Sleep Stage Classification using Machine Learning

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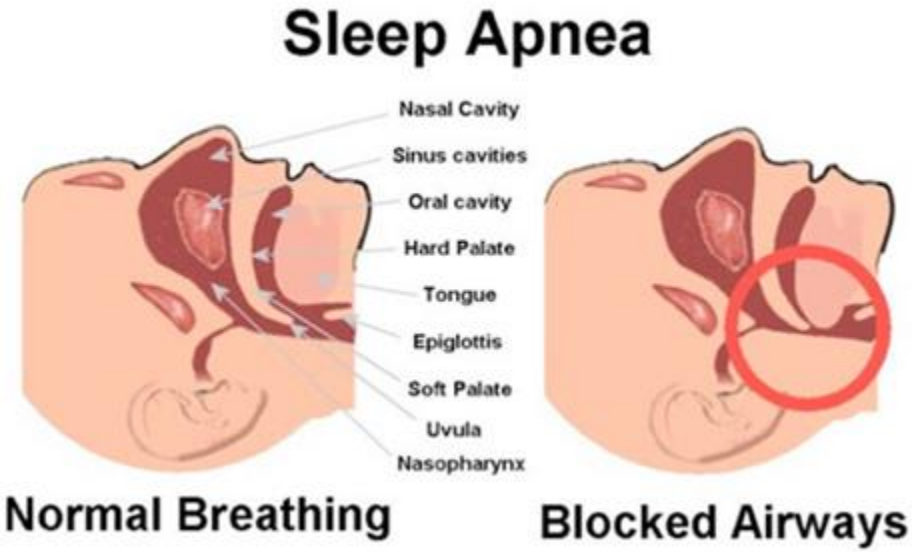
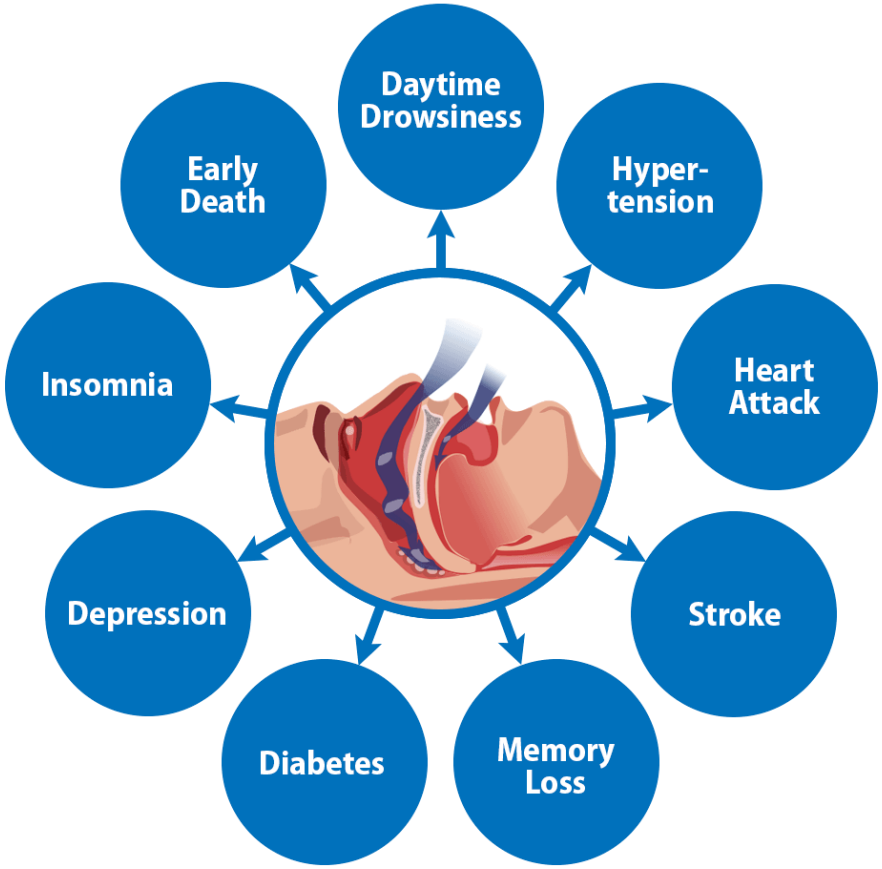
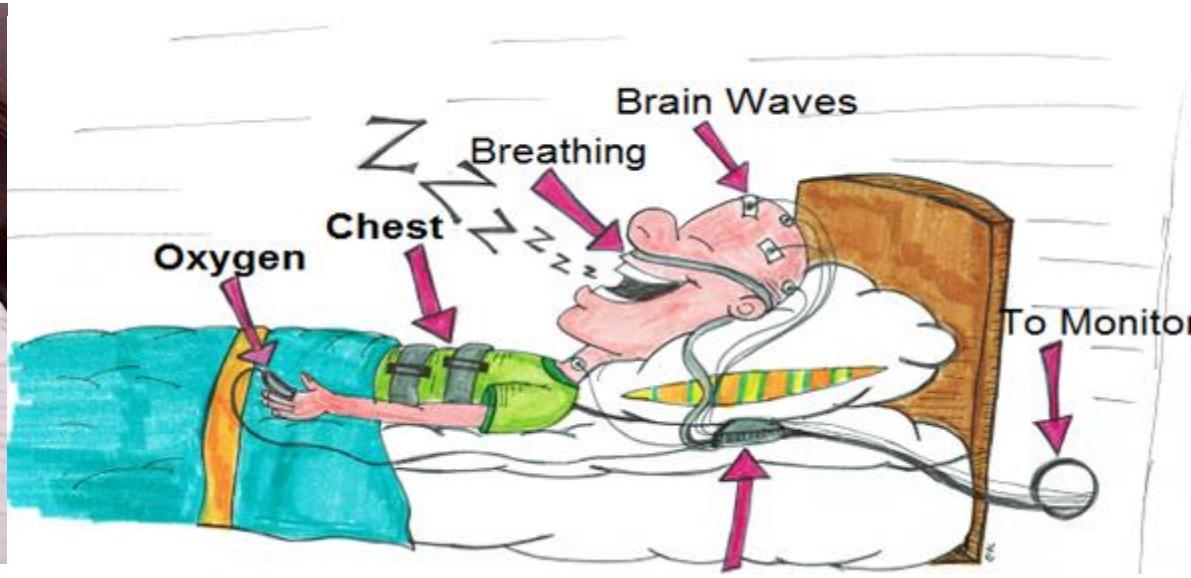
Outline

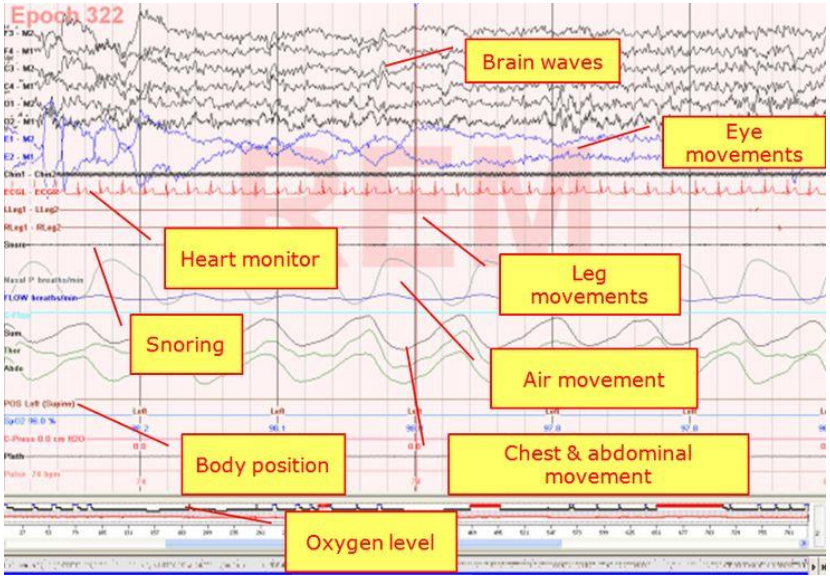
- Latar belakang
- Metode
- Hasil dan Analisis
- Simpulan

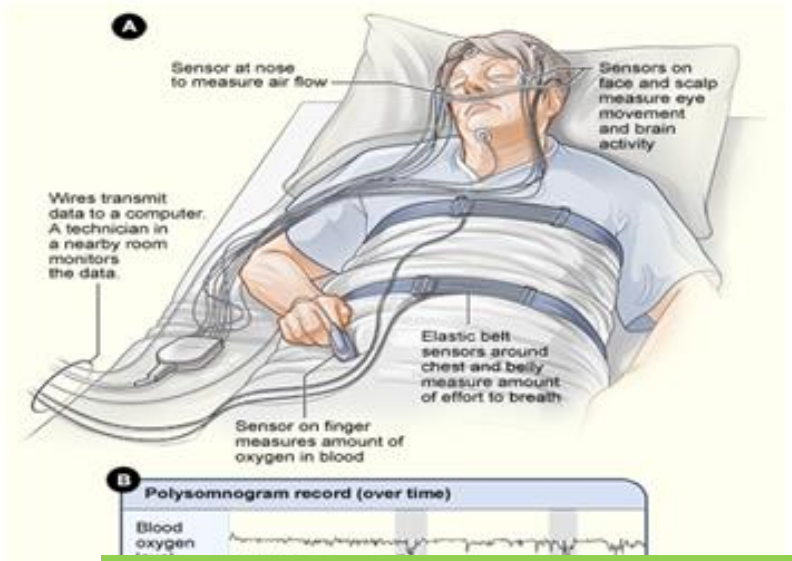
Latar belakang






Brain Waves
Breathing
Chest
Oxygen
To Monitor

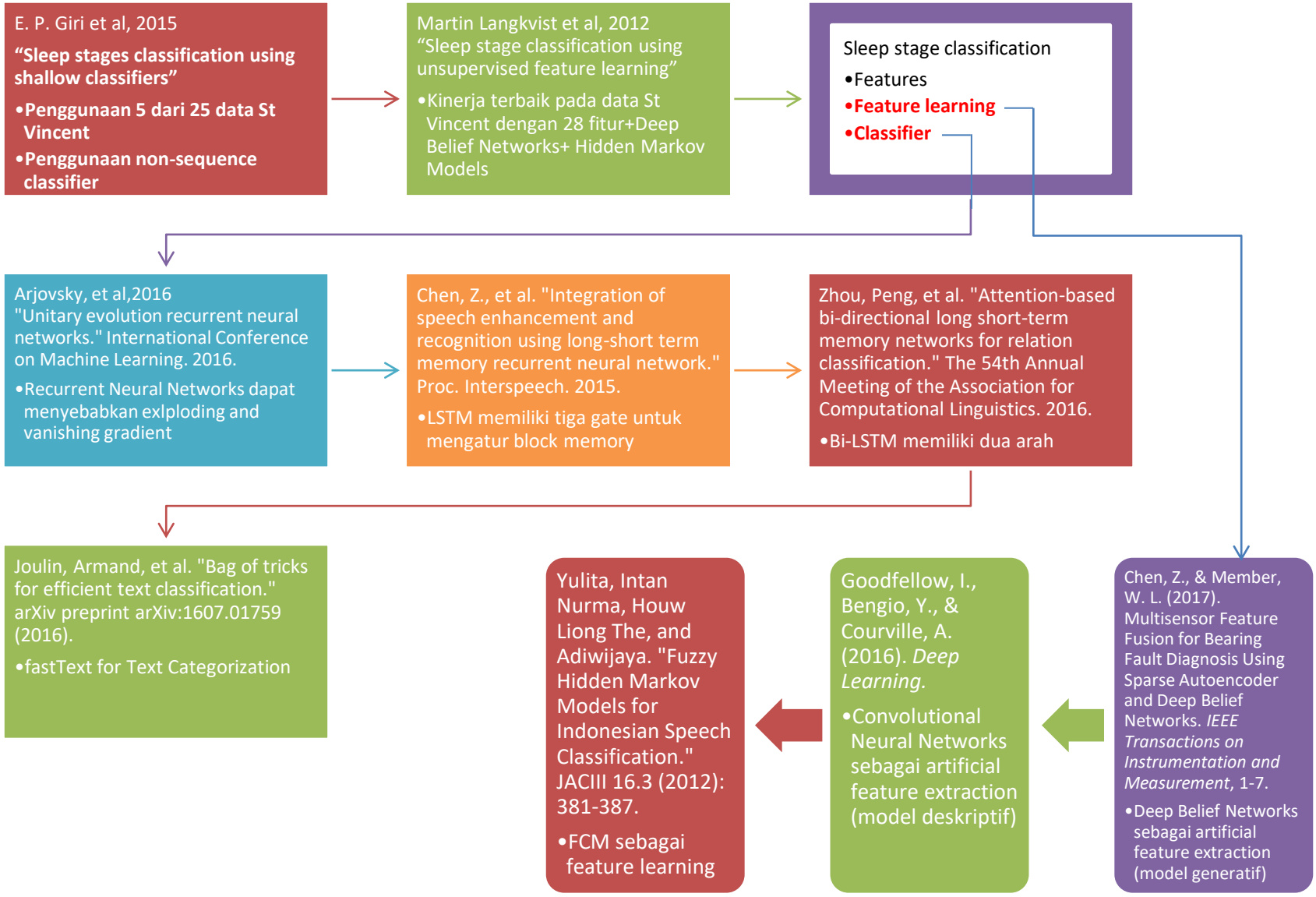

Epoch 322
Brain waves
Eye movements
Heart monitor
Leg movements
Snoring
Air movement
Body position
Chest & abdominal movement
Oxygen level



Automatic Sleep Stages Classification

>3 days

State of The Art



Rumusan

- Bagaimana mengolah dataset *polysomnogram?*
- Apa *handcrafted feature extraction* yang optimal*?*
- Metode apa yang paling tepat untuk *artificial feature extraction?*
- Apa *sequence classifier* yang paling optimal ?
- Bagaimana menggabungkan struktur antara *feature extraction* dan *sequence classifier*?
- Bagaimana mengukur performansi?

Tantangan yang dihadapi

Preprocessing

- Pra-proses dan data yang diperlukan

Handcrafted feature extraction

- Fitur yang optimal

Imbalance class

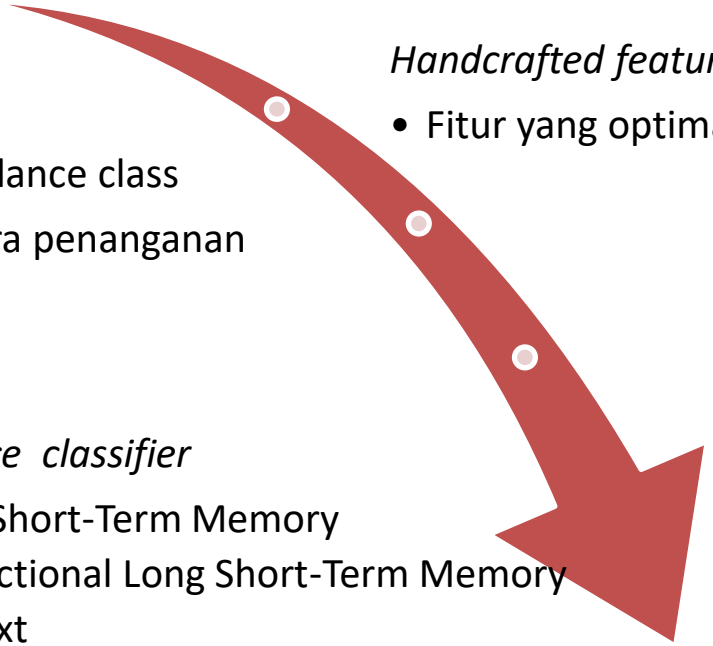
- Cara penanganan

Artificial feature extraction

- Kuantisasi DBN
- N *artificial features* DBN
- N *artificial features* FCM
- N *artificial features* CNN

Sequence classifier

- Long Short-Term Memory
- Bidirectional Long Short-Term Memory
- fastText



Batasan masalah

Penelitian ini terfokus pada penerapan artificial feature extraction dan classification

Preprocessing, handcrafted feature extraction, dan penanangan imbalance class tidak dieksplorasi lebih jauh

Data polysomonography yang digunakan hanya EEG, EMG, dan EOG

Kontribusi

- Kebaharuan penggunaan *artificial feature set* yang berasal dari derajat keanggotaan suatu data terhadap semua *stages* yang ada.
- Kebaharuan penerapan FCM sebagai *artificial feature extraction*
- Kebaharuan metode fastConvolutional untuk *sleep stage classification.*

Dataset

Terdiri atas dua data, yaitu:

- *Dataset St. Vincent's University Hospital* and *University College Dublin* yang terdiri dari 25 pasien (21 laki-laki dan 4 perempuan) yang mengalami *sleep disorder*.
- Dataset Rumah Sakit Mitra Kemayoran Grogol (MKG) yang melibatkan 10 responden berbadan sehat.

- ❑ Penskoran berdasarkan aturan Rechtschaffen and Kales
- ❑ Sleep stages terdiri dari *slow wave sleep* (SWS), *stage* 1, *stage* 2, *rapid eye movement* (REM), dan *awake.*

Perekaman Data

Karakteristik Tahap Tidur

Tahap tidur	Rate frekuensi EEG (Hz)	Amplitudo EEG	Waveband
N1	6-8 Frekuensi campuran	Rendah	Theta
N2	4-7 Sleep-spindles: 9-16 K-kompleks : 0.5-2 Frekuensi rendah	Medium	Theta
N3	1-4 Frekuensi rendah	Tinggi	Delta
R	Diatas 8 Frekuensi campuran	Rendah	Alpha/Beta

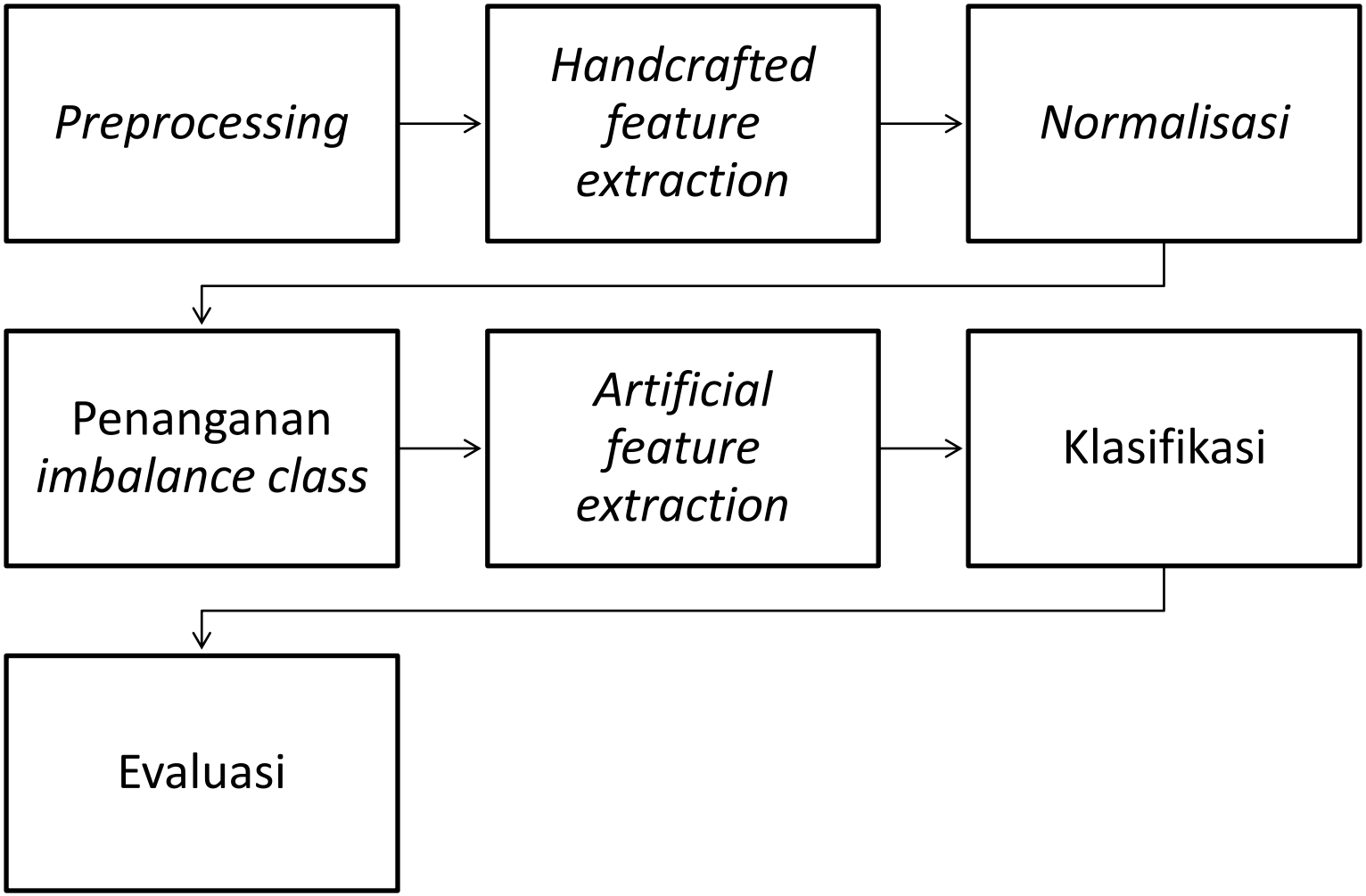
Data 1
(St Vincent)

Data	SWS	S2	S1	REM	Awake
1	2,610	5,160	6,390	4,650	3,630
2	4,920	7,620	3,180	5,700	5,040
3	1,560	7,530	2,670	3,750	9,270
4	7,440	2,850	5,430	5,760	2,760
5	3,810	12,420	1,680	3,960	2,520
6	2,490	9,060	2,280	990	7,890
7	4,230	7,320	7,830	2,670	5,700
8	2,370	13,950	3,600	5,070	2,220
9	3,540	8,850	2,670	1,260	10,680
10	4,380	10,110	1,740	5,820	3,870
11	3,330	5,190	4,290	2,010	9,510
12	0	8,010	7,800	2,460	4,950
13	4,380	8,820	6,000	2,040	6,240
14	1,950	11,760	1,080	5,790	3,090
15	4,110	8,400	1,740	570	9,840
16	5,880	10,560	1,410	5,580	2,130
17	1,920	4,650	6,240	4,680	5,070
18	3,810	11,100	3,660	3,840	4,980
19	3,930	6,450	2,100	1,320	9,810
20	2,070	6,810	6,780	1,710	8,460
21	4,110	9,930	3,390	5,040	4,650
22	270	3,720	11,070	1,380	4,890
23	4,170	7,230	3,000	7,380	3,360
24	1,050	15,900	1,860	4,170	3,810
25	1,560	6,150	4,200	2,880	6,840
Total	79,890	209,550	102,090	90,480	141,210

Data 2 (RS Mitra Keluarga Kemayoran)

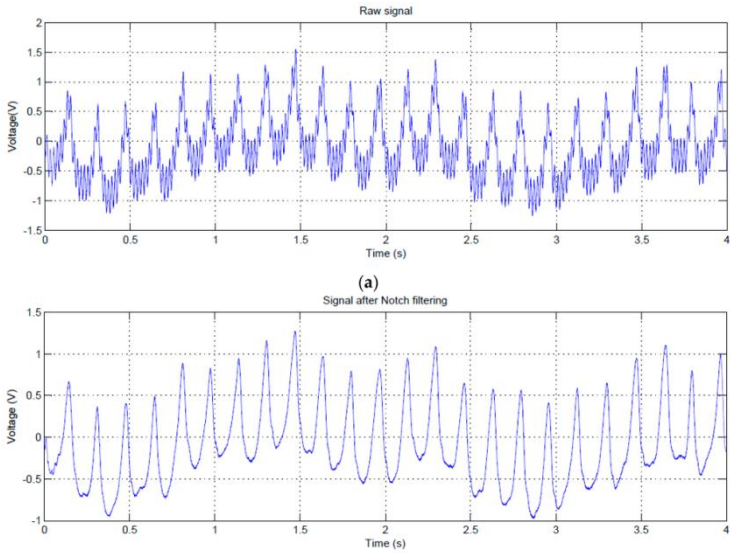
Data	N1	N2	N3	R	Awake
1	27	307	170	122	234
2	49	396	164	128	114
3	24	244	205	224	114
4	27	389	111	106	138
5	51	249	121	152	208
6	35	271	145	47	186
7	49	359	115	196	65
8	49	413	63	84	119
9	24	253	68	196	114
10	37	408	213	149	94
Total	372	3,289	1,375	1,404	1,386

The proposed automatic sleep stage classification

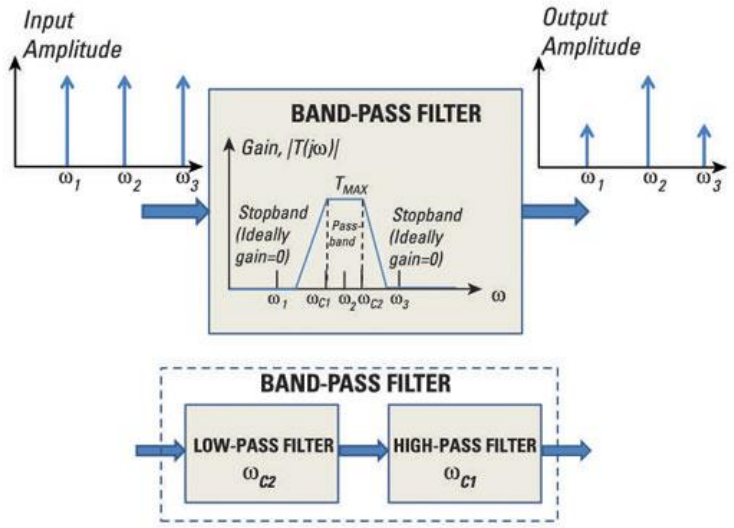


Preprocessing

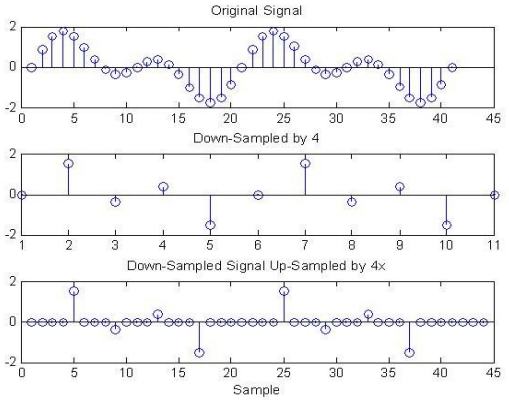
- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi



Notch Filtering

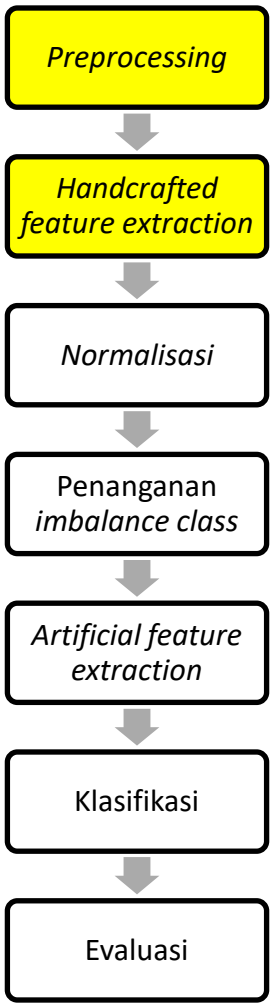


Down-Sampling and Up-Sampling



Signal yang digunakan:
electroencephalography (EEG) sebanyak satu *channel, electromyography* (EMG) sebanyak satu *channel,* dan *electrooculography* (EOG) sebanyak *dua channel.*

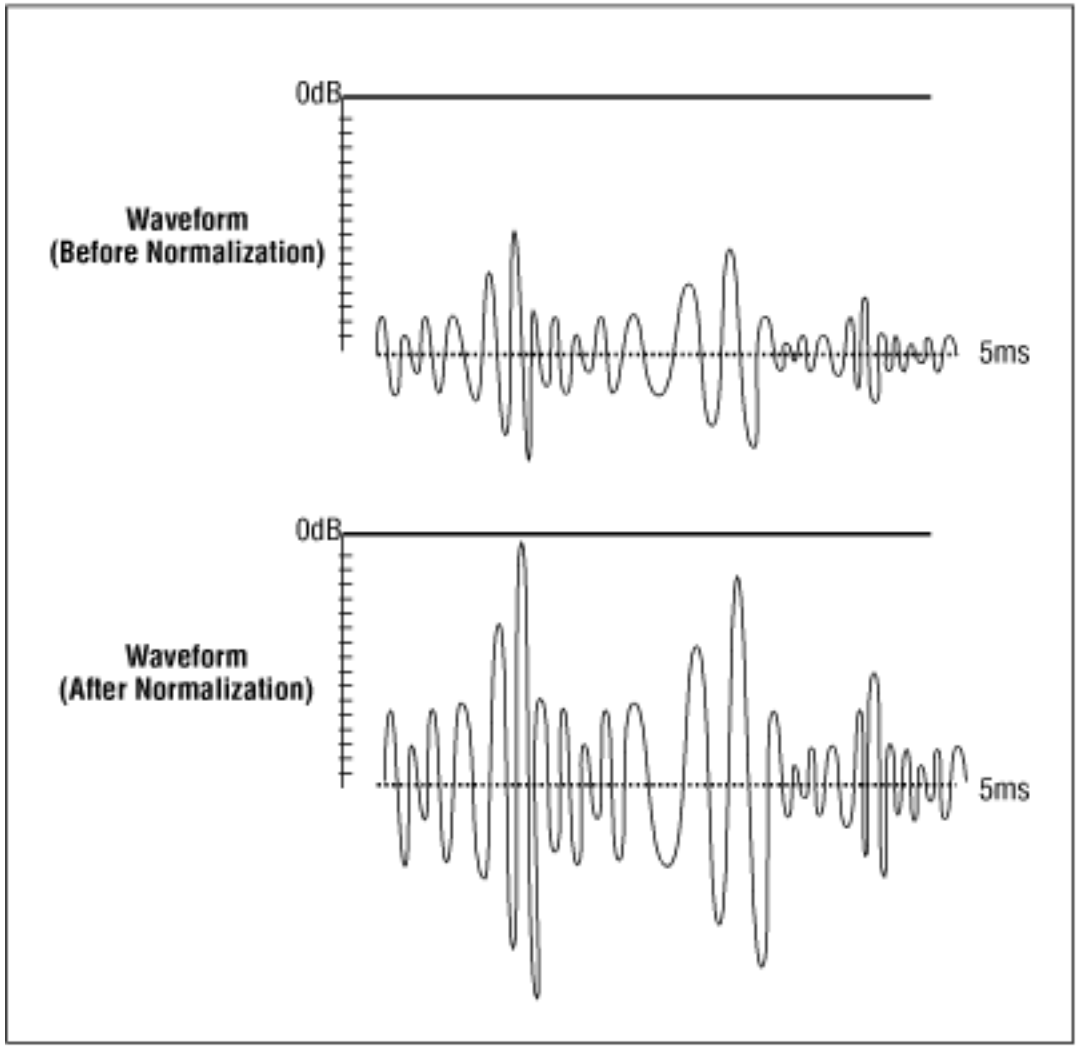
Handcrafted Feature Extraction



No	Features	Description
1	EEG delta	the relative power of frequency bands in delta (0.5-4 Hz) for signal EEG, EOG, and EMG
2	EOG delta	
3	EMG delta	
4	EEG theta	the relative power of frequency bands in theta (4-8 Hz) for signal EEG, EOG, and EMG
5	EOG theta	
6	EMG theta	
7	EEG alpha	the relative power of frequency bands in alpha (8-13 Hz) for signal EEG, EOG, and EMG
8	EOG alpha	
9	EMG alpha	
10	EEG beta	the relative power of frequency bands in beta (13-20 Hz) for signal EEG, EOG, and EMG
11	EOG beta	
12	EMG beta	
13	EEG gamma	the relative power of frequency bands in gamma (20-64 Hz) for signal EEG
14	EOG gamma	
15	EOG gamma	
16	EMG median	The average for the absolute value of signal EMG
17	EOG correlation	The eye correlation value of the OOG (left and right)
18	EEG kurtosis	The kurtosis of signal EEG, EOG, EMG
19	EOG kurtosis	
20	EMG kurtosis	
21	EOG standard deviation	The standard deviation of signal EOG
22	EEG entropy	The entropy of signal EEG, EOG, EMG
23	EOG entropy	
24	EMG entropy	
25	EEG spectral mean	The spectral mean of signal EEG, EOG, EMG
26	EOG spectral mean	
27	EMG spectral mean	
28	EEG fractal	The slope of a linear match of spectral density that is negative in the double logarithmic graph

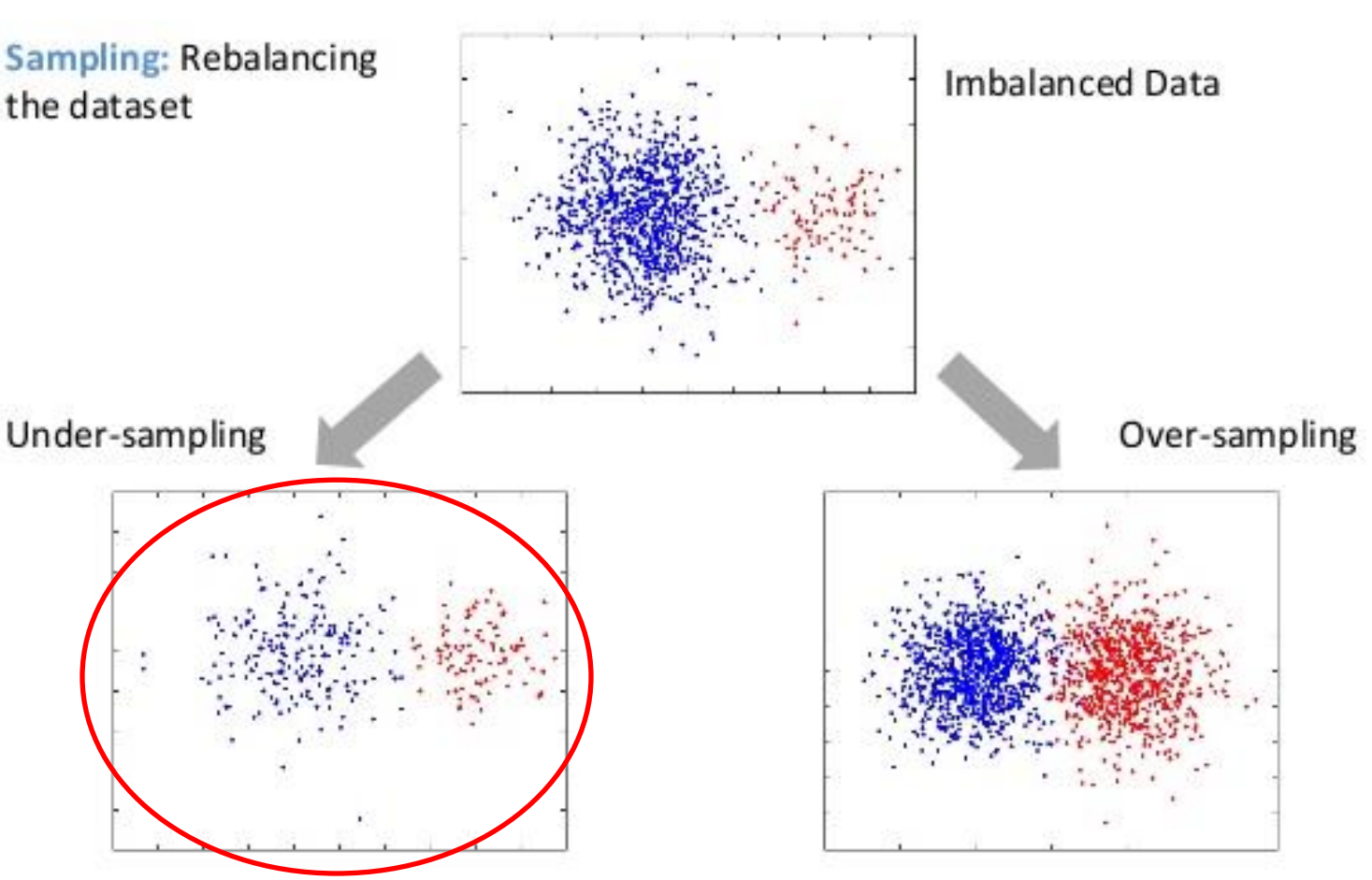
Normalisasi

- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi

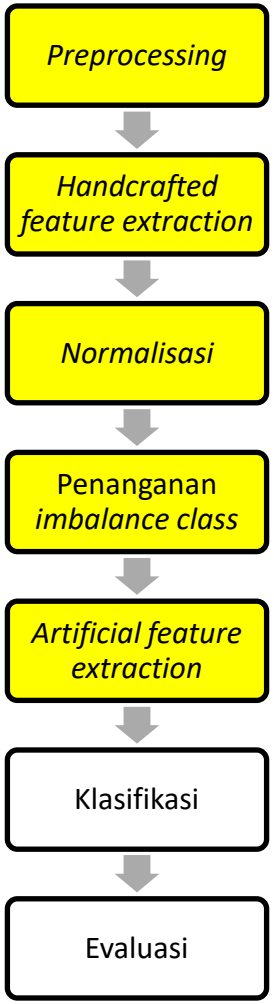


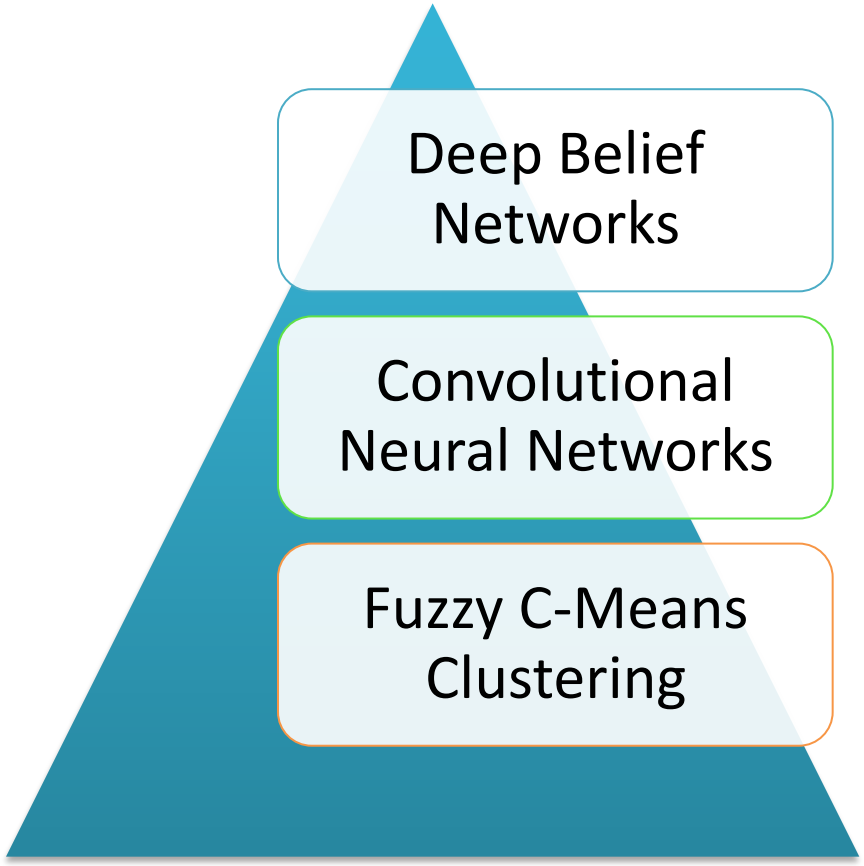
Penanganan Imbalance Class

- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi



Artificial Feature Extraction





Artificial Feature Extraction: Deep Belief Networks (DBN)

- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi

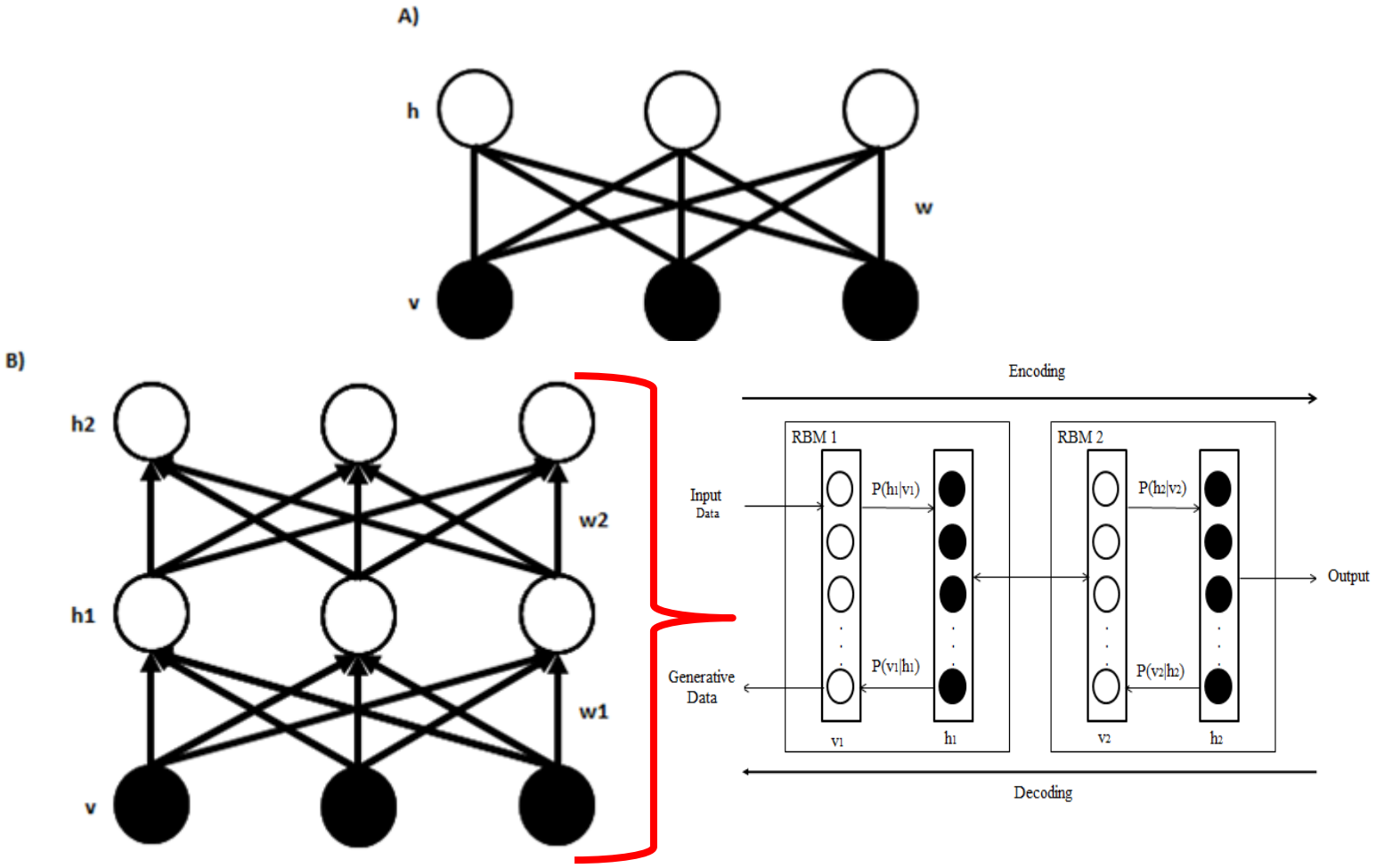
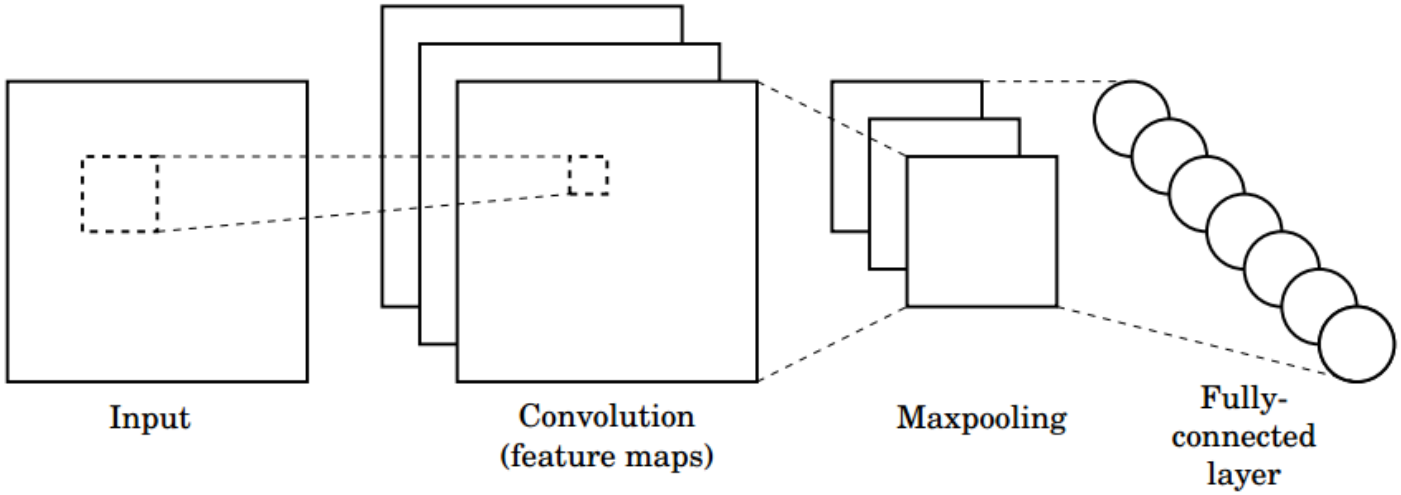


Fig. 1. (a) RBM; (b) DBN.

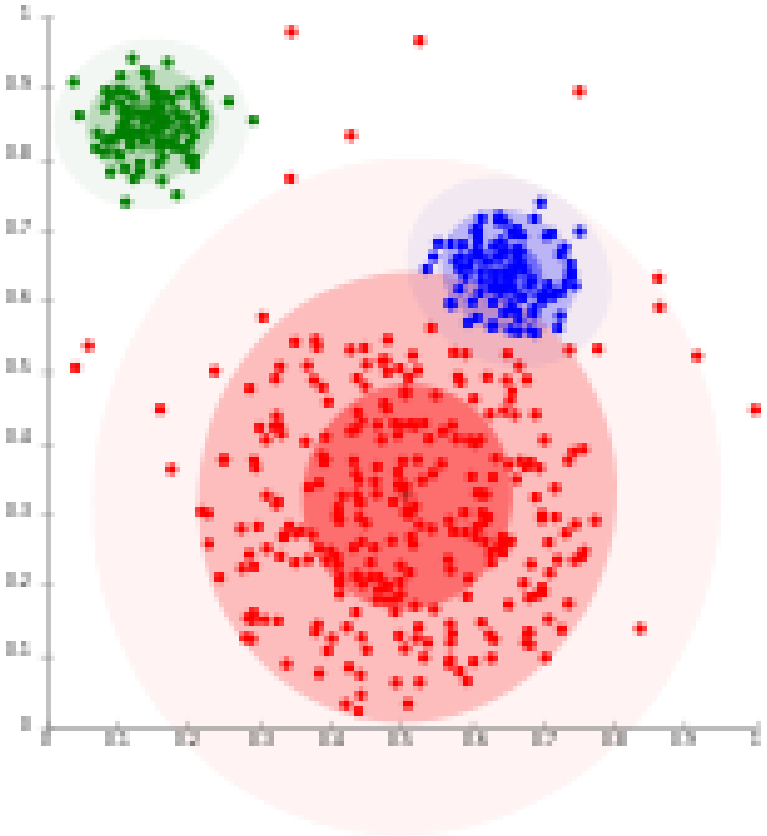
Artificial Feature Extraction: Convolutional Neural Networks (CNN)

- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi

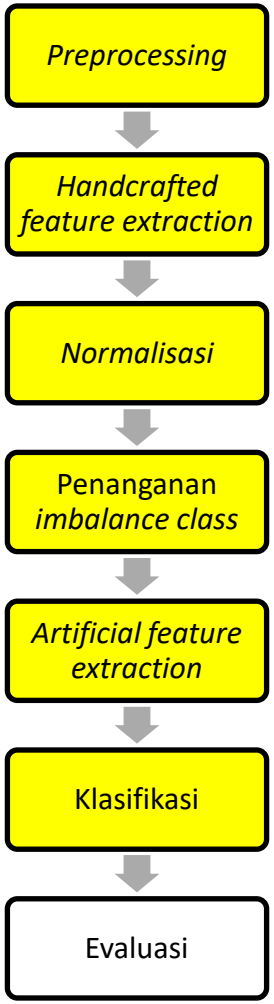


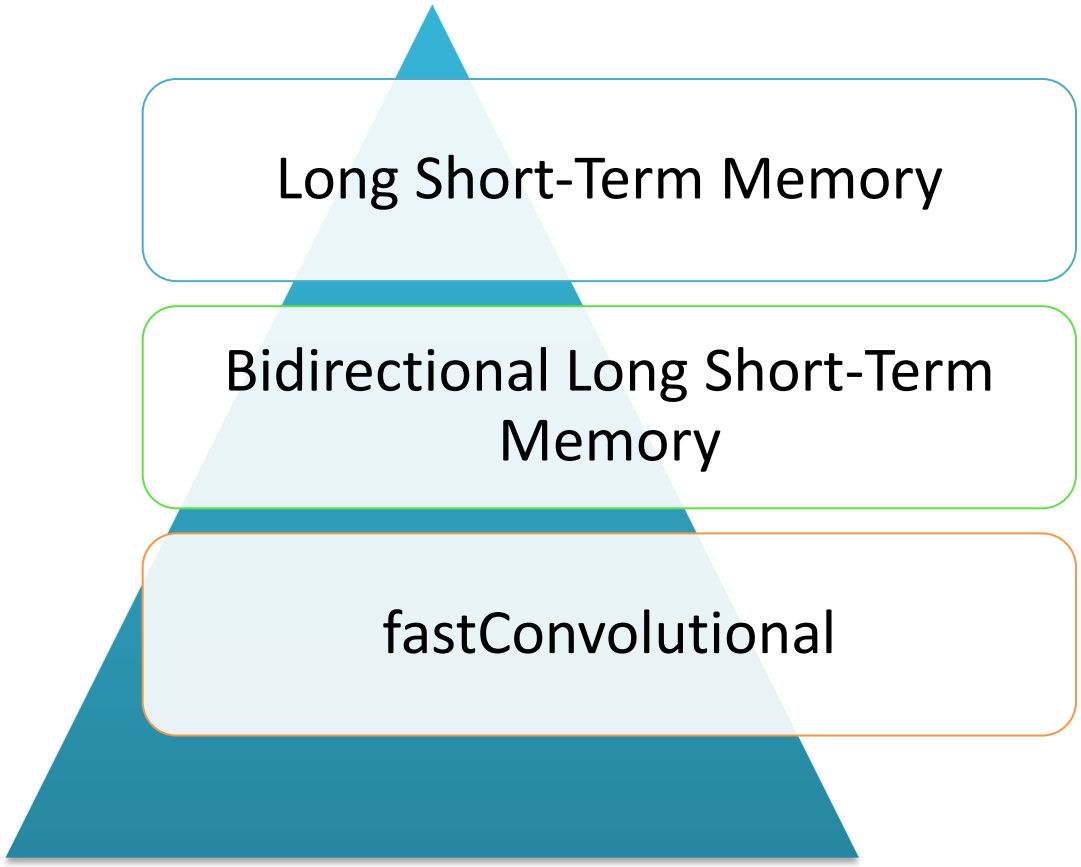
Artificial Feature Extraction: Fuzzy C-Means Clustering (FCM)

- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi



Klasifikasi





Klasifikasi:
Long Short Term-Memory

Preprocessing

Handcrafted feature extraction

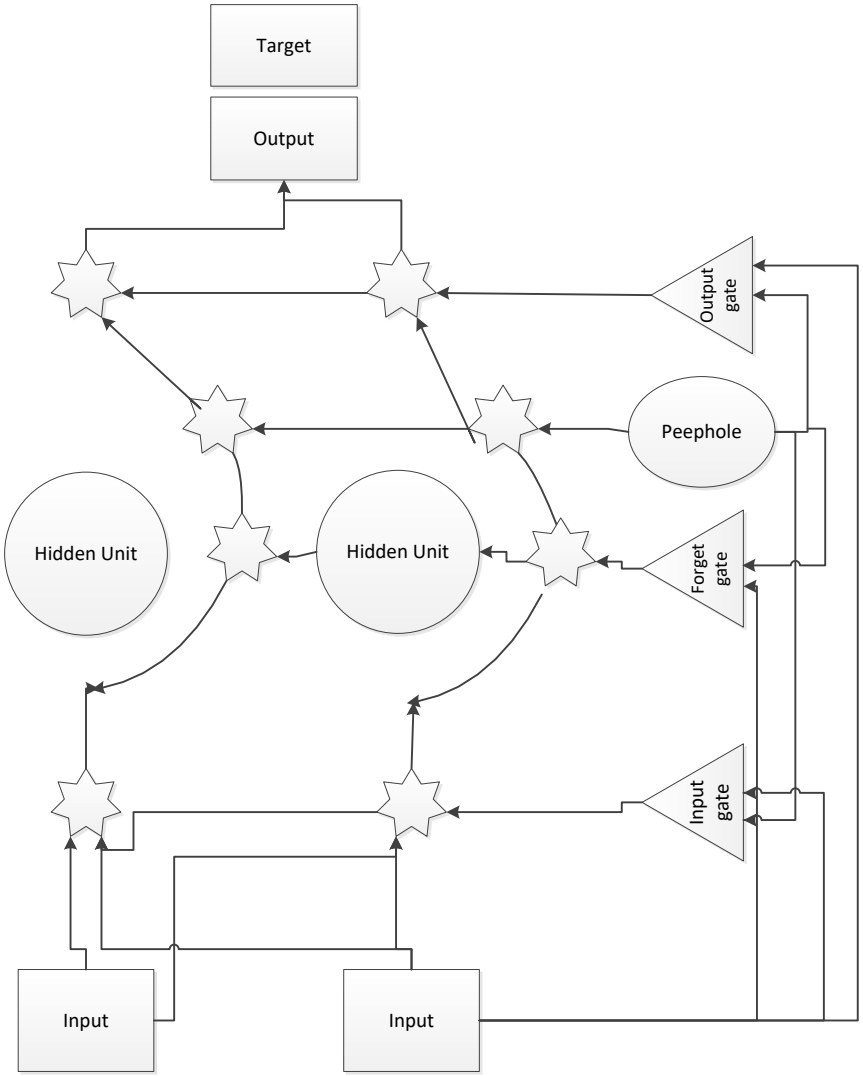
Normalisasi

Penanganan *imbalance class*

Artificial feature extraction

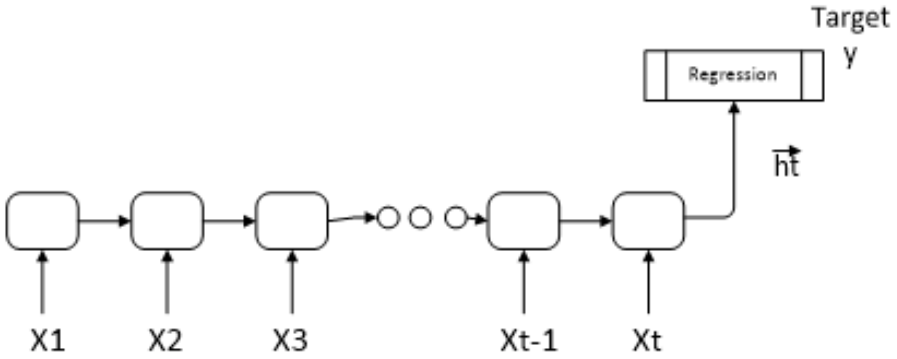
Klasifikasi

Evaluasi

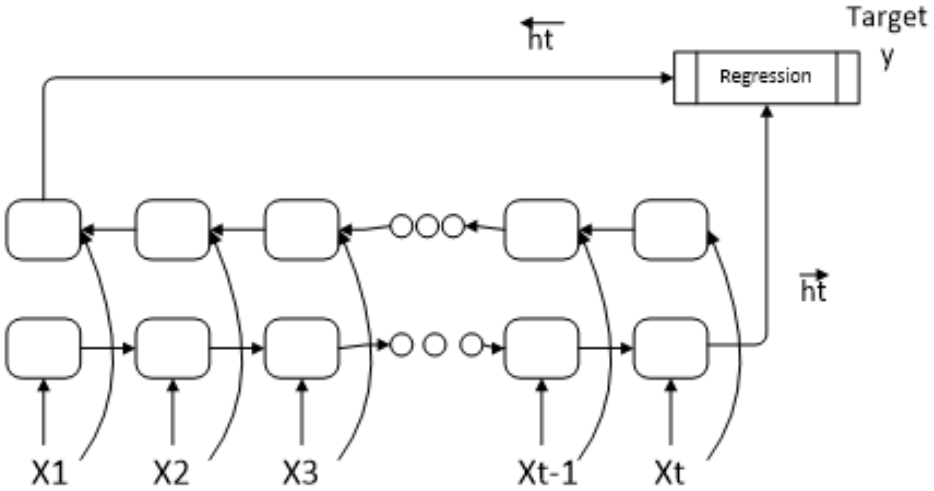


Klasifikasi:
Bidirectional Long Short Term-Memory

- *Preprocessing*
- *Handcrafted feature extraction*
- *Normalisasi*
- Penanganan *imbalance class*
- *Artificial feature extraction*
- Klasifikasi
- Evaluasi

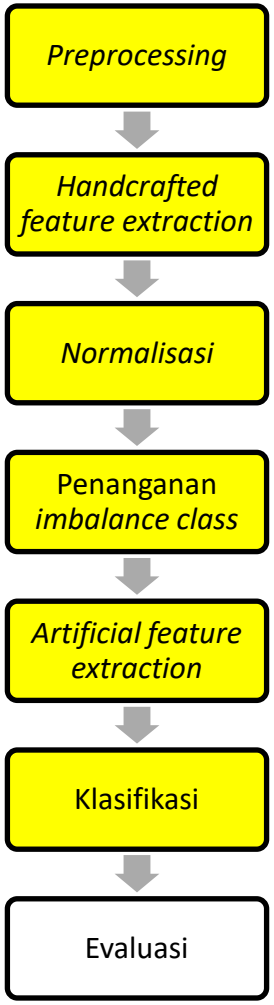


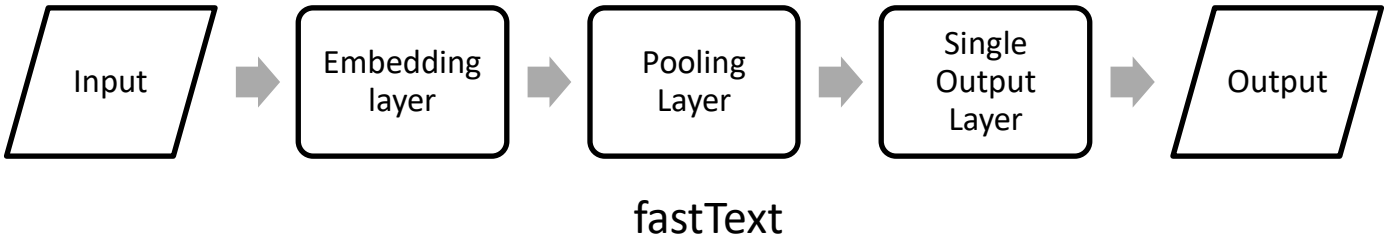
Gambar 2-2 Mekanisme LSTM



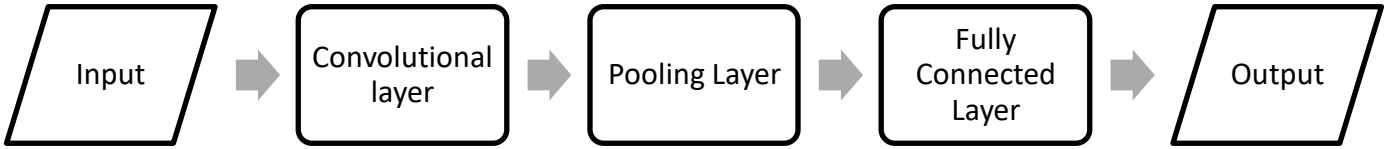
Gambar 2-3 Mekanisme Bi-LSTM

Klasifikasi: fastConvolutional

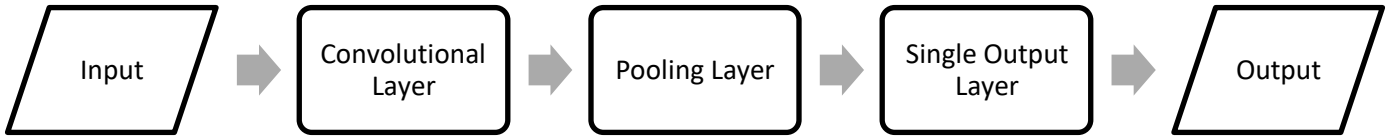




fastText

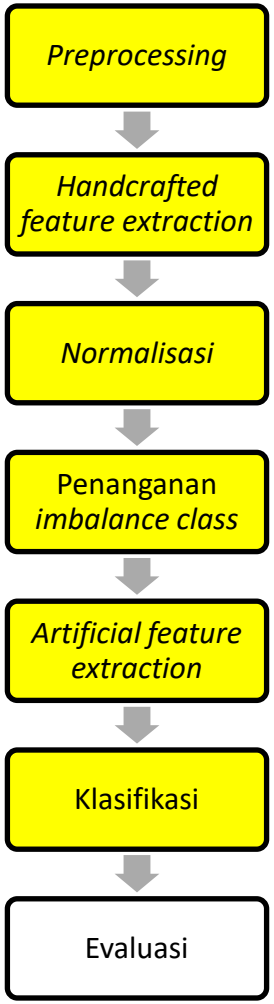


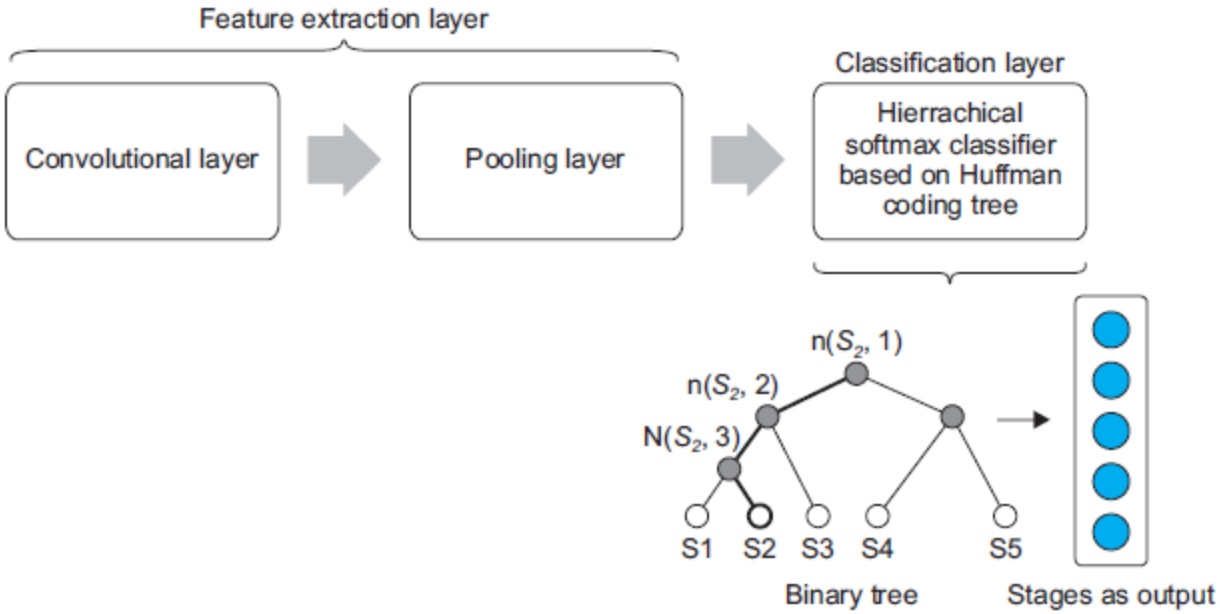
Convolutional Neural Networks



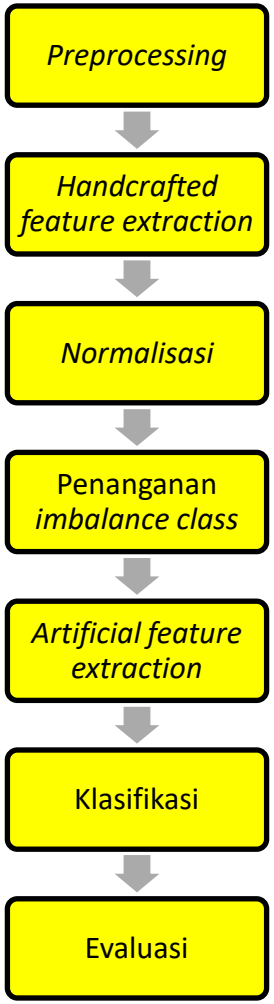
fastConvolutional

Klasifikasi: fastConvolutional (cont'd)





Evaluasi



- Akurasi
- Precision
- Recall
- F-measure

Hasil dan Analisis

- Features
- Shallow classifier
- Deep Belief Networks
- Hidden Markov Models
- Long Short-Term Memory
- Bidirectional Long Short-Term Memory
- fastConvolutional

Features: data mentah (MKG)

No	Metode	Dataset	Akurasi	*Precision*	*Recall*	*F-measure*
1	CNN Bi-LSTM (fold 1 s/d 9) *Filters* = 64 *Activation=Sigmoid* *Optimizer=Adam* *Epoch*=100	MKG	0.57	0.61	0.59	0.58
2	CNN LSTM (fold 1 s/d 5) *Filters* = 128 *Activation=Softmax* *Optimizer=Rmsprop* *Epoch*=1000	MKG	0.58	0.61	0.58	0.57

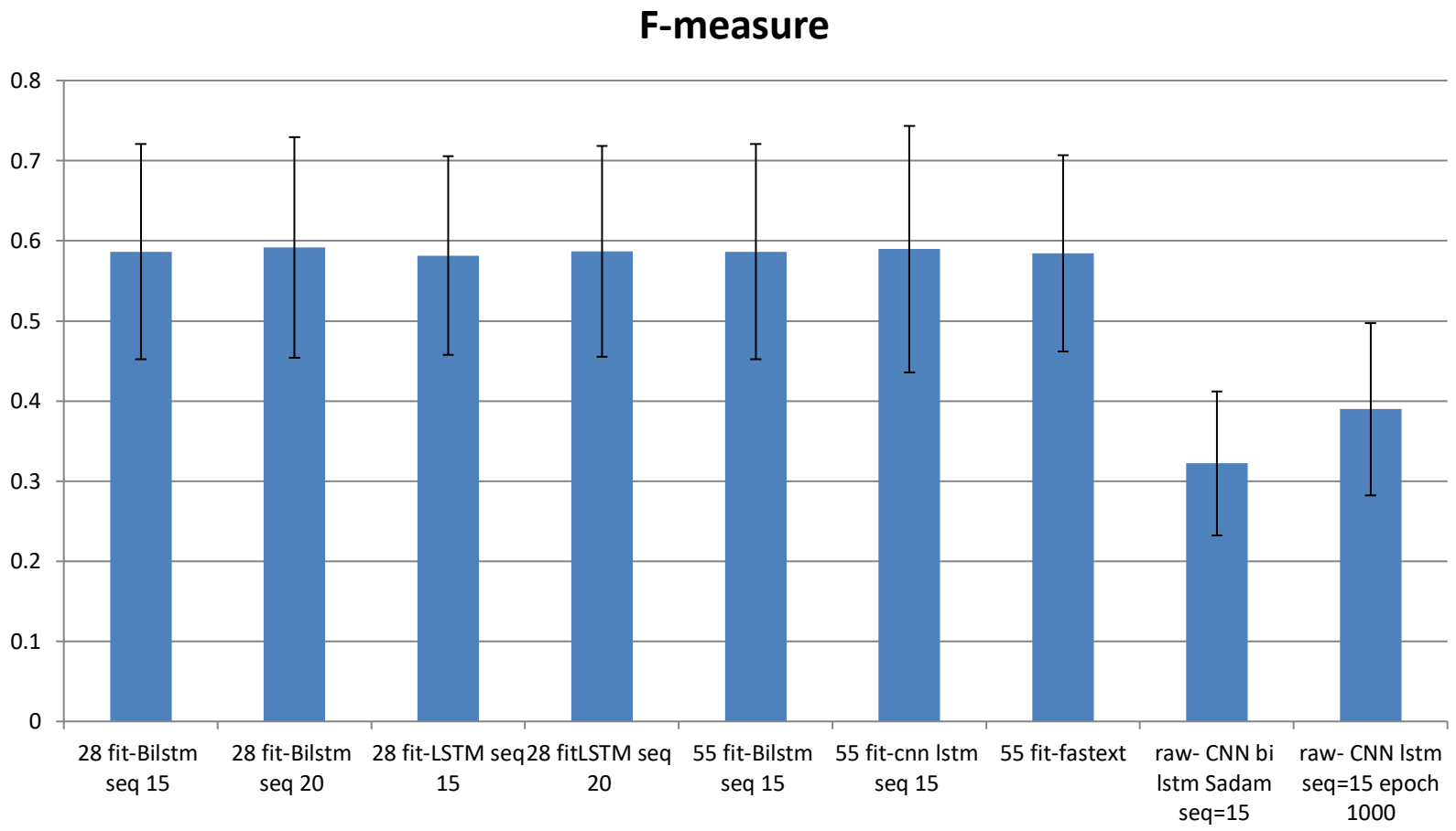
Features: 28 Handcrafted Features

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*
1	LSTM *Activation=softmax* *Optimizer=rmsprop* *Epoch*=100	MKG	64	5	0.54	0.57	0.54	0.54
2	LSTM *Activation=softmax* *Optimizer=rmsprop* *Epoch*=100	MKG	64	10	0.57	0.59	0.57	0.56
3	LSTM *Activation=softmax* *Optimizer=rmsprop* *Epoch*=100	MKG	64	15	0.59	0.61	0.59	0.59
4	LSTM *Activation=softmax* *Optimizer=rmsprop* *Epoch*=100	MKG	64	20	0.59	0.63	0.59	0.59
5	BI-LSTM *Activation=softmax* *Optimizer=rmsprop* *Epoch*=100	MKG	128, 64, 32	15	0.58	0.61	0.59	0.58

Features: 55 Handcrafted Features

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*
1	Bi-LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	64	15	0.58	0.61	0.59	0.58
2	CNN LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	128	15	0.58	0.61	0.59	0.58
3	CFasttext *Activation=tanh,soft max* *Optimizer=Rmsprop* *Epoch*=100	MKG	128	No	0.57	0.61	0.59	0.58

Simpulan: Hand-crafted Features



Shallow classifier (St Vincent)

Tabel 4-4 Implementasi Shallow Classifier dan 28 handcrafted feature extraction

Parameter	MLP	Logit	J48	KNN	BN	Bagging	Adabost	SMO	RF	NB
Akurasi	59.87%	57.19%	54.54%	53.93%	54.59%	64.76%	35.29%	57.88%	64.62%	51.30%
Precision	59.30%	56.20%	54.30%	53.40%	54.00%	64.20%	13.90%	56.90%	64.00%	52.70%
Recall	59.90%	57.20%	54.50%	53.90%	54.60%	64.80%	35.30%	57.90%	64.60%	51.30%
F-Measure	59.00%	56.40%	54.40%	53.30%	53.90%	64.20%	19.90%	57.00%	64.00%	50.80%
Training time (s)	2257.78	222.9	606.74	0.14	20.85	3586.51	5.07	3229.37	617.44	4.06

Tabel 4-5 Implementasi DBN +Shallow Classifier

Parameter	MLP	Logit	j48	KNN	BN	Bagging	Adabost	SMO	RF	NB
Akurasi	57.46%	58.51%	56.76%	53.04%	56.75%	57.89%	36.56%	58.07%	56.07%	57.21%
Precision	56.50%	57.20%	55.40%	52.00%	57.00%	56.70%	16.50%	57.40%	54.90%	55.2%
Recall	57.50%	58.50%	56.80%	53.00%	56.70%	57.90%	36.60%	58.10%	56.10%	57.2%
F-Measure	56.20%	57.40%	55.70%	52.20%	56.60%	56.90%	22.00%	57.50%	55.30%	55.1%
Training time (s)	380.54	382.94	112.34	0.04	4.33	690.49	1.52	2573.27	213.06	0.81

Note:

DT=decision tree, NB=Naïve Bayes

BN=Bayesian Networks, SVM=Support Vector Machines

KNN=K-Nearest Neighbor, DBN=Deep Belief Networks

Deep Belief Networks (DBN)

Fold	Akurasi	Precision	Recall	F-measure	Training time (s)
1	49.65%	54.09%	51.57%	51.78%	4807.47
2	62.10%	59.87%	58.87%	60.97%	4151.39
3	52.61%	51.51%	51.39%	52.06%	3908.76
4	56.56%	59.24%	57.14%	57.87%	3651.32
5	58.79%	72.09%	55.20%	64.76%	8030.59
6	58.50%	46.01%	43.36%	51.51%	3985.46
7	60.23%	64.13%	59.93%	62.12%	3237.94
8	54.93%	62.96%	42.88%	58.67%	7292.61
9	47.51%	47.70%	45.22%	47.61%	3354.14
10	75.78%	63.70%	65.35%	69.22%	2178.66
11	53.26%	50.74%	46.27%	51.97%	2515.04
12	56.83%	38.05%	40.96%	45.58%	3251.04
13	52.48%	58.48%	51.83%	55.32%	2837.93
14	52.51%	29.35%	41.71%	37.66%	1985.18
15	71.36%	43.80%	51.37%	54.28%	2132.02
16	57.28%	49.39%	50.32%	53.04%	4239.12
17	45.78%	54.58%	40.91%	49.79%	3425.02
18	67.93%	71.16%	61.67%	69.51%	2095.93
19	65.84%	58.06%	54.10%	61.71%	1939.35
20	68.31%	42.87%	47.02%	52.68%	3192.24
21	66.88%	53.88%	51.23%	59.68%	2174.01
22	24.05%	20.11%	28.32%	21.90%	1524.74
23	76.52%	58.17%	43.58%	66.09%	2455.82
24	51.41%	42.50%	33.64%	46.53%	1249.67
25	54.51%	35.94%	37.01%	43.32%	732.05
Rata-rata	57.66%	51.53%	48.43%	53.82%	3213.9

%	**Classified as**				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	79.15	14.05	3.63	2.57	0.59
Stage 2	20.98	51.68	11.22	13.5	2.61
Stage 1	6.27	27.3	26.27	10.04	30.13
REM	4.68	16.27	7.74	63.57	7.74
Awake	1.92	4.54	19.14	13.08	61.32

DBN HMM

Fold	Akurasi	Precision	Recall	F-measure	Training time of HMM (s)	Training time of DBN HMM (s)
1	69.18%	73.15%	73.56%	71.11%	0.21	4807.68
2	81.25%	75.93%	81.49%	78.50%	0.18	4151.57
3	71.27%	63.27%	66.65%	67.03%	0.13	3908.89
4	77.07%	85.51%	80.95%	81.07%	0.11	3651.43
5	73.77%	82.55%	68.77%	77.91%	0.11	8030.70
6	84.09%	49.56%	57.16%	62.36%	0.08	3985.54
7	70.88%	75.54%	66.13%	73.13%	0.08	3238.02
8	86.49%	87.57%	74.30%	87.03%	0.08	7292.69
9	59.10%	63.07%	55.03%	61.02%	0.08	3354.22
10	92.16%	75.17%	79.10%	82.80%	0.08	2178.74
11	67.34%	57.09%	55.08%	61.79%	0.06	2515.10
12	76.72%	44.31%	41.62%	56.17%	0.04	3251.08
13	75.24%	76.22%	71.10%	75.73%	0.07	2838.00
14	66.60%	35.80%	43.88%	46.57%	0.08	1985.26
15	95.77%	58.09%	60.00%	72.32%	0.09	2132.11
16	84.70%	68.12%	69.60%	75.51%	0.05	4239.17
17	66.26%	77.06%	66.16%	71.25%	0.07	3425.09
18	91.12%	76.98%	77.78%	83.46%	0.06	2095.99
19	93.69%	77.11%	68.50%	84.60%	0.06	1939.41
20	99.96%	59.90%	59.96%	74.91%	0.02	3192.26
21	91.20%	68.58%	63.24%	78.29%	0.04	2174.05
22	16.34%	21.25%	30.97%	18.48%	0.02	1524.76
23	79.56%	56.07%	56.28%	65.78%	0.03	2455.85
24	87.63%	50.86%	55.38%	64.36%	0.04	1249.71
25	66.54%	46.77%	43.08%	54.93%	0.03	732.08
Rata-rata	76.96%	64.22%	62.63%	69.05%	0.03	3213.98

%	**Classified as**				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	90.24	9.57	0.02	0.01	0.16
Stage 2	4.14	82.86	6.92	5.71	0.37
Stage 1	0.14	30.39	37.24	5.65	26.58
REM	0	11.02	2.99	80.59	5.4
Awake	0.01	3.06	13.66	7.7	75.58

LSTM: **Tanpa *artificial feature extraction***

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*	*Training time (s)*
1	LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	128,64,32	5	0.56	0.58	0.56	0.55	2193.3
2	LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	128,64,32	15	0.58	0.61	0.59	0.58	5818.31
3	LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	128,64,32	20	0.58	0.61	0.59	0.58	6226.91
4	LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	*St Vincent*	128,64,32	20	0.71	0.85	0.71	0.74	2508.55

LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**

No	Methods	Length of Previous Data	Accuracy	Precision	F-measure	Training Time (s)
1	qLSTM	10	69.36%	84.42%	73.10%	12523.07
2	qLSTM	15	70.60%	85.16%	74.09%	8542.661
3	qLSTM	20	71.64%	85.44%	74.93%	15959.27
4	qLSTM	25	72.20%	85.93%	75.22%	16126.8

LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**

•Confusion Matrix for qLSTM with length=10

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	69.17	0.17	3.33	17.15	10.18
Stage 2	0.16	88.45	10.72	0.40	0.27
Stage 1	1.13	8.94	70.13	11.06	8.74
REM	31.03	1.60	27.08	31.97	8.32
Awake	5.62	0.53	12.90	5.81	75.14

•Confusion Matrix for qLSTM with length=15

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	69.59	0.11	3.29	17.20	9.81
Stage 2	0.15	88.12	11.36	0.27	0.11
Stage 1	0.81	7.26	73.37	10.55	8.01
REM	29.68	1.02	27.42	33.79	8.09
Awake	5.70	0.37	12.48	5.94	75.51

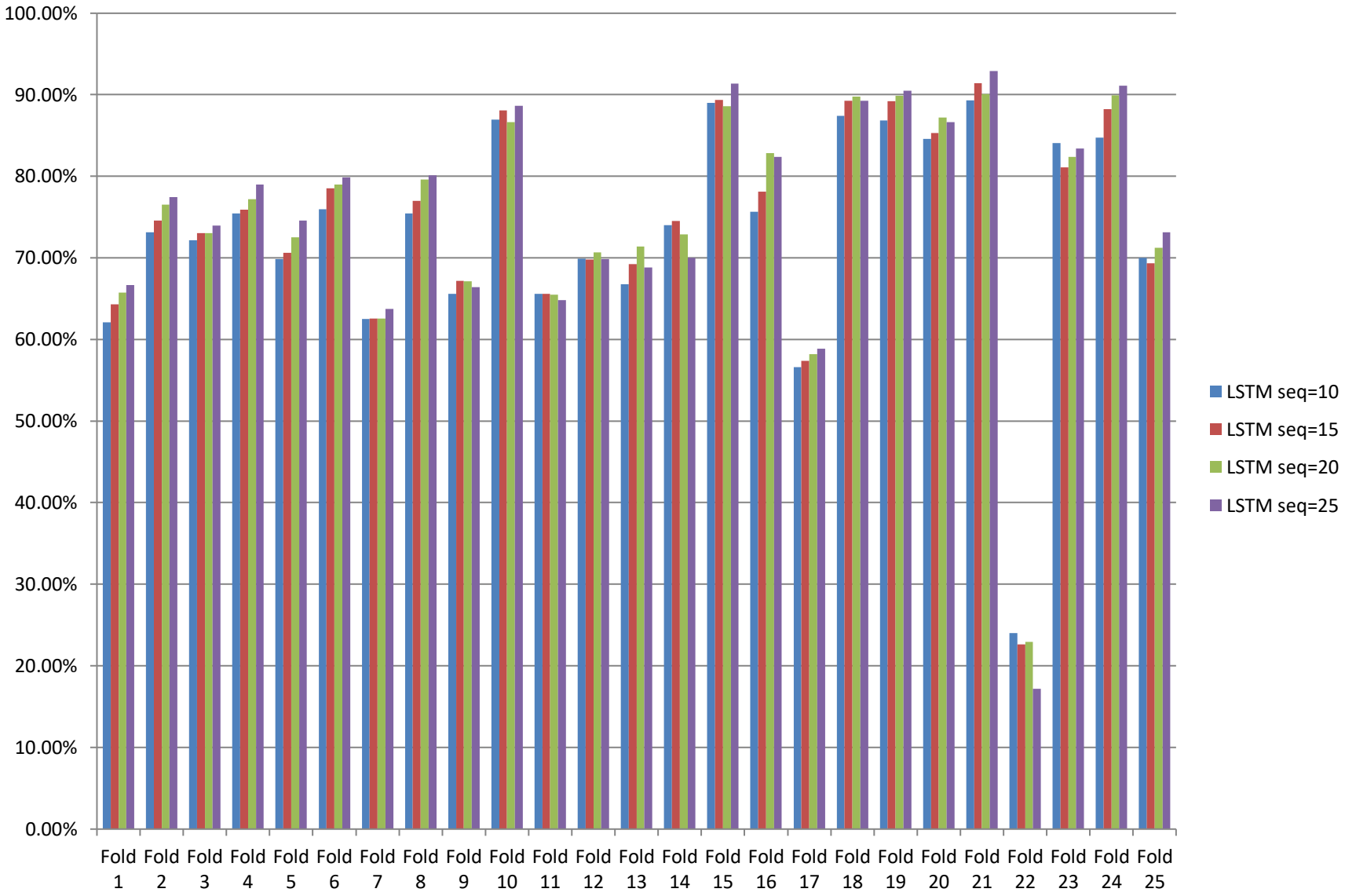
•Confusion Matrix for qLSTM with length=20

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	69.08	0.05	3.59	15.51	11.76
Stage 2	0.12	94.10	5.63	0.03	0.12
Stage 1	0.85	5.32	74.98	10.84	8.01
REM	42.77	0.45	21.56	21.44	13.79
Awake	7.61	0.31	10.70	3.91	77.48

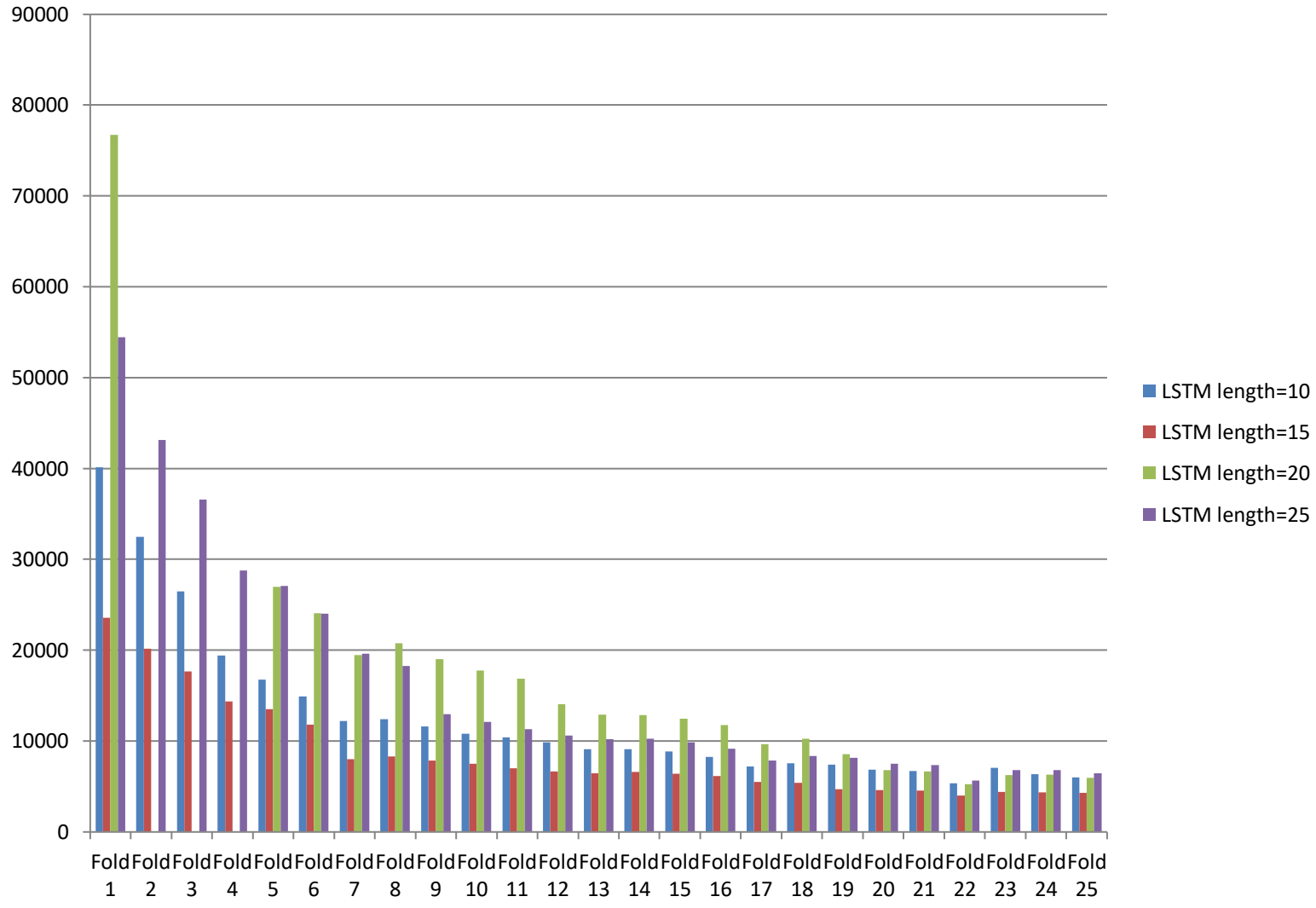
•Confusion Matrix for qLSTM with length=25

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	70.73	0.09	3.49	16.78	8.91
Stage 2	0.16	89.47	10.03	0.23	0.12
Stage 1	0.64	6.54	75.53	9.37	7.92
REM	28.50	0.33	26.63	36.15	8.40
Awake	5.88	0.27	11.75	4.73	77.38

LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**
Analisis F-measure per fold



LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**
Analisis training time per fold (s)



LSTM: **Deep Belief Networks sebagai *artificial feature extraction***

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*
1	DBN LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	128,64,32	5	0.60	0.62	0.60	0.59
2	DBN LSTM *Activation=softmax* *Optimizer=Rmsprop* *Epoch*=100	MKG	128,64,32	15	0.57	0.61	0.59	0.58
3	DBN LSTM (fold 1 s/d 5) *Activation=sigmoid* *Optimizer=Rmsprop* *Epoch*=100	MKG	128,64,32	20	0.56	0.61	0.58	0.58

LSTM: **Convolutional Neural Networks sebagai *artificial feature extraction***

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*
1	CNN LSTM *Activation=tanh,softmax Optimizer=Rmsprop Epoch*=100	MKG	128	5	0.58	0.59	0.58	0.56
2	CNN LSTM *Activation=tanh,softmax Optimizer=Rmsprop Epoch*=100	MKG	128	10	0.60	0.63	0.60	0.58
3	CNN LSTM *Activation=tanh,softmax Optimizer=Rmsprop Epoch*=100	MKG	128	15	0.53	0.60	0.58	0.57
4	CNN LSTM *Activation=tanh,softmax Optimizer=Rmsprop Epoch*=100	MKG	128	20	0.53	0.60	0.58	0.57
5	CNN LSTM *Activation=sigmoid Optimizer=Adam Epoch*=100	MKG	128	20	0.52	0.60	0.58	0.57
6	CNN LSTM *Activation=softmax Optimizer=Rmsprop Epoch*=100	*St Vincent*	128	5	0.65	0.78	0.65	0.68
7	CNN LSTM *Activation= softmax Optimizer=Rmsprop Epoch*=100	*St Vincent*	128	15	0.69	0.84	0.69	0.73

LSTM: **Fuzzy C-Means *Cluster*ing sebagai *artificial feature extraction (St Vincent)***

Banyaknya *cluster*	Akurasi	*Precision*	*F-measure*	Training time (s)
4	0.63	0.80	0.67	2475.62
5	0.65	0.80	0.69	2584.37
6	0.67	0.81	0.7	3746.79
7	0.69	0.83	0.72	7343.18
8	0.69	0.83	0.72	4123.10
9	0.70	0.83	0.73	4944.17

LSTM: **Fuzzy C-Means *Cluster*ing sebagai *artificial feature extraction (St Vincent)***

Confusion Matrix for clusters=4

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	55.62	1.79	5.94	24.10	12.55
Stage 2	0.07	91.28	8.06	0.34	0.24
Stage 1	2.18	9.16	65.17	15.47	8.01
REM	33.16	3.02	22.15	31.28	10.39
Awake	14.29	0.55	17.16	6.57	61.43

Confusion Matrix for clusters=5

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	64.06	1.96	4.72	18.00	11.26
Stage 2	0.04	89.78	9.59	0.22	0.37
Stage 1	1.01	8.28	68.55	13.81	8.35
REM	33.21	2.12	28.46	26.83	9.38
Awake	15.20	0.80	13.41	7.60	62.98

Confusion Matrix for clusters=6

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	62.69	1.82	4.52	18.64	12.34
Stage 2	0.03	90.40	9.04	0.22	0.31
Stage 1	1.03	8.18	70.59	12.00	8.21
REM	34.60	2.54	25.98	27.18	9.70
Awake	12.75	0.74	12.37	6.90	67.24

Confusion Matrix for clusters=7

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	65.28	2.28	4.14	15.43	12.86
Stage 2	0.05	91.39	7.79	0.25	0.52
Stage 1	0.68	8.27	73.22	9.65	8.17
REM	33.89	2.53	27.76	27.07	8.75
Awake	7.43	0.95	11.65	7.01	72.96

Confusion Matrix for clusters=8

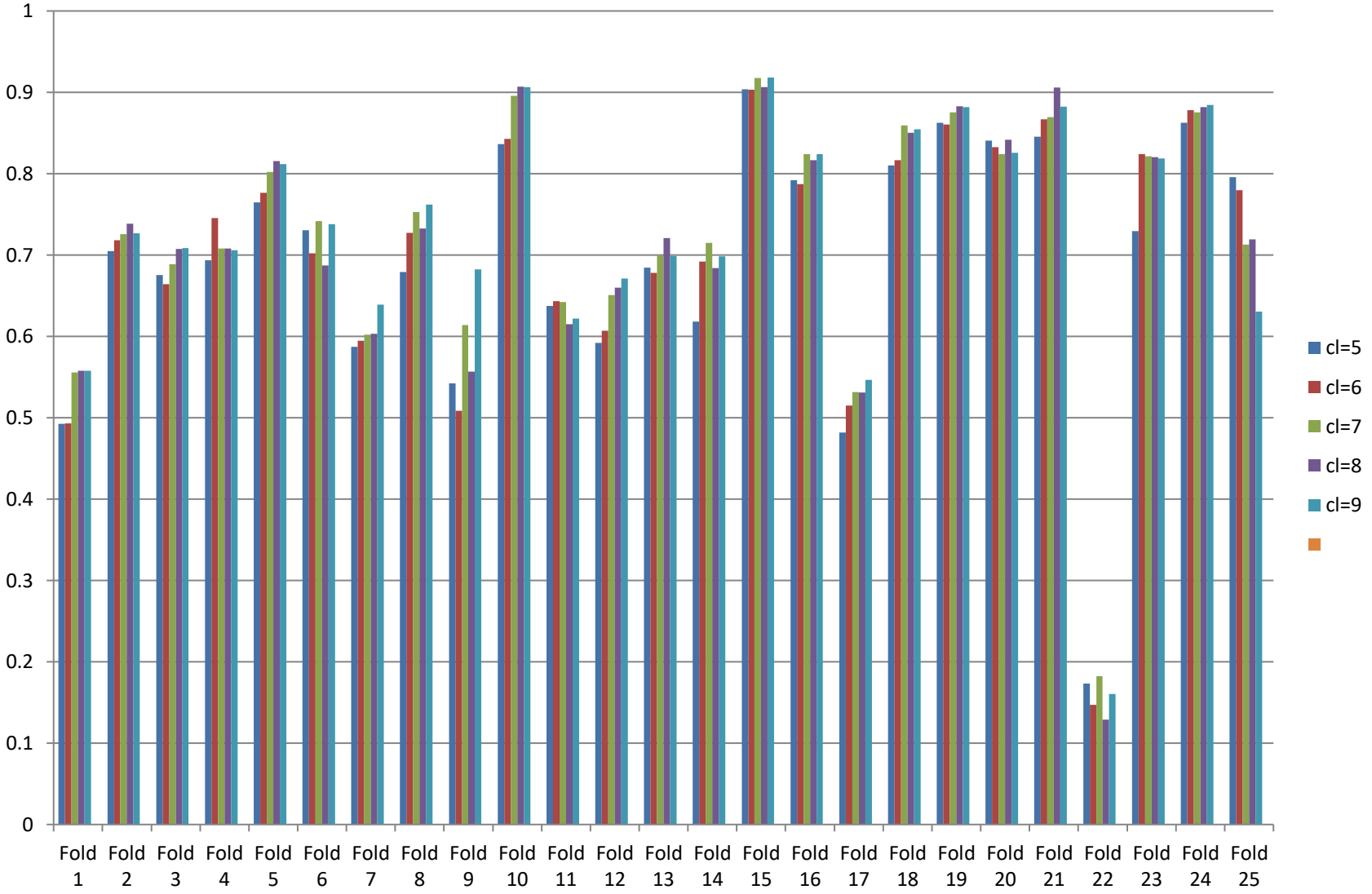
%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	63.01	2.20	4.07	17.97	12.75
Stage 2	0.05	91.94	7.22	0.26	0.54
Stage 1	0.68	7.84	73.99	9.92	7.57
REM	34.39	2.48	27.22	26.95	8.96
Awake	6.48	0.68	13.87	6.74	72.23

Confusion Matrix for clusters=9

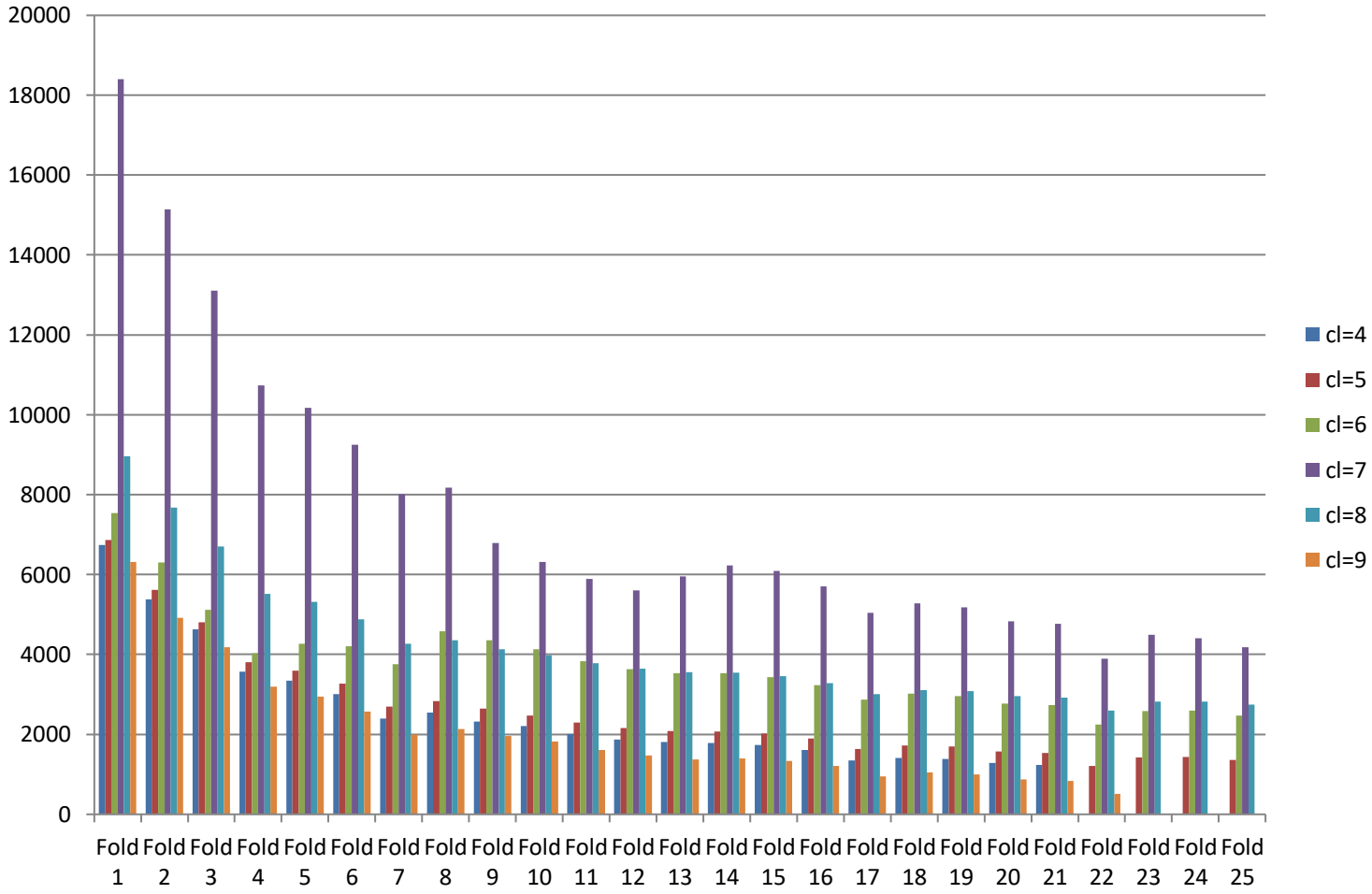
%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	64.87	2.02	4.21	16.93	11.97
Stage 2	0.03	91.52	7.67	0.24	0.55
Stage 1	0.55	7.99	74.46	9.53	7.47
REM	31.17	1.96	27.42	30.37	9.07
Awake	6.01	0.70	13.76	6.31	73.22

LSTM: **Fuzzy C-Means *Cluster*ing sebagai *artificial feature extraction (St Vincent)***

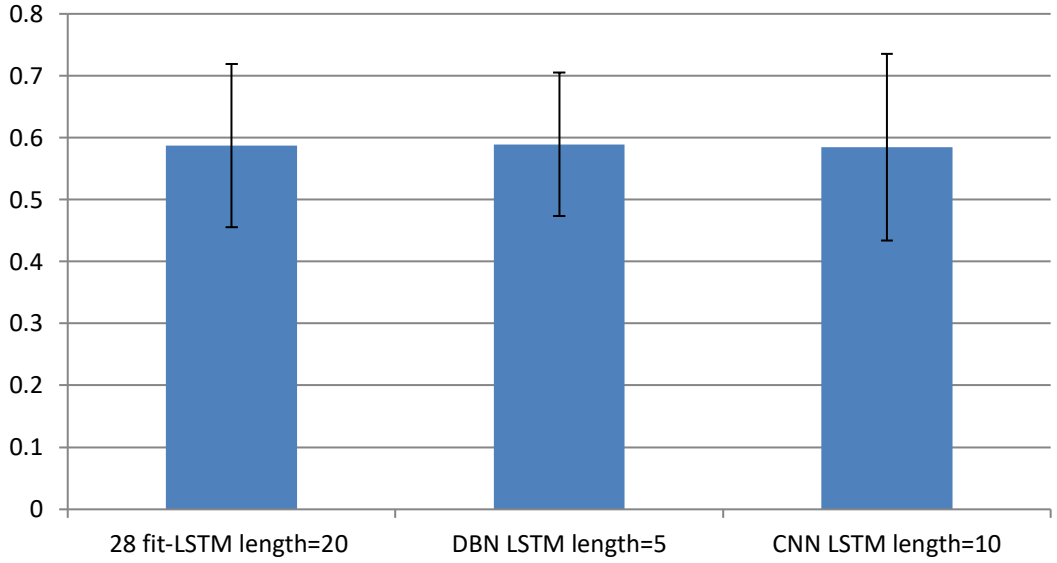
Analisis F-measure tiap fold



LSTM: **Fuzzy C-Means *Cluster*ing sebagai *artificial feature extraction (St Vincent)***
Analisis training time tiap fold (s)

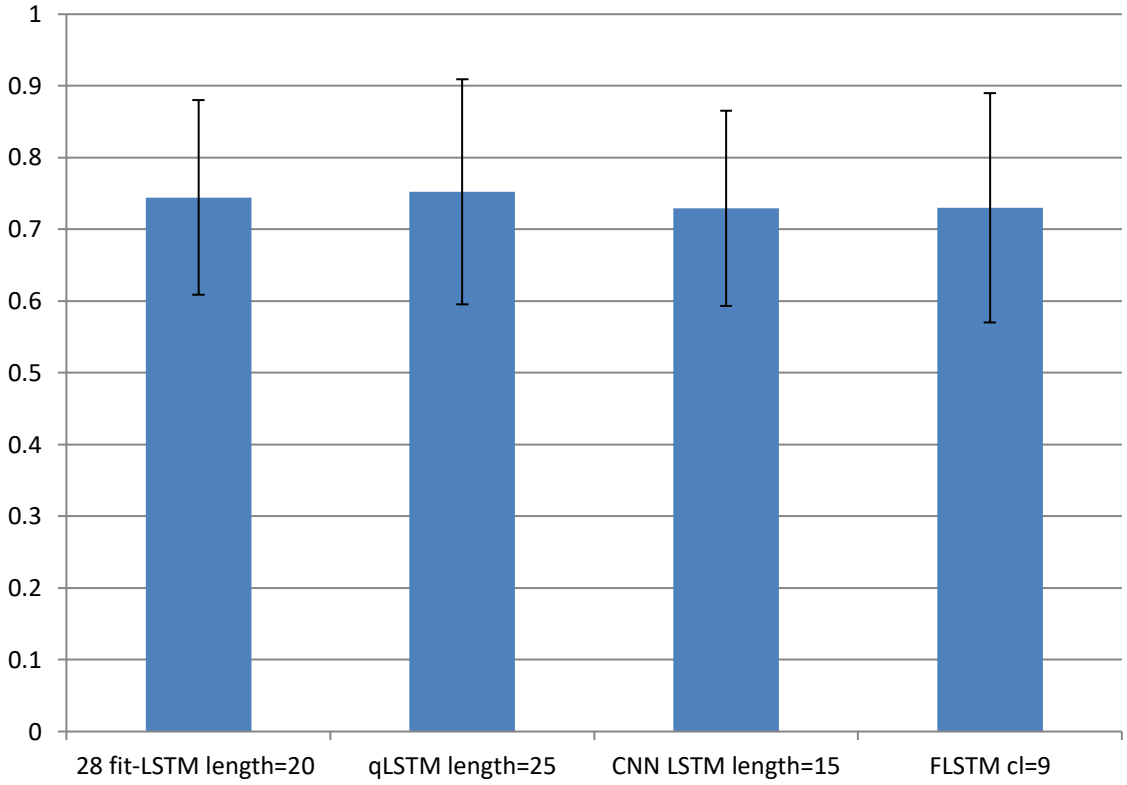


Simpulan pengaruh *artificial feature extraction* terhadap LSTM pada MKG (F-measure)



Metode	mean	stdev
28 fit-LSTM length=20	0.59	0.13
DBN LSTM length=5	0.59	0.12
CNN LSTM length=10	0.58	0.15

Simpulan pengaruh *artificial feature extraction* terhadap LSTM pada St Vincent (F-measure)



Metode	mean	stdev
28 fit-LSTM length=20	0.74	0.14
qLSTM length=25	0.75	0.16
CNN LSTM length=15	0.73	0.14

Bi-LSTM: **Tanpa *artificial feature extraction***

Dataset	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*	*Training time (s)*
MKG	5	0.54	0.57	0.54	0.54	3511.55
MKG	10	0.57	0.59	0.57	0.56	4843.31
MKG	15	0.59	0.61	0.59	0.59	6654.73
MKG	20	0.59	0.63	0.59	0.59	8938.18
St Vincent	10	0.7	0.84	0.70	0.74	7365.78
St Vincent	15	0.71	0.85	0.71	0.74	3243.71
St Vincent	20	0.72	0.85	0.72	0.75	12935.48

Filters=64, fungsi aktivasi=softmax, optimizer=rmsprop, epoch=100

Bi-LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**

No	Metode	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*	*Training time (s)*
1	qBi-LSTM	10	0.69	0.84	0.69	0.73	11114.04
2	qBi-LSTM	15	0.71	0.85	0.71	0.74	9785.246
3	qBi-LSTM	20	0.72	0.86	0.72	0.75	15777.84

Bi-LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)-cont'd**

•Confusion Matrix for qBi-LSTM with length=10

%	Classified as				
	SWS	*Stage 2*	*Stage 1*	*REM*	*Awake*
SWS	68.95	0.16	3.35	17.56	9.98
Stage 2	0.15	87.28	11.88	0.47	0.22
Stage 1	1.07	8.50	70.63	11.09	8.70
REM	31.30	1.46	26.16	32.19	8.89
Awake	5.48	0.52	12.87	6.32	74.81

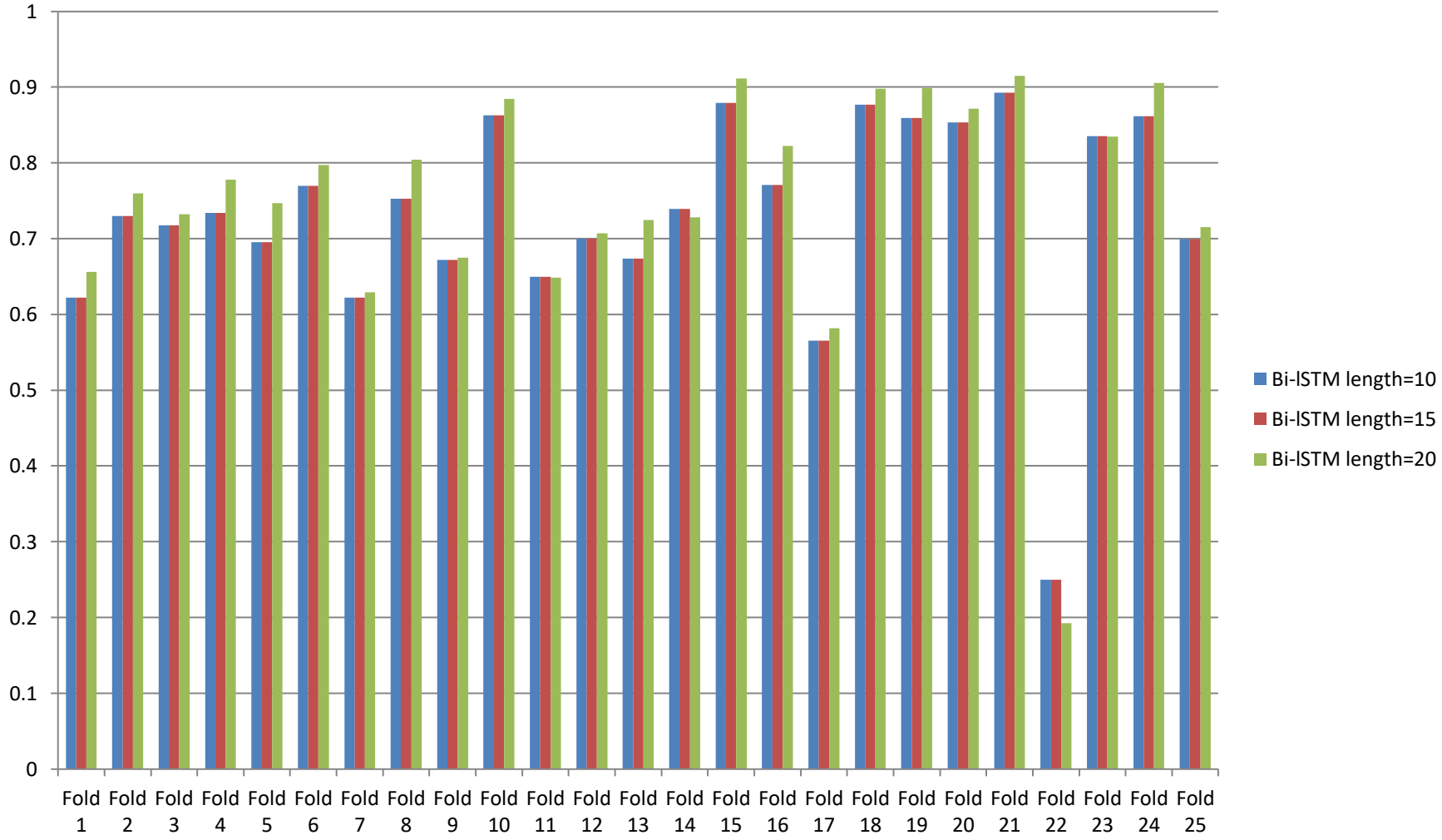
•Confusion Matrix for qBi-LSTM with length=15

%	Classified as				
	SWS	*Stage 2*	*Stage 1*	*REM*	*Awake*
SWS	69.74	0.09	3.28	17.19	9.70
Stage 2	0.14	89.76	9.68	0.29	0.13
Stage 1	0.79	7.63	73.40	10.36	7.83
REM	28.99	0.99	27.60	34.35	8.07
Awake	5.67	0.36	12.70	5.67	75.60

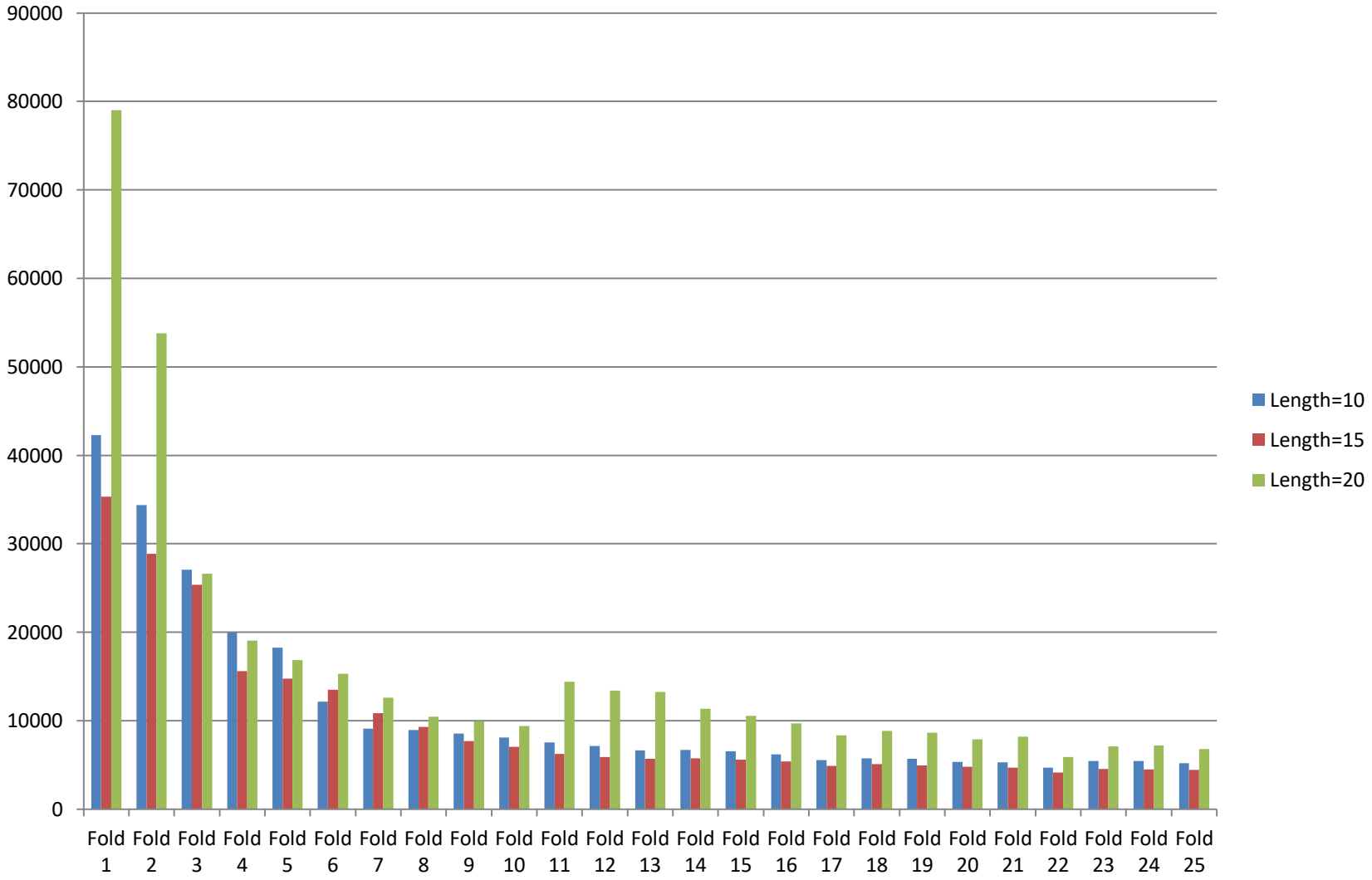
•Confusion Matrix for qBi-LSTM with length=20

%	Classified as				
	SWS	*Stage 2*	*Stage 1*	*REM*	*Awake*
SWS	69.78	0.09	3.33	17.57	9.22
Stage 2	0.16	90.1	9.43	0.21	0.09
Stage 1	0.64	6.66	75.37	10.42	6.91
REM	29.2	0.36	28.16	34.8	7.47
Awake	5.95	0.29	12.69	5.66	75.41

Bi-LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**
Analisis F-measure per fold



Bi-LSTM: **Deep Belief Networks sebagai kuantisasi (St Vincent)**
Analisis training time per fold (s)



Bi-LSTM: **Convolutional Neural Networks sebagai *artificial feature extraction***

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*
1	CNN BI-LSTM *Activation=Softmax* *Optimizer=Rmspro p* *Epoch*=100	*St Vincent*	128	15	0.72	0.85	0.72	0.75

Bi-LSTM: **Deep Belief Networks sebagai *artificial feature extraction***

No	Metode	Dataset	*Filters*	*Length*	Akurasi	*Precision*	*Recall*	*F-measure*
1	DBN BI-LSTM *Activation=softmax Optimizer=Rmspro p Epoch*=100	MKG	64	5	0.59	0.62	0.59	0.58
2	DBN BI-LSTM *Activation=Adam Optimizer=Rmspro p Epoch*=100	MKG	64	15	0.56	0.61	0.58	0.57
3	DBN BI-LSTM *Activation=Adam Optimizer=Rmspro p Epoch*=100	MKG	64	20	0.57	0.61	0.58	0.58
4	DBN BI-LSTM *Activation=Softmax Optimizer=Rmspro p Epoch*=100	*St Vincent*	64	15	0.72	0.86	0.72	0.76

Bi-LSTM: **Deep Belief Networks sebagai *artificial feature extraction (cont'd)***

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	70.37	0.25	3.14	17.47	8.77
Stage 2	0.24	89.36	10.01	0.24	0.15
Stage 1	0.92	6.03	75.63	10.83	6.58
REM	28.37	0.83	25.52	37.22	8.06
Awake	6.54	0.32	12.54	5.05	75.56

Pengujian DBN Bi-LSTM membutuhkan waktu rata-rata 5742.55 detik

Bi-LSTM: **Fuzzy C-Means *Cluster*ing sebagai *artificial feature extraction (St Vincent)***

No	nCluster	%			Training time (s)
		Accuracy	***Precision***	***F-Measure***	
1	4	61.94	79.57	66.43	3079.89
2	5	64.92	80.72	68.97	3239.08
3	6	66.55	81.29	70.21	4533.11
4	7	68.97	82.97	72.23	5638.97
5	8	68.7	82.94	71.75	4968.41
6	9	69.67	83.6	72.75	5786.99

Bi-LSTM: **Fuzzy C-Means *Cluster*ing sebagai *artificial feature extraction (St Vincent)***

Confusion Matrix for clusters=4

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	54.34	1.80	5.45	25.06	13.36
Stage 2	0.09	91.77	7.53	0.38	0.22
Stage 1	1.57	8.85	66.06	15.50	8.03
REM	33.47	2.72	22.92	31.11	9.78
Awake	15.28	0.59	16.75	7.27	60.11

Confusion Matrix for clusters=5

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	63.43	1.87	4.69	19.13	10.87
Stage 2	0.04	89.95	9.37	0.22	0.42
Stage 1	1.02	7.83	67.87	14.80	8.48
REM	34.63	2.08	27.57	26.55	9.17
Awake	14.45	0.82	13.09	7.99	63.65

Confusion Matrix for clusters=6

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	62.79	1.78	4.57	18.74	12.12
Stage 2	0.02	89.94	9.21	0.20	0.63
Stage 1	0.94	7.73	70.50	12.77	8.05
REM	34.84	2.38	25.54	27.29	9.95
Awake	12.22	0.66	12.15	7.41	67.56

Confusion Matrix for clusters=7

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	64.48	2.24	4.22	17.23	11.82
Stage 2	0.03	90.76	8.47	0.24	0.49
Stage 1	0.67	7.68	73.49	10.50	7.66
REM	32.43	2.57	27.72	28.41	8.88
Awake	7.99	0.82	11.83	6.90	72.45

Confusion Matrix for clusters=8

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	62.78	2.26	3.98	17.66	13.33
Stage 2	0.06	91.88	7.09	0.19	0.78
Stage 1	0.72	7.52	73.70	10.57	7.49
REM	34.07	2.07	27.54	27.14	9.18
Awake	6.01	0.71	13.80	6.78	72.70

Confusion Matrix for clusters=9

%	Classified as				
	SWS	***Stage 2***	***Stage 1***	***REM***	***Awake***
SWS	63.27	1.83	4.07	17.24	13.59
Stage 2	0.04	91.16	8.19	0.25	0.35
Stage 1	0.57	7.43	74.63	9.94	7.42
REM	31.46	1.89	26.60	31.05	9.00
Awake	5.92	0.62	12.58	6.44	74.45

Fast Convolutional (data 1)

Method	Precision (%)	Recall (%)	F-measure (%)	Training time (s)
Multi-layer perceptron	59.30	59.90	59.00	2,257.80
Decision tree	54.30	54.50	54.40	606.70
K-nearest neighbor	53.40	53.90	53.30	0.10
Bayesian networks	54.00	54.60	53.90	20.90
Bagging	64.20	64.80	64.20	3,586.50
AdaBoost	13.90	35.30	19.90	5.10
Support vector machine	56.90	57.90	57.00	3,229.40
Random forest	64.00	64.60	64.00	617.40
Naive Bayes	52.70	51.30	50.80	4.10
DBN HMM	64.20	62.60	69.10	3,214.00
Fast convolutional	84.00	70.40	73.50	42.60

	SWS	Stage 2	Stage 1	REM	Awake
SWS	66.90	0.70	3.30	16.10	13.00
Stage 2	0.20	88.70	9.80	0.50	0.90
Stage 1	0.60	7.40	74.40	10.40	7.30
REM	15.00	2.20	26.80	43.10	12.90
Awake	7.90	0.50	11.80	5.50	74.20

Fast Convolutional (data 2)

Method	Precision (%)	Recall (%)	F-measure (%)	Training time (s)
Multi-layer perceptron	46.36	49.05	47.51	62.39
Decision tree	45.73	43.65	44.63	1.27
K-nearest neighbor	46.63	45.12	45.83	0.01
Bayesian networks	48.41	43.70	45.67	0.33
Bagging	46.99	52.23	49.29	28.95
AdaBoost	47.56	31.92	40.70	40.70
Support vector machine	45.32	65.15	53.41	8.33
Random forest	47.94	46.22	46.96	11.02
Naive Bayes	43.52	34.84	38.42	0.10
Fast convolutional	59.15	61.52	56.32	0.06

Simpulan

- 28 handcrafted features lebih baik dibanding data mentah dan lebih efisen dari 55 handcrafted features
- Performansi Shallow classifier lebih rendah dibanding penggunaan sequence classifier.
- Performansi tertinggi LSTM pada data MKG dicapai oleh LSTM dengan menggunakan DBN sebagai artificial feature extraction. Sedangkan data St Vincent tercapai dengan DBN sebagai kuantisasi.
- Penerapan Bi-LSTM pada data MKG tertinggi tercapai tanpa menggunakan artificial feature extraction. Untuk data St Vincent, performansi tertinggi melalui penggunaan DBN sebagai artificial feature extraction.
- FCM sebagai artificial feature extraction menunjukkan performansi terendah
- Fast Convolutional lebih tinggi tanpa artificial feature extraction untuk data MKG.
- Sistem terbaik untuk dataset MKG tercapai ketika penerapan LSTM dengan menggunakan DBN sebagai artificial feature extraction, Bi-LSTM, dan CfastText
- Sistem terbaik untuk dataset St Vincent dengan DBN sebagai artificial feature extraction bagi Bi-LSTM.

Rekam JejakPenelitian

No	Judul	Konferensi / Jurnal	Data	Hasil
1	Gesture Recognition using Latent-Dynamic based on Conditional Random Fields and Scalar Features --published	2016 Mathematics, Science, and Computer Science Education International Seminar	Gesture Phase Segmentation	Penggunaaan scalar feature meningkatkan performansi Latent-Dynamic based on Conditional Random Fields
2	Gesture Recognition using Latent-Dynamic based on Conditional Random Fields and Scalar Features --published	Journal of Physics: Conference Series	Gesture Phase Segmentation	Penggunaaan scalar feature meningkatkan performansi Latent-Dynamic based on Conditional Random Fields
3	Fuzzy Latent-Dynamic Conditional Neural Fields for Gesture Recognition in Video --accepted	International Journal on Information and Communication Tcehnology (IJOICT)	Gesture Phase Segmentation	Kombinasi Latent-Dynamic Conditional Neural Fields dan Fuzzy C Means *Cluster*ing menghasilkan performansi tertinggi dibandingkan varian dari Conditional Random Fields lainnya
4	Combining Deep Belief Networks and Bidirectional Long Short Term Memory (Case Study: Sleep Stages Classification) --accepted	2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2017)	*St Vincent*	Implementasi DBN pada Bi-LSTM meningkatkan performansinya untuk implementasi sleep state classification

Rekam JejakPenelitian (2)

No	Judul	Konferensi / Jurnal	Data	Hasil
5	Sleep Stage Classification using Combination Fuzzy Clustering and Bidirectional Long Short Term Memory --accepted	5th ICSIIT 2017, the International Conference on Soft Computing, Intelligent System and Information Technology	*St Vincent* dataset	Implementasi Fuzzy sebagai feature representation pada Bi-LSTM untuk implementasi sleep state classification
6	Bi-directional Long Short-Term Memory using Quantized data of Deep Belief Networks for Sleep Stage Classification --under review	2nd International Conference on Computer Science and Computational Intelligence (ICCSCI)	*St Vincent* dataset	Implementasi DBN sebagai kuantisasi pada Bi-LSTM untuk implementasi sleep state classification
7	Sleep Stage Classification using Convolutional Neural Networks and Bidirectional Long Short-Term Memory --under review	2017 International Conference on Advanced Computer Science and Information Systems (ICACSIS)	*St Vincent* dataset	Implementasi CNN pada Bi-LSTM meningkatkan performansinya untuk implementasi sleep state classification
88	Fast Convolutional for Automatics Sleep Stage Classification	Healthcare Informatics Research	*St Vincent* dataset/RS Mitra	Fast Convolutional untuk implementasi sleep state classification

Rekam JejakPenelitian (3)

9	Shallow Classifier with Sampling for Sleep Stage Classification of Autism Patients (diterima)	International Conference on Enhanced Computer Research, Engineering, And Advanced Multimedia	Penjabaran metode dari shallow classifier dengan resampling dalam klasifikasi tahap tidur pada data autisme
10	Random Subspace Method for Sleep Stage Classification of Autism Patients	International Seminar on Research of Information Technology and Intelligent Systems	Penjabaran metode dari random subspace dengan resampling dalam klasifikasi tahap tidur pada data autisme

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