulation tests, constructing an ML model, and executing testing on actual patients.

# Acknowledgments

The authors would like to thank Asia Pacific University of Technology & Innovations (APU) for providing a research grant (RDIG/02/2024) and MyTIGER 2024 (Embassy of France in Malaysia) for this study. The authors also acknowledge the anonymous reviewers for their valuable feedback and comments.

# References

1. A.P. Porsteinsson, R.S. Isaacson, S. Knox, M.N. Sabbagh, and I. Rubino, “Diagnosis of Early Alzheimer’s Disease: Clinical Practice in 2021,” The Journal of Prevention of Alzheimer’s Disease **8**(3), 371–386 (2021).
2. J.W. Błaszczyk, “Energy Metabolism Decline in the Aging Brain—Pathogenesis of Neurodegenerative Disorders,” Metabolites 10(11), 450 (2020).
3. X.-X. Zhang, Y. Tian, Z.-T. Wang, Y.-H. Ma, L. Tan, and J.-T. Yu, “The Epidemiology of Alzheimer’s Disease Modifiable Risk Factors and Prevention,” The Journal of Prevention of Alzheimer’s Disease **8**(3), 313–321 (2021).
4. A.A. Tahami Monfared, M.J. Byrnes, L.A. White, and Q. Zhang, “Alzheimer’s Disease: Epidemiology and Clinical Progression,” *Neurol Ther* **11**(2), 553–569 (2022).
5. T. Ayodele, E. Rogaeva, J.T. Kurup, G. Beecham, and C. Reitz, “Early-Onset Alzheimer’s Disease: What Is Missing in Research?,” Curr Neurol Neurosci Rep **21**(2), 4 (2021).
6. H. Hampel, L.M. Shaw, P. Aisen, C. Chen, A. Lleó, T. Iwatsubo, A. Iwata, M. Yamada, T. Ikeuchi, J. Jia, H. Wang, C.E. Teunissen, E. Peskind, K. Blennow, J. Cummings, and A. Vergallo, “State‐of‐the‐art of lumbar puncture and its place in the journey of patients with Alzheimer’s disease,” Alzheimer’s & Dementia **18**(1), 159–177 (2022).
7. D.P. Veitch, M.W. Weiner, P.S. Aisen, L.A. Beckett, C. DeCarli, R.C. Green, D. Harvey, C.R. Jack, W. Jagust, S.M. Landau, J.C. Morris, O. Okonkwo, R.J. Perrin, R.C. Petersen, M. Rivera‐Mindt, A.J. Saykin, L.M. Shaw, A.W. Toga, D. Tosun, J.Q. Trojanowski, and Alzheimer’s Disease Neuroimaging Initiative, “Using the Alzheimer’s Disease Neuroimaging Initiative to improve early detection, diagnosis, and treatment of Alzheimer’s disease,” Alzheimer’s & Dementia **18**(4), 824–857 (2022).
8. M.J. Zare Sakhvidi, J. Yang, E. Lequy, J. Chen, K. De Hoogh, N. Letellier, M. Mortamais, A. Ozguler, D. Vienneau, M. Zins, M. Goldberg, C. Berr, and B. Jacquemin, “Outdoor air pollution exposure and cognitive performance: findings from the enrolment phase of the CONSTANCES cohort,” The Lancet Planetary Health **6**(3), e219–e229 (2022).
9. A. Singh S, M.N. Ansari, G. M. Elossaily, C. Vellapandian, and B. Prajapati, “Investigating the Potential Impact of Air Pollution on Alzheimer’s Disease and the Utility of Multidimensional Imaging for Early Detection,” ACS Omega **9**(8), 8615–8631 (2024).
10. M. Florian, S. Margaux, and D. Khalifa, “Cognitive tasks modelization and description in VR environment for Alzheimer’s disease state identification,” in *2020 Tenth International Conference on Image Processing Theory, Tools and Applications (IPTA)*, (IEEE, Paris, France, 2020), pp. 1–7.
11. F. Mirakhori, M. Moafi, M. Milanifard, A.A. Rizi, and H. Tahernia, “Diagnosis and treatment methods in Alzheimer’s patients based on modern techniques: The Orginal article,” Journal of Pharmaceutical Negative Results **13**(S01), (2022).
12. J. Li, and P. Carayon, “Health Care 4.0: A vision for smart and connected health care*,”* IISE Transactions on Healthcare Systems Engineering, 1–10 (2021).
13. S. LoTemplio, S. Johnson, M. Rice, R. Masters, S.-A. Collins, J. Hoefecker, J. Rivera, D. Schreiber, V. Interrante, F. Ortega, and D. Davalos, “Aging Naturally: Virtual reality nature vs real-world nature’s effects on executive functioning and stress recovery in older adults,” in *2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, (IEEE, Orlando, FL, USA, 2024), pp. 1061–1062.
14. B. Xiong, N. Li, Y. Liao, and P. Zhou, “Gamified Alzheimer’s Disease Diagnosis via Virtual Reality,” in *2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, (IEEE, Orlando, FL, USA, 2024), pp. 1182–1183.
15. A.S. Alatrany, A. Hussain, S.S.J. Alatrany, J. Mustafina, and D. Al-Jumeily, “Comparison of Machine Learning Algorithms for classification of Late Onset Alzheimer’s disease,” in *2023 15th International Conference on Developments in eSystems Engineering (DeSE)*, (IEEE, Baghdad & Anbar, Iraq, 2023), pp. 60–64.
16. N.K. Kumar, V.D. Ambeth Kumar, D. Quamar, B.S.K. Reddy, R. Yogendra, and N. Poojitha, “Enhanced Alzheimer’s Disease Prediction through Advanced Imaging: A Study of Machine Learning and Deep Learning Approaches,” in *2024 5th International Conference on Smart Electronics and Communication (ICOSEC)*, (IEEE, Trichy, India, 2024), pp. 1177–1182.
17. A.D. Arya, S. Singh Verma, P. Chakarabarti, and R. Bishnoi, “Prediction of Alzheimer’s disease - A Machine Learning Perspective with Ensemble Learning,” in *2023 6th International Conference on Contemporary Computing and Informatics (IC3I)*, (IEEE, Gautam Buddha Nagar, India, 2023), pp. 2308–2313.
18. R. Patient, F. Ghali, H. Kolivand, W. Hurst, and N. John, “Application of Virtual Reality and Electrodermal Activity for the Detection of Cognitive Impairments,” in *2021 14th International Conference on Developments in eSystems Engineering (DeSE)*, (IEEE, Sharjah, United Arab Emirates, 2021), pp. 156–161.
19. S.Y. Kim, B. Park, D. Kim, H. Choi, J. Park, H. Ryu, and K. Seo, “Early Screening of Mild Cognitive Impairment using Multimodal VR-EP-EEG-MRI (VEEM) Biomarkers via Machine Learning,” in *2024 International Conference on Electronics, Information, and Communication (ICEIC)*, (IEEE, Taipei, Taiwan, 2024), pp. 1–4.
20. M. Kallel, B. Park, K. Seo, and S.-E. Kim, “Multimodal Machine Learning Model For MCI Detection Using EEG, MRI and VR Data,” in *2024 International Technical Conference on Circuits/Systems, Computers, and Communications (ITC-CSCC)*, (IEEE, Okinawa, Japan, 2024), pp. 1–6.
21. M.F. Folstein, S.E. Folstein, and P.R. McHugh, “‘Mini-mental state,’” Journal of Psychiatric Research **12**(3), 189–198 (1975).
22. Z.S. Nasreddine, N.A. Phillips, V. Bédirian, S. Charbonneau, V. Whitehead, I. Collin, J.L. Cummings, and H. Chertkow, “The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool for Mild Cognitive Impairment,” J American Geriatrics Society **53**(4), 695–699 (2005).