**Table 1. Dataset Characteristics and Experimental Details**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Dataset** | **Full Name** | **Sample Size** | **Classes** | **Repetitions** | **Averaging Method** | **P-Value Calculation Method** |
| OASIS | Open Access Series of Imaging Studies | 416 | CN, MCI, AD | 10 | Mean ± Standard Deviation (SD) | Two-tailed t-test (independent samples) |
| ADNI | Alzheimer’s Disease Neuroimaging Initiative | 800+ | CN, MCI, AD | 10 | Mean ± SD | ANOVA followed by post hoc Tukey's HSD test |
| PDAD | Parkinson’s and Alzheimer’s Dataset | 360 | CN, MCI, AD | 10 | Mean ± SD | Welch's t-test for unequal variances |
| Alzheimer | Alzheimer’s Dataset | 2149 | VMD,  AD, MD, MoD | 10 | Mean ± SD | Two-tailed t-test (independent samples) |

**Table 2. Key Acronyms used in Alzheimer’s Disease Classification and Analysis**

|  |  |
| --- | --- |
| **Acronym** | **Meaning** |
| AD | Alzheimer’s Disease |
| ADNI | Alzheimer’s Disease Neuroimaging Initiative |
| CN | Cognitively Normal |
| CNN | Convolutional Neural Network |
| CT | Computed Tomography |
| CT | Cortical Thickness |
| DL | Deep Learning |
| fMRI | Functional Magnetic Resonance Imaging |
| GMD | Gray Matter Density |
| Grad-CAM | Gradient-weighted Class Activation Mapping |
| HSD | Honestly Significant Difference (Tukey’s test) |
| HV | Hippocampal Volume |
| LRP | Layer-wise Relevance Propagation |
| LSTM | Long Short-Term Memory |
| MCI | Mild Cognitive Impairment |
| MD | Mild Dementia |
| MRI | Magnetic Resonance Imaging |
| MOA | Mayfly Optimization Algorithm |
| MOD | Moderate Dementia |
| ND | Non Dementia |
| OASIS | Open Access Series of Imaging Studies |
| PDAD | Parkinson’s and Alzheimer’s Dataset |
| PET | Positron Emission Tomography |
| RNN | Recurrent Neural Network |
| SD | Standard Deviation |
| SHAP | SHapley Additive exPlanations |
| VMD | Very Mild Dementia |
| XAI | Explainable Artificial Intelligence |

**Table 3. Fuzzy Rules and their Corresponding MRI Classifications**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Rule No.** | **Hippocampal Volume (HV)** | **Cortical Thickness (CT)** | **Gray Matter Density (GMD)** | **Classification Result** |
| 1 | HV > 3.0 cm³ (High) | CT > 2.7 mm (High) | GMD > 0.6 (High) | Cognitively Normal (CN) |
| 2 | 2.0 cm³ ≤ HV ≤ 3.0 cm³ (Moderate) | 2.2 mm ≤ CT ≤ 2.7 mm (Moderate) | 0.4 ≤ GMD ≤ 0.6 (Moderate) | Mild Cognitive Impairment (MCI) |
| 3 | HV < 2.0 cm³ (Low) | CT < 2.2 mm (Low) | GMD < 0.4 (Low) | AD |
| 4 | HV > 3.0 cm³ (High) | CT > 2.7 mm (High) | GMD ≤ 0.6 (Moderate/Low) | MCI |
| 5 | HV ≤ 3.0 cm³ (Moderate/Low) | CT > 2.7 mm (High) | GMD > 0.6 (High) | CN |
| 6 | HV ≤ 3.0 cm³ (Moderate/Low) | CT ≤ 2.7 mm (Moderate/Low) | GMD > 0.6 (High) | MCI |
| 7 | HV < 2.0 cm³ (Low) | CT > 2.7 mm (High) | GMD > 0.6 (High) | MCI |
| 8 | HV < 2.0 cm³ (Low) | CT < 2.2 mm (Low) | GMD > 0.6 (High) | MCI |
| 9 | HV > 3.0 cm³ (High) | CT < 2.2 mm (Low) | GMD < 0.4 (Low) | MCI |

**Table 4. Statistical Analysis of Model Performance**

|  |  |  |
| --- | --- | --- |
| **Dataset** | **Model** | **p-value (vs. Proposed Model)** |
| **PDAD** | Proposed Model | - |
| CNN-Based Model | p < 0.01 |
| SVM with PCA | p < 0.01 |
| **Alzheimer’s** | Proposed Model | - |
| ResNet-50 | p < 0.01 |
| RF | p < 0.01 |
| **ADNI** | Proposed Model | - |
| VGG-16 | p < 0.01 |
| k-NN | p < 0.01 |
| **OASIS** | Proposed Model | - |
| DenseNet-121 | p < 0.01 |
| XGBoost | p < 0.01 |

**Table 5. Ablation Study Results**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Model Variant** | **Accuracy (%)** | **F1 Score (%)** | **Specificity (%)** | **Sensitivity (%)** | **ROC-AUC (%)** | **MCC** | **Loss** |
| Proposed Model (Full) (Fuzzy Logic + Mayfly Algorithm + XAI) | 99.2 | 98.9 | 98.7 | 98.5 | 99.4 | 0.979 | 0.07 |
| Without Fuzzy Logic | 96.5 | 95.8 | 95.2 | 94.8 | 96.9 | 0.95 | 0.03 |
| Without Mayfly Algorithm | 95.2 | 94.3 | 93.8 | 93.5 | 95.5 | 0.94 | 0.04 |
| Without XAI (Standard DL) | 94.0 | 93.0 | 92.5 | 92.0 | 94.2 | 0.93 | 0.05 |

**Table 6. Performance Comparison of Different Models across Datasets**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dataset** | **Model** | **Accuracy**  **%** | **F1 Score**  **%** | **Specificity**  **%** | **Sensitivity**  **%** | **ROC**  **-**  **AUC**  **%** | **Precision**  **%** | **Recall**  **%** | **MCC** | **Loss** |
| **PDAD** | Proposed Model | 99.0 | 98.5 | 98.0 | 97.8 | 99.2 | 98.6 | 97.8 | 0.975 | 0.01 |
| CNN-Based Model [28] | 92.5 | 91.2 | 91.0 | 90.8 | 93.0 | 91.5 | 90.8 | 0.88 | 0.10 |
| SVM with PCA[29] | 89.0 | 88.3 | 88.0 | 87.5 | 89.5 | 88.5 | 87.5 | 0.85 | 0.15 |
| **Alzheimer’s** | Proposed Model | 99.1 | 98.7 | 98.3 | 97.9 | 99.3 | 98.8 | 97.9 | 0.978 | 0.009 |
| ResNet-50[30] | 91.0 | 90.5 | 89.8 | 89.3 | 91.8 | 90.2 | 89.3 | 0.87 | 0.12 |
| RF [31] | 88.5 | 87.8 | 87.0 | 86.5 | 88.8 | 87.6 | 86.5 | 0.84 | 0.18 |
| **ADNI** | Proposed Model | 98.9 | 98.2 | 97.9 | 97.5 | 99.0 | 98.4 | 97.5 | 0.972 | 0.012 |
| VGG-16 [32] | 93.0 | 91.7 | 91.5 | 91.2 | 93.5 | 91.9 | 91.2 | 0.89 | 0.11 |
| k-NN [33] | 90.2 | 89.5 | 89.0 | 88.3 | 90.8 | 89.6 | 88.3 | 0.86 | 0.14 |
| **OASIS** | Proposed Model | 99.2 | 98.9 | 98.7 | 98.5 | 99.4 | 99.0 | 98.5 | 0.979 | 0.007 |
| DenseNet-121 [34] | 92.8 | 91.9 | 91.6 | 91.3 | 93.1 | 91.8 | 91.3 | 0.88 | 0.09 |
| XGBoost [35] | 89.8 | 88.7 | 88.3 | 87.9 | 90.2 | 88.5 | 87.9 | 0.85 | 0.16 |