Comparison of Legendre and united moments in the classification of Alzheimer conditions using T1 weighted MR images

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Alzheimer's disease (AD) is a progressive neurodegenerative disorder that causes brain regions to undergo structural changes. Shape descriptors are useful in reflecting the morphological alterations of brain structures in AD conditions compared to volume based measures. In this work, moment based shape descriptors are used to classify control, mild cognitive impairment (MCI) and AD subjects. Lattice Boltzmann criterion-based hybrid level set method (LSM) is used to delineate lateral ventricles. Legendre and United moments are extracted from the segmented binary images and are statistically analysed using Statistical Package for Social Science (SPSS). The performance of significant moments in the shape analysis is validated using machine learning algorithm. Results demonstrate that, level set is able to delineate ventricles and found to have high similarity index with ground truth. The area under curve (AUC) values for Legendre moment is found to be 1.0, 0.75 and 1.0 for Control-MCI, MCI-AD and Control-AD subjects. Rather, the AUC for United moment is found to be 0.98, 0.76 and 0.98 for Control-MCI, MCI-AD and Control-AD subjects respectively. Further, machine learning algorithm could classify Control from AD subjects with high accuracy of 99.25% using Legendre moments and hence the study seems to be clinically significant.

Introduction: The Alzheimer's disease (AD) is an irreversible, progressive degenerative disorder that slowly destroys brain cells which leads to disruption of memory and thinking skills [1]. It is a major form of dementia, where more than 35 million people are affected all over the world. This might get doubled in the next five years and it is estimated that by the year 2050 the figure will reach up to 135 million [2]. Deposition of proteins such as neurofibrillary tangles and amyloid plaques are stated to be major characteristic of AD. This results in brain tissue atrophy leading to the enlargement of ventricles and are thus considered as important image biomarker for the progression of the disease [3]. The use of segmentation, feature extraction and machine learning algorithms assist physicians for the better diagnosis of AD.

In this work, a hybrid level set method (LSM) is implemented for the segmentation of brain ventricles. Owing to the change in shape of ventricles during disease progression, it is proposed to use moment-based shape descriptors to describe the alterations in the geometry of segmented ventricles for control, mild cognitive impairment (MCI) and AD subjects. The performance measure of these shape descriptors is analysed using linear support vector machine (SVM) classifier.

Proposed method: The general block diagram of our proposed method is represented as in Fig. 1.

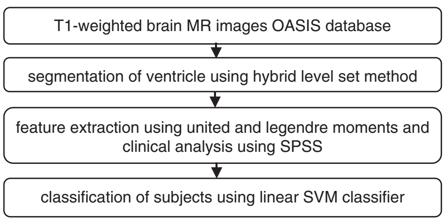

Fig. 1 *Flow diagram of proposed method*

MR imaging dataset: The skull stripped T1-weighted transaxial view MR images are acquired from a public domain Open Access Series of Imaging Studies dataset. With the use of Clinical Dementia Rating score a total of 90 right-handed control, MCI and AD subjects (control = 30, MCI = 30 and AD = 30) are considered for the study. The MR scan used in the current study is bias field corrected and atlas registered. The imaging procedure and preprocessing details are reported in the literature. In this study, 90th MR image slice is used with a resolution of 256 × 256 pixels and considered for the further image analysis [4].

Hybrid level set segmentation: Hybrid level set is an edge-based and region-based active contour method, was implemented to segment structural area namely ventricles from brain MR image. The Lattice Boltzmann equation for the evolution of curves can be represented as

$$\frac{\partial\phi}{\partial t}=\delta(\phi)\left[\begin{array}{l}\left(1-(\alpha m_1+\beta m_2)\right)\left(\dfrac{1}{1+|\nabla I|^n}+\exp\{\mu(|I-I_{\text{mean}}|-\eta)\}\right)\\ +v\,\text{div}\left(\dfrac{\nabla\phi}{|\nabla\phi|}\right)\end{array}\right]$$
$$\alpha+\beta=1,\quad \alpha>0,\quad \beta>0 \tag{1}$$

where η and μ are positive parameters. ϕ is the level set function, m_1 and m_2 are mean values and I is the pixel intensity.

Extraction of united moment measures: The calculation of united moment invariant (UMI) is based on the region and boundary of an image. The definition of discrete, boundary and normal scaling equation is given as follows:

$$\eta_{pq}=\frac{\mu_{pq}}{\mu_{00}^{(p+q+2)/2}}\quad \eta'_{pq}=\rho^{p+q}\eta_{pq}=\frac{\rho^{p+q}\mu_{pq}}{\mu_{00}^{(p+q+2)/2}}$$
$$\eta''_{pq}=\frac{\mu_{pq}}{\mu_{00}^{p+q+1}} \tag{2}$$

where η is normalised central moment derived from the central moment μ The seven formulas for UMI are given in

$$\begin{array}{ll}\theta_1=\sqrt{\phi_2}\div\phi_1 & \theta_4=\phi_5\div(\phi_3\times\phi_4)\\ \theta_2=\phi_6\div(\phi_1\times\phi_4) & \theta_5=(\phi_1\times\phi_6)\div(\phi_2\times\phi_3)\\ \theta_3=\sqrt{\phi_5}\div\phi_4 & \theta_6=\left(\phi_1\times\sqrt{\phi_2}\right)\phi_3\div\phi_6\\ \theta_7=(\phi_1\times\phi_5)\div(\phi_3\times\phi_6) & \end{array} \tag{3}$$

where θ is the UMI.

Extraction of Legendre moment measures: The Legendre moment of order $(m+n)$ with image intensity function $f(x, y)$ is defined as

$$\lambda_{mn}=\frac{(2m+1)(2n+1)}{4}\sum_{j=0}^{m}\sum_{k=0}^{n}a_{mj}a_{nk}M_{jk} \tag{4}$$

where $m, n=0, 1, 2, \ldots, \infty$. λ_{mn} is the Legendre moment.

Results and discussion: The transaxial view brain MR images considered for the study are shown in Figs. 2*a* and *b*. It is observed that the ventricles appear as a single connected region and are found to be enlarged in AD subjects as compared to control subjects.

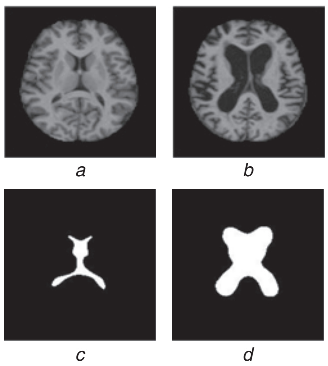

Fig. 2 *Representative set of*
a Control
b AD T1-weighted MR images
c, *d* its corresponding segmented lateral ventricles

The increase in size of ventricles results in disease progression and depicts enlargement of frontal and occipital horns of ventricles in AD subjects. These irregularity in the shape of ventricles varies from individual to individual, posing a major challenge in the extraction and analysis of particular brain region. The segmentation of ventricles is performed using Lattice Boltzmann Hybrid LSM set method as shown in Figs. 2*c* and *d*. It is observed that the area of delineated ventricles are in high correlation with the ground truth area and its performance is evaluated using the dice score measure. The dice score values of 0.81, 0.84 and 0.88 were obtained for control, MCI and AD subjects, respectively, which results in proper segmentation of ventricles.

Legendre moment measures are extracted from the delineated images to quantify the morphological variations of enlarged ventricles. Sixty-four moments have been computed from the segmented image of lateral ventricles for finding the feature vectors. Out of 64 moments 58 moments were found be statistically significant ($P < 0.05$). Table 1 shows the change in percentage value for control, MCI and AD subjects (first moment). The percentage change for control–AD ($P < 0.05$) subject is higher as compared to control–MCI ($P < 0.05$) and MCI–AD ($P < 0.05$) subjects.

Table 1: Percentage changes in Legendre and united moments measure for Control, MCI and AD subjects ($P < 0.05$)

Legendre and united moments measure	Control–MCI (%)	MCI–AD (%)	Control–AD (%)
L1	73.80	26.31	80.70
U1	71.26	23.32	77.68

The variations of significant Legendre moment shape features for control, MCI and AD subjects (90 subject data) are shown in Fig. 3*a*. The boxplot shows the variation in Legendre moment values according to the shape changes of ventricles in the feature space.

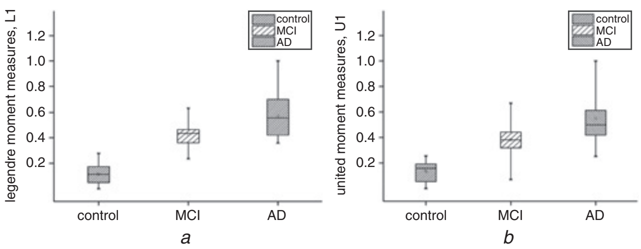

Fig. 3 *Box plot representation of*
a Legendre moment
b United moment measures in lateral ventricles for control, MCI and AD

On the other hand, seven united moment measures are extracted from the segmented image of control, MCI and AD subjects (Fig. 3*b*). Only the first moment in the feature space is found to be significant ($P < 0.05$), while the other moments were insignificant. Also, the change in percentage value from control versus MCI versus AD is higher for Legendre moment as compared to united moment (Table 1). This claims that the Legendre moment performs better than united moment shape descriptor in differentiating the shape of ventricles among control, MCI and AD subjects.

Receiver operating curve (ROC) analysis is performed using Statistical Package for Social Science (SPSS) to select the cut-off values of each class for Legendre and united moment measures (Table 2). The cut-off values of 0.29 and 0.13 are obtained for Legendre moment and united moment, respectively, for the control–AD subject. Although there is a variation in the cutoff values for moments, the area under curve (AUV) result shows better performance of Legendre moment over united moment for the discrimination of subjects. Further, this Legendre moment is given as input to the linear SVM classifier and its performance is analysed for the classification of control, MCI and AD subjects (Table 3).

In this study, multiclass classifier approach is adapted for the characterisation of subjects. SVM performed well in terms of specificity, accuracy and sensitivity. The most significant moment values achieved a high classification accuracy of 99.25%, respectively. Hence the proposed Legendre moment shape descriptor performs better than united moment for the validation of structural changes of ventricles in control, MCI and AD subjects and confirmed clinically by the ROC and classification results.

Table 2: Summary of ROC curve analysis in control, MCI and AD subjects for Legendre moment and united moment features

Features	Class	AUC	Cut-off	Sensitivity	Specificity
Legendre moment (L1)	control versus MCI	1.0	0.25	1.0	1.0
	MCI versus AD	0.75	0.06	0.73	0.33
	control versus AD	1.0	0.29	1.0	1.0
united moment (U1)	control versus MCI	0.98	0.12	0.93	0.94
	MCI versus AD	0.76	0.02	0.70	0.30
	control versus AD	0.98	0.13	0.96	0.97

Table 3: Classifier performance for lateral ventricle using Legendre moment features

Classifier	Class	Accuracy (%)	Sensitivity (%)	Specificity (%)
linear SVM	control	**99.25**	**99.0**	**100**
	MCI	73.33	73.30	78.40
	AD	75.59	75.60	75.55

Conclusion: In this work, moment-based shape descriptors are used to analyse the morphological variations of lateral ventricles for Control, MCI and AD subjects. Moment-based shape features are extracted from the segmented MR image and are statistically analysed using SPSS. The performance metric of statistically significant moments are evaluated using linear SVM classifier.

The proposed Legendre moment shape descriptors are able to discriminate control, MCI and AD subjects and are found to be statistically significant. The ROC analysis and classification of subjects using machine learning algorithms performed better in terms of specificity, accuracy and sensitivity measures for Legendre moments. As the Legendre moments could capture the shape alterations of lateral ventricles and discriminate between control and AD conditions, the study seems to be clinically significant.

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One or more of the Figures in this Letter are available in colour online.

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