Supplementary material

Forty-six popular publicly available datasets in Table I are employed to evaluate the proposed algorithm. The MlFCM and TIEB are compared to the proposed method. Additionally, another two groups of ensemble algorithms have also been adopted as the comparison algorithms. The first group comprises eight classical ensemble algorithms: RUSBoost(RBO), SMOTEBoost(SBO), UnderBagging(UBAG), SMOTEBagging(SBAG), BalancedBagging(BBAG), EasyEnsemble(EYEE), BalanceCascade(BACE), GBDT. Each one of these methods represents a distinct combination of an ensemble method (e.g., bagging, boosting and hybrid method). For comparison with more sophisticated algorithms, the second group uses six state-of-the-art ensemble algorithms: CBIS, SPE, EASE, HOEC, HD-Ensemble, Imbalance-XGBoost.

Decision tree C4.5 was adopted as the base classifier in the experiment. 5-fold cross validation procedure (5-CV) was adopted and the 5-CV procedure was repeated 10 times on every experimental dataset to eliminate the effect of randomness.

TABLE I
CHARACTERISTICS OF 46 IMBALANCED DATASETS

Dataset	f	s	IR	Dataset	f	s	IR	Dataset	f	s	IR
Iris0	4	150	2	Glass016vs2	9	192	10.29	Yeast5	8	1484	32.73
Glass0	9	214	2.06	Ecoli0147vs2356	7	336	10.59	Ozone-onehr	72	2536	33.74
Vertebral	6	310	2.1	climate	18	540	10.7	krvsk3vs11	6	2935	35.23
Haberman	3	306	2.78	Glass2	9	214	11.59	Abalone21vs8	8	581	40.5
Vehicle1	18	846	2.9	german	24	324	12.5	Yeast6	8	1484	41.4
Ecoli1	7	336	3.36	Shuttle-c0-vs-c4	9	1829	13.87	Winequality-white3vs7	11	900	44
New-thyroid1	5	215	5.14	Yeast1vs7	8	459	14.3	Winequality-red8vs67	11	855	46.5
Ecoli2	7	336	5.46	Ecoli4	7	336	15.8	krvsk0vs8	6	1460	53.07
Musk	166	6598	5.48	Page-blocks13vs4	10	472	15.86	Shuttle-2vs5	9	3316	66.67
Glass6	9	214	6.38	Dermatology-6	34	358	16.9	kddbufferoverflowvsback	41	2233	73.43
Yeast3	8	1484	8.10	svmguide3	22	312	18.5	krvsk0vs15	6	2193	80.22
Ecoli3	7	336	8.6	Yeast1458vs7	8	693	22.1	kddrootkitback	41	2225	100.14
Page-blocks0	10	5472	8.79	Yeast4	8	1484	28.10	skinnonskin	3	20034	588.24
Yeast2vs4	8	514	9.08	Winequality-red-4	11	1599	29.17	cod	8	19871	763.27
Yeast05679vs4	8	528	9.35	Yeast1289vs7	8	947	30.57				
Vowel0	10	988	9.98	Abalone3vs11	8	502	32.47				

Evaluation Metrics and Parameter Setting

To assess the performance of the methods, this paper used AUC, F-measure (F-M), G-mean (G-M), Matthews correlation coefficient (Mcc) criteria. Moreover, the nonparametric statistical test methods were adopted to detect statistical differences between all the methods.

For the proposed method, three parameters need to be determined before running the learning procedure: (1) ρ , as defined in Eq.(3),which determines the number of subsets, (2) K ,which means the number of nearest neighbor samples for SNC, (3) L ,which is used to determine the number of layers for DSEN-LG. $\rho=1, K=3, L=3$ in this paper. In SlFCM, the difference in the number of samples before and after clustering is set to 1, the fuzzification coefficient $m=2$ and $\varepsilon=10^{-5}$ .In LGSCM, $\sigma=0.01, \lambda=\lambda_1=1$ and the Gaussian kernel function $k\left(x_i, x_j\right)=\exp(-\left\|x_i-x_j\right\|^2/2\gamma^2)$ was used in the study, where $\gamma=1.2$. All the results are obtained under this setting. For all compared methods except CBIS, HOEC and HD-Ensemble, the number of the base classifiers are set to $\lfloor IR \rfloor$. For SMOTEBoost, SMOTEBagging, the number of neighbors is set to 3. For SPE, the number of bins is assigned 20 as to the original paper. For Imbalance-XGBoost, the focal loss is used and focal_gamma = [1.0,1.5,2.0,2.5,3.0] following the original paper. Other parameters are default.

Verification of DSEN-LG by Ablation Method

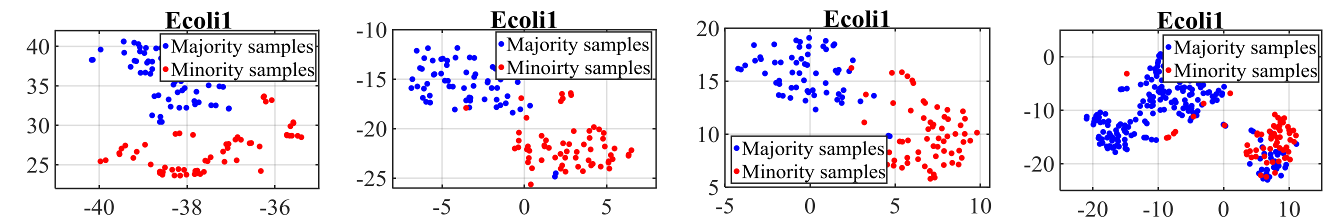
To demonstrate the effectiveness of deep envelope samples obtained by DSEN-LG, ablation method was adopted to compare the proposed algorithm with the MlFCM and TIEB. Table II is the comparison results between the TIEB, MlFCM and proposed DSEN-LGIE. TIEB denotes the traditional imbalanced ensemble methods with bagging. MlFCM means the original dataset is clustered by MlFCM. From Table II, the proposed algorithm shows a large improvement in performance on all four metrics compared to MlFCM and TIEB method for most datasets. This indicates envelope samples generated through DSEN-LG network are of high quality and very effective. The DSEN-LGIE is better than the TIEB. It means that the multilayer clustering can obtain envelope samples with high-quality, which are more helpful for imbalanced learning. The DSEN-LGIE is better than the MlFCM. It means that the LGSCM can well enhance the consistency of the interlayer samples of MlFCM, thereby contributing to improving the quality of the envelope samples.

TABLE II
ABLATION METHOD FOR THE PROPOSED METHOD

Dataset	Measure	TIEB	MIFCM	DSEN-LGIE	Dataset	Measure	TIEB	MIFCM	DSEN-LGIE
Iris0	AUC	98.80±2.78	78.15±4.03	**1±0**	Glass0	AUC	74.62±6.70	67.11±3.92	**76.35±6.29**
	F-M	98.70±3.12	35.69±3.64	**1±0**		F-M	65.52±10.0	59.79±2.90	**67.19±9.05**
	G-M	98.75±2.95	75.69±4.34	**1±0**		G-M	73.02±7.98	58.12±6.76	**74.24±7.32**
	Mcc	98.23±4.09	34.68±5.10	**1±0**		Mcc	51.64±13.5	38.10±5.74	**57.95±12.6**
Vertebral	AUC	76.96±5.15	68.33±10.6	**83.98±7.29**	Haberman	AUC	55.41±7.27	53.31±6.87	**61.81±9.38**
	F-M	68.64±7.27	58.33±14.7	**78.41±7.08**		F-M	37.86±9.36	38.89±7.01	**43.65±8.57**
	G-M	76.10±5.89	68.31±10.1	**82.98±8.10**		G-M	54.11±8.89	52.29±6.58	**60.19±7.30**
	Mcc	54.69±10.0	34.44±14.4	**71.45±8.29**		Mcc	9.76±13.32	5.98±12.31	**21.59±8.67**
Vehicle1	AUC	66.52±3.54	63.18±4.31	**82.70±6.54**	Ecoli1	AUC	85.89±4.51	81.85±5.21	**92.47±4.39**
	F-M	50.54±4.09	46.30±5.32	**67.23±6.25**		F-M	69.34±6.91	64.82±6.97	**80.42±7.52**
	G-M	66.40±3.56	62.65±4.62	**81.74±7.15**		G-M	84.94±5.21	81.19±5.29	**92.09±4.84**
	Mcc	29.33±6.45	23.97±7.87	**57.01±9.87**		Mcc	61.84±8.75	54.87±9.68	**80.48±9.12**
New-thyroid1	AUC	95.06±4.83	70.00±11.7	**99.80±1.41**	Ecoli2	AUC	71.31±5.20	74.33±4.32	**93.62±7.25**
	F-M	85.92±10.2	53.99±23.6	**99.78±1.57**		F-M	39.84±5.18	42.42±3.79	**82.79±7.79**
	G-M	94.85±5.12	60.96±18.8	**99.79±1.49**		G-M	66.16±7.71	70.86±5.04	**92.76±7.51**
	Mcc	84.10±11.4	58.01±19.1	**1±0**		Mcc	31.95±6.89	35.53±5.89	**82.01±7.24**
Musk	AUC	86.32±2.74	55.52±5.58	**98.56±0.76**	Glass6	AUC	92.02±5.97	72.97±8.45	**98.13±5.07**
	F-M	58.88±4.88	16.46±1.63	**92.59±4.20**		F-M	77.01±12.4	37.50±15.0	**95.91±7.79**
	G-M	85.61±3.01	31.90±2.62	**98.55±0.77**		G-M	91.83±6.13	67.78±9.49	**97.96±5.68**
	Mcc	55.00±5.43	11.35±5.22	**91.50±4.82**		Mcc	74.46±13.7	32.56±17.9	**95.77±7.92**
Yeast3	AUC	91.46±2.54	67.95±3.16	**97.71±1.99**	Ecoli3	AUC	86.28±3.68	78.15±4.03	**95.70±4.69**
	F-M	69.97±4.52	28.62±1.78	**83.33±1.02**		F-M	50.22±5.68	35.69±3.64	**73.37±6.77**
	G-M	91.40±2.57	64.06±2.77	**97.68±2.09**		G-M	85.79±3.59	75.69±4.34	**95.50±4.98**
	Mcc	67.93±4.81	22.81±3.97	**82.56±1.12**		Mcc	49.37±6.15	34.68±5.10	**74.30±6.93**
Page-blocks0	AUC	92.68±1.05	69.23±2.92	**98.14±0.39**	Yeast 2vs4	AUC	92.40±4.01	84.37±4.90	**99.44±1.37**
	F-M	64.61±3.00	35.59±3.62	**90.43±3.06**		F-M	65.58±8.91	51.82±7.79	**76.08±11.6**
	G-M	92.56±1.05	67.98±4.15	**98.12±0.40**		G-M	92.23±4.06	84.26±4.93	**99.44±1.39**
	Mcc	64.06±2.90	27.96±4.28	**89.80±3.21**		Mcc	64.96±9.15	49.43±8.70	**76.48±11.7**
Yeast 05679vs4	AUC	75.05±5.13	67.02±6.83	**96.77±1.11**	Vowel0	AUC	95.34±1.66	83.94±5.31	**1±0**
	F-M	31.67±3.73	26.19±4.51	**72.73±2.89**		F-M	72.67±5.09	42.88±5.40	**1±0**
	G-M	72.78±4.93	65.00±6.46	**96.72±1.15**		G-M	95.28±1.66	83.05±5.95	**1±0**
	Mcc	29.87±6.11	20.26±8.16	**73.11±2.92**		Mcc	72.34±4.86	42.98±6.50	**1±0**
Glass 016vs2	AUC	70.45±12.5	58.71±2.73	**89.39±11.6**	Ecoli 0147vs2356	AUC	75.39±5.08	74.25±7.69	**97.81±3.15**
	F-M	**29.99±11.1**	19.07±2.87	22.22±10.9		F-M	29.94±3.56	31.70±7.55	**81.97±10.5**
	G-M	68.78±13.3	41.15±7.41	**88.76±12.5**		G-M	73.50±4.68	70.62±10.6	**97.73±3.37**
	Mcc	25.27±15.8	13.45±3.14	**31.38±12.9**		Mcc	29.04±5.71	31.85±9.79	**77.34±10.8**
climate	AUC	85.60±4.43	50.00±0.00	**79.93±4.80**	Glass2	AUC	71.87±10.4	61.98±2.76	**87.69±4.45**
	F-M	47.50±6.38	0.000±0.00	**70.60±4.56**		F-M	**26.12±7.01**	18.52±2.56	24.72±9.54
	G-M	85.35±4.44	0.000±0.00	**74.74±4.30**		G-M	70.07±10.1	48.62±5.79	**86.70±5.05**
	Mcc	47.25±6.91	0.000±0.00	**73.87±4.09**		Mcc	24.09±11.5	15.57±2.65	**32.47±9.00**
german	AUC	54.17±8.29	54.00±14.6	**84.48±9.24**	Shuttle-c0-vs-c4	AUC	99.07±0.33	90.57±9.19	**1±0**
	F-M	14.75±4.44	14.16±5.96	**23.08±5.05**		F-M	88.76±3.57	84.48±13.0	**1±0**
	G-M	52.72±7.71	52.06±14.5	**83.05±10.6**		G-M	99.07±0.33	89.71±10.2	**1±0**
	Mcc	4.500±8.90	3.760±14.7	**29.23±10.4**		Mcc	88.55±3.51	83.83±13.7	**1±0**
Yeast 1vs7	AUC	71.74±6.88	60.30±7.95	**83.72±6.06**	Ecoli4	AUC	80.30±5.24	74.92±2.66	**98.54±4.88**
	F-M	22.83±4.01	16.92±4.73	**30.00±8.23**		F-M	26.51±5.03	20.29±1.70	**87.87±8.94**
	G-M	70.50±7.30	58.68±9.12	**82.12±6.46**		G-M	78.51±6.00	70.50±3.81	**98.37±5.72**
	Mcc	22.17±7.03	10.74±8.29	**34.50±8.12**		Mcc	30.37±5.55	23.73±2.37	**88.61±8.51**
Page-blocks 13vs4	AUC	94.47±2.45	72.19±15.8	**98.50±1.38**	Dermatology-6	AUC	91.24±5.72	97.78±1.30	**1±0**
	F-M	55.13±11.1	45.72±22.2	**77.11±9.46**		F-M	58.79±11.0	74.47±12.3	**1±0**
	G-M	94.27±2.64	65.29±21.3	**98.49±1.41**		G-M	90.94±5.93	97.75±1.33	**1±0**
	Mcc	58.41±9.70	44.34±25.5	**78.88±7.20**		Mcc	60.14±10.4	75.74±11.3	**1±0**
svmguide3	AUC	78.72±10.0	51.98±7.20	**80.70±8.98**	Yeast 1458vs7	AUC	58.38±8.88	51.85±7.52	**72.14±9.29**
	F-M	**24.49±6.03**	9.520±2.70	15.38±3.27		F-M	10.20±2.41	8.580±1.60	**15.08±3.70**
	G-M	77.36±10.8	49.86±10.3	**78.36±7.87**		G-M	55.14±7.50	43.88±6.27	**68.13±10.8**
	Mcc	**27.62±9.51**	1.760±10.4	17.37±5.21		Mcc	7.020±7.41	1.700±7.15	**18.43±7.42**
Yeast4	AUC	84.70±3.80	74.62±5.99	**87.71±4.70**	Winequality-red-4	AUC	62.93±4.27	41.53±9.49	**71.33±9.39**
	F-M	20.68±2.11	14.56±2.38	**43.34±6.42**		F-M	8.790±0.83	4.750±3.94	**17.53±5.74**
	G-M	83.90±3.54	73.78±5.68	**85.19±4.89**		G-M	57.22±3.80	36.21±8.60	**69.22±9.92**
	Mcc	28.11±3.25	18.71±4.68	**47.68±6.85**		Mcc	9.680±3.17	5.650±8.11	**19.25±8.39**
Yeast 1289vs7	AUC	64.99±5.72	61.78±8.39	**81.23±8.50**	Abalone 3vs11	AUC	96.67±6.73	99.99±0.07	**1±0**
	F-M	9.510±1.31	9.060±2.42	**29.30±1.67**		F-M	96.00±8.08	99.71±2.02	**1±0**
	G-M	63.11±4.76	60.78±8.14	**71.24±8.26**		G-M	96.33±7.41	99.99±0.07	**1±0**
	Mcc	10.60±4.03	8.410±6.05	**34.32±2.50**		Mcc	96.25±7.58	99.72±1.96	**1±0**
Yeast5	AUC	94.90±1.31	86.39±1.55	**97.55±5.15**	Ozone-onehr	AUC	68.32±2.51	60.79±2.25	**84.95±1.95**
	F-M	38.17±6.16	18.49±1.85	**63.43±9.52**		F-M	8.760±0.62	7.080±0.41	**58.20±4.42**
	G-M	94.75±1.39	85.29±1.82	**97.52±5.95**		G-M	62.31±3.03	48.59±2.24	**77.24±3.23**
	Mcc	46.02±5.24	27.22±2.04	**66.92±8.83**		Mcc	12.57±1.60	8.480±1.68	**44.99±4.56**
krvsk 3vs11	AUC	98.54±0.32	64.21±1.65	**1±0**	Abalone21vs8	AUC	54.44±3.64	74.04±11.8	**91.95±1.57**
	F-M	66.39±5.17	7.360±0.36	**1±0**		F-M	5.140±0.89	10.47±3.70	**51.85±3.22**
	G-M	98.53±0.32	53.23±3.08	**1±0**		G-M	29.77±8.94	72.44±11.5	**91.17±1.68**

	Mcc	69.51±4.30	10.42±0.85	**1±0**		Mcc	4.620±2.49	15.47±7.85	**56.87±2.91**
Yeast6	AUC	82.39±4.41	79.01±5.10	**96.01±2.03**	Winequality-white3vs7	AUC	77.32±5.75	67.99±12.4	**92.63±6.79**
	F-M	14.99±1.65	11.70±1.55	**30.30±4.05**		F-M	10.48±1.68	10.88±4.87	**35.39±22.7**
	G-M	81.89±4.09	77.89±4.67	**95.92±3.47**		G-M	75.89±4.90	64.82±15.5	**91.99±8.05**
	Mcc	22.54±2.94	18.57±3.38	**40.54±3.30**		Mcc	16.91±3.49	13.14±8.99	**46.85±20.3**
Winequality-red8vs67	AUC	71.33±8.76	64.28±6.25	**76.50±8.75**	krvsk0vs8	AUC	97.16±0.73	60.36±13.3	**98.17±2.02**
	F-M	7.740±1.68	6.170±1.17	**10.18±2.75**		F-M	40.80±6.94	4.750±1.43	**58.30±3.89**
	G-M	68.96±7.87	61.80±4.64	**75.24±8.72**		G-M	97.12±0.75	55.30±11.0	**98.14±2.06**
	Mcc	12.30±5.00	8.200±3.48	**16.19±5.53**		Mcc	49.16±5.63	57.20±7.22	**64.55±3.31**
Shuttle-2vs5	AUC	99.30±0.23	57.96±11.5	**1±0**	kddbufferoverflowvsback	AUC	98.17±3.87	75.00±5.34	**1±0**
	F-M	68.77±7.45	11.76±13.0	**1±0**		F-M	97.96±4.37	66.67±8.73	**1±0**
	G-M	99.29±0.24	54.37±10.7	**1±0**		G-M	98.06±4.12	70.71±3.69	**1±0**
	Mcc	71.99±6.18	15.63±14.7	**1±0**		Mcc	98.04±4.17	70.47±10.3	**1±0**
krvsk0vs15	AUC	98.25±0.51	78.07±13.3	**1±0**	kddrootkitback	AUC	96.70±7.17	70.00±8.12	**98.76±5.04**
	F-M	42.81±7.48	9.900±6.29	**1±0**		F-M	**95.93±9.09**	57.14±10.3	87.19±2.95
	G-M	98.24±0.52	70.06±18.2	**1±0**		G-M	96.31±8.15	63.25±8.36	**98.58±5.93**
	Mcc	51.26±5.98	18.52±4.89	**1±0**		Mcc	**96.28±8.20**	63.03±10.5	84.53±2.64
skinnonskin	AUC	89.55±0.29	55.82±0.17	**99.29±0.86**	cod	AUC	96.70±5.64	53.34±0.43	**98.62±0.19**
	F-M	1.600±0.12	0.380±0.02	**78.32±3.93**		F-M	23.02±15.2	0.280±0.04	**54.67±1.64**
	G-M	88.93±0.33	34.13±0.49	**99.11±0.86**		G-M	96.62±5.84	25.78±1.66	**98.61±0.19**
	Mcc	7.990±0.33	1.490±0.04	**82.18±3.83**		Mcc	33.40±15.9	0.960±0.02	**61.48±1.97**

Fig.6 compared intuitively the envelope samples' distribution generated by the proposed algorithm and the original samples' distribution of the compared algorithms SPE, EASE and Imbalance-XGBoost on Ecoli1. It can be seen the envelope samples are more separable than the original samples.



(a) (b) (c) (d)

Fig.6. Sample distribution with different algorithms for Ecoli1: (a) is the envelope samples distribution with DSEN-LGIE; (b) is the original samples distribution with SPE; (c) is the original samples distribution with EASE; (d) is the original samples distribution with Imbalance-XGBoost. The envelope samples are more separable than original samples

Besides, four diversity indicators such as Disagreement(dis), Correlation coefficient(ς), Q-statistic, and Kappa (κ) are applied to measure the diversity of base classifiers. Higher values of dis are associated with higher diversity, and, conversely, smaller values of ς , Q-statistic, κ are associated with higher diversity. Table III records the results of four diversity indicators on Ecoli3 and Yeast1458vs7 obtained using DSEN-LGIE, BBAG, SBAG and UBAG, and Kappa-AUC, F-M, G-M and Mcc diagrams are designed in Fig.7. From Table III, it can be observed that DSEN-LGIE got better scores on each indicator. That is, DSEN-LGIE has higher diversity. In the Fig.7, it can also be seen the points obtained by DSEN-LGIE are located in the upper left corner of the figure. It means the kappa values are smaller and AUC, F-M, G-M and Mcc values are higher with the proposed algorithm, indicating the base classifiers of the proposed algorithm have higher diversity and higher performance than other imbalanced ensemble methods.

TABLE III
DIVERSITY ANALYSIS OF BASE CLASSIFIER

Dataset	Indicators	DSEN-LGIE	BBAG	SBAG	UBAG
Ecoli3	dis	**0.1190**	0.1134	0.0452	0.1029
	ς	**0.0039**	0.5024	0.7619	0.5176
	Q-statistic	**0.2252**	0.8128	0.9753	0.8091
	κ	**0.0026**	0.4882	0.7590	0.5032
Yeast1458vs7	dis	**0.5002**	0.3814	0.1326	0.4231
	ς	**0.0053**	0.3041	0.5790	0.2108
	Q-statistic	**0.0185**	0.4746	0.7727	0.3458
	κ	**0.0055**	0.3072	0.5597	0.2484

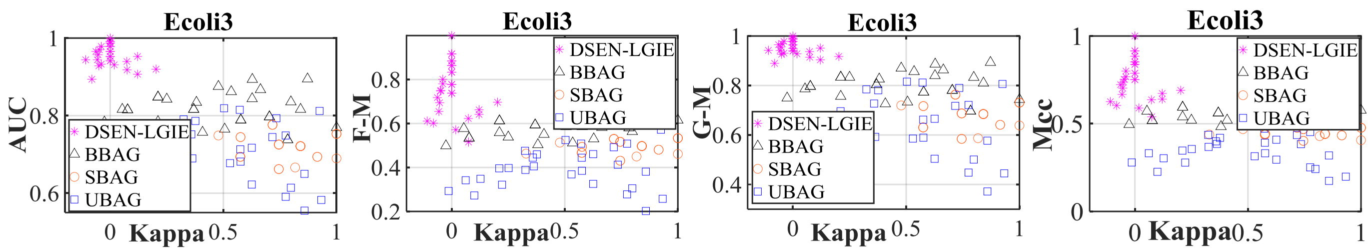


Fig.7. Diversity and performance analysis of base classifiers performance for Ecoli3.

Table III shows the high diversity of base classifier in DSEN-LGIE. The base classifiers are constructed based on the envelope samples and the final prediction results through the voting mechanism. Except for the diversity of base classifiers, Table IV discusses the predictive accuracy of the base classifiers for minority samples in DSEN-LGIE and TIEB for dataset 'Ecoli1'. The sample number (SN) for the minority samples is '1-16', and the actual labels (AL) for the minority samples are '0'. The number of basic classifier (BC) is 3 and the prediction fusion (PF) of three basic classifiers can be obtained by voting mechanism. As shown in Table IV, for the sample 12, the first base classifier (BC1) prediction is inconsistent with the actual label (AL), however, the labels of base classifier 2 (BC2) and base classifier 3 (BC3) are predicted correctly to realize error correction. Similarly, for the samples 14, 15 and 16, the second base classifier prediction is inconsistent with the actual label, but the base classifier 1 and 3 predicted correctly to realize error correction. The proposed algorithm guarantees both high prediction accuracy and diversity of base classifiers. However, for traditional method, the diversity is limited.

TABLE IV
ERROR CORRECTION OF BASE CLASSIFIER FOR ECOLI1

		DSEN-LGIE					TIEB			
SN	AL	PF	BC1	BC2	BC3		PF	BC1	BC2	BC3
1	0	0	0	0	0		0	0	0	0
…	…	…	…	…	…	…	…	…	…	…
11	0	0	0	0	0		0	0	0	0
12	**0**	**0**	**1**	**0**	**0**		**0**	**0**	**0**	**0**
13	0	0	0	0	0		0	0	0	0
14	**0**	**0**	**0**	**1**	**0**		**0**	**0**	**0**	**0**
15	**0**	**0**	**0**	**1**	**0**		**0**	**0**	**0**	**0**
16	**0**	**0**	**0**	**1**	**0**		**0**	**0**	**0**	**0**

Comparison with Classical Imbalanced Ensemble Methods

Tables V lists the average AUC, F-M, G-M and Mcc values obtained by classical imbalanced ensemble methods and proposed DSEN-LGIE method. It can be seen an overwhelming improvement of DSEN-LGIE over the other imbalanced ensemble methods on all four criteria. In particular, when considering AUC and G-M, it is observable the method proposed in this paper provided the best performance on 40 and 39 datasets respectively, and never showed the worst performance on any dataset. For F-M and Mcc, the proposed method provided the best performance on 29 and 31 datasets respectively. Thus, DSEN-LGIE perform best in most imbalanced datasets.

TABLE V
COMPARISON RESULTS OF THE ENSEMBLE METHODS ON 46 EXPERIMENTAL DATASETS

Data set	Mea sure	RBO	SBO	UBAG	SBAG	BBAG	EYEE	BACE	GBDT	DSEN-LGIE
Iris0	AUC	99.90±0.70	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	99.00±2.00	**1±0**
	F-M	99.89±0.74	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	98.95±2.11	**1±0**
	G-M	99.90±0.72	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	98.97±2.05	**1±0**
	Mcc	99.85±1.04	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	98.52±2.97	**1±0**
Glass0	AUC	78.40±6.84	72.03±2.65	79.19±2.50	77.84±6.31	**80.97±5.19**	79.54±7.01	77.14±7.00	76.60±6.44	76.35±6.29
	F-M	70.27±8.72	62.09±3.89	71.81±4.20	69.88±8.30	**73.46±6.27**	71.62±8.73	68.37±8.54	68.42±8.84	67.19±9.05
	G-M	77.56±7.42	70.92±3.41	78.93±2.16	77.25±6.68	**80.87±5.20**	79.33±7.27	76.50±7.67	75.63±7.10	74.24±7.32
	Mcc	56.87±11.7	44.51±4.29	57.17±8.05	55.41±12.2	**59.49±9.73**	56.90±12.9	52.34±12.2	54.14±12.9	57.95±12.6
Vertebral	AUC	74.00±4.48	74.57±5.36	82.40±3.88	80.36±3.97	82.64±2.36	79.62±4.63	78.43±6.03	78.29±6.00	**83.98±7.29**
	F-M	64.32±6.09	65.33±7.93	75.35±4.93	73.18±5.46	75.78±3.07	71.21±5.41	70.15±7.39	70.39±8.03	**78.41±7.08**
	G-M	73.04±5.27	73.19±6.35	82.19±3.96	80.04±4.12	82.45±2.54	79.39±4.53	78.06±6.28	77.42±6.63	**82.98±8.10**
	Mcc	47.69±7.66	50.96±10.3	63.11±7.42	60.26±8.11	63.76±4.74	55.99±8.84	55.59±10.7	57.51±10.9	**71.45±8.29**
Haberman	AUC	53.29±4.33	57.41±6.98	59.47±6.51	52.00±8.36	58.89±1.56	56.06±2.80	51.95±4.99	54.43±4.35	**61.81±9.38**
	F-M	30.50±7.85	40.62±8.01	43.01±7.45	30.40±9.85	42.16±2.11	40.10±2.00	34.04±6.35	23.07±10.6	**43.65±8.57**
	G-M	47.55±7.64	56.81±7.09	58.82±6.65	46.75±8.88	57.88±1.70	55.52±2.38	50.65±5.46	36.59±12.5	**60.19±7.30**
	Mcc	6.240±8.40	13.67±13.1	17.31±11.9	4.970±16.9	16.99±2.99	11.04±5.38	3.620±9.07	13.60±13.2	**21.59±8.67**
Vehicle1	AUC	66.51±5.23	70.29±4.56	78.03±3.79	72.62±3.32	75.10±4.23	79.12±3.30	76.12±3.77	53.78±2.83	**82.70±6.54**
	F-M	49.55±8.93	55.56±6.30	64.67±4.67	59.01±4.72	61.53±5.43	65.87±4.05	62.55±4.55	14.91±9.90	**67.23±6.25**
	G-M	63.22±7.82	69.06±5.12	77.91±3.81	71.53±3.81	74.72±4.60	79.03±3.28	75.88±3.96	26.58±12.7	**81.74±7.15**

	Mcc	34.03±9.72	39.60±8.56	51.20±6.83	44.54±6.31	47.00±7.45	52.93±5.97	48.29±6.45	17.91±9.50	**57.01±9.87**
	AUC	84.31±5.21	86.15±5.44	87.70±4.01	88.00±4.28	87.17±4.89	88.39±5.33	88.17±3.95	82.52±7.21	**92.47±4.39**
Ecoli	F-M	75.80±7.99	77.33±7.31	77.14±5.42	80.38±6.32	77.44±6.94	78.07±7.29	77.96±5.23	75.53±11.4	**80.42±7.52**
1	G-M	83.68±5.71	85.71±5.90	87.52±4.19	87.70±4.53	86.93±5.13	88.18±5.60	88.03±4.06	80.73±9.29	**92.09±4.84**
	Mcc	69.04±10.3	70.84±9.35	70.45±7.01	74.78±8.27	70.82±9.06	71.79±9.59	71.48±6.94	70.97±12.3	**80.48±9.12**
New	AUC	98.84±2.27	98.10±2.93	98.47±1.74	97.96±2.98	98.23±2.33	98.42±1.62	98.22±2.67	96.49±5.29	**99.80±1.41**
-thy	F-M	97.10±3.97	96.23±4.63	93.30±7.09	95.61±5.14	94.06±6.43	92.99±6.77	95.81±4.94	95.22±6.30	**99.78±1.57**
roid	G-M	98.81±2.34	98.05±3.02	98.44±1.79	97.91±3.07	98.20±2.39	98.39±1.66	98.17±2.76	96.29±5.71	**99.79±1.49**
1	Mcc	96.62±4.65	95.64±5.40	92.36±7.96	94.92±5.99	93.19±7.32	92.00±7.62	95.16±5.71	94.75±6.81	**1±0**
	AUC	90.14±5.05	84.02±6.30	89.29±7.92	87.75±7.21	89.01±7.40	87.02±6.84	87.16±7.98	87.12±4.49	**93.62±7.25**
Ecoli	F-M	**83.43±3.96**	70.21±8.79	77.19±12.8	82.55±7.52	77.28±11.3	74.32±10.0	77.22±9.39	80.65±7.76	82.79±7.79
2	G-M	89.55±5.73	83.25±7.12	88.85±8.37	86.57±8.19	88.62±7.72	86.50±7.31	86.07±9.36	86.38±6.16	**92.76±7.51**
	Mcc	81.38±3.88	64.79±10.7	73.38±15.3	81.37±7.62	73.33±13.6	70.00±12.2	74.26±10.4	78.60±7.58	**82.01±7.24**
	AUC	87.03±1.32	92.67±0.51	95.21±0.61	91.38±1.40	93.22±1.05	95.00±0.77	96.55±1.29	67.55±2.05	**98.56±0.76**
Mus	F-M	78.83±1.23	86.87±1.47	88.91±1.86	87.23±1.76	85.82±2.71	88.63±1.97	**93.87±1.39**	51.84±4.40	92.59±4.20
k	G-M	86.49±1.60	92.55±0.52	95.20±0.62	91.10±1.51	93.16±1.06	94.98±0.78	96.51±1.33	59.16±3.40	**98.55±0.77**
	Mcc	75.18±1.51	84.46±1.74	86.95±2.15	85.08±2.01	83.24±3.18	86.62±2.25	**92.77±1.63**	55.94±3.42	91.50±4.82
	AUC	91.98±6.05	89.92±7.78	92.84±3.64	89.98±7.16	91.17±6.87	93.05±4.18	92.57±2.30	86.74±8.27	**98.13±5.07**
Glas	F-M	85.39±9.35	83.73±10.2	84.02±12.3	82.47±8.23	81.87±12.1	85.17±5.98	81.80±6.30	80.23±11.9	**95.91±7.79**
s6	G-M	91.55±6.54	89.03±8.70	92.58±3.76	89.28±7.80	90.80±7.26	92.84±4.32	92.34±2.39	85.22±10.6	**97.96±5.68**
	Mcc	83.62±10.5	82.59±11.0	82.61±12.6	80.42±9.48	79.57±13.8	83.21±7.08	80.00±6.29	79.16±11.1	**95.77±7.92**
	AUC	84.85±4.52	87.88±3.09	93.94±2.08	88.45±2.14	91.10±2.41	89.39±2.54	86.74±2.54	85.75±4.49	**97.71±1.99**
Yeas	F-M	62.65±4.75	65.88±5.13	77.50±4.20	81.25±5.94	69.77±3.41	72.73±3.61	71.23±2.32	68.76±7.76	**83.33±1.02**
t3	G-M	84.63±5.65	87.83±3.41	93.94±2.12	87.92±2.28	91.10±2.51	89.28±2.57	86.38±2.76	84.62±6.16	**97.68±2.09**
	Mcc	58.54±4.78	62.65±3.41	75.67±4.59	79.04±6.87	67.47±4.00	69.70±4.14	67.65±2.72	81.36±7.58	**82.56±1.12**
	AUC	78.70±8.84	77.00±8.62	86.93±7.10	76.72±8.26	85.94±7.35	87.04±5.71	85.67±6.93	66.33±9.03	**95.70±4.69**
Ecoli	F-M	59.14±12.8	55.54±13.0	62.06±10.0	58.74±13.6	62.22±10.6	62.46±8.16	64.54±9.51	44.79±11.2	**73.37±6.77**
3	G-M	75.91±12.1	74.05±12.0	86.48±7.68	73.34±11.6	85.35±8.12	86.69±6.07	84.97±7.78	53.63±11.4	**95.50±4.98**
	Mcc	55.88±13.1	51.21±14.0	59.41±11.5	55.02±14.6	59.28±12.0	59.80±9.09	61.51±10.8	46.14±11.6	**74.30±6.93**
Page	AUC	87.48±3.40	93.79±1.72	95.67±1.09	93.89±1.39	95.15±1.12	95.70±1.07	95.32±0.88	80.54±2.58	**98.14±0.39**
-bloc	F-M	78.10±4.43	84.13±3.75	81.20±2.29	86.29±2.07	81.49±2.55	81.25±2.20	85.73±2.09	73.79±3.91	**90.43±3.06**
ks0	G-M	86.78±3.98	93.71±1.78	95.66±1.09	93.79±1.46	95.14±1.13	95.69±1.07	95.29±0.89	78.23±3.27	**98.12±0.40**
	Mcc	75.84±4.67	82.51±3.99	79.93±2.43	84.77±2.30	80.07±2.66	79.98±2.35	84.34±2.24	73.28±3.68	**89.80±3.21**
Yeas	AUC	93.92±6.61	98.92±9.14	95.70±3.44	94.37±5.44	98.39±5.01	95.16±2.31	98.39±7.62	90.00±5.50	**99.44±1.37**
t	F-M	67.14±12.8	69.74±11.8	65.61±7.49	73.47±10.1	66.13±8.34	66.13±9.15	71.55±7.84	69.82±8.79	**76.08±11.6**
2vs4	G-M	93.84±7.99	98.92±10.4	95.60±3.48	94.30±6.16	98.37±5.23	95.04±2.28	98.37±8.24	89.44±7.21	**99.44±1.39**
	Mcc	64.20±14.1	67.20±10.9	63.52±8.13	71.22±10.7	64.11±9.23	64.08±9.92	69.60±8.43	69.42±8.80	**76.48±11.7**
Yeas	AUC	89.21±5.02	89.74±3.98	93.42±4.99	88.44±4.72	93.16±3.99	91.88±3.43	89.21±6.44	84.47±7.79	**96.77±1.11**
t	F-M	60.00±8.18	62.07±5.55	**81.82±2.86**	76.19±7.59	62.86±5.80	64.00±5.51	60.00±8.33	77.78±6.97	72.73±2.89
0567	G-M	89.21±7.49	89.74±5.85	93.34±5.29	88.03±5.79	92.91±4.71	86.12±3.84	89.21±8.15	83.22±6.30	**96.72±1.15**
9vs4	Mcc	58.62±8.79	60.60±5.94	**80.12±3.73**	73.68±9.20	62.90±6.71	60.98±6.25	58.62±9.68	76.29±7.08	73.11±2.92
	AUC	94.55±4.45	95.20±3.48	96.85±1.94	96.27±2.71	96.41±2.33	97.19±1.72	97.15±2.02	90.57±5.83	**1±0**
Vow	F-M	88.72±6.38	89.43±5.55	83.01±5.73	92.31±4.34	82.90±6.01	83.98±5.09	90.37±4.72	86.56±7.07	**1±0**
el0	G-M	94.35±4.74	95.07±3.66	96.82±1.96	96.18±2.85	96.38±2.36	97.17±1.73	97.12±2.06	89.88±6.69	**1±0**
	Mcc	87.76±6.99	88.55±6.00	82.30±5.74	91.66±4.71	82.05±6.21	83.25±5.20	89.64±5.03	86.01±6.89	**1±0**
Glas	AUC	80.48±11.9	84.64±11.8	81.79±14.4	72.14±7.86	79.05±12.1	88.57±12.4	80.00±13.8	63.81±2.70	**89.39±11.6**
s	F-M	57.14±19.3	**66.67±18.8**	54.55±14.0	50.00±18.2	50.00±12.6	42.86±12.1	30.00±9.44	33.33±7.22	22.22±10.9
016v	G-M	79.28±29.2	84.09±30.0	81.50±23.6	68.66±25.9	78.07±21.5	87.83±22.7	77.46±21.4	56.06±10.4	**88.76±12.5**
s2	Mcc	53.56±22.5	**62.88±20.4**	50.26±19.0	44.29±20.3	46.34±16.5	45.87±15.9	32.54±16.3	27.62±8.11	31.38±12.9
Ecoli	AUC	81.78±8.88	82.11±9.93	86.16±7.91	83.53±11.3	84.90±8.10	85.40±8.96	89.01±8.29	70.72±12.9	**97.81±3.15**
0147	F-M	67.54±14.2	61.42±14.4	63.72±11.6	73.42±17.9	63.96±12.2	61.06±12.4	73.94±13.0	52.88±13.7	**81.97±10.5**
vs23	G-M	79.42±11.4	80.08±12.5	85.17±9.74	80.76±14.9	83.86±9.19	84.38±10.5	88.17±9.49	60.73±12.3	**97.73±3.37**
56	Mcc	66.05±15.2	59.07±15.7	61.81±12.4	72.96±17.9	61.43±13.3	58.96±13.7	72.57±14.0	54.93±13.3	**77.34±10.8**
	AUC	70.39±8.93	72.73±6.92	**85.62±6.38**	80.81±8.66	81.82±7.45	85.35±5.39	81.31±6.74	75.00±6.45	79.93±4.80
clim	F-M	45.73±15.4	45.83±10.9	54.29±8.92	60.00±14.0	51.49±8.40	60.87±6.79	63.16±8.85	66.67±17.1	**70.60±4.56**
ate	G-M	64.69±13.2	69.29±9.46	**85.25±7.24**	79.56±12.2	80.95±8.31	85.02±5.76	79.98±7.87	70.71±17.3	74.74±4.30
	Mcc	41.41±16.9	40.88±12.2	52.64±10.0	56.31±14.5	48.64±10.0	58.18±7.68	59.71±10.0	68.97±17.7	**73.87±4.09**
	AUC	69.83±4.81	60.10±8.63	70.07±13.8	57.13±7.50	66.55±9.52	69.46±6.24	67.10±11.1	59.94±5.29	**87.69±4.45**
Glas	F-M	**33.59±2.85**	21.46±11.9	28.50±11.9	20.38±17.0	27.68±10.8	28.83±6.06	23.91±6.97	28.57±15.5	24.72±9.54
s2	G-M	67.20±7.17	44.22±22.8	66.30±21.0	32.37±26.5	63.51±12.6	68.11±8.18	65.10±13.0	48.70±18.8	**86.70±5.05**
	Mcc	28.44±3.93	13.20±14.0	24.26±16.7	15.95±18.1	21.78±13.2	24.12±7.88	19.05±12.1	22.60±18.1	**32.47±9.00**
	AUC	67.35±11.2	82.52±10.9	82.73±9.16	81.15±10.8	83.68±8.56	82.85±10.6	**84.67±8.61**	82.67±13.2	84.48±9.24
germ	F-M	39.00±21.0	64.44±17.1	59.41±13.7	**73.43±9.06**	62.06±14.3	59.68±16.7	69.25±13.1	72.18±12.3	23.08±5.05
an	G-M	55.82±24.5	79.95±14.4	80.88±11.7	77.11±17.0	82.04±11.1	80.68±13.8	82.98±10.7	78.44±10.0	**83.05±10.6**
	Mcc	36.42±22.6	63.10±17.3	58.36±14.4	**74.71±7.98**	60.65±14.6	58.58±17.5	68.14±13.7	73.03±10.9	29.23±10.4
Shutt	AUC	98.90±6.99	99.95±0.08	99.91±0.08	99.95±0.09	99.91±0.11	99.90±0.12	99.91±0.04	99.43±1.12	**1±0**
le-c0	F-M	96.70±13.8	99.37±1.14	98.73±1.17	99.29±1.23	98.74±1.46	98.71±1.52	98.82±1.18	98.83±1.51	**1±0**
-vs-c	G-M	97.90±13.9	99.95±0.08	99.91±0.08	99.95±0.09	99.91±0.11	99.90±0.12	99.91±0.08	99.42±1.14	**1±0**
4	Mcc	96.61±13.8	99.33±1.21	98.65±1.23	99.25±1.30	98.66±1.54	98.63±1.60	98.74±1.25	98.76±1.60	**1±0**
	AUC	61.35±3.44	63.74±8.35	71.96±8.88	60.15±9.02	70.55±11.5	75.41±11.6	73.26±7.97	59.31±7.53	**83.72±6.06**
Yeas	F-M	28.49±5.22	25.59±10.3	31.13±9.80	28.31±8.71	28.48±10.8	**33.51±9.57**	27.18±5.93	27.29±8.31	30.00±8.23
t	G-M	49.89±7.80	56.75±14.6	70.16±10.8	41.49±10.8	67.17±16.7	73.62±13.5	72.42±7.94	38.39±11.7	**82.12±6.46**
1vs7	Mcc	25.03±4.71	20.15±12.0	28.04±12.0	25.61±8.00	25.36±14.1	31.72±13.4	25.91±8.63	29.97±10.2	**34.50±8.12**
Ecoli	AUC	89.67±9.28	86.71±7.42	90.61±5.46	89.84±9.40	91.99±5.99	92.15±5.92	91.71±6.46	82.18±12.6	**98.54±4.88**

4	F-M	76.06±15.3	74.81±7.46	69.88±5.80	85.48±13.3	63.43±7.79	68.55±16.5	81.11±11.8	71.84±13.9	**87.87±8.94**
	G-M	88.61±10.9	85.37±8.79	90.15±5.79	88.65±10.8	91.73±6.23	91.82±6.18	91.25±6.83	76.01±11.3	**98.37±5.72**
	Mcc	75.61±15.9	74.82±7.53	69.47±5.93	85.79±12.8	63.84±8.42	69.40±15.8	80.07±12.6	73.09±13.6	**88.61±8.51**
Page	AUC	98.05±4.29	96.21±6.54	98.74±0.97	97.34±3.94	98.90±1.00	98.80±0.70	**99.76±0.37**	96.25±5.54	98.50±1.38
-bloc	F-M	89.57±10.5	92.61±9.92	84.63±9.25	94.28±6.33	86.62±10.6	84.71±8.36	**96.77±4.97**	92.92±7.63	77.11±9.46
ks13	G-M	97.95±4.64	95.86±7.52	98.73±0.99	97.23±4.12	98.89±1.02	98.78±0.78	**99.76±0.38**	96.00±6.03	98.49±1.41
vs4	Mcc	89.52±10.6	92.52±9.94	84.88±8.68	94.11±6.60	86.89±10.2	84.94±7.88	**96.71±5.01**	92.89±7.62	78.88±7.20
Der	AUC	99.99±0.10	**1±0**	**1±0**	**1±0**	97.72±4.79	**1±0**	99.93±0.22	97.37±5.54	**1±0**
mato	F-M	99.78±1.56	**1±0**	**1±0**	**1±0**	96.98±5.71	**1±0**	98.89±3.33	95.05±7.25	**1±0**
logy-	G-M	99.99±0.10	**1±0**	**1±0**	**1±0**	97.56±5.14	**1±0**	99.93±0.22	97.14±6.15	**1±0**
6	Mcc	99.78±1.57	**1±0**	**1±0**	**1±0**	97.03±5.62	**1±0**	98.88±3.37	95.13±6.99	**1±0**
svmg	AUC	57.08±11.8	62.67±11.8	67.89±12.8	55.48±7.56	67.10±16.1	66.56±16.0	72.36±8.46	57.03±9.75	**80.70±8.98**
uide	F-M	16.26±12.5	**25.01±18.3**	21.24±10.3	15.37±10.1	20.78±12.5	20.12±12.1	20.52±5.21	18.94±14.2	15.38±3.27
3	G-M	30.34±21.3	48.28±26.6	62.41±22.3	21.16±27.0	59.33±27.7	57.87±28.7	71.32±8.23	23.80±19.8	**78.36±7.87**
	Mcc	12.13±10.1	21.18±20.0	19.28±14.1	15.23±12.2	18.50±17.6	17.82±17.2	**21.30±8.00**	19.71±16.1	17.37±5.21
Yeas	AUC	56.01±10.1	57.18±10.0	62.65±8.40	51.06±3.30	63.31±13.0	60.66±12.9	63.30±7.91	50.42±2.27	**72.14±9.29**
t	F-M	13.93±10.4	13.86±10.6	14.49±4.43	4.440±3.89	14.54±6.69	13.74±7.82	11.78±2.29	2.090±7.12	**15.08±3.70**
1458	G-M	40.01±22.8	43.72±25.1	58.89±10.2	8.100±16.2	59.06±16.8	55.62±17.5	60.54±6.59	3.260±11.0	**68.13±10.8**
vs7	Mcc	8.670±13.0	9.23±12.83	11.94±7.61	2.970±9.22	12.35±11.7	10.31±12.5	10.95±6.52	1.700±9.33	**18.43±7.42**
	AUC	74.42±8.23	75.98±1.78	82.24±6.18	68.48±4.35	81.61±9.49	79.25±4.25	81.04±3.07	60.13±1.41	**87.71±4.70**
Yeas	F-M	38.82±9.91	38.81±3.85	29.76±4.97	40.14±7.27	30.87±7.82	28.43±4.16	28.98±4.05	27.75±3.23	**43.34±6.42**
t4	G-M	70.40±11.1	73.49±2.45	81.81±6.61	61.36±6.88	80.63±10.4	78.53±4.84	80.72±3.24	45.94±2.96	**85.19±4.89**
	Mcc	37.77±10.9	38.14±3.40	33.62±6.60	38.73±7.26	34.19±10.2	31.23±4.68	32.47±4.44	27.45±3.60	**47.68±6.85**
Wine	AUC	54.75±5.08	55.89±5.23	67.73±6.74	51.61±2.87	62.18±6.80	67.51±6.66	55.46±7.47	51.52±3.46	**71.33±9.39**
quali	F-M	9.950±5.88	11.29±6.04	16.59±4.02	6.010±7.74	13.29±4.48	16.66±4.36	7.580±1.82	5.330±9.51	**17.53±5.74**
ty-re	G-M	36.12±15.6	39.70±13.9	65.02±9.21	13.04±16.2	56.95±11.1	64.74±9.08	54.65±7.23	10.27±16.9	**69.22±9.92**
d-4	Mcc	6.370±6.67	7.800±6.88	16.80±6.17	4.860±8.84	11.70±6.48	16.75±6.31	3.910±5.36	4.490±10.9	**19.25±8.39**
Yeas	AUC	54.05±8.28	65.20±3.98	74.33±8.92	54.29±4.40	66.69±11.6	74.17±11.5	61.98±8.57	57.86±6.35	**81.23±8.50**
t	F-M	11.70±7.50	19.22±5.55	17.85±4.74	13.89±11.3	14.72±6.27	18.98±6.23	8.970±2.33	22.87±6.86	**29.30±1.67**
1289	G-M	27.37±21.2	59.79±5.85	71.66±11.1	24.38±19.9	62.16±17.1	**72.45±13.0**	59.67±9.25	33.61±12.2	71.24±8.26
vs7	Mcc	8.060±9.27	17.95±5.94	20.99±7.69	13.21±13.1	14.99±10.1	21.74±9.80	8.590±6.12	25.22±9.04	**34.32±2.50**
Abal	AUC	99.51±0.48	99.98±0.09	99.63±0.45	99.98±0.10	99.63±0.45	99.60±0.43	99.90±0.21	99.93±0.18	**1±0**
one	F-M	87.65±10.8	99.43±2.80	90.64±10.5	99.43±2.80	90.64±10.5	89.71±10.0	97.14±5.71	98.00±4.96	**1±0**
3vs1	G-M	99.50±0.49	99.98±0.10	99.63±0.45	99.98±0.10	99.63±0.45	99.60±0.43	99.90±0.21	99.93±0.18	**1±0**
1	Mcc	88.33±10.1	99.45±2.71	91.14±9.82	99.45±2.71	91.14±9.82	90.22±9.36	97.23±5.54	98.06±4.80	**1±0**
	AUC	89.95±7.84	87.01±8.12	95.40±3.60	86.57±6.90	95.36±3.54	95.07±3.92	93.41±6.76	74.50±8.43	**97.55±5.15**
	F-M	61.05±10.3	67.05±12.2	57.02±7.87	**69.70±9.17**	57.63±7.60	55.29±6.57	67.23±9.45	55.94±14.5	63.43±9.52
Yeas	G-M	89.10±9.51	85.67±9.92	95.32±3.70	85.26±8.38	95.28±3.64	94.97±4.05	92.97±7.85	69.12±12.7	**97.52±5.95**
t5	Mcc	62.30±10.5	66.80±12.6	60.77±7.09	**69.50±9.31**	61.26±6.71	59.25±6.21	68.47±9.54	56.55±14.6	66.92±8.83
	AUC	64.75±7.27	64.27±6.17	80.79±5.34	67.65±4.51	78.30±5.52	80.40±5.03	80.15±5.54	59.59±3.13	**84.95±1.95**
Ozon	F-M	36.36±7.63	33.33±7.23	30.11±3.58	47.62±5.14	30.14±3.69	24.81±3.63	20.58±3.13	27.27±8.65	**58.20±4.42**
e-on	G-M	55.95±13.4	55.25±11.1	**80.26±5.94**	59.64±4.41	77.36±6.42	79.89±5.57	79.84±5.82	44.54±4.53	77.24±3.23
ehr	Mcc	37.52±8.68	34.28±8.13	37.72±4.99	**49.58±5.11**	33.95±5.03	29.22±4.90	25.83±4.70	27.86±8.26	44.99±4.56
Krvs	AUC	98.71±1.84	96.49±3.57	97.82±2.42	95.12±4.59	97.41±2.63	97.35±2.52	98.18±2.52	93.62±4.10	**1±0**
k	F-M	93.03±5.14	94.65±4.67	83.64±5.94	93.56±5.58	83.94±7.24	83.39±6.66	95.28±5.05	92.18±4.68	**1±0**
3vs1	G-M	98.68±1.88	96.35±3.83	97.78±2.50	94.87±4.92	97.36±2.71	97.30±2.59	98.13±2.60	93.30±4.43	**1±0**
1	Mcc	93.04±5.06	94.66±4.57	84.12±5.51	93.64±5.45	84.27±6.97	83.78±6.33	95.22±5.09	92.28±4.51	**1±0**
Abal	AUC	84.83±2.86	83.56±4.31	85.87±9.92	79.03±5.03	87.35±2.63	86.51±1.43	88.42±1.22	69.88±1.36	**91.95±1.57**
one	F-M	50.08±3.52	56.34±3.61	35.27±3.23	**59.40±3.03**	35.88±2.99	35.60±1.33	45.06±3.08	44.24±2.63	51.85±3.22
21vs	G-M	81.93±8.40	78.58±4.23	84.75±9.25	71.06±7.78	85.17±8.05	84.38±6.85	86.97±3.50	55.80±3.03	**91.17±1.68**
8	Mcc	51.94±3.81	57.56±3.16	39.96±3.97	**61.02±3.14**	41.06±4.53	40.52±1.79	49.28±3.43	45.03±2.75	56.87±2.91
	AUC	94.31±9.34	90.79±1.35	95.34±6.56	92.51±8.61	96.37±6.84	**98.10±7.43**	93.60±6.32	91.65±8.30	96.01±2.03
Yeas	F-M	29.79±11.1	48.00±9.51	34.15±5.43	**80.00±1.49**	40.00±6.04	56.00±6.66	27.45±6.00	60.00±7.74	30.30±4.05
t6	G-M	94.14±12.2	90.65±11.6	95.23±7.13	92.26±1.25	96.30±7.64	**98.09±8.29**	93.38±7.34	91.46±8.16	95.92±3.47
	Mcc	39.38±11.6	51.86±8.15	43.21±6.52	**79.67±1.52**	48.15±6.96	61.17±7.96	37.25±6.44	61.77±7.16	40.54±3.30
Wine	AUC	71.31±11.1	72.73±10.6	81.53±12.6	84.09±10.4	84.38±12.7	82.10±12.6	81.25±11.5	87.50±9.37	**92.63±6.79**
quali	F-M	21.05±15.8	28.57±11.0	21.43±8.81	31.58±25.0	33.33±9.06	23.08±7.87	20.69±8.16	28.57±9.14	**35.39±22.7**
ty-w	G-M	68.05±29.6	69.08±23.5	81.27±20.1	83.60±29.2	83.85±18.4	81.79±20.1	81.01±19.4	86.60±8.17	**91.99±8.05**
hite 3vs7	Mcc	18.76±17.0	29.25±12.8	27.35±12.0	36.36±27.1	37.84±12.1	28.89±11.3	26.64±10.2	27.48±10.3	**46.85±20.3**
Wine	AUC	57.37±1.13	57.09±7.51	61.09±2.44	54.45±6.64	60.90±2.41	60.57±2.37	58.00±8.88	54.22±6.40	**76.50±8.75**
quali	F-M	10.23±1.12	9.840±8.98	7.190±3.81	**13.27±3.80**	7.380±4.40	7.050±4.08	5.120±1.44	11.16±1.52	10.18±2.75
ty-re	G-M	30.68±3.08	33.70±7.75	55.00±1.87	17.75±4.81	52.70±4.18	53.35±3.06	52.37±7.59	18.36±2.45	**75.24±8.72**
d 8vs6 7	Mcc	9.070±1.38	8.300±8.68	7.270±3.16	14.33±2.16	7.430±8.49	7.010±8.23	5.010±7.21	10.71±1.68	**16.19±5.53**
krvs	AUC	86.32±8.68	89.42±7.19	91.72±8.44	85.67±4.22	90.72±7.28	94.10±5.58	94.60±7.21	70.19±10.7	**98.17±2.02**
k	F-M	53.45±8.77	74.17±8.89	31.87±7.68	**77.07±6.94**	32.43±8.99	33.68±6.15	59.07±8.41	46.24±19.4	58.30±3.89
0vs8	G-M	84.72±8.12	88.48±8.26	91.20±9.49	83.25±4.45	90.37±7.80	93.89±5.99	94.20±7.15	61.25±17.8	**98.14±2.06**
	Mcc	55.36±8.47	74.58±8.89	39.95±8.90	**78.68±5.07**	39.93±9.18	42.35±6.50	62.46±8.48	47.53±19.0	64.55±3.31
Shutt	AUC	99.97±0.09	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**
le-2v	F-M	98.24±5.38	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**
s5	G-M	99.97±0.09	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**
	Mcc	98.35±5.01	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**

kddb	AUC	99.49±2.59	99.33±3.27	99.16±2.51	99.00±3.96	99.82±1.17	98.33±4.41	99.67±2.33	1±0	**1±0**
uffer	F-M	98.81±3.96	99.20±3.92	98.63±3.92	98.80±4.75	98.76±3.18	97.77±5.54	99.60±2.80	1±0	**1±0**
overf	G-M	99.45±2.83	99.27±3.60	99.12±2.63	98.90±4.36	99.81±1.22	98.20±4.80	99.63±2.57	1±0	**1±0**
lowv										
sbac	Mcc	98.84±3.82	99.26±3.63	98.64±3.92	98.89±4.40	98.80±3.08	97.87±5.25	99.63±2.59	1±0	**1±0**
k										
krvs	AUC	98.90±3.37	94.25±6.90	96.99±6.26	91.63±6.54	95.51±8.29	99.51±0.50	99.91±0.15	89.15±9.00	**1±0**
k	F-M	96.41±8.16	91.94±8.81	84.72±6.46	89.36±7.96	79.38±8.41	84.56±3.36	94.16±8.39	83.60±13.2	**1±0**
0vs1	G-M	98.83±3.61	93.77±7.62	96.72±6.95	90.46±7.25	94.88±4.31	98.27±5.74	99.91±0.15	87.84±10.8	**1±0**
5	Mcc	96.57±7.83	92.29±8.44	85.45±5.77	90.38±7.32	80.44±7.84	85.41±2.67	94.50±7.65	84.45±12.4	**1±0**
kddr	AUC	96.75±5.50	95.45±5.63	93.99±7.07	94.35±7.71	93.79±7.36	93.34±7.69	95.69±5.54	94.04±5.78	**98.76±5.04**
ootk	F-M	89.51±19.1	**94.68±6.66**	92.41±9.18	93.22±9.70	91.70±10.1	91.03±10.3	94.30±6.59	92.51±6.89	87.19±2.95
itbac	G-M	96.53±5.92	95.15±6.01	93.46±7.95	93.77±8.72	93.22±9.70	92.69±8.73	95.41±5.91	93.65±6.17	**98.58±5.93**
k	Mcc	90.51±17.0	**94.92±6.37**	92.88±8.45	93.73±8.78	92.10±9.63	91.56±9.54	94.55±6.32	92.83±6.63	84.53±2.64
skinn	AUC	99.72±0.11	98.68±2.80	99.38±0.08	97.09±3.56	99.38±0.10	99.49±0.09	**99.98±0.00**	97.09±4.34	99.29±0.86
onski	F-M	39.67±9.84	95.40±4.47	21.76±2.64	**95.52±4.74**	21.97±2.75	25.33±3.52	88.62±7.19	92.61±7.70	78.32±3.93
n	G-M	99.72±0.11	98.63±2.91	99.38±0.08	96.98±3.71	99.38±0.10	99.49±0.09	**99.98±0.00**	96.93±4.61	99.11±0.86
	Mcc	49.49±7.79	95.54±4.34	34.68±2.39	**95.63±4.67**	34.87±2.49	37.83±3.03	89.36±6.49	92.80±7.59	82.18±3.83
	AUC	96.92±4.43	92.55±7.87	96.90±4.11	92.96±7.45	97.08±3.71	96.88±4.35	96.03±5.38	82.91±11.5	**98.62±0.19**
cod	F-M	16.42±8.10	82.76±6.13	10.99±1.63	**87.75±9.06**	11.16±1.34	11.11±1.64	47.01±8.28	64.39±20.9	54.67±1.64
	G-M	96.78±4.77	91.81±9.01	96.78±4.36	92.31±8.49	96.99±3.88	96.75±4.67	95.78±5.79	79.19±17.7	**98.61±0.19**
	Mcc	28.48±6.84	83.48±6.09	23.28±1.75	**88.24±9.63**	23.55±1.64	23.45±2.15	53.89±7.37	65.14±20.7	61.48±1.97

Assuming the first rank for the method with the best performance and the ninth rank for the method with the worst performance, so for AUC, F-M, G-M and Mcc, the average ranks of each method on the experimental datasets can be calculated and analyzed. Table VI gives the average ranks of AUC, F-M, G-M and Mcc of each method on the 46 datasets. Table VI shows the proposed DSEN-LGIE method achieves the lowest average ranks. So the performance of proposed method is the best.

TABLE VI
AVERAGE RANKS OF ALL COMPARED ENSEMBLE METHODS

Algorithm	AUC	F-M	G-M	Mcc
DSEN-LGIE	**1.500**	**2.717**	**1.630**	**2.326**
RBO	6.413	5.782	6.326	6.152
SBO	6.108	4.369	6.087	4.587
UBAG	3.478	5.304	3.413	5.261
SBAG	6.369	3.761	6.391	3.652
BBAG	4.021	5.413	4.043	5.695
EYEE	3.804	5.608	3.782	5.674
BACE	4.109	4.804	4.022	4.826
GBDT	7.848	5.869	7.935	5.522

Whether there were the statistically significant differences with other imbalanced ensemble methods in terms of average ranks was analyzed. the results of Holm's test are recorded in Table VII. In the Holm's test, the proposed method was taken as the control method, and the level of significance is α / n_c ,where $\alpha = 0.05$ and n_c is the number of comparisons between algorithms. The results of Holm's test are recorded in Table VII. From Table VII, It's obvious that all the hypothesis of equivalence have been rejected, indicating the proposed method DSEN-LGIE performs better than the other imbalanced ensemble methods significantly. The results indicate that the deep envelope samples generated by DSEN-LG are more competitive.

TABLE VII
P-VALUES FROM HOLM'S TEST FOR ALL COMPARED METHODS

Method	AUC		F-M		G-M		Mcc	
	$\alpha_{0.05}$ (α / n_c)	P-value	$\alpha_{0.05}$ (α / n_c)	P-value	$\alpha_{0.05}$ (α / n_c)	P-value	$\alpha_{0.05}$ (α / n_c)	P-value
RBO	0.0071	**1.05E-28**	0.0071	**9.59E-09**	0.0083	**4.51E-27**	0.0063	**4.62E-13**
SBO	0.01	**7.31E-26**	0.025	**1.70E-03**	0.01	**2.72E-24**	0.025	**1.27E-05**
UBAG	0.05	**1.82E-06**	0.0125	**1.11E-06**	0.05	**1.77E-05**	0.0125	**1.87E-08**
SBAG	0.0083	**2.70E-28**	0.05	**4.67E-02**	0.0071	**4.51E-27**	0.05	**9.86E-03**
BBAG	0.0167	**1.62E-09**	0.01	**4.00E-07**	0.0125	**8.53E-09**	0.0071	**1.38E-10**
EYEE	0.025	**3.16E-08**	0.0083	**5.82E-08**	0.025	**2.52E-07**	0.0083	**1.79E-10**
BACE	0.0125	**4.65E-10**	0.0167	**7.85E-05**	0.0167	**1.14E-08**	0.0167	**1.47E-06**
GBDT	0.0063	**4.71E-43**	0.0063	**3.77E-09**	0.0063	**2.64E-42**	0.01	**1.05E-09**

Comparison with State-of-the-art Imbalanced Ensemble Methods

Table VIII records comparison results between the proposed DSEN-LGIE method and six state-of-the-art imbalanced ensemble methods. The comparisons in Table VIII clearly demonstrated that the proposed DSEN-LGIE provide better performance in terms of the four metrics than compared methods, suggesting that DSEN-LGIE generates high-quality and high- separability envelope samples.

TABLE VIII
THE COMPARISON RESULTS BETWEEN CBIS, HD-ENSEMBLE, EASE, HOEC, SPE, IMBALANCE-XGBOOST AND DSEN-LGIE

Dataset	Iris0				Glass0			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	99.00	--	--	--	88.50	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	1±0	1±0	1±0	1±0	74.73±6.66	65.85±8.34	74.45±6.85	47.40±12.8
HOEC	--	--	--	--	--	--	--	--
SPE	1±0	1±0	1±0	1±0	**78.95±6.88**	**71.31±8.55**	**78.67±6.97**	56.55±13.5
Imbalance-XGBoost	98.90±2.07	98.77±2.38	98.88±2.13	98.25±3.40	76.44±5.55	67.95±7.63	75.49±6.34	53.46±10.5
DSEN-LGIE	**1±0**	**1±0**	**1±0**	**1±0**	76.35±6.29	67.19±9.05	74.24±7.32	**57.95±12.6**
Dataset	Vertebral				Haberman			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	**64.80**	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	77.55±5.01	68.94±6.12	77.25±5.12	52.69±9.54	57.73±8.78	41.78±9.68	56.24±8.28	13.95±15.7
HOEC	--	--	--	--	62.42±1.93	--	--	--
SPE	78.93±6.12	70.89±7.88	78.53±6.54	56.70±11.4	60.02±6.32	**43.82±7.77**	59.31±7.02	17.92±11.3
Imbalance-XGBoost	79.28±6.07	71.49±8.06	78.75±6.65	58.11±11.3	56.06±6.19	32.83±11.5	48.27±11.6	12.94±13.5
DSEN-LGIE	**83.98±7.29**	**78.41±7.08**	**82.98±8.10**	**71.45±8.29**	61.81±9.38	43.65±8.57	**60.19±7.30**	**21.59±8.67**
Dataset	Vehicle1				Ecoli1			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	82.50	--	--	--	**95.70**	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	72.21±3.97	57.13±4.82	72.05±4.04	39.96±7.13	86.43±2.94	76.61±4.16	86.17±3.11	69.79±5.47
HOEC	75.96±1.35	--	--	--	88.16±0.87	--	--	--
SPE	77.44±3.50	63.92±4.39	77.31±3.68	50.11±6.22	86.33±4.22	78.46±5.92	85.88±4.66	72.40±7.57
Imbalance-XGBoost	69.99±3.92	55.32±5.73	67.96±4.81	40.75±7.38	84.71±6.62	76.63±9.26	83.80±7.64	70.74±11.0
DSEN-LGIE	**82.70±6.54**	**67.23±6.25**	**81.74±7.15**	**57.01±9.87**	92.47±4.39	**80.42±7.52**	**92.09±4.84**	**80.48±9.12**
Dataset	New-thyroid1				Ecoli2			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	99.70	--	--	--	93.40	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	98.84±2.22	97.13±4.08	98.81±2.29	96.68±4.72	86.45±5.62	72.88±10.4	86.14±5.79	68.01±12.4
HOEC	--	--	--	--	91.28±1.53	--	--	--
SPE	98.21±2.89	96.82±4.74	98.15±2.99	96.37±5.41	89.92±6.36	80.67±7.85	89.38±7.10	77.87±8.93
Imbalance-XGBoost	96.36±4.44	93.68±6.26	96.22±4.67	92.68±7.30	84.47±6.84	75.63±10.6	83.23±7.92	72.18±12.2
DSEN-LGIE	**99.80±1.41**	**99.78±1.57**	**99.79±1.49**	**1±0**	**93.62±7.25**	**82.79±7.79**	**92.76±7.51**	**82.01±7.24**
Dataset	Musk				Glass6			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	93.40	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	95.18±0.79	88.56±0.71	95.16±0.81	86.54±0.82	91.51±6.12	81.26±8.85	91.14±6.55	78.99±10.1
HOEC	--	--	--	--	--	--	--	--
SPE	97.17±0.98	**95.97±1.21**	97.14±1.00	**95.27±1.42**	91.64±5.68	83.00±8.67	91.30±6.07	80.74±9.97
Imbalance-XGBoost	92.25±1.43	89.63±2.12	91.99±1.53	88.01±2.45	89.68±8.85	82.29±13.6	88.56±11.1	80.91±13.6
DSEN-LGIE	**98.56±0.76**	92.59±4.20	**98.55±0.77**	91.50±4.82	**98.13±5.07**	**95.91±7.79**	**97.96±5.68**	**95.77±7.92**
Dataset	Yeast3				Ecoli3			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	96.90	--	--	--	93.30	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	88.49±4.32	73.00±6.18	88.14±4.71	69.99±6.96	81.43±6.36	58.59±8.97	80.38±7.35	54.40±10.3
HOEC	--	--	--	--	87.34±1.96	--	--	--
SPE	88.77±3.79	75.68±5.65	88.39±4.16	72.83±6.34	83.68±7.73	61.37±8.98	82.59±9.19	57.91±10.5
Imbalance-XGBoost	84.42±3.93	73.96±5.68	83.28±4.76	71.16±6.04	75.70±9.93	56.94±16.7	71.57±14.1	53.86±17.1
DSEN-LGIE	**97.71±1.99**	**83.33±1.02**	**97.68±2.09**	**82.56±1.12**	**95.70±4.69**	**73.37±6.77**	**95.50±4.98**	**74.30±6.93**
Dataset	Page-blocks0				Yeast2vs4			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	**98.70**	--	--	--	98.00	--	--	--
HD-Ensemble	--	--	--	--	98.33±1.10	--	94.20±3.70	--
EASE	93.24±1.36	83.68±1.74	93.14±1.42	81.93±1.94	98.91±5.64	75.43±8.74	98.91±6.18	73.09±9.85
HOEC	92.94±0.30	--	--	--	--	--	--	--
SPE	93.24±1.73	86.24±2.03	93.09±1.83	84.72±2.26	**99.46±1.53**	75.31±9.87	**99.46±1.40**	73.04±10.7
Imbalance-XGBoost	92.11±2.08	85.80±2.76	91.87±2.24	84.23±3.05	95.00±6.19	76.58±10.8	**94.87±7.37**	74.53±11.8
DSEN-LGIE	98.14±0.39	**90.43±3.06**	**98.12±0.40**	**89.80±3.21**	99.44±1.37	**76.08±11.6**	99.44±1.39	**76.48±11.7**
Dataset	Yeast05679vs4				Vowel0			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc

CBIS	--	--	--	--	98.10	--	--	--
HD-Ensemble	90.84±4.10	--	82.27±7.40	--	99.99±0.20	--	97.53±1.40	--
EASE	89.27±8.38	60.00±13.6	89.27±10.4	58.68±15.4	97.48±2.14	93.29±4.99	97.44±2.19	92.82±5.22
HOEC	--	--	--	--	--	--	--	--
SPE	90.83±5.67	66.67±7.16	90.83±6.32	65.05±8.48	96.39±3.45	93.80±4.52	96.27±3.68	93.33±4.78
Imbalance-XGBoost	92.92±6.92	**78.26±11.8**	92.87±7.04	**76.49±12.1**	95.24±3.60	90.52±4.90	95.09±3.81	89.71±5.32
DSEN-LGIE	**96.77±1.11**	72.73±2.89	**96.72±1.15**	73.11±2.92	**1±0**	**1±0**	**1±0**	**1±0**
Dataset	Glass016vs2				Ecoli0147vs2356			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	71.30	--	--	--	--	--	--	--
HD-Ensemble	86.06±8.70	--	77.11±13.3	--	--	--	--	--
EASE	60.14±13.0	22.84±16.2	48.03±27.9	14.40±19.3	87.17±7.64	73.12±12.7	86.16±8.75	71.93±13.4
HOEC	--	--	--	--	84.71±1.33	--	--	--
SPE	64.18±14.5	24.65±10.6	60.18±20.4	17.15±17.1	84.76±8.88	63.31±11.9	83.43±10.6	61.22±13.2
Imbalance-XGBoost	51.85±6.62	**28.57±16.4**	49.28±22.6	21.76±17.1	79.41±10.9	66.98±18.3	75.40±15.6	67.33±16.7
DSEN-LGIE	**89.39±11.6**	22.22±10.9	**88.76±12.5**	**31.38±12.9**	**97.81±3.15**	**81.97±10.5**	**97.73±3.37**	**77.34±10.8**
Dataset	climate				Glass2			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	76.60	--	--	--
HD-Ensemble	--	--	--	--	86.65±7.41	--	76.44±14.1	--
EASE	77.86±5.01	49.80±5.75	76.38±6.07	45.74±6.72	63.35±12.3	**25.13±13.6**	54.23±13.7	18.53±16.7
HOEC	**85.61±1.65**	--	--	--	77.96±2.12	--	--	--
SPE	80.86±6.40	45.64±8.02	**80.34±7.62**	43.23±9.28	72.52±12.2	24.07±9.93	71.19±13.0	18.21±14.3
Imbalance-XGBoost	70.11±8.66	51.10±17.1	62.05±15.8	51.54±16.8	53.43±7.19	25.00±18.2	49.35±15.2	22.66±19.8
DSEN-LGIE	79.93±4.80	**70.60±4.56**	74.74±4.30	**73.87±4.09**	**87.69±4.45**	24.72±9.54	**86.70±5.05**	32.47±9.00
Dataset	german				Shuttle-c0-vs-c4			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	**1**	--	--	--
HD-Ensemble	80.01±9.90	--	69.61±16.0	--	**1±0**	--	**1±0**	--
EASE	**85.67±10.2**	**74.84±16.8**	83.64±13.5	73.76±17.4	99.53±1.21	99.15±1.37	99.52±1.24	99.10±1.44
HOEC	--	--	--	--	--	--	--	--
SPE	85.30±8.69	66.28±11.6	**83.85±10.4**	65.03±12.1	99.50±1.01	98.91±1.35	99.50±1.03	98.84±1.43
Imbalance-XGBoost	82.27±9.96	73.86±15.1	79.45±12.7	**74.47±14.3**	99.94±0.09	99.17±1.26	99.94±0.09	99.12±1.33
DSEN-LGIE	84.48±9.24	23.08±5.05	83.05±10.6	29.23±10.4	**1±0**	**1±0**	**1±0**	**1±0**
Dataset	Yeast1vs7				Ecoli4			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	77.50	--	--	--	96.40	--	--	--
HD-Ensemble	**84.41±8.70**	--	77.67±7.70	--	**98.83±1.90**	--	94.05±4.80	--
EASE	74.22±8.44	**36.93±10.7**	72.04±11.1	34.10±12.3	89.80±8.76	79.61±12.4	88.78±10.1	79.40±12.7
HOEC	77.07±1.94	--	--	--	--	--	--	--
SPE	72.46±7.07	26.67±5.30	71.78±7.72	24.96±7.80	90.88±8.87	76.76±12.1	89.90±10.6	77.03±11.6
Imbalance-XGBoost	61.99±8.12	33.11±9.73	44.70±12.3	34.51±11.2	81.72±12.6	71.95±20.9	78.04±16.7	73.19±20.1
DSEN-LGIE	83.72±6.06	30.00±8.23	**82.12±6.46**	**34.50±8.12**	98.54±4.88	**87.87±8.94**	**98.37±5.72**	**88.61±8.51**
Dataset	Page-blocks13vs4				Dermatology-6			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	--	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	99.57±1.40	96.44±4.46	99.56±1.48	96.37±4.53	99.87±0.28	98.00±4.27	99.87±0.28	97.98±4.31
HOEC	--	--	--	--	--	--	--	--
SPE	**99.78±0.34**	**96.83±4.70**	**99.77±0.34**	**96.77±4.76**	99.94±0.20	99.11±3.01	99.94±0.20	99.10±3.05
Imbalance-XGBoost	97.03±5.90	92.58±9.80	96.77±6.77	92.47±9.91	97.87±5.18	95.62±7.05	97.67±5.78	95.69±6.79
DSEN-LGIE	98.50±1.38	77.11±9.46	98.49±1.41	78.88±7.20	**1±0**	**1±0**	**1±0**	**1±0**
Dataset	svmguide3				Yeast1458vs7			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	63.80	--	--	--
HD-Ensemble	79.43±10.8	--	67.37±18.7	--	69.16±10.9	--	63.08±10.7	--
EASE	71.22±12.7	**29.80±14.6**	65.37±21.3	**27.97±17.1**	62.92±9.26	**17.33±7.88**	55.63±18.3	14.44±10.3
HOEC	--	--	--	--	66.08±3.44	--	--	--
SPE	63.50±10.6	14.42±5.91	60.22±10.6	12.17±10.0	58.98±7.58	10.71±2.34	57.55±7.01	7.380±6.24
Imbalance-XGBoost	53.58±7.79	10.73±10.4	12.99±14.7	10.83±12.9	51.09±3.08	4.210±9.68	6.520±14.9	4.460±12.3
DSEN-LGIE	**80.70±8.98**	15.38±3.27	**78.36±7.87**	17.37±5.21	**72.14±9.29**	15.08±3.70	**68.13±10.8**	**18.43±7.42**
Dataset	Yeast4				Winequality-red-4			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	**91.40**	--	--	--	--	--	--	--
HD-Ensemble	--	--	--	--	--	--	--	--
EASE	75.84±6.81	39.11±7.71	72.67±9.10	38.48±8.61	62.14±6.95	15.80±6.17	53.65±14.1	13.81±7.81
HOEC	79.29±1.23	--	--	--	61.84±2.14	--	--	--
SPE	81.80±7.09	30.25±5.45	80.96±8.71	33.82±7.09	66.32±6.91	11.60±2.22	65.49±7.80	12.34±5.06
Imbalance-XGBoost	65.18±6.67	37.70±4.43	54.15±3.71	37.38±5.05	51.31±2.67	4.700±7.94	9.260±15.1	4.55±9.43
DSEN-LGIE	87.71±4.70	**43.34±6.42**	**85.19±4.89**	**47.68±6.85**	**71.33±9.39**	**17.53±5.74**	**69.22±9.92**	**19.25±8.39**
Dataset	Yeast1289vs7				Abalone3vs11			

Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	60.50	--	--	--	--	--	--	--
HD-Ensemble	78.14±8.20	--	68.73±13.1	--	--	--	--	--
EASE	70.70±8.00	23.96±6.91	66.80±10.5	24.11±8.67	99.93±0.18	98.00±4.96	99.93±0.18	98.06±4.80
HOEC	--	--	--	--	--	--	--	--
SPE	65.18±8.30	10.64±2.66	64.10±8.79	11.18±6.03	99.97±0.12	99.14±3.39	99.97±0.12	99.17±3.29
Imbalance-XGBoost	55.95±6.68	16.42±6.96	25.16±14.9	17.11±8.71	99.56±2.33	96.74±6.18	99.53±2.56	96.86±5.96
DSEN-LGIE	**81.23±8.39**	**29.30±1.67**	**71.24±8.26**	**34.32±2.50**	**1±0**	**1±0**	**1±0**	**1±0**
Dataset	Yeast5				Ozone-onehr			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	97.00	--	--	--	--	--	--	--
HD-Ensemble	**99.12±0.50**	--	95.89±0.90	--	--	--	--	--
EASE	86.04±7.59	**68.27±11.1**	84.57±9.31	**68.05±11.4**	72.22±5.23	32.02±6.19	68.03±7.31	31.44±6.93
HOEC	--	--	--	--	73.97±1.88	--	--	--
SPE	93.64±6.24	60.38±9.32	93.31±6.98	62.81±9.23	81.96±4.76	24.74±3.09	**81.62±5.19**	29.87±4.25
Imbalance-XGBoost	79.10±8.98	62.77±13.6	75.55±11.9	62.91±13.5	55.02±4.91	15.68±3.81	53.23±8.41	17.66±5.49
DSEN-LGIE	97.55±5.15	63.43±9.52	**97.52±5.95**	66.92±8.83	**84.95±1.95**	**58.20±4.42**	77.24±3.23	**44.99±4.56**
Dataset	krvsk3vs11				Abalone21vs8			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	--	--	--	--
HD-Ensemble	1±0	--	99.87±0.10	--	--	--	--	--
EASE	96.59±2.91	93.75±3.94	96.48±3.06	93.77±3.96	80.41±1.50	**57.06±2.63**	73.1±2.79	**57.49±2.70**
HOEC	--	--	--	--	--	--	--	--
SPE	98.01±3.00	97.07±3.69	97.94±3.15	97.09±3.63	88.42±2.75	46.72±5.15	85.25±2.12	50.88±4.97
Imbalance-XGBoost	94.50±3.94	92.81±4.90	94.24±4.26	92.86±4.78	71.90±1.69	47.27±3.08	56.40±3.49	49.19±3.18
DSEN-LGIE	**1±0**	**1±0**	**1±0**	**1±0**	**91.95±1.57**	51.85±3.22	**91.17±1.68**	56.87±2.91
Dataset	Yeast6				Winequality-white3vs7			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	88.40	--	--	--	--	--	--	--
HD-Ensemble	94.19±3.80	--	86.59±6.10	--	--	--	--	--
EASE	91.65±7.97	42.11±9.21	91.46±8.29	41.90±9.53	86.08±2.12	**50.00±20.2**	85.36±3.00	**51.61±21.0**
HOEC	--	--	--	--	--	--	--	--
SPE	**96.21±5.68**	38.89±8.67	**96.13±6.07**	47.23±9.97	81.82±12.9	22.22±5.92	81.53±20.4	28.10±9.84
Imbalance-XGBoost	84.51±9.89	**52.63±8.82**	83.49±10.3	**53.17±8.34**	74.43±9.61	23.79±22.9	70.31±9.07	25.32±24.8
DSEN-LGIE	96.01±2.03	30.30±4.05	95.92±3.47	40.54±3.30	**92.63±6.79**	35.39±22.7	**91.99±8.05**	46.85±20.3
Dataset	Winequality-red8vs67				krvsk0vs8			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	--	--	--	--
HD-Ensemble	--	--	--	--	**1±0**	--	**99.57±0.20**	--
EASE	61.96±1.11	9.560±5.26	49.52±2.58	9.770±8.48	86.35±1.09	**70.42±1.80**	84.24±1.39	**70.75±1.81**
HOEC	68.09±3.80	--	--	--	--	--	--	--
SPE	58.27±1.09	5.330±1.87	56.57±1.02	4.740±6.23	93.97±6.99	53.39±9.04	93.57±8.00	57.71±8.77
Imbalance-XGBoost	52.86±6.10	8.730±1.78	10.92±2.19	9.610±2.07	71.73±1.71	51.59±1.06	63.21±1.93	54.08±1.01
DSEN-LGIE	**76.50±8.75**	**10.18±2.75**	**75.24±8.72**	**16.19±5.53**	98.17±2.02	58.30±3.89	98.14±2.06	64.55±3.31
Dataset	Shuttle-2vs5				kddbufferoverflowvsback			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	--	--	--	--
HD-Ensemble	**1±0**	--	99.86±0.10	--	**1±0**	--	**1±0**	--
EASE	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	99.69±1.51	**1±0**	99.70±1.47
HOEC	--	--	--	--	--	--	--	--
SPE	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	99.85±1.08	**1±0**	99.85±1.05
Imbalance-XGBoost	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**
DSEN-LGIE	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**	**1±0**
Dataset	krvsk0vs15				kddrootkitback			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	--	--	--	--
HD-Ensemble	**1±0**	--	**1±0**	--	**1±0**	--	**1±0**	--
EASE	98.42±3.75	97.07±5.33	98.32±4.01	97.14±5.25	97.75±4.25	85.71±4.74	97.62±4.50	86.50±4.54
HOEC	--	--	--	--	--	--	--	--
SPE	99.98±0.04	98.63±3.15	99.98±0.04	98.67±3.07	95.40±7.49	**94.64±10.2**	95.02±8.59	**94.98±9.48**
Imbalance-XGBoost	91.89±8.95	87.38±12.8	90.92±10.6	88.17±11.6	94.25±6.64	93.34±7.95	93.79±7.30	93.74±7.35
DSEN-LGIE	**1±0**	**1±0**	**1±0**	**1±0**	98.76±5.04	87.19±2.95	98.58±5.93	84.53±2.64
Dataset	skinnonskin				cod			
Measure	AUC	F-M	G-M	Mcc	AUC	F-M	G-M	Mcc
CBIS	--	--	--	--	--	--	--	--
HD-Ensemble	**1±0**	--	99.93±0.00	--	96.23±5.60	--	83.06±16.7	--
EASE	**1±0**	**98.67±2.67**	**1±0**	**98.71±2.59**	90.29±7.36	63.47±9.91	89.38±8.32	64.22±9.50
HOEC	--	--	--	--	--	--	--	--
SPE	98.52±2.96	96.08±5.05	98.46±3.08	96.20±4.89	92.74±7.83	75.15±11.3	92.02±8.92	76.69±10.6
Imbalance-XGBoost	96.31±6.24	93.76±9.07	95.97±7.10	94.10±8.33	86.26±11.1	**76.57±18.1**	83.93±14.4	**77.76±18.1**
DSEN-LGIE	99.29±0.86	78.32±3.93	99.11±0.86	82.18±3.83	**98.62±0.19**	54.67±1.64	**98.61±0.19**	61.48±1.97

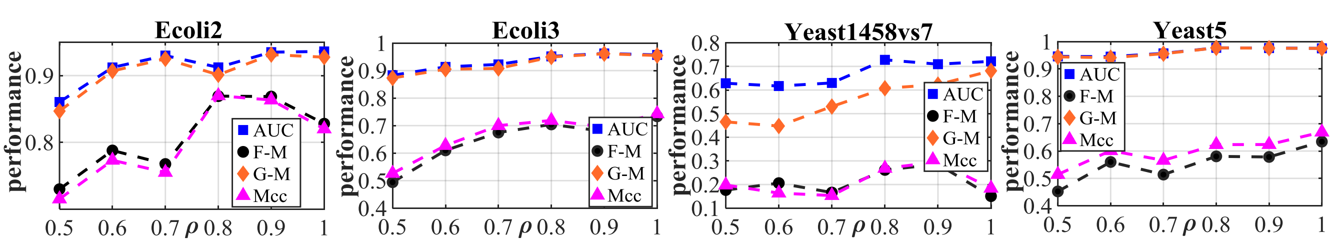
To verify the statistically significant difference between the methods, Wilcoxon paired signed-rank test was adopted, and six comparisons DSEN-LGIE vs CBIS, DSEN-LGIE vs HD-Ensemble, DSEN-LGIE vs EASE, DSEN-LGIE vs HOEC, DSEN-LGIE vs SPE and DSEN-LGIE vs Imbalance-XGBoost were tested. Table IX records the results. In Table IX, R+ is the sum of ranks for the datasets in which the first algorithm outperforms the second algorithm and R- is the sum of ranks for the second algorithm outperforms the first algorithm. It can be found R+ is always larger than R-, and all P-values are smaller than 0.05. P-value <0.05 means the hypothesis of equivalence in six comparisons were rejected. Thus, it can be stated that DSEN-LGIE is clearly better than the six state-of-the-art imbalanced ensemble methods.

TABLE IX
RESULT OF WILCOXON PAIRWISE TEST

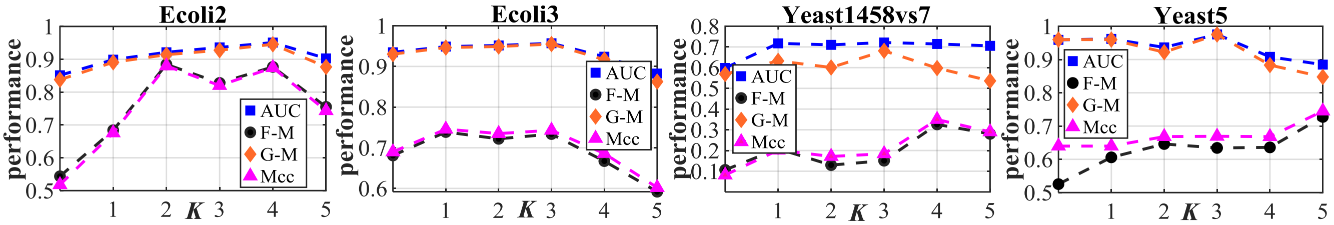
Comparison	Measure	R+	R-	P-value	Hypothesis (0.05)
DSEN-LGIE vs CBIS	AUC	189	64	4.24E-02	**Rejected**
	F-M	--	--	--	--
	G-M	--	--	--	--
	Mcc	--	--	--	--
DSEN-LGIE vs HD-Ensemble	AUC	118	35	4.95E-02	**Rejected**
	F-M	--	--	--	--
	G-M	178	12	8.37E-04	**Rejected**
	Mcc	--	--	--	--
DSEN-LGIE vs EASE	AUC	924	22	5.16E-08	**Rejected**
	F-M	666.5	323.5	4.53E-02	**Rejected**
	G-M	909	37	1.40E-07	**Rejected**
	Mcc	797	193	4.24E-04	**Rejected**
DSEN-LGIE vs HOEC	AUC	114	6	8.54E-04	**Rejected**
	F-M	--	--	--	--
	G-M	--	--	--	--
	Mcc	--	--	--	--
DSEN-LGIE vs SPE	AUC	897.5	48.5	2.96E-07	**Rejected**
	F-M	722	268	8.07E-03	**Rejected**
	G-M	856	90	3.75E-06	**Rejected**
	Mcc	786	204	6.84E-04	**Rejected**
DSEN-LGIE vs Imbalance-XGBoost	AUC	988	2	8.75E-09	**Rejected**
	F-M	719	271	8.95E-03	**Rejected**
	G-M	986	4	1.00E-08	**Rejected**
	Mcc	792	198	5.28E-04	**Rejected**

Parameter Analysis

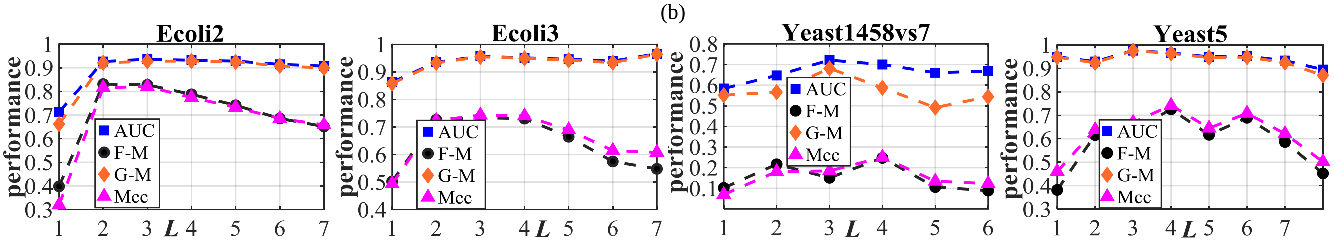
Fig. 8 visualize the effects of three parameters ρ, K, L on the performance of DSEN-LGIE. Let $\rho = 0.5, 0.6, 0.7, 0.8, 0.9, 1$, $K = 0, 1, 2, 3, 4, 5$. Four datasets which represented two types of datasets are chosen (e.g., high- and low-IR), including Ecoli2, Ecoli3, Yeast1458vs7 and Yeast5. As depicted in Fig.8, the performance of DSEN-LGIE on the four datasets increases when ρ increases. The possible reason is that SG is performed based on feature weighting, rather than random sampling or clustering. It ensures that the majority class samples in each subset are different, so an increase in ρ ensures that more majority class samples are used for training. For K, L, the performance of DSEN-LGIE on the four datasets increases in the preliminary stage. $K = 0$, $L = 0$ mean there are no SNC and multilayer sample transformation, and the increase of algorithm performance in the preliminary stage further illustrates the effectiveness of proposed DSEN-LG network. After K, L reach a certain value, the performance of DSEN-LGIE decreases. The possible reason is that a large K can lead to an increase in the dimensionality of the envelope sample and thus cause dimensional redundancy, which causes poor performance and if L is too large, poor quality deep envelope samples will be generated due to the fact that the high-layer samples contain less information. In summary, ρ could be selected between 0.7 and 1, K could be selected between 1 and 4, L could be selected between 3 and 6 considering four criteria.



(a)



(b)



(c)

Fig.8. Performance with different parameters on the DSEN-LGIE: (a) is for different ρ , (b) is for different K ,(c) is for different L