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INTELEGENCE PATTERN RECOGNITION OF OSTEOARTHRITIS SEVERITY BASED JUNCTION SPACE WIDTH (JSW) PARAMETER USING SELF ORGANIZING MAP (SOM)

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Abstract- Osteoarthritis is one of an incurable disease. So far, to reduce the patient's pain, treatment is usually carried out and pain-reducing drugs are given. The purpose of this research is to propose a method of knee osteoarthritis by implementing supervised learning Self Organizing Map (SOM) based on the Junction Space Width (JSW) data, at JSW (0.150) to JSW (0.300). The stages in this study are learning data based on Junction Space Width (JSW) data, minimum JSW medial compartment (mJSW) and JSW fixed location (JSW (x)) at JSW (0.150) to JSW (0.300) using SOM, and to get the performance of the system testing process is carried out. There are 799 data has observed contain: 724 testing data, 75 training data (15 data for normal condition, and 15 data for each the KL-grade. The steps of the research are initialization, determination of cluster number, determine the value of learning rate and iteration value, then calculate the minimum distance between the data and input weight. The experimental results show that using number of iteration 1500 and α_0=0.6 that afford system accuracy 59.20%, Grade 0 28.125%, first grade 22.58%, second grade 43.82%, third 89.33 %, and fourth 97.33% are recommended.

Keywords: Classification, Junction Space Width, Knee Osteoarthritis, Self-Organizing Map, Severity.

1. INTRODUCTION

Indonesian osteoarthritis patients in 2004 in were 17,533,304 [1]. Osteoarthritis is a joint disorder that affects all joint tissues. Osteoarthritis is an incurable disease; it causes progressive and irreversible articular cartilage damage and over time results in joint failure as a whole organ. Efforts to prevent osteoarthritis from getting worse are usually given to patients with treatment. The higher the severity of osteoarthritis, the higher the pain felt by the patient. During this time to reduce pain patients are usually given pain-relieving drugs [2-4].

X-ray, arthroscopy, osteo CT and MRI are most widely used in order to know the osteoarthritis joints status [5, 6]. However, X-ray and MRI image is commonly used in Indonesia to predict severity of osteoarthritis. The manual classification process takes more time so the researchers sought to make an approach how this osteoarthritis classification can be done automatically. In addition, manually classifying allows high inter- and intra-observer variabilities [7].

Some methods have been implemented to determine the osteoarthritis status, e.g., using x-ray selected images to be gold standard in order to find the junction space area. Image normalization is implemented then combined with scanning process, and classify based on texture of the x-ray images [8]. Developed method using active shape model to determine the location of junction space area [7]. Other implemented method by finding distance between the femur and tibia, it is carried out by calculated both vertically and horizontally based on tibia and femur image. [9]. Gabor filter-based morphology process was implemented to segment knee osteoarthritis on x-ray image [10]. Approach method to classify osteoarthritis using SOM based on gabor kernel and CLAHE [11]. Another study to classify osteoarthritis using hybrid of S2DPCA and SVM already implemented [13]. These methods are implemented to investigate x-ray medical images based on the texture.

Another study was to diagnose the early stages of osteoarthritis in the knee using deep learning, this study obtained 98% accuracy results [14]. The hybrid quantum CNN model method was also used to classify the severity of osteoarthritis and obtained high accuracy results [15]. The implementation of quadtree analysis is also used to detect osteoarthritis in the knee based on X-ray images, based on experiments that have been carried out, AUC value result is 0.917 [16]. The research importance in identifying early stages and the goal of classifying the severity of osteoarthritis are two different things, as a stepwise and structured approach is required in clinical practice or clinical research [17]. So, a clearer approach is needed regarding the needs whether used for early-stage identification or identification. When we identify the severity of osteoarthritis in the knee or determine the initial stage of osteoarthritis, we need knowledge of patterns based on Junction Space Width (JSW), therefore a pattern model is really needed for each level of osteoarthritis severity.

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Previous research has discussed the classification of the severity of osteoarthritis using various methods, but unfortunately it has not reviewed the pattern modeling for each level of osteoarthritis severity in the knee. We proposed intelligence pattern recognition for knee osteoarthritis severity determination by implementing Self Organizing Map (SOM) based on the Junction Space Width (JSW) data, at point JSW (0.150) to JSW (0.300). The main aspects considered in this paper are accuracy and speed of operation. The contribution of this research is that it is hoped that it can become support system in osteoarthritis severity determination of knee patient and also determining the early stage.

2. MATERIALS, METHODS AND EVALUATION

2.1. Materials

We observed 799 Osteoarthritis Initiate (OAI) knee medical x-ray images dataset [10]. There are 724 data for testing process and 75 data for training/learning process which is divided into 15 data for normal condition, and 15 data for each KL-Grade. The method used to obtain x-ray images is at 10 degrees fixed-flexion knee X-rays [18]. The Kellgren and Lawrence Grade is method commonly used in classifying the severity of osteoarthritis. It used five levels, KL-Grade 0 to KL-Grade 4, where KL-Grade 0 is a normal condition and KL-Grade 4 is the worst condition.

2.2. Methods

Self-Organizing Map (SOM) has been implemented and used in various areas of life [19]-[24]. The steps of the learning process are: initialization, the number of cluster determination, determine the value of learning rate and iteration value, then calculate the minimum distance between the data and input weight. Algorithm of SOM network is formulated as follows [6]:

1) Iteration (epoch) number determination
2) Weights (w_{ij}) initialization for each cluster
3) Setting topological of SOM (d_0)
4) Determine learning rate value
5) If the iteration number meet or less than number of iterations (T) determine before, then the process will return to step 3 to step 6
6) Learning the randomly input vector in the training set.
7) Determining the distance between neuron j and vector w_j using minimum distance, so that the closest distance will be the winner neuron. Neuron j has the closest distance is the winner, the formula of $D_{\min}(t)$ in Equation (1).

$$D_{\min}(t) = \min \sum (x_{ij}(t) - w_{ij}(t))^2 \quad (1)$$

8) Updating the weight vectors using formula:

$$W_{(t+1)} = W_{(t)} + (\alpha_{(t)}(x - W_{(t)}))\forall i \in N_i \quad (2)$$

where, $\alpha_{(t)}$ is a learning rate at t

9) Carried out $t = t+1$ calculation, if the result is less than T then return to step 3 and otherwise learning process has been completed.

The most important task in osteoarthritis severity determination is data learning. Data learning based on the Junction Space Width (JSW) data, at fixed location JSW (JSW(x)) at JSW (0.150), JSW (0.175), JSW (0.200), JSW (0.225), JSW (0.250), JSW (0.275), and JSW (0.300). The smallest amount of femoral and tibial joint distance margins. The measurement method on JSW is shown in Figure 1.

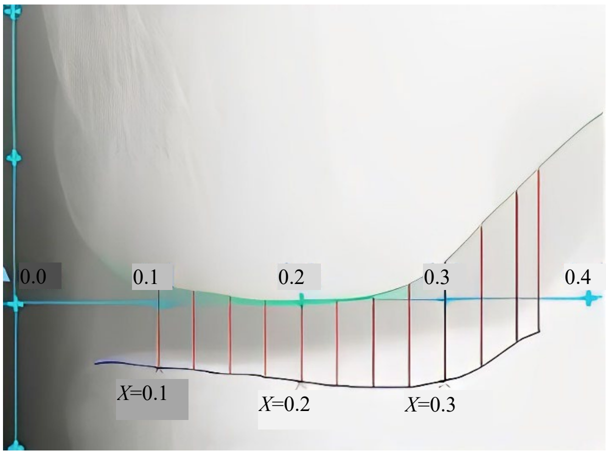


Figure 1. JSW(x) measurement with increments value of 0.025 [21]

Measurement of medial fixed location junction space width (JSW) carried out by digitized knee images at each point. Then it can be described mJSW is the smallest amount of femoral and tibial joint distance margins [25]. The number of iteration values used in this research is 500 to 10000, while the learning rate values used are from 0.1 to 0.9. Iterations number and the learning rate value used in this research more detail is illustrated in Table 1.

Table 1. The value of the iterations number and the learning rate value used

Experiment	Number of iterations	Learning rate value
1	500	0.1-0.9
2	1000	0.1-0.9
3	1500	0.1-0.9
4	2000	0.1-0.9
5	3000	0.1-0.9
6	4000	0.1-0.9
7	5000	0.1-0.9
8	6000	0.1-0.9
9	7000	0.1-0.9
10	8000	0.1-0.9
11	9000	0.1-0.9
12	10000	0.1-0.9

2.3. Evaluation

The most frequently used to evaluate comprehensively in machine learning is a ROC curve [26]. ROC curve is obtained from the results of true positive fraction (TPF) versa false positive fraction (FPF) plotting [27-28]. Equations (3) to (6) is an Equation to find accuracy, specifications, and sensitivity used to plot ROC curve [29].

$$accuracy = \frac{TN + TP}{TP + FP + TN + FN} \quad (3)$$

$$TNF = \frac{TN}{TN + FP} \quad (4)$$

$$TPF = \frac{TP}{TP + FN} \quad (5)$$

$$FPF = 1 - TNF \quad (6)$$

The criteria for ROC results determined by the area under the ROC curve calculation. Criteria whether the learning machine can succeed or fail recognize the object can indicate by Area Under Curve (*AUC*) value. Table 1 shows the performance level based on *AUC* value.

Table 2. Criteria of performance based on AUC value [27]

Criteria	*AUC*
Excellent	1.00≥*AUC*>0.90
Good	0.90≥*AUC*>0.80
Fair	0.80≥*AUC*>0.70
Poor	0.70≥*AUC*>0.60
Fail	0.60≥*AUC*

3. RESULTS AND DISCUSSION

The learning process was carried out using a learning rate of 0.1 to 0.9, and a number of iterations of 500 to 10,000 epochs. From the learning results, a weight value is obtained for each learning rate value used. This weight is recalled during the testing process. In this research, performance analysis was carried out by calculating accuracy, specifications, and sensitivity used to plot the ROC curve. This analysis has also been used in testing the reliability of previous systems [30]. The first experiment results that used 500 iterations and learning rate value from 0.1 to 0.9 figured in Figure 2. It shows that the system accuracy value is better if learning rate 0.2, 0.3, and 0.4 implemented. The accuracy system is 55.46%, while accuracy for first KL-Grade to fourth KL-Grade were 32.26%, 38.21%, 25.94%, 90.22%, and 97.33%.

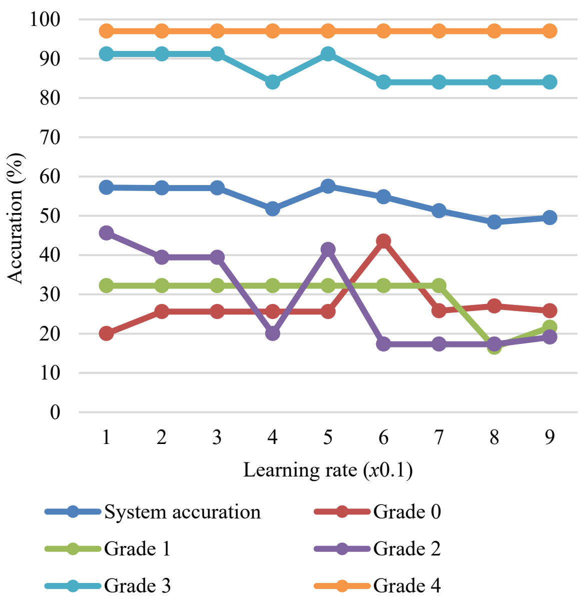


Figure 2. The results of first experiment with parameter: learning rate=0.1 to 0.9, number of iterations 500

Another element that is taken into consideration is the speed of the learning process using certain parameters. Speed of operation for the first experiment is figured in Figure 3. Figure 3 shows that time process for learning using value 0.2 and 0.3 are 0.405 second, while using learning rate value 0.4 is 0.359 second.

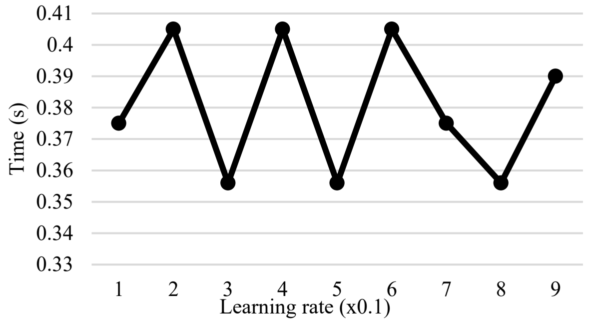


Figure 3. Time needed for training process using learning rate value 0.1 to 0.9 with the number of iterations 500

Table 3. Accusation of the system (in %) using learning rate $\alpha_{(t)}$ 0.1-0.5

Experiment	$\alpha_{(t)}$				
	0.1	0.2	0.3	0.4	0.5
1	54.22	55.46	55.46	24.34	55.46
2	53.94	54.91	54.91	25.31	55.88
3	53.80	54.91	54.91	25.31	24.34
4	53.80	54.91	54.91	54.91	54.91
5	53.80	54.91	54.91	54.91	25.31
6	53.80	54.91	54.91	55.88	55.88
7	53.80	54.91	54.91	55.88	54.91
8	53.80	54.91	54.91	55.88	54.91
9	53.80	54.91	54.91	55.88	54.91
10	53.80	54.91	54.91	25.31	54.91
11	53.80	54.91	54.91	24.91	24.34
12	53.80	54.91	54.91	25.31	25.31

Speed of training process the training time needed in experiments 1 to 12 are 0.356, 0.7, 1.14, 1.48, 2.2, 2.87, 3.63, 4.52, 5.26, 6.02, 6.66, and 7.43 second. So, if it is considered based on accuracy and speed, the best performance is if used number of iteration 1500 and learning rate value 0.6.

The accuracy of the system is explained in Table 3 and 4, which is Table 3 explains the accuracy of the first to twelfth experiments using a learning rate of 0.1 to 0.5. Table 4 explains the system accuracy of the twelve experiments using a learning rate of 0.6 to 0.9. In general, this experiment proves that the parameters for selecting the number of epochs used and the learning rate value have an impact on system accuracy. The first to twelfth experiments have been implemented. The best performance of second experiment using learning rate value 0.5 and 0.6, while speed of process is 0.70 and 0.78 second. The third experiment result shows that the system using learning rate value 0.6 yield accuracy 59.20% for the system, for normal grade 28.125%, first grade 22.58%, second grade 43.82%, third grade 89.33%, and fourth grade 97.33%. Time needs for learning leaning process is 1.14 second.

Overall, the system could determine the osteoarthritis into normal condition, first KL-Grade to fourth KL-Grade. Based on Table 3 and 4, the best performance is third and fifth experiment. Third experiment used number of iteration 1500 and learning rate value 0.6, while fifth experiment used number of iteration 3000 and learning rate value 0.8. After finding out the experiments that produced the highest accuracy then continued with an analysis of the speed of the training process. The level of speed is obtained from calculating the time needed during the training process.

Table 4. Accuracy of the system (in %) using learning $\alpha_{(t)}$ 0.6-0.9

Experiment	$\alpha_{(t)}$			
	0.6	0.7	0.8	0.9
1	30.84	24.34	24.48	24.34
2	55.88	25.31	24.48	54.91
3	59.20	26.83	29.88	16.32
4	16.74	18.26	58.23	4.15
5	55.88	58.23	59.20	7.05
6	30.98	33.20	52.01	53.53
7	22.13	19.09	27.80	29.32
8	30.98	25.31	31.12	13.14
9	24.34	25.31	26.83	20.06
10	30.98	25.31	30.98	19.78
11	15.77	33.20	19.09	33.33
12	34.02	27.80	4.43	49.65

Based on Tables 3 and 4, analysis was then carried out and a summary table was created of the highest accuracy values for each experiment that had been carried out. Table 5 illustrates the highest system accuracy in each experiment. This is done to obtain the best parameters (number of epochs and learning rate values) to be used as pattern representatives for each KL-Grade.

Table 5. Accuracy of best performance for each experiment (in %)

Exp	α	Accuracy (%)					
		System	0	1	2	3	4
1	0.4	55.46	32.26	38.21	25.94	90.22	97.33
2	0.5	55.88	28.125	37.9	27.71	89.33	97.33
3	0.6	59.2	28.125	22.58	43.82	89.33	97.33
4	0.8	58.22	28.125	16.93	43.82	89.33	97.33
5	0.8	59.2	28.125	22.58	43.82	89.33	97.33
6	0.5	55.88	28.125	37.93	27.72	89.33	97.33
7	0.4	55.88	28.125	37.93	27.72	89.33	97.33
8	0.4	55.88	28.125	37.93	27.72	89.33	97.33
9	0.4	55.88	28.125	37.93	27.72	89.33	97.33
10	0.3	54.91	28.125	37.93	25.01	89.33	97.33
11	0.2	54.91	28.125	37.93	25.01	89.33	97.33
12	0.3	54.91	28.125	37.93	25.01	89.33	97.33

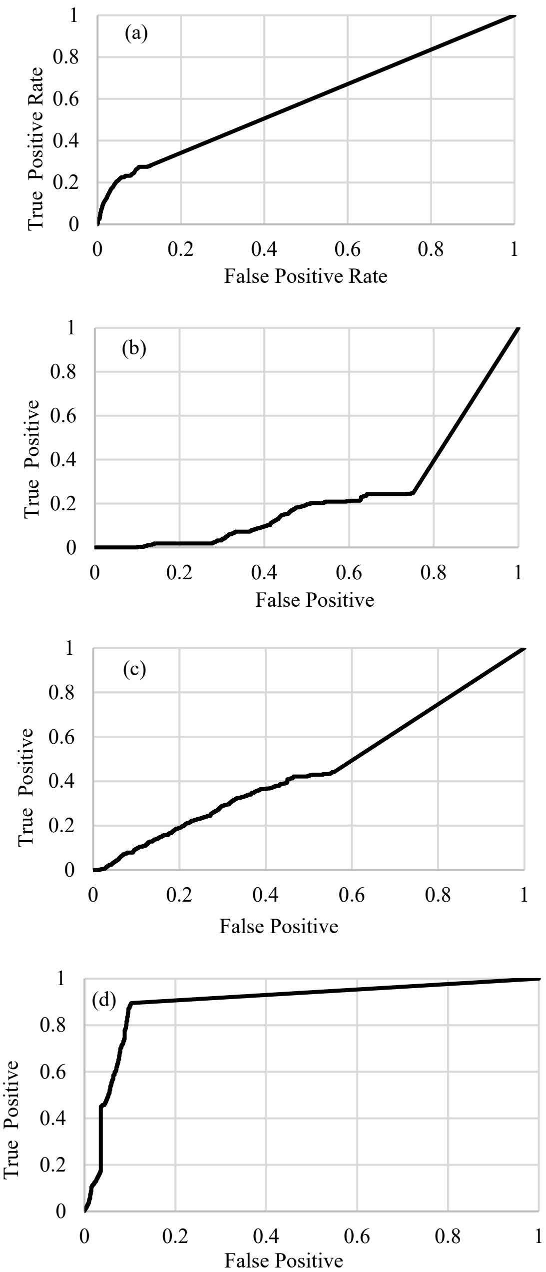
Based on Table 5, there are 2 conditions that have the highest accuracy, namely in experiment 3 and experiment 5. Experiment 3 used 1500 epoch and a learning rate of 0.6, while experiment 5 used parameters for a number of epochs of 3000 and a learning rate value of 0.8. Apart from considering accuracy, this research also considers the speed of the learning process. In experiment 3 it took 1.14 seconds, while in experiment 5 it took 2.20 seconds. Based on the 2 considerations above, the parameters used for the third experiment were chosen, whereas using a number of epochs of 1500 and a learning rate value of 0.6.

The next analysis is calculated confusion matrix from the best performance which is shown in Table 6. Based on this confusion matrix we know the reason why the system classifies data incorrectly, for example in normal condition cluster, it has an accuracy of 28.13%, this is because the data is classified 28.13 % were classified as first KL-Grade, 21.88% were classified as second KL-Grade, and 21.88% were classified as third KL-Grade. Based on Table 6, we can also analyze why this happens, and in reality, most osteoarthritis is only discovered by the patient is in a rather serious condition.

Table 6. Confusion matrix using number of iteration 1500 and learning rate value 0.6

Result / Grade	0	1	2	3	4
0	28.13	28.13	21.88	21.88	0.00
1	20.74	24.47	32.45	20.74	1.60
2	25.09	27.72	43.82	3.37	0.00
3	0.00	9.78	0.89	89.33	0.00
4	0.00	0.00	0.00	2.67	97.33

Analysis that is no less important is analyzing the ROC of the system. ROC graphs for normal condition cluster to fourth KL-Grade using number of iterations 1500 and learning rate value 0.6 is figured Figure 4. The ROC graph is used to find out and describe how the testing process is carried out, this process can be known as each data is tested one by one. Based on this graph, the *AUC* value for each cluster can be calculated, which can then determine the system performance criteria.



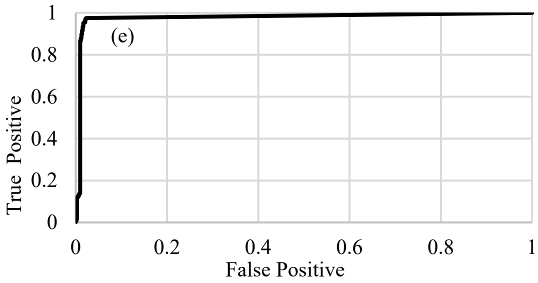


Figure 4. ROC, a) normal condition, b) first grade, c) second grade, d) third grade, e) fourth grade

The *AUC* graph is shown in Figure 5, the *AUC* values of normal condition to fourth KL-Grade are 0.284, 0.247, 0.440, 0.896, and 0.976. Based on Table 2. criteria of accuracy based on *AUC*, the system's ability to classify data for cluster 1 (KL-Grade 0) to cluster 3 (KL-Grade 2) is failed. Meanwhile, the ability to classify cluster 4 (KL-Grade 2) was good, and cluster 4 (KL-Grade 4) was excellent.

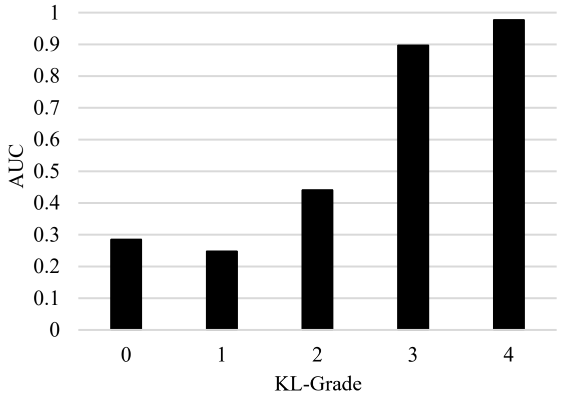


Figure 5. AUC value based on ROC graph

This fact that occurs answers the question of why the determination of KL-Grade 1 and 2 is sometimes not felt by patients, and this is in line with the results of this study. Based on experimental results has not obtained good results, if we observe in more detail, this is because this closeness of the data between normal condition cluster to second KL-Grade is very high. This is illustrated in Figure 7 (graph of JSW distance on JSW 0.150 for all clusters). JSW distance on JSW (0.150) is overlapping for between normal condition cluster to second KL-Grade.

Figure 8 is the JSW distance on JSW (0.200) for normal condition, and first KL-Grade1 to fourth KL-Grade. Similarly, the position of KL-Grade 2 at the point JSW (0.200) is located between KL-Grade 0 and KL-Grade 2, it causes the system sometimes classify KL-Grade 2 as KL-Grade 1, KL-Grade 2 or KL-Grade 3, this condition is illustrated in Figure 7. Microscopically this also occurs at the point JSW (0.175) to JSW (0.300), this makes KL-Grade 2 still difficult to classify appropriately. This fact also supports why patients are not aware of osteoarthritis in the early stages.

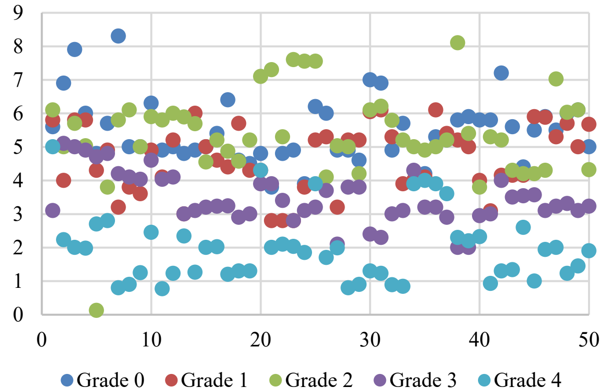


Figure 6. JSW distance on JSW (0.150) for normal condition to fourth KL-Grade

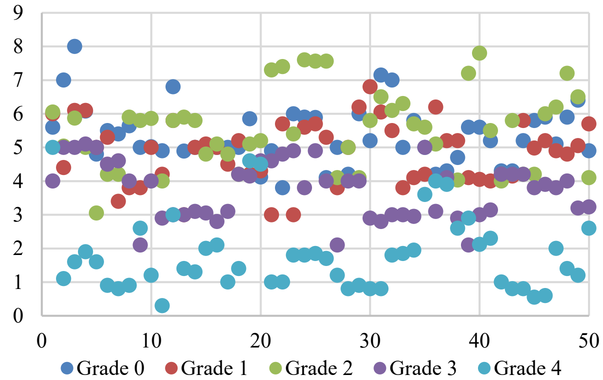


Figure 7. JSW distance on JSW (0.200) for normal condition to fourth KL-Grade

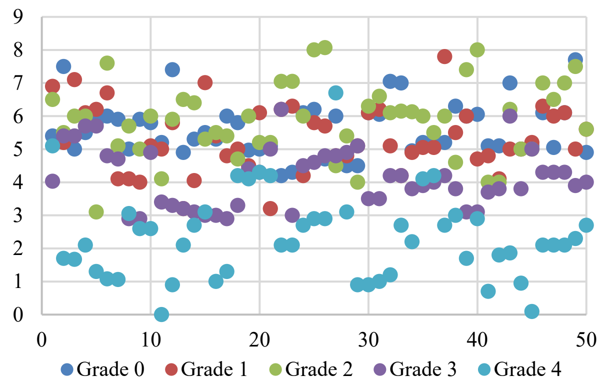


Figure 8. JSW distance on JSW (0.225) for normal condition to fourth KL-Grade

This fact also occurs in the JSW position of 0.225 which is depicted in Figure 9. The positions of the three KL-Grades (KL-Grades 0 to 2) are very close. This is very different from what happens in KL-Grade 3 and 4, the data patterns for these two clusters are very different so this supports the fact that many patients are aware that they have osteoarthritis at this stage. KL-Grades 3 and 4 have been identified at both the 0.150 position (Figure 7), the 0.200 position (Figure 8), and the 0.225 position (Figure 9). The originality of this research is to obtain the model pola data of normal condition, first KL-Grade to fourth KL-Grade based on Junction Space Width (JSW) data, JSW minimum medial compartment data (mJSW) and JSW (0.275), JSW (0.250), JSW (0.275), and JSW (0.300) using SOM. This paper has also discussed the pattern-based data learning process, testing process, to microscopic analysis of JSW position data for each cluster.

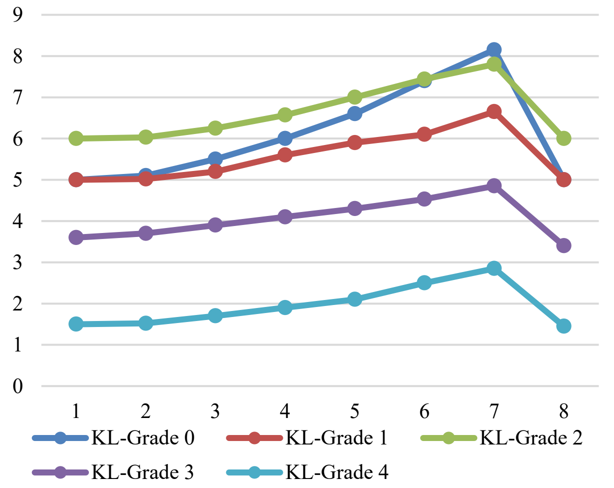


Figure 9. Trend graph model from Junction Space Width (JSW), JSW minimum medial compartment data (mJSW) and JSW (0.275), JSW (0.250), JSW (0.275), and JSW (0.300) using SOM

The results of the analysis above show that the JSW position for normal condition cluster to second grade does have some overlapping data, but if we look again there are differences in the JSW position pattern for the entire cluster (from normal cluster to fourth grade). Fig. 9 illustrates the weight generated from the best learning that is iterations number of 1500 and learning rate 0.6, this proves that for each KL-Grade has its own pattern.

4. CONCLUSION

The purpose of this research is to propose intelligence pattern recognition for knee osteoarthritis using SOM based on the Junction Space Width (JSW) data. Experiment results shows that that using number of iteration 1500 and learning rate value 0.6 produced accuracy rate 59.20%, Grade 0 28.125%, first grade 22.58%, second grade 43.82%, third 89.33 %, and fourth 97.33%. The ability to classify data into normal condition cluster to second grade cannot still be said to be good, it can be seen that some of the JSW data points in this cluster have some overlap. This is one of the factors that radiographs often find difficult to differentiate between grades. Third and fourth grade differentiated accurately from another grade, because the JSW position data pattern is very different. However, even though several clusters have a tendency to have similarities in JSW position, based on experimental results, each KL-Grade has a certain and specific data pattern at each JSW position.

NOMENCLATURES

1. Acronyms

SOM	Self Organizing Map
AUC	Area Under the Curve
ROC	Receiver operating characteristic curve
JSW	Junction Space Width
KL-grade	Kellgren and Lawrence Grade
MRI	Magnetic Resonance Imaging
TNF	True Negative False
TPF	True Positive False
FPF	False Positive False
TP	True Positive
TN	True Negative
FP	False Positive

2. Symbols / Parameters

*D*_min: Minimum distance
D: Distance
x_ij (*t*): Input data *ij*
$W_{(t)}$: Weight of *ij*
$W_{(t+1)}$: Updated weight
$\alpha_{(t)}$: learning rate at *t*

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